Switzerland's

Greenhouse Gas Inventory

1990–2018

National Inventory Report

Including reporting elements under the Kyoto Protocol

Submission of April 2020
under the United Nations Framework Convention on Climate Change
and under the Kyoto Protocol

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

Publisher
Federal Office for the Environment FOEN, Climate Division, 3003 Bern, Switzerland
www.bafu.admin.ch/climate
www.climatereporting.ch

Inventory Process Manager		
	Regine Röthlisberger	FOEN, Climate Division, Bern
National Inventory Compiler		
	Anouk-Aimée Bass	FOEN, Air Pollution Control and Chemicals Division, Bern
Sector responsibilities		
Energy	Anouk-Aimée Bass	FOEN, Air Pollution Control and Chemicals Division, Bern
IPPU	Sabine Schenker	FOEN, Air Pollution Control and Chemicals Division, Bern
	Cornelia Stettler	Carbotech, Basel
Agriculture	Daniel Bretscher	Agroscope, Zürich
LULUCF & KP-LULUCF	Andreas Schellenberger	FOEN, Climate Division, Bern
	Nele Rogiers	FOEN, Forest Division, Bern
	Beat Rihm	Meteotest, Bern
Waste	Rainer Kegel	FOEN, Air Pollution Control and Chemicals Division, Bern
	Daiana Leuenberger	FOEN, Air Pollution Control and Chemicals Division, Bern
Other	Michael Bock	FOEN, Climate Division, Bern
Indirect Emissions	Adrian Schilt	FOEN, Climate Division, Bern
QA/QC Officer & NIR Compiler		
	Michael Bock	FOEN, Climate Division, Bern
National Registry Administrator		
	Stefan Meier	FOEN, Climate Division, Bern

Bern, April 2020

Switzerland's Greenhouse Gas Inventory 1990–2018

National Inventory Report 2020

Including reporting elements under the Kyoto Protocol

Submission of April 2020
under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol

Acknowledgements
The GHG inventory preparation is a joint effort which is based on input from many federal agencies, institutions, associations, companies and individuals. Their effort was essential for the successful completion of the present inventory report.

The Federal Office for the Environment (FOEN) would like to acknowledge the valuable support it has received from the many contributors to this document. In particular, it would like to thank all the data suppliers, including the Office of the Environment of the Principality of Liechtenstein for providing its fossil fuel consumption data, as well as experts, authors and both national and international reviewers.

In the following contributors are listed in alphabetical order.

Albrecht-Widler, Simon (Meteotest); Ammann, Christoph (Agroscope); Anderson, Keith (FOEN); Bass, Anouk-Aimée (FOEN); Baumann, Pia (SFOE); Blatter, Gabriela (FOEN); Becker, Caroline (Carbotech); Bock, Michael (FOEN); Bretscher, Daniel (Agroscope); Brunner, Dominik (EMPA); Bühler, Michael (SFSO); Didion, Markus (WSL); Eggli, Dominik (Meteotest); Felder, Daniel (FOAG); Foglia, Amilcare Santino (VTG); Gardi, Oliver (BFH-HAFL); Gubler, Andreas (Agroscope); Gubler, Lena (WSL); Henne, Stephan (EMPA); Hügi, Michael (FOEN); Keel, Sonja (Agroscope); Kegel, Rainer (FOEN); Keller, Armin (Kompetenzzentrum Boden); Könitzer, Christoph (Sigmaplan); Leifeld, Jens (Agroscope); Leuenberger, Daiana (FOEN); Lindenmann, Martin (Sigmaplan); Mathys, Lukas (Nategra); Meier, Stefan (FOEN); Müller, Beat (FOEN); Müller, Stefan (Meteotest); Notter, Benedict (INFRAS); Paul, Sonja (Agroscope); Reimann, Stefan (EMPA); Renz, Patrick (SECO); Riedener, Susanne (FOEN); Rihm, Beat (Meteotest); Rindlisbacher, Theo (FOCA); Rogiers, Nele (FOEN); Röthlisberger, Regine (FOEN); Schellenberger, Andreas (FOEN); Schenker, Sabine (FOEN); Schilt, Adrian (FOEN); Spörri, Dina (FOEN); Stettler, Cornelia (Carbotech); Stumpf, Felix (Kompetenzzentrum Boden); Sutter, Antonia (SDC); Thürig, Esther (WSL); Weber, Felix (INFRAS); Wegmann, Fabio (FOEN); Wöhrnschimmel, Henry (FOEN); Wüst, Chloé (Agroscope); Zundel, Christine (FOAG)

Reader's comments

Comments regarding the content of this report should be addressed to:

Federal Office for the Environment FOEN
Climate Division
3003 Bern
Switzerland

E-Mail: climate@bafu.admin.ch

CHE-2020-NIR

Proposed citation:

FOEN 2020: Switzerland's Greenhouse Gas Inventory 1990–2018: National Inventory Report and reporting tables (CRF). Submission of April 2020 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

Table of Contents

Table of Contents 5

Glossary..... 8

Executive summary 12

PART 1 24

1 Introduction 24

1.1 Background information on Swiss greenhouse gas inventories, climate change and supplementary information of the Kyoto Protocol (KP)..... 24

1.2 National inventory arrangements..... 27

1.3 Inventory preparation and data collection, processing, and storage 34

1.4 Methodologies and data sources..... 35

1.5 Description of key categories 37

1.6 General uncertainty evaluation..... 46

1.7 General assessment of completeness 51

2 Trends in greenhouse gas emissions and removals 54

2.1 Aggregated greenhouse gas emissions 2018 (UNFCCC) 54

2.2 Emission trends by gas..... 57

2.3 Emission trends by sources and sinks 59

2.4 Emission trends for precursor gases and SO_2 65

2.5 Emission trends (Kyoto Protocol) 68

3 Energy..... 70

3.1 Overview..... 70

3.2 Source category 1A – Fuel combustion activities..... 76

3.3 Source category 1B – Fugitive emissions from fuels 188

3.4 Source category 1C – CO_2 transport and storage..... 197

4 Industrial processes and product use (IPPU) 198

4.1 Overview..... 198

4.2 Source category 2A – Mineral industry..... 202

4.3 Source category 2B – Chemical industry 217

4.4 Source category 2C – Metal industry 227

4.5 Source category 2D – Non-energy products from fuels and solvent use..... 236

4.6 Source category 2E – Electronics industry..... 249

4.7 Source category 2F – Product uses as substitutes for ozone depleting substances..... 251

4.8 Source category 2G – Other product manufacture and use..... 264

4.9 Source category 2H – Other ... 278
5 Agriculture ... 282
5.1 Overview ... 282
5.2 Source category 3A – Enteric fermentation ... 285
5.3 Source category 3B – Manure management ... 298
5.4 Source category 3C – Rice cultivation ... 316
5.5 Source category 3D – Agricultural soils ... 317
5.6 Source category 3E – Prescribed burning of savannahs ... 336
5.7 Source category 3F – Field burning of agricultural residues ... 336
5.8 Source category 3G – Liming ... 336
5.9 Source category 3H – Urea application ... 338
6 Land use, land-use change and forestry (LULUCF) ... 340
6.1 Overview of LULUCF ... 340
6.2 Land-use definitions and classification systems ... 355
6.3 Approaches used for representing land areas, land-use databases ... 362
6.4 Category 4A – Forest land ... 367
6.5 Category 4B – Cropland ... 404
6.6 Category 4C – Grassland ... 416
6.7 Category 4D – Wetlands ... 432
6.8 Category 4E – Settlements ... 437
6.9 Category 4F – Other land ... 440
6.10 Categories 4(III) and 4(IV) – N_2O emissions ... 441
6.11 Category 4G – Harvested wood products (HWP) ... 444
7 Waste ... 451
7.1 Overview ... 451
7.2 Source category 5A – Solid waste disposal ... 456
7.3 Source category 5B – Biological treatment of solid waste ... 462
7.4 Source category 5C – Incineration and open burning of waste ... 467
7.5 Source category 5D – Wastewater treatment and discharge ... 472
7.6 Source category 5E – Other ... 482
8 Other ... 485
8.1 Overview ... 485
8.2 Source category 6 – Other ... 486
9 Indirect CO_2 and N_2O emissions ... 490
9.1 Overview ... 490

9.2 Methodological issues 494
10 Recalculations and improvements 499
10.1 Explanations and justifications for recalculations and responses to the review process 499
10.2 Implications for emission levels 513
10.3 Implications for emissions trends, including time series consistency 517
10.4 Planned improvements, including in response to the review process 517
PART 2 519
11 KP-LULUCF 519
11.1 General information 522
11.2 Land-related information 524
11.3 Activity-specific information 527
11.4 Article 3.3. 537
11.5 Article 3.4 542
11.6 Other information 549
11.7 Information relating to Article 6 549
12 Information on accounting of Kyoto units 550
12.1 Background information 550
12.2 Summary of information reported in the SEF tables 550
12.3 Discrepancies and notifications 551
12.4 Publicly accessible information 551
12.5 Calculation of the Commitment Period Reserve (CPR) 552
12.6 KP-LULUCF accounting 552
13 Information on changes in National Registry 553
14 Information on minimization of adverse impacts in accordance with Article 3, Paragraph 14 554
Annexes 559
Annex 1 Key category analysis (KCA) 559
Annex 2 Assessment of uncertainty 562
Annex 3 Other detailed methodological descriptions for individual source or sink categories 568
Annex 4 National energy balance and reference approach 595
Annex 5 Additional information on verification activities 601
Annex 6 Information on the CRF reporter 618
References 620
References to EMIS database comments 660

Glossary

AAU	Assigned Amount Unit (under the Kyoto Protocol)
AD	Activity data
AFOLU	Agriculture, Forestry and Other Land Use
AREA1	Swiss Land Use Statistics 1979/85 (ASCH1 data re-evaluated according to the AREA set of land-use and land-cover categories)
AREA2	Swiss Land Use Statistics 1992/97 (ASCH2 data re-evaluated according to the AREA set of land-use and land-cover categories)
AREA3	Swiss Land Use Statistics, third survey 2004/09
AREA4	Swiss Land Use Statistics, forth survey 2013/18
ART	Agroscope Reckenholz-Tänikon Research Station (formerly FAL) since 2014 Agroscope
ASCH1	Swiss Land Use Statistics, first survey 1979/85
ASCH2	Swiss Land Use Statistics, second survey 1992/97
Avenergy	Avenergy Suisse (Swiss Petroleum Association) formerly Erdöl-Vereinigung (EV)
BAFU	Bundesamt für Umwelt (German for FOEN)
BCEF, BEF	Biomass conversion and expansion factor, biomass expansion factor
Carbura	Swiss organisation for the compulsory stockpiling of oil products
Cemsuisse	Association of the Swiss Cement Industry
CER	Certified Emission Reduction (under the Kyoto Protocol)
CC	Combination category
CDM	Clean Development Mechanism (under the Kyoto Protocol)
CFC	Chlorofluorocarbon (organic compound: refrigerant, propellant)
CH_4	Methane, 2006 IPCC GWP: 25 (UNFCCC 2014a, Annex III)
CHP	Combined heat and power
chp.	Chapter
CNG	Compressed natural gas
CLRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
CO_2, CO_2 eq	Carbon dioxide, carbon dioxide equivalent
CORINAIR	CORe INventory of AIR emissions (under the European Topic Centre on Air Emissions and under the European Environment Agency)
CRF	Common Reporting Format
CSC	Carbon stock change
DBH	Diameter (of trees) at breast height
DDPS	Federal Department of Defence, Civil Protection and Sport
DETEC	Dept. of the Environment, Transport, Energy and Communications
EF	Emission factor

EMEP	European Monitoring and Evaluation Programme (under the Convention on Long-range Transboundary Air Pollution)
EMIS	Swiss Emission Information System (German: Emissions Informations System Schweiz)
EMPA	Swiss Federal Laboratories for Material Testing and Research
ERT	Expert review team (under the UNFCCC and the Kyoto Protocol)
ERU	Emission Reduction Unit (under the Kyoto Protocol)
ETS	Emission Trading System
EV	Erdöl-Vereinigung (Swiss Petroleum Association), since 1. July 2019 Avenergy Suisse
FAL	Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART; since 2014 Agroscope)
FAO	Food and Agriculture Organization of the United Nations
FCA	Federal Customs Administration
FEDRO	Swiss Federal Roads Office
FiBL	Research Institute of Organic Agriculture
FMRL	Forest management reference level
FOAG	Federal Office for Agriculture
FOCA	Federal Office of Civil Aviation
FOD	First order decay (model)
FOEN	Federal Office for the Environment (former name SAEFL until 2005)
GHG	Greenhouse gas
GL	Guidelines
g	Gram
GVS	Swiss Foundry Association
GWP	Global Warming Potential
ha	hectare
HFC	Hydrofluorocarbons (e.g. HFC-32 difluoromethane)
HWP	Harvested wood products
ICAO	International Civil Aviation Organization
IDM	FOEN Internal Document Management System
IDP	Inventory Development Plan
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
JI	Joint Implementation (under the Kyoto Protocol)
KCA	Key category analysis
kha	Kilo hectare
kt	Kilo tonne (1’000 tonnes)
L1, L2	Key category according to level assessment with approach 1, approach 2

LPG	Liquefied Petroleum Gas (Propane/Butane)
LTO	Landing-Take-off-Cycle (Aviation)
LULUCF	Land Use, Land-Use Change and Forestry
MOFIS	Swiss federal vehicle registration database
MSW	Municipal solid waste
NABO	Swiss Soil Monitoring Network
NCV	Net calorific value
NCAC	(livestock) not covered by agricultural census
NF_3	Nitrogen trifluoride 2006 IPCC GWP: 17’200 (UNFCCC 2014a, Annex III)
NFI1, NFI2	First (1983–1985), Second (1993–1995), Third (2004–2006)
NFI3, NFI4	and Fourth (2009–2017) National Forest Inventory
NIR	National Inventory Report
NIS	National Inventory System
NFR	Nomenclature for Reporting (under the UNECE)
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous oxide; 2006 IPCC GWP: 298 (UNFCCC 2014a, Annex III)
NO_x	Nitrogen oxides
ODS	Ozone-depleting substances (CFCs, halons etc.)
PFC	Perfluorinated carbon compounds (e.g. Tetrafluoromethane)
SAEFL	Swiss Agency for the Environment, Forests and Landscape (since 2006: Federal Office for the Environment FOEN)
SEF	Standard Electronic Format (under the Kyoto Protocol)
SBV	Schweizerischer Bauernverband; Swiss Farmers Union
SCR	Selective catalytic reduction
SF_6	Sulphur hexafluoride, 2006 IPCC GWP: 22’800 (UNFCCC 2014a, Annex III)
SGWA	Swiss Gas and Water Industry Association
SECO	State Secretariat for Economic Affairs
SDC	Swiss Agency for Development and Cooperation (German: DEZA)
SFOE	Swiss Federal Office of Energy
SFSO	Swiss Federal Statistical Office
SGWA	Swiss Gas and Water Industry Association (see SVGW/SSIGE)
SKW	Schweizerischer Kosmetik- und Waschmittelverband (Swiss Association of cosmetics and detergents)
SO_2	Sulphur dioxide
SOC	Soil organic carbon
SOLV	Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector

SVGW/SSIGE	Schweizerischer Verein des Gas- und Wasserfaches / Société Suisse de l'Industrie du Gaz et des Eaux (Swiss Gas and Water Industry Association)
SWISSMEM	Swiss Mechanical and Electrical Engineering Industries (Schweizer Maschinen-, Elektro- und Metallindustrie)
T1, T2	Key category according to trend assessment with approach 1, approach 2
tCER	Temporary Certified Emission Reduction (under the Kyoto Protocol)
QA/QC	Quality assurance/Quality control
QMS	Quality management system
RMU	Removal Unit (under the Kyoto Protocol)
UBA	Umweltbundesamt (Federal Environment Agency in Germany)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds
VSG	Verband der Schweizerischen Gasindustrie / Association Suisse de l'Industrie Gazière (ASIG) (Swiss Gas Industry Association)
VSZ	Verband Schweizerische Ziegelindustrie (Swiss association of brick and tile industry)
VSLF	Swiss association for coating and paint applications
VSTB	Swiss Association of Grass Drying Plants
VTG	Swiss Armed Forces – Defense
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
WWT	Wastewater treatment
ZPK	Verband der Schweizerischen Zellstoff-, Papier- und Kartonindustrie

Executive summary

Responsibilities for Executive summary	
Author	Regine Röthlisberger (FOEN)
EMIS database operation	Anouk-Aimée Bass (FOEN)
Annual updates (NIR text, tables, figures)	Regine Röthlisberger (FOEN), Felix Weber (INFRAS)
Quality control (annual updates)	Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
Internal review	Michael Bock (FOEN)

ES 1 Background information on greenhouse gas inventories, climate change and supplementary information required under Art. 7.1. KP

ES 1.1 Background information on climate change

In 2016, a comprehensive assessment of climate change and its impacts in Switzerland, both in the past and in the future, has been published by the Swiss Academies of Sciences (SCNAT 2016). Long-term measurements indicate a marked shift towards a warmer climate for Switzerland. Between 1864 and 2016, the average temperature in Switzerland has increased by +2.0 degrees Celsius compared to +0.9 degrees Celsius globally (FOEN 2018d).

In the course of the 21st century, Swiss climate is projected to depart significantly from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40% depending on the emission scenario, while winter precipitation will likely increase, particularly in Southern Switzerland. The expected trends in precipitation will have a marked impact on the hydrological cycle. Furthermore, higher intensity of storms as well as reduced snowfall and snow cover duration are expected, increasing the risk and frequency of floods, landslides and debris flows.

The retreat and massive loss of volume of glaciers in the Alps is the most apparent indicator of the recent increase in atmospheric temperature. In recent years a dramatic acceleration of glacial melting was observed. From the ca. 2’900 square kilometres of glacier area in the mid-1970s, only about 2’100 square kilometres remained in 2003 and an estimated 1’900 square kilometres in 2013 (FOEN 2018d).

Concerning biodiversity, climate change is expected to affect species composition, distribution, their cycles, synchronicity, the overall genetic diversity, and the provision of ecosystem services. This in turn will increase the vulnerability of forests and potentially impair their protective, productive, and social functions. Species distribution will shift upward to higher elevations, thermophile species will spread, new species from warmer areas will arrive, and phenological shifts will occur.

For agriculture, climate change is expected to entail a shift of suitable areas for agricultural production, and to involve both positive (e.g. a longer vegetation period) and negative (e.g. increasing incidence of pest infestations owing to milder winters) aspects. Changes in the nature of extreme weather events, in particular more frequent, intense and longer-lasting summer heat waves, could also challenge agriculture, e.g. by reducing the yields.

Various sectors of the Swiss economy are likely to be adversely affected by progressing climate change: in particular, winter tourism will suffer from increased scarcity of snow, hydroelectric power stations are confronted with altered runoff and sediment transport regimes, and insurance companies may face increased losses due to winter storms and floods. Natural hazards and extreme weather events potentially pose a growing risk to infrastructures and settlements. Heat waves in combination with elevated tropospheric ozone levels present a serious threat to human health. Finally, it remains to be seen to what extent vector borne diseases spread due to changing climatic conditions. Recently, Switzerland analysed these challenges in detail and developed an effective adaptation strategy in order to hedge against negative effects resulting from climate change in Switzerland (FOEN 2012b, FOEN 2017k).

ES.1.2 Background information on greenhouse gas inventories

On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC Guidelines. From 1998 onwards, the inventories have been submitted in the Common Reporting Format (CRF). In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

On 9 July 2003, Switzerland ratified the Kyoto Protocol (KP) under the UNFCCC. The Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol was implemented and is fully operational since.

The Federal Office for the Environment (FOEN) is in charge of compiling the emission data and bears overall responsibility for Switzerland’s national greenhouse gas inventory and the national registry. In addition to the FOEN, the Swiss Federal Office of Energy (SFOE), Agroscope, the Swiss centre of excellence for agricultural research, and the Federal Office of Civil Aviation (FOCA) participate directly in the compilation of the inventory. Several other administrative offices and research institutions are involved in the preparation of the inventory.

In preparing the national greenhouse gas inventory, Switzerland takes recommendations and encouragements of the review process into account. The changes in response to the review process are documented in chp. 10.1.1.

ES.1.3 Background information on supplementary information required under article 7.1. of the Kyoto Protocol (KP)

Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest management are capped in the second commitment period. This cap is set at 3.5% of the 1990 emissions (excluding LULUCF).

Switzerland will account for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d) over the entire second commitment period. In addition to the mandatory submission of the inventory years 2013–2018, selected data for the time series since 1990 are shown in chp. 11.

ES.2 Summary of national emissions and removals related trends, and emissions and removals from KP-LULUCF activities

ES.2.1 Greenhouse gas (GHG) inventory

In 2018, Switzerland emitted 46’333 kt CO_2 eq (kilo tonnes of CO_2 equivalent), corresponding to 5.4 t CO_2 eq per capita (CO_2: 4.3 t per capita), to the atmosphere, excluding emissions from international aviation and marine bunkers (5’687 kt CO_2 eq), excluding indirect greenhouse gas emissions (99 kt CO_2 eq) and excluding emissions and removals from Land use, land-use change, and forestry (LULUCF, -1’291 kt CO_2 eq). For emissions that are relevant under the Kyoto Protocol see chapter ES.3.3.

Key category analysis (KCA)

Several key category analyses are carried out by level (years 1990 and 2018) and trend assessment (period 1990–2018), both including LULUCF categories (see details in chp. 1.5.1.2 and IPCC (2006)).

- Approach 1: For 2018, 32 categories among a total of 164 are identified as level key categories. About half of these categories are part of sector 1 Energy, accounting for the largest share of total national emissions.
- Approach 2: For 2018, 26 categories among a total of 164 are identified as level key categories. Under Approach 2, the most important categories stem from sectors 3 Agriculture and 4 LULUCF.

Key category analyses are also performed excluding LULUCF categories. They are not represented in the NIR but are available on request.

Switzerland’s GHG emissions by gases

Table E- 1 shows Switzerland’s annual GHG emissions by individual gases from 1990 (base year) to 2018. Total emissions excluding LULUCF reach a minimum in 2018 with 13.8% below 1990.

Table E- 1 Greenhouse gas emissions in CO_2 equivalent (kt) by gas (excluding indirect CO_2). HFC emissions increased by more than 5 million percent when compared to 1990 levels (1990 = 0.025 kt CO_2 equivalent).

Greenhouse Gas Emissions	**1990**	**1995**	**2000**	**2005**
	CO_2 equivalent (kt)			
CO_2 emissions including net CO_2 from LULUCF	42'136	39'846	49'416	43'585
CO_2 emissions excluding net CO_2 from LULUCF	44'154	43'413	43'618	45'788
CH_4 emissions including CH_4 from LULUCF	6'074	5'749	5'321	5'218
CH_4 emissions excluding CH_4 from LULUCF	6'044	5'729	5'307	5'204
N_2O emissions including N_2O from LULUCF	3'381	3'382	3'353	3'162
N_2O emissions excluding N_2O from LULUCF	3'327	3'333	3'307	3'117
HFCs	0.02	244	636	1'048
PFCs	117	17	61	50
SF_6	137	93	152	207
NF_3	NO	NO	NO	NO
Total (including LULUCF)	**51'844**	**49'331**	**58'939**	**53'270**
Total (excluding LULUCF)	**53'779**	**52'830**	**53'081**	**55'414**

Greenhouse Gas Emissions	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2018 vs.1990**
	CO_2 equivalent (kt)										%
CO_2 emissions including net CO_2 from LULUCF	40'582	42'561	39'879	40'623	41'380	38'898	36'601	37'049	36'799	35'521	-15.7%
CO_2 emissions excluding net CO_2 from LULUCF	43'535	45'050	40'986	42'255	43'186	39'234	38'733	39'193	38'182	36'895	-16.4%
CH_4 emissions including CH_4 from LULUCF	5'194	5'167	5'114	5'084	5'020	5'017	4'987	4'946	4'882	4'878	-19.7%
CH_4 emissions excluding CH_4 from LULUCF	5'181	5'154	5'099	5'071	5'007	5'004	4'974	4'930	4'868	4'840	-19.9%
N_2O emissions including N_2O from LULUCF	2'914	3'058	2'988	3'047	2'949	2'929	2'958	2'938	3'129	2'925	-13.5%
N_2O emissions excluding N_2O from LULUCF	2'869	3'013	2'942	3'001	2'901	2'881	2'910	2'889	3'083	2'880	-13.4%
HFCs	1'272	1'308	1'380	1'453	1'432	1'469	1'508	1'480	1'504	1'524	see caption
PFCs	35	38	36	39	28	23	26	20	32	36	-69.4%
SF_6	183	151	164	218	263	266	261	213	203	157	14.7%
NF_3	7.6	12.7	9.3	0.54	0.14	0.61	0.73	0.77	0.80	0.50	-
Total (including LULUCF)	**50'189**	**52'297**	**49'571**	**50'464**	**51'071**	**48'602**	**46'341**	**46'646**	**46'551**	**45'041**	**-13.1%**
Total (excluding LULUCF)	**53'082**	**54'727**	**50'616**	**52'037**	**52'816**	**48'877**	**48'412**	**48'725**	**47'873**	**46'333**	**-13.8%**

With regard to the distribution of emissions by individual greenhouse gases, CO_2 is the largest single contributor accounting for 80% of total GHG emissions (excluding LULUCF) in 2018. The shares of CH_4 and N_2O are about 10% and 6%, respectively. The shares of the three gases show slightly decreasing trends in the period 1990–2018, whereas aggregated F-gases, which contributed only 0.5% in 1990, increased to a share of almost 4% in 2018 (Table E- 2).

Table E- 2 Contribution of individual gases to total emissions (excluding LULUCF, excluding indirect CO_2) in CO_2 equivalent (kt) and (%).

Greenhouse Gas Emissions	**1990**		**1995**		**2000**		**2005**		**2010**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	44'154	82.1%	43'413	82.2%	43'618	82.2%	45'788	82.6%	45'050	82.3%
CH_4	6'044	11.2%	5'729	10.8%	5'307	10.0%	5'204	9.4%	5'154	9.4%
N_2O	3'327	6.2%	3'333	6.3%	3'307	6.2%	3'117	5.6%	3'013	5.5%
HFCs	0	0.0%	244	0.5%	636	1.2%	1'048	1.9%	1'308	2.4%
PFCs	117	0.2%	17	0.0%	61	0.1%	50	0.1%	38	0.1%
SF_6	137	0.3%	93	0.2%	152	0.3%	207	0.4%	151	0.3%
NF_3	NO	-	NO	-	NO	-	NO	-	12.7	0.0%
Total (excluding LULUCF)	**53'779**	**100%**	**52'830**	**100%**	**53'081**	**100%**	**55'414**	**100%**	**54'727**	**100%**

Greenhouse Gas Emissions	**2014**		**2015**		**2016**		**2017**		**2018**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	39'234	80.3%	38'733	80.0%	39'193	80.4%	38'182	79.8%	36'895	79.6%
CH_4	5'004	10.2%	4'974	10.3%	4'930	10.1%	4'868	10.2%	4'840	10.4%
N_2O	2'881	5.9%	2'910	6.0%	2'889	5.9%	3'083	6.4%	2'880	6.2%
HFCs	1'469	3.0%	1'508	3.1%	1'480	3.0%	1'504	3.1%	1'524	3.3%
PFCs	23	0.0%	26	0.1%	20	0.0%	32	0.1%	36	0.1%
SF_6	266	0.5%	261	0.5%	213	0.4%	203	0.4%	157	0.3%
NF_3	0.61	0.0%	0.73	0.0%	0.77	0.0%	0.80	0.0%	0.50	0.0%
Total (excluding LULUCF)	**48'877**	**100%**	**48'412**	**100%**	**48'725**	**100%**	**47'873**	**100%**	**46'333**	**100%**

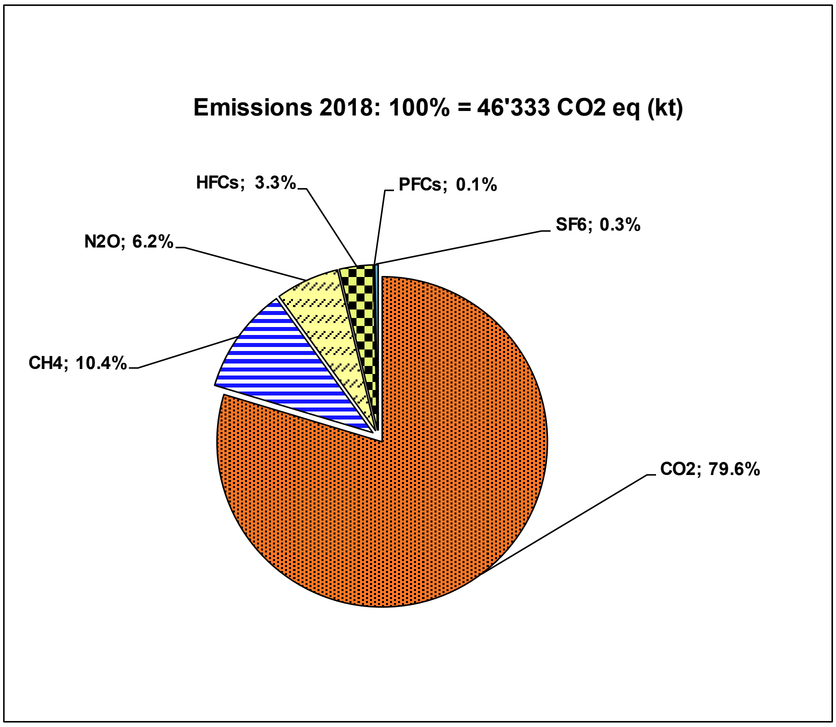


Figure E- 1 Contribution of individual gases to total greenhouse gas emissions (excluding LULUCF, excluding indirect CO_2) in 2018.

Uncertainty analysis

Uncertainties were assessed with Approach 1, including and excluding LULUCF categories for the years 1990 and 2018 (level) and for the period 1990–2018 (trend) (see details in chp. 1.6 and IPCC (2006)). The uncertainty results for Approach 1 are displayed in Table E- 3. Due to high uncertainties in sector 4 LULUCF, uncertainties are generally higher for the analyses including LULUCF categories compared to the analyses excluding LULUCF categories.

Table E- 3 Relative uncertainties for national total GHG emissions excluding and including the LULUCF sector – Approach 1: Level uncertainties 2018 and trend uncertainties 1990–2018. The uncertainty analysis is based on emissions including indirect CO_2 emissions.

Approach 1 Uncertainty Analysis		
Inventory	**Level uncertainty 2018**	**Trend uncertainty 1990-2018**
excl. LULUCF	5.48%	1.53%
incl. LULUCF	6.45%	2.73%

Recalculations

For the latest recalculated year (2017), the total national emissions (excluding LULUCF, excluding indirect CO_2) increased from 47’159 kt CO_2 eq in the previous submission (FOEN 2019) to 47’873 kt CO_2 eq (latest submission). See detailed explanations of the recalculations in the sectoral chapters and the summary in chp. 10.

ES.2.2 KP-LULUCF activities

Switzerland reports the mandatory LULUCF activities Afforestation and Deforestation (Reforestation is not occurring in Switzerland) under Article 3, paragraph 3, of the Kyoto Protocol, and Forest management as a mandatory activity under Article 3, paragraph 4, of the Kyoto Protocol. The total contribution of these activities is shown in Table E- 4. All activities include net emissions and removals of all GHG (i.e. CO_2, CH_4, N_2O) from Harvested wood products (HWP), biomass burning, drainage and N mineralisation, where appropriate (see chp. 11.3).

Table E- 4 Net CO_2 eq emissions (positive sign) and removals (negative sign) for activities accounted for under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4, of the Kyoto Protocol in kt CO_2 eq.

	1990	1995	2000	2005
	kt CO_2 equivalent			
A. Article 3.3 activities	83.38	105.67	122.87	133.58
B. Article 3.4 Forest managament	-2'327.76	-4'596.93	4'211.75	-3'428.59

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt CO_2 equivalent									
A. Article 3.3 activities	135.17	141.41	143.74	144.98	146.27	129.28	117.06	109.93	135.59	148.54
B. Article 3.4 Forest managament	-3'243.70	-3'198.49	-1'747.90	-2'954.60	-2'739.69	-1'435.20	-2'973.65	-2'920.35	-2'751.26	-1'278.37

ES.3. Overview of source and sink category estimates and trends, including KP-LULUCF activities

ES.3.1 GHG inventory (Convention on Climate Change)

Table E- 5 shows the GHG emissions and removals by the main source and sink categories. Sector 1 Energy clearly dominates national emissions, accounting for more than three quarters of the total GHG emissions (excluding LULUCF, excluding indirect CO_2), as shown in Table E- 6. Sectors 2 Industrial processes and product use (IPPU) and 3 Agriculture contribute a considerable share of GHG emissions as well, while sectors 5 Waste and 6 Other are of minor importance. The totals of LULUCF categories from sector 4 are a net GHG sink over the inventory period except for the year 2000.

Overall, Switzerland's GHG emissions decreased in 2018 compared to 1990. This effect is mainly driven by decreases in the Energy and Agriculture sectors, which outweigh the increase in the Industrial processes and product use sector.

Table E- 5 Greenhouse gas emissions (excluding indirect CO_2) in CO_2 equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

Source and Sink Categories	1990	1995	2000	2005
	CO_2 equivalent (kt)			
1. Energy	41'862	41'916	42'231	43'993
1A1 Energy industries	2'519	2'643	3'172	3'816
1A2 Manufacturing industries and construction	6'571	6'295	6'007	6'041
1A3 Transport	14'676	14'305	15'977	15'858
1A4 Other sectors	17'514	18'081	16'565	17'827
1A5 Other	220	163	151	139
1B Fugitive emissions from fuels	363	430	359	312
2. Industrial processes and product use	4'014	3'420	3'775	4'429
3. Agriculture	6'826	6'612	6'232	6'132
5. Waste	1'064	870	830	846
6. Other	12	12	13	14
Total (excluding LULUCF)	53'779	52'830	53'081	55'414
4. Land use, land-use change and forestry	-1'935	-3'499	5'858	-2'145
Total (including LULUCF)	51'844	49'331	58'939	53'270

Source and Sink Categories	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. 1990*
	CO_2 equivalent (kt)										%
1. Energy	41'846	43'216	39'155	40'549	41'471	37'426	37'095	37'489	36'503	35'235	*-15.8%*
1A1 Energy industries	3'674	3'846	3'598	3'641	3'736	3'607	3'294	3'379	3'298	3'360	*33.4%*
1A2 Manufacturing industries and construction	5'759	5'864	5'435	5'432	5'498	5'100	4'980	4'986	4'950	4'820	*-26.6%*
1A3 Transport	16'447	16'337	16'158	16'275	16'185	16'079	15'344	15'178	14'916	14'918	*1.6%*
1A4 Other sectors	15'567	16'753	13'556	14'810	15'683	12'276	13'124	13'587	12'991	11'791	*-32.7%*
1A5 Other	133	137	125	132	133	139	135	139	128	127	*-42.4%*
1B Fugitive emissions from fuels	268	279	283	259	235	226	218	219	220	219	*-39.7%*
2. Industrial processes and product use	4'264	4'519	4'526	4'503	4'509	4'511	4'459	4'408	4'561	4'422	*10.2%*
3. Agriculture	6'170	6'203	6'160	6'232	6'089	6'207	6'132	6'113	6'107	5'991	*-12.2%*
5. Waste	789	776	761	739	733	722	713	703	690	671	*-36.9%*
6. Other	13	12	13	14	14	12	12	12	13	14	*10.6%*
Total (excluding LULUCF)	53'082	54'727	50'616	52'037	52'816	48'877	48'412	48'725	47'873	46'333	*-13.8%*
4. Land use, land-use change and forestry	-2'893	-2'430	-1'045	-1'573	-1'745	-276	-2'072	-2'079	-1'323	-1'291	*-33.3%*
Total (including LULUCF)	50'189	52'297	49'571	50'464	51'071	48'602	46'341	46'646	46'551	45'041	*-13.1%*

As shown in Figure E- 2 GHG emissions in the period 1990–2018 are subject to fluctuations with a decreasing trend starting after 2005. The fluctuations derive from the year-to-year variability of the energy sector emissions caused by changing winter temperatures and hence, changing heating fuel use. Since around 2006, a growing decoupling of fuel combustion emissions and winter temperature is observed, reflecting the impact of emission reduction measures in the building sector.

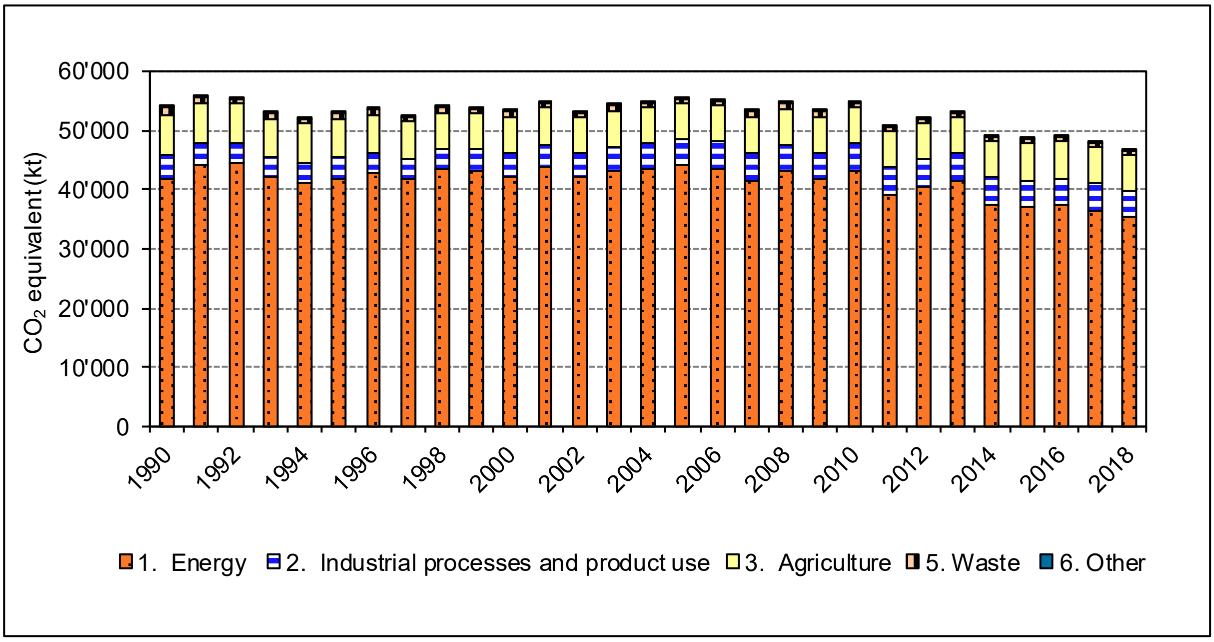


Figure E- 2 Greenhouse gas emissions in CO_2 equivalent (kt) by sectors (excluding LULUCF, excluding indirect CO_2).

Table E- 6 provides more detailed information on individual sectors' contributions to total emissions for selected years (excluding LULUCF). In general, the relative contributions of the different sectors have been rather stable between 1990 and 2018. When comparing the contributions in 2018 to 1990, the following development can be observed:

- Slightly lower relative contribution of sectors 1 Energy and 5 Waste.
- Larger relative contribution of sector 2 Industrial processes and product use.
- Similar relative contribution of sector 3 Agriculture.

Table E- 6 Greenhouse gas emissions (excluding LULUCF, excluding indirect CO_2) in CO_2 equivalent (kt) and the relative contribution of individual source categories.

Source and Sink Categories	1990		1995		2000		2005		2010	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1. Energy	41'862	77.8%	41'916	79.3%	42'231	79.6%	43'993	79.4%	43'216	79.0%
1A1 Energy industries	*2'519*	*4.7%*	2'643	*5.0%*	3'172	*6.0%*	3'816	*6.9%*	3'846	7.0%
1A2 Manufacturing industries and construction	*6'571*	*12.2%*	6'295	*11.9%*	6'007	*11.3%*	6'041	*10.9%*	5'864	*10.7%*
1A3 Transport	*14'676*	*27.3%*	14'305	*27.1%*	15'977	*30.1%*	15'858	*28.6%*	16'337	*29.9%*
1A4 Other sectors	*17'514*	*32.6%*	18'081	*34.2%*	16'565	*31.2%*	17'827	*32.2%*	16'753	*30.6%*
1A5 Other	*220*	*0.4%*	163	*0.3%*	151	*0.3%*	139	*0.3%*	137	*0.3%*
1B Fugitive emissions from fuels	*363*	*0.7%*	430	*0.8%*	359	*0.7%*	312	*0.6%*	279	*0.5%*
2. Industrial processes and product use	4'014	7.5%	3'420	6.5%	3'775	7.1%	4'429	8.0%	4'519	8.3%
3. Agriculture	6'826	12.7%	6'612	12.5%	6'232	11.7%	6'132	11.1%	6'203	11.3%
5. Waste	1'064	2.0%	870	1.6%	830	1.6%	846	1.5%	776	1.4%
6. Other	12	0.0%	12	0.0%	13	0.0%	14	0.0%	12	0.0%
Total (excluding LULUCF)	53'779	100.0%	52'830	100.0%	53'081	100.0%	55'414	100.0%	54'727	100.0%

Source and Sink Categories	2014		2015		2016		2017		2018	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1. Energy	37'426	76.6%	37'095	76.6%	37'489	76.9%	36'503	76.2%	35'235	76.0%
1A1 Energy industries	3'607	*7.4%*	3'294	*6.8%*	3'379	*6.9%*	3'298	*6.9%*	3'360	*7.3%*
1A2 Manufacturing industries and construction	5'100	*10.4%*	4'980	*10.3%*	4'986	*10.2%*	4'950	*10.3%*	4'820	*10.4%*
1A3 Transport	16'079	*32.9%*	15'344	*31.7%*	15'178	*31.2%*	14'916	*31.2%*	14'918	*32.2%*
1A4 Other sectors	12'276	*25.1%*	13'124	*27.1%*	13'587	*27.9%*	12'991	*27.1%*	11'791	*25.4%*
1A5 Other	139	*0.3%*	135	*0.3%*	139	*0.3%*	128	*0.3%*	127	*0.3%*
1B Fugitive emissions from fuels	226	*0.5%*	218	*0.5%*	219	*0.4%*	220	*0.5%*	219	*0.5%*
2. Industrial processes and product use	4'511	9.2%	4'459	9.2%	4'408	9.0%	4'561	9.5%	4'422	9.5%
3. Agriculture	6'207	12.7%	6'132	12.7%	6'113	12.5%	6'107	12.8%	5'991	12.9%
5. Waste	722	1.5%	713	1.5%	703	1.4%	690	1.4%	671	1.4%
6. Other	12	0.0%	12	0.0%	12	0.0%	13	0.0%	14	0.0%
Total (excluding LULUCF)	48'877	100.0%	48'412	100.0%	48'725	100.0%	47'873	100.0%	46'333	100.0%

ES.3.2 KP-LULUCF activities

An overview of net CO_2 eq emissions and removals of activities under Article 3, paragraph 3 and Forest management under paragraph 4 of the Kyoto Protocol is shown in Table E- 7 and Figure E- 3.

Detailed quantitative information for selected years in the period 1990–2018 is reported in chp. 11.4, chp. 11.5, and displayed in Table 11-1. Annual changes in the emissions from Afforestation and Deforestation can be directly attributed to the changes in their area (Table 11-2). The relative changes in the area of managed forest are comparatively small and fluctuations of the annual net carbon stock changes in Forest management can primarily be explained by changes in the losses from the (1) living biomass pool, (2) dead wood pool and (3) litter pool. The extraordinary high emissions of the Forest management sector in 2000 and the small removals in the following year 2001 originate from winter storm “Lothar” at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007. Peak values in 2006 and 2007 resulted in small removals from Forest management. Because harvesting rates started to decline in 2008 (Table 6-18) due to the international and domestic economic framework conditions, removals from Forest management are increasing since 2008 with a clear year-to-year variability. The small net removals in 2011, 2014 and 2018 are due to comparably high harvesting rates and above-average losses in the litter pool (related to climatic circumstances). Fluctuations in the Harvested wood products (HWP) pool are mainly caused by changes in the production of sawnwood and panels (see Table 6-36 and Figure 6-14).

Table E- 7 Net CO_2 eq emissions (positive sign) and removals (negative sign) of activities accounted for under Article 3, paragraph 3 (Afforestation, Deforestation) and paragraph 4 (Forest management, Harvested wood products HWP) of the Kyoto Protocol in kt CO_2 eq.

	1990	1995	2000	2005
	kt CO_2 equivalent			
A. Article 3.3 activities	83.38	105.67	122.87	133.58
Afforestation	-2.97	-14.69	-19.19	-22.92
Deforestation	86.35	120.36	142.06	156.50
B. Article 3.4 Forest Management	-2'327.76	-4'596.93	4'211.75	-3'428.59
Forest management excl. HWP	-1'158.94	-4'109.87	4'934.71	-2'700.72
HWP	-1'168.82	-487.06	-722.96	-727.87

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt CO_2 equivalent									
A. Article 3.3 activities	135.17	141.41	143.74	144.98	146.27	129.28	117.06	109.93	135.59	148.54
Afforestation	-25.47	-23.79	-21.60	-20.80	-19.82	-17.65	-19.18	-18.94	-18.58	-16.15
Deforestation	160.64	165.20	165.34	165.79	166.10	146.93	136.25	128.87	154.17	164.69
B. Article 3.4 Forest Management	-3'243.70	-3'198.49	-1'747.90	-2'954.60	-2'739.69	-1'435.20	-2'973.65	-2'920.35	-2'751.26	-1'278.37
Forest management excl. HWP	-2'820.77	-2'740.99	-1'392.37	-2'820.17	-2'796.59	-1'319.49	-2'873.51	-2'863.08	-2'727.28	-1'200.03
HWP	-422.92	-457.49	-355.53	-134.43	56.90	-115.71	-100.14	-57.27	-23.97	-78.34

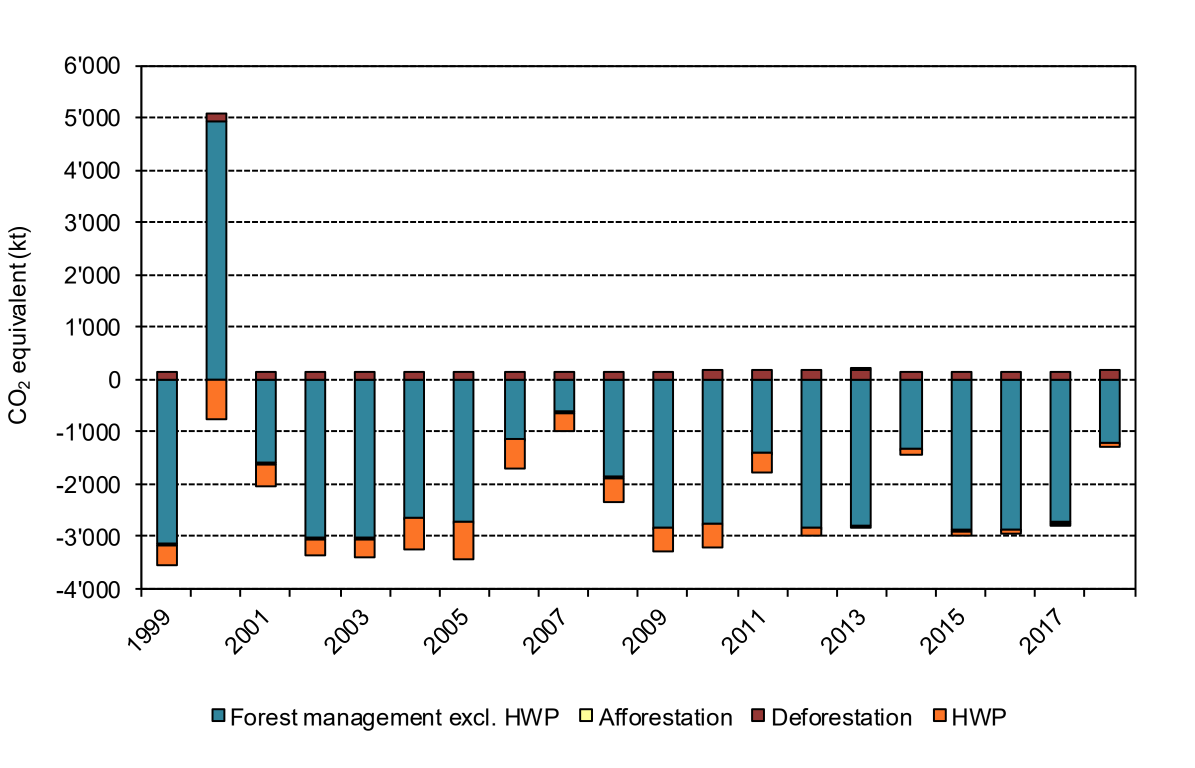


Figure E- 3 Greenhouse gas emissions (positive sign) and removals (negative sign) from Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP, and HWP under Article 3, paragraph 4.

ES.3.3 GHG inventory (Kyoto Protocol)

Relevant emissions and removals under the Kyoto Protocol by sectors and gases are shown in Table E- 8 and Table E- 9. Total emissions reported under the Kyoto Protocol differ from those reported under the UNFCCC because sectors 4 LULUCF, 6 Other, and international bunkers are not accounted for under the Kyoto Protocol. However, activities under Article 3, paragraph 3 (Afforestation, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, and Revegetation) as well as indirect CO_2 emissions are included in the tables. Under the activities of Article 3, paragraph 4, of the Kyoto Protocol, Switzerland only accounts for Forest management. Base year emissions (as shown in Table E- 8 and Table E- 9), which are relevant for calculating the cap on activities under Art. 3.4 (see decision 2/CMP.7, paragraph 13) are reported in

Switzerland's Second Initial Report (FOEN 2016c) and the update to the report following the UNFCCC in-country review (FOEN 2016d).

Table E- 8 Summary of greenhouse gas emissions in CO_2 equivalent (kt) as well as emissions and removals under KP-LULUCF by sectors. Excluded are emissions and removals from sectors 4 LULUCF, 6 Other, and from International bunkers.

		Sector	Base year inital report	1990	1991	1992	1993	1994	1995	1996	1997	1998
			CO_2 equivalent (kt)									
Annex A sources		1 Energy + indirect CO_2 from this sector	41'881	41'906	44'302	44'344	42'167	41'050	41'943	42'816	41'896	43'466
Annex A sources		2 Industrial processes and product use + indirect CO_2 from this sector	3'887	4'348	3'968	3'746	3'482	3'649	3'648	3'540	3'504	3'529
Annex A sources		3 Agriculture	6'804	6'826	6'757	6'648	6'634	6'609	6'612	6'442	6'265	6'233
Annex A sources		5 Waste + indirect CO_2 from this sector	1'135	1'066	975	977	928	870	872	862	850	836
Annex A sources		**Total (Annex A sources)**	**53'707**	**54'146**	**56'003**	**55'715**	**53'211**	**52'178**	**53'075**	**53'660**	**52'515**	**54'064**

		Sector	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
			CO_2 equivalent (kt)									
Annex A sources		1 Energy + indirect CO_2 from this sector	43'257	42'248	43'662	42'058	43'250	43'568	44'006	43'620	41'573	42'966
Annex A sources		2 Industrial processes and product use + indirect CO_2 from this sector	3'630	3'936	4'005	4'133	4'109	4'390	4'542	4'580	4'661	4'608
Annex A sources		3 Agriculture	6'124	6'232	6'242	6'159	6'028	6'000	6'132	6'089	6'204	6'245
Annex A sources		5 Waste + indirect CO_2 from this sector	826	832	847	861	839	856	848	847	830	813
Annex A sources		**Total (Annex A sources)**	**53'837**	**53'247**	**54'756**	**53'210**	**54'224**	**54'815**	**55'527**	**55'135**	**53'268**	**54'632**
KP-LULUCF	Art.3.3	Afforestation & Reforestation										-25
KP-LULUCF	Art.3.3	Deforestation										154
KP-LULUCF	Art.3.4	Forest management										-2'303
KP-LULUCF	Art.3.4	Cropland management										NA
KP-LULUCF	Art.3.4	Grazing land management										NA
KP-LULUCF	Art.3.4	Revegetation										NA

		Sector	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. base year*
			CO_2 equivalent (kt)										*%*
Annex A sources		1 Energy + indirect CO_2 from this sector	41'857	43'224	39'163	40'558	41'480	37'434	37'102	37'495	36'509	35'241	*-16%*
Annex A sources		2 Industrial processes and product use + indirect CO_2 from this sector	4'370	4'626	4'631	4'606	4'609	4'607	4'553	4'498	4'651	4'513	*16%*
Annex A sources		3 Agriculture	6'170	6'203	6'160	6'232	6'089	6'207	6'132	6'113	6'107	5'991	*-12%*
Annex A sources		5 Waste + indirect CO_2 from this sector	791	777	762	740	734	723	714	704	691	672	*-41%*
Annex A sources		**Total (Annex A sources)**	**53'188**	**54'830**	**50'716**	**52'136**	**52'912**	**48'971**	**48'501**	**48'810**	**47'958**	**46'417**	***-14%***
KP-LULUCF	Art.3.3	Afforestation & Reforestation	-25	-24	-22	-21	-20	-18	-19	-19	-19	-16	
KP-LULUCF	Art.3.3	Deforestation	161	165	165	166	166	147	136	129	154	165	
KP-LULUCF	Art.3.4	Forest management	-3'244	-3'198	-1'748	-2'955	-2'740	-1'435	-2'974	-2'920	-2'751	-1'278	
KP-LULUCF	Art.3.4	Cropland management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
KP-LULUCF	Art.3.4	Grazing land management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
KP-LULUCF	Art.3.4	Revegetation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Table E- 9 Contribution of individual gases to total emissions (excluding 4 LULUCF, 6 Other, and International bunkers) in CO_2 equivalent (kt), as well as emissions and removals under KP-LULUCF.

		GHG	Base year inital report	1990	1991	1992	1993	1994	1995	1996	1997	1998
			CO₂ equivalent (kt)									
Annex A sources		CO_2 + indirect CO_2	44'516	44'522	46'479	46'330	43'892	42'941	43'660	44'328	43'250	44'810
Annex A sources		CH_4	6'086	6'043	5'972	5'890	5'780	5'729	5'729	5'668	5'519	5'448
Annex A sources		N_2O	2'852	3'326	3'312	3'258	3'351	3'300	3'333	3'258	3'240	3'173
Annex A sources		HFCs	0.0	0.0	1.5	16	33	80	244	296	360	456
Annex A sources		PFCs	117	117	99	81	35	21	17	20	21	24
Annex A sources		SF_6	137	137	139	141	121	107	93	90	125	153
Annex A sources		NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Annex A sources		**Total (Annex A sources)**	**53'707**	**54'146**	**56'003**	**55'715**	**53'211**	**52'178**	**53'075**	**53'660**	**52'515**	**54'064**

		GHG	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
			CO₂ equivalent (kt)									
Annex A sources		CO_2 + indirect CO_2	44'626	43'785	45'239	43'611	44'782	45'354	45'902	45'488	43'478	44'823
Annex A sources		CH_4	5'362	5'306	5'347	5'303	5'222	5'188	5'203	5'220	5'202	5'272
Annex A sources		N_2O	3'144	3'307	3'247	3'274	3'077	3'004	3'116	3'009	3'105	2'979
Annex A sources		HFCs	533	636	736	827	910	1'010	1'048	1'160	1'253	1'275
Annex A sources		PFCs	32	61	37	36	67	69	50	62	52	45
Annex A sources		SF_6	140	152	151	161	166	190	207	197	178	239
Annex A sources		NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Annex A sources		**Total (Annex A sources)**	**53'837**	**53'247**	**54'756**	**53'210**	**54'224**	**54'815**	**55'527**	**55'135**	**53'268**	**54'632**
KP-LULUCF	Art.3.3	CO_2										127
KP-LULUCF	Art.3.3	CH_4										NO
KP-LULUCF	Art.3.3	N_2O										2.5
KP-LULUCF	Art.3.4	CO_2										-2'307
KP-LULUCF	Art.3.4	CH_4										2.7
KP-LULUCF	Art.3.4	N_2O										1.2

		GHG	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. base year*
			CO₂ equivalent (kt)										*%*
Annex A sources		CO_2 + indirect CO_2	43'642	45'154	41'087	42'355	43'283	39'329	38'823	39'278	38'268	36'981	*-17%*
Annex A sources		CH_4	5'180	5'154	5'099	5'070	5'006	5'003	4'973	4'930	4'868	4'839	*-20%*
Annex A sources		N_2O	2'868	3'012	2'941	3'001	2'901	2'881	2'910	2'889	3'082	2'879	*1%*
Annex A sources		HFCs	1'272	1'308	1'380	1'453	1'432	1'469	1'508	1'480	1'504	1'524	*see caption*
Annex A sources		PFCs	35	38	36	39	28	23	26	20	32	36	*-69%*
Annex A sources		SF_6	183	151	164	218	263	266	261	213	203	157	*15%*
Annex A sources		NF_3	7.6	12.7	9.3	0.5	0.1	0.6	0.7	0.8	0.8	0.5	*NA*
Annex A sources		**Total (Annex A sources)**	**53'188**	**54'830**	**50'716**	**52'136**	**52'912**	**48'971**	**48'501**	**48'810**	**47'958**	**46'417**	***-14%***
KP-LULUCF	Art.3.3	CO_2	132	139	141	142	143	126	114	107	133	146	
KP-LULUCF	Art.3.3	CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
KP-LULUCF	Art.3.3	N_2O	2.7	2.7	2.8	2.8	2.8	2.9	2.8	2.8	2.8	2.9	
KP-LULUCF	Art.3.4	CO_2	-3'248	-3'202	-1'754	-2'958	-2'743	-1'439	-2'977	-2'928	-2'756	-1'282	
KP-LULUCF	Art.3.4	CH_4	2.7	2.3	4.1	2.2	2.2	2.4	2.4	5.1	3.1	2.5	
KP-LULUCF	Art.3.4	N_2O	1.2	1.0	2.2	1.0	1.0	1.1	1.1	2.9	1.6	1.2	

ES.4. Other information

Emissions from precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-9). A strict air pollution control policy led to strong decreases in emissions of precursor gases and SO_2 over the period 1990–2018. The main reduction measures were abatement of exhaust emissions from road vehicles and stationary combustion equipment, taxation of solvents and sulphured fuels, and voluntary agreements within the industry sector.

PART 1

1 Introduction

Responsibilities for Introduction	
Author	Regine Röthlisberger (FOEN)
Calculation KCA	Anouk Bass (FOEN)
Calculation Uncertainties	Anouk Bass (FOEN), Michael Bock (FOEN)
Annual updates (NIR text, tables, figures)	Felix Weber (INFRAS, KCA, Uncertainties)
Quality control (annual updates)	Dominik Eggli (Meteotest, KCA), Beat Rihm (Meteotest, Uncertainties)
Internal review	Michael Bock (FOEN)

1.1 Background information on Swiss greenhouse gas inventories, climate change and supplementary information of the Kyoto Protocol (KP)

1.1.1 Information on climate change

The Swiss Academies of Sciences have published a comprehensive assessment of climate change and its impacts in Switzerland, both in the past and in the future (SCNAT 2016). Long-term measurements indicate a marked shift towards a warmer climate for Switzerland. Between 1864 and 2016, the average temperature in Switzerland has increased by +2.0 degrees Celsius compared to +0.9 degrees Celsius globally (FOEN 2018d).

In the course of the 21st century, Swiss climate is projected to depart significantly from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40%, while winter precipitation will likely increase, particularly in Southern Switzerland.

The retreat and massive loss of volume of glaciers in the Alps is the best visible indicator of the recent increase in atmospheric temperature. The changes of the glaciers in the Swiss Alps are measured every year and compiled by the network GLAMOS (www.glamos.ch). In recent years, evidence of vigorous impacts on glaciers has been accumulated, including collapse of structures on the glacier surface, disintegration into pieces, separation of glacier tongues from the main ice body at steep slopes, leaving dead ice in formerly covered areas. At various locations all over the Swiss Alps, glacier lakes have formed or grown as a result of continuing glacier retreat. From the ca. 2’900 square kilometres of glacier area in the mid-1970s, only about 2’100 square kilometres remained in 2003 and an estimated 1’900 square kilometres in 2013. Several studies indicate that Alpine glaciers are far out of balance with the current climate. Due to delayed response effects, glaciers would continue to shrink even without any further increase in temperature. If temperatures are going to increase further as projected by climate models e.g. Swiss Climate Change Scenarios (CH2018 2018), the loss of glacier mass will be even more dramatic. Modelling studies indicate a strong future area loss of 50–90% (for a temperature increase between two and six degrees Celsius) by 2100 for Switzerland and the entire Alps (FOEN 2018d).

The change in summer mean precipitation will have a marked impact on the hydrological cycle: on the Central Plateau and in the very south of Switzerland, small and medium watercourses will dry up more frequently and natural replenishment of groundwater will decrease accordingly. Apart from changes to the mean temperature and precipitation, the nature of extreme events is also expected to change (CH2018 2018). More frequent, intense and longer-lasting summer warm spells and heat waves are expected, while the number of cold winter days and nights decrease in the projections for future climate in Switzerland. This is particularly relevant for alpine areas, tourism and forestry due to the risk of more frequent floods, landslides and debris flows.

The warming trend and changing precipitation patterns are expected to have significant effects on ecosystems. The Biodiversity Monitoring Switzerland reports that impacts of climate change are already being observed with indicators such as the phenological spring phases, flowering indices and animal specific indices (FOEN 2018g). They show significant changes in a wide range of ecosystems during the last decades. Generally, climate change is expected to affect species composition, distribution, their cycles, synchronicity, the overall genetic diversity and the provision of ecosystem services. It will raise the vulnerability of forests and impair their protective, productive and social functions. Species distribution shifts towards higher elevations, spread of thermophile species, colonisation by new species from warmer areas, and phenological shifts. In the driest areas, increasing droughts are affecting tree survival and fish species are suffering from warm temperatures in lowland regions. River ecosystems will be doubly affected by climate change, i.e. by both the higher air temperature and the seasonal redistribution of river flows. Higher air temperatures together with the associated higher water temperatures and lower water levels in summer are likely to put pressure on river ecology and thereby also on fishing (FOEN 2018d).

In general, climate change in Switzerland is expected to entail a shift of suitable areas for agricultural production, and to involve both positive (e.g. a longer vegetation period) and negative (e.g. increasing incidence of pest infestations owing to milder winters) aspects. Changes in the nature of extreme weather events, in particular more frequent, intense and longer-lasting summer heat waves, could also challenge agriculture, e.g. by reducing the reliability of harvests. The extent to which climate change will affect agriculture will depend, however, on the regional settings, the overall political framework and the specific economic situation of the farms. Economic considerations are expected to play a crucial role for the adoption of adaptation measures (FOEN 2018d).

Various sectors of the Swiss economy are likely to be affected by progressing climate change. In particular, the tourism industry will be hit, as the potentially beneficial effects for summer tourism will not compensate for the loss of income in mountain resorts during winter due to scarcity of snow. Cable car stations may suffer from loosening of their anchorage due to instabilities of thawing permafrost soils. Hydroelectric power stations may be affected by altered runoff and sediment transport regimes, and insurance companies may face increased losses due to winter storms and floods. Natural hazards and extreme weather events potentially pose a growing risk to infrastructure and human health. Heat waves and elevated tropospheric ozone levels are cause for serious concern, as evidenced by the impacts of the heat waves in 2003, 2015, and 2018 (FOEN 2016l, FOEN 2019j). Finally, it remains to be seen to what extent vector borne diseases spread due to changing climatic conditions. Switzerland has recently analysed these challenges in detail and developed an effective adaptation strategy in order to hedge against negative effects resulting from climate change in Switzerland (FOEN 2012b).

1.1.2 Information on the greenhouse gas inventory

On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 1992). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC guidelines. From 1998 onwards, the inventories have been submitted in the Common Reporting Format (CRF). In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

On 9 July 2003, Switzerland ratified the Kyoto Protocol under the UNFCCC (UNFCCC 1998). In November 2006 Switzerland submitted its Initial Report under Article 7, paragraph 4 of the Kyoto Protocol (FOEN 2006h). The Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol has been implemented in 2006 and is fully operational. On 6 December 2007, the NIS quality management system was certified to comply with ISO 9001:2000 requirements; it has been audited and recertified several times with the latest audit on 19th June 2019 (ISO 9001:2015, Swiss Safety Center 2019). The quality management system includes the accounting and reporting of the National Registry as well. The April 2008 submission of the Swiss GHG inventory (FOEN 2008) has been Switzerland's first submission under both the UNFCCC and the Kyoto Protocol.

On 28 August 2015, Switzerland submitted its instrument of acceptance of the Doha amendment to the Kyoto Protocol (UNFCCC 2012) to the UNFCCC. The Initial Report for the second commitment period (FOEN 2016c) was submitted simultaneously with the inventory 2016. An update following the in-country review by an expert review team was submitted on 7th November 2016 to the UNFCCC secretariat (FOEN 2016d). In 2015, the inventory submission under the UNFCCC and under the Kyoto Protocol was restructured in accordance with the Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention (UNFCCC 2014a) and the Guidance for reporting information on activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (UNFCCC 2014b).

The 2020 inventory submission under the UNFCCC and under the Kyoto Protocol includes the NIR on hand, the greenhouse gas inventory 1990 to 2018, the Kyoto Protocol LULUCF tables 2008 to 2018 in the Common Reporting Format (CRF) and the Standard Electronic Format (SEF) tables as well as the standard independent assessment report (SIAR) from the National Registry.

1.1.3 Supplementary information required under art. 7.1. KP

Supplementary information required under art. 7.1 of the Kyoto Protocol is provided in Part 2 of the NIR. Information on KP-LULUCF is provided in chp. 11.

Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest management are capped in the second commitment period. Thus, for Switzerland the cap amounts to 3.5% of the 1990 emissions (excluding LULUCF).

Switzerland will account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d). In addition to the mandatory submission of the inventory years 2013–2018, selected data for the years 1990–2012 are shown in chp. 11

1.2 National inventory arrangements

1.2.1 Institutional, legal and procedural arrangements

Based on the Organisation Ordinance for the Federal Department of the Environment, Transport, Energy and Communications (DETEC), the Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. According to the decree of the Federal Council of 8 November 2006, the FOEN is in charge of the National Inventory System (NIS) (Figure 1-1). The Swiss National Inventory System was formally set up in 2006 in compliance with the requirements of the UNFCCC and the Kyoto Protocol (FOEN 2006h). In this context, the FOEN established the process "Climate Reporting", which covers maintaining the National Inventory System and fulfilling all reporting obligations under the UNFCCC and the Kyoto Protocol. The process, led and managed by the Climate division of the FOEN, is fully operational ever since and ensures timely fulfilment of Switzerland's reporting obligations.

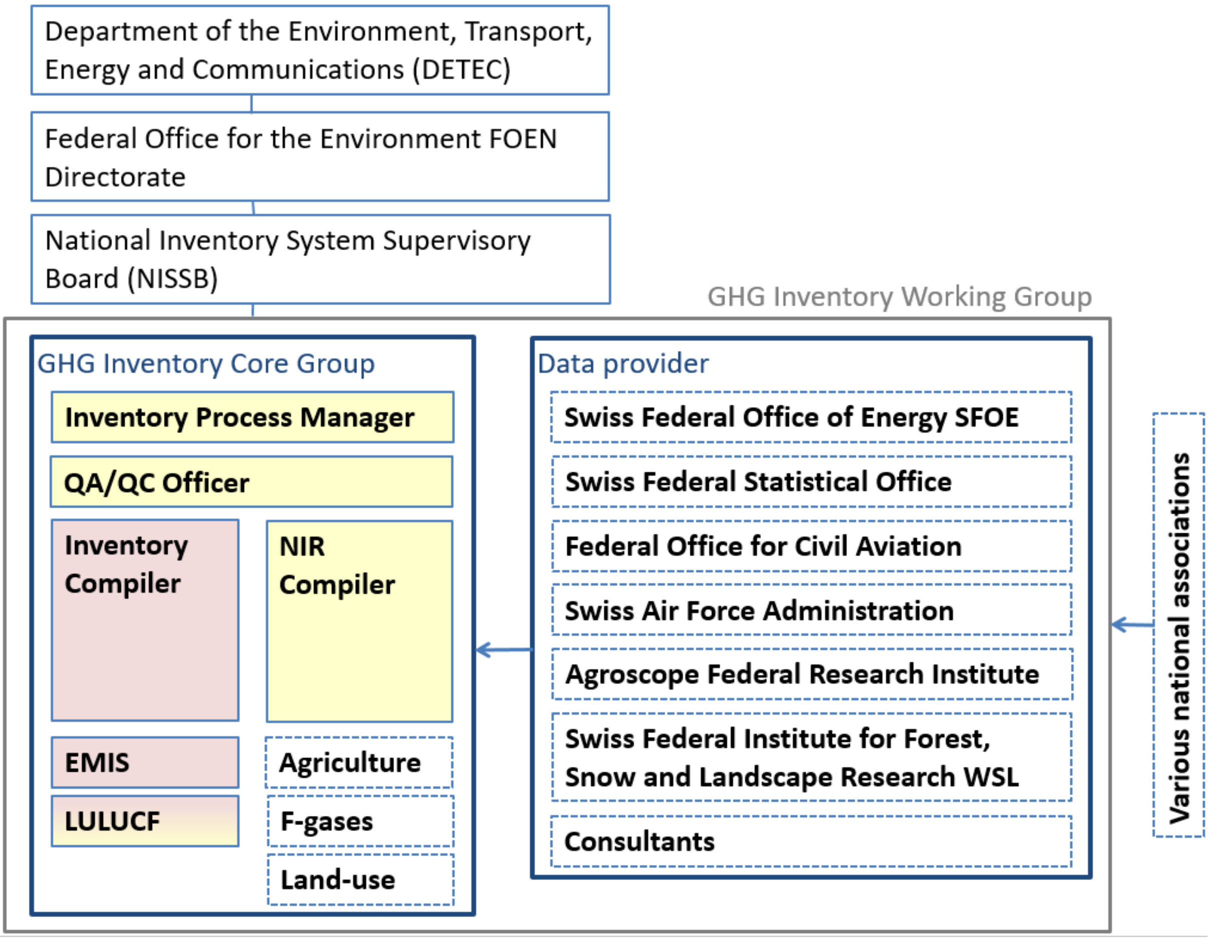


Figure 1-1 Institutional arrangements of the National Inventory System. Colours refer to divisions at FOEN. Yellow: Climate division, red: Air Pollution Control and Chemicals division, Forest division. Boxes with dashed lines refer to external mandates.

Legal arrangements

The CO_2 act (Swiss Confederation 2011) and the CO_2 ordinance (Swiss Confederation 2012) are the main legal instruments regarding climate policies. They also define the implementing bodies and, for all measures that are regulated at the national level, sanctions for non-compliance to climate policies and measures. The FOEN plays a central role in the development, evaluation and implementation of policies and measures.

With regard to statistical investigations, the legal basis is laid down in the Federal Statistics Act (Swiss Confederation 1992a) and the corresponding Ordinance on the Conduct of Federal Statistical Surveys (Swiss Confederation 1993). The greenhouse gas inventory, the institution responsible for it and the institutions contributing to it are explicitly listed in the ordinance.

Institutional arrangements

There are well-established agreements and long-standing collaborations with institutions of the federal administration and private entities (Table 1-1) that guarantee the continuity of the National Inventory System (Figure 1-1). While agreements with institutions of the federal administration are normally open-ended, several large contracts with private entities are on a four-year basis, with an option for renewal for another four-year term. This enables continuous collaboration and ensures the technical competence and experience of the staff involved.

The overall responsibility for the greenhouse gas inventory lies with the Climate division of the FOEN. The Air Pollution Control and Chemicals division of the FOEN maintains and updates the emissions database (greenhouse gases and air pollutants), named EMIS, in very close collaboration with the Climate division. The national energy statistics from the Federal Office of Energy (SFOE) provides the basis for the Energy sector. The Federal Office for Civil Aviation (FOCA) delivers the domestic and international aviation emissions. A consultancy (Carbotech) is mandated to survey and model fluorinated gases use and emissions and to provide an annual update thereof. Agriculture emissions are compiled by the Federal Research Institute Agroscope. For LULUCF, detailed area survey data are provided by the Swiss Federal Statistical Office (SFSO). Two consultancies (Sigmaplan/Meteotest) are mandated to process the area survey data to derive land-use and land-use change data and related emissions. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is in charge of the national forest inventory and forestry-related modelling, providing the relevant input for the Forest division of the FOEN, who is compiling forestry emissions and removals. The LULUCF sector is coordinated by a member of the Climate division of the FOEN. A collaboration between two consultancies (Meteotest/Infras) is mandated to support data handling in EMIS and updating the National Inventory Report (NIR).

Single national entity with overall responsibility for the inventory:

Federal Office for the Environment (FOEN)
Climate Division, Climate Reporting and Adaptation Section
Dr. Regine Röthlisberger, process manager
CH-3003 Bern, Switzerland
+41 58 462 92 59
climate@bafu.admin.ch
www.climatereporting.ch

Table 1-1 Overview of the institutional arrangements and tasks

Institutions of the federal administration	
FOEN Climate division	Overall responsibility for the greenhouse gas inventory
FOEN Air Pollution Control and Chemicals division	EMIS data base and data archiving
FOEN Forest division	Forestry emissions and removals
Swiss Federal Office of Energy (SFOE)	Energy statistics
Federal Office of Civil Aviation (FOCA)	Aviation emissions
Swiss Federal Statistical Office (SFSO)	Area surveys for (KP-) LULUCF
Swiss Federal Institute for Forest, Snow and Landscape Research WSL	National forest inventory, forestry related modelling
Agroscope Federal Research Institute	Agriculture emissions and removals
Private entities	
Carbotech	Fluorinated gases emissions
Meteotest	Harvested Wood Products
Sigmaplan / Meteotest	(KP-) LULUCF
Meteotest / Infras	Data handling and NIR editing

1.2.2 Overview of inventory planning, preparation and management

The process of inventory planning, preparation and management in Switzerland is well-established. Responsibilities and decision-making power are assigned to specific people or groups of people (Figure 1-1). The management responsibility for the NIS lies with the **National Inventory System Supervisory Board** (NISSB). The board consists of a member of the FOEN directorate and FOEN division heads of the relevant divisions (Climate, Forest, Air Pollution Control and Chemicals, International Affairs). In 2014 the NISSB, which originally covered the National Inventory System as well as the National Registry, was formally split into two separate boards with separate mandates and responsibilities. Since then, the NISSB is overseeing all aspects related to reporting obligations under the UNFCCC (including reporting of the National Registry in the NIR), while the Emission Registry Supervisory Board (ERSB) deals with management issues related to the National Registry.

At the operational level, the process of planning, preparation and management of the greenhouse gas inventory is led by the **process manager**. The **QA/QC officer** oversees design, development, and operation of the quality management system and is the primary contact point during the UN review process. The **Greenhouse gas (GHG) inventory core group** is the committee that combines all technical expertise required for greenhouse gas inventory planning, preparation and management. It consists of the process manager, the QA/QC officer, the inventory compiler, sectoral experts, as well as the NIR compiler. Additional experts join the core group as required. The GHG inventory core group ensures conformity of the inventory with the relevant UNFCCC reporting guidelines (UNFCCC 2014a), timely inventory preparation, and consideration and approval of methodological changes, choice of data and recalculations. The **GHG inventory working group** encompasses all technical personnel involved in the inventory preparation process or representing institutions that play a significant role as suppliers of data.

Inventory planning, preparation, and management follow an annual cycle according to a plan-do-check-act cycle (Table 1-2). Planning of the inventory cycle starts with the first meeting of the GHG inventory core group in May, where work is scheduled, priorities with regard to inventory development are set and decisions regarding planned improvements are taken. Data compilation usually starts in June with the first data sets for the preceding year becoming available. Quality control activities form part of the data acquisition process. They are routinely carried out by the EMIS (Swiss Emission Information System) experts and the sectoral experts. Usually, the UN review process in September provides further input to the inventory development plan (IDP). Recommendations and suggestions are discussed in the core group and future work is prioritized. The NIS supervisory board (NISSB) is provided with the management review in October and asked for formal approval of the planned way of proceeding. An important stage in inventory preparation is the preparation and quality control of the reporting tables (CRF) in December and January and the key category and uncertainty analyses towards end of January. The editing of the National Inventory Report (NIR) progresses alongside data compilation, with a draft of the NIR going into internal review in March. Suggestions from the internal review are dealt with before submission as far as possible. If the internal review suggests large revisions, they are taken up in the IDP for future improvements. The inventory is presented to the NISSB for official consideration and approval around end of March. Submission is coordinated by the process manager and carried out by the national inventory compiler. Archiving of inventory material is performed after submission by the EMIS and sectoral experts, by the contributing authors and by the QA/QC officer.

Table 1-2 Annual cycle of inventory planning, preparation and management

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Data compilation												
QC EMIS Experts												
QC Sectoral Experts												
UN Review												
Inventory Development Plan												
CRF Tables												
QC CRF Tables												
KCA / Uncertainties												
NIR												
Internal review NIR and CRF Tables												
Official consideration and approval												
Submission												x
Archiving												
Meeting of Core Group	x				x			x		x		
Meeting of Working Group												x
Meeting of NIS Supervisory Board						x					x	

1.2.3 Quality assurance, quality control and verification plan

The national inventory system has an established quality management system (QMS) that complies with the requirements of ISO 9001:2015. Certification has been obtained in 2007 and is upheld since through annual audits (Swiss Safety Center 2019). The QMS is designed to comply with the UNFCCC reporting guidelines (UNFCCC 2014a) to ensure and continuously improve transparency, consistency, comparability, completeness, accuracy, and confidence in national GHG emission and removal estimates. The quality manual (FOEN 2020a) contains all relevant information regarding the QMS. It is updated annually and made available to everyone contributing to the GHG inventory.

General QC procedures

The general QC activities as described in Table 6.1 of the IPCC reporting guidelines (IPCC 2006) are implemented in the annual cycle of inventory compilation (Table 1-2). Routine annual quality control procedures comprise checks related to new data and database operations, spot-checks for transcription errors, correct use of conversion factors and units, and correct calculations. There are checklists for the most important sectoral data suppliers and EMIS database experts.

Integrity of the database is ensured by creating a new database for every single submission and comparing the results from the new database with those from the previous version. Consistency of data between categories is to a large extent ensured by the design of the database, where specific emission factors and activity data that apply to various categories are used jointly by all categories to calculate emissions.

Checks regarding the correct aggregation are done on initial set-up of the various aggregations. There are also automated checks implemented in the database in order to identify incorrect internal aggregation processes.

Recalculations are compiled in a document and made available to the data compilers and the members of the GHG inventory core group, including the NIR authors. The recalculations file is of great importance in the QC procedures regarding the reporting tables (CRF) and in the preparation of the NIR. QC procedures regarding the reporting tables (CRF) comprise a detailed comparison of the reporting tables (CRF) of the previous submission with those of the latest submission for the base year and the latest common year. In addition, the time-series consistency is incrementally checked by comparing the latest inventory year with the preceding year. Any exceptional deviations are investigated by the sectoral or the EMIS database experts. These checks are performed in an iterative process: a first check is done by collaborators of the Climate division and sectoral experts, providing feedback and comments to the EMIS database experts. Based on the comments, changes to the reporting tables or database are made as required. The process is repeated two times before producing the final reporting tables.

The NIR is subject to an internal review prior to submission. The review of every section is carried out by personnel not involved in the preparation of the reviewed section, but who is familiar with the reporting under the UNFCCC. Archiving of the database and related internal documentation is carried-out by the inventory compiler, while any other material is archived on the internal data management system by the QA/QC officer. Publicly available material is published after submission on the website owned by the FOEN (www.climatereporting.ch).

Category-specific QC procedures

Whenever new emission factors are considered, they are compared to the IPCC default values and to the values used in previous years. If the values are based on better or more appropriate data and compare reasonably well with the IPCC default values (or if differences can be explained), the new values are presented to the core group for adoption in future inventories. Similarly, if new activity data have become available for a particular category, a comparison between existing and new activity data is made and if the new data provide a more consistent or more reliable basis for the inventory, they are again presented to the core group for inclusion in future inventories. Quite often, sectoral and/or EMIS experts commission research to look into a particular topic in more detail. Results from these mid- to long-term projects are presented to the inventory core group. The core group decides on how to best implement the results and documents the agreed procedure in the inventory development plan. The general procedures regarding category-specific QC is also described in the quality manual (FOEN 2020a), while specific activities are documented in the corresponding sectoral chapters.

Quality assurance procedures

As required by ISO 9001 there are periodic internal audits covering all processes. In addition, an external organisation is mandated to do the annual audit of the ISO 9001 quality management system.

Apart from these audits, there are expert peer reviews for specific sectors commissioned on a case-by-case basis. The results and suggestions for improvements from these reviews are discussed in the core group and specific tasks for future implementation are taken up into the inventory development plan. In 2017, an expert peer review for Harvested wood products (HWP) has been conducted (Didion 2017). In 2018, an expert peer review for wastewater treatment was completed with experts by the Eawag (Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz) (EAWAG 2018). In 2019, an expert peer review concerning F-gases has been conducted and results have been considered by the sectoral expert and the core group in the latest inventory preparation cycle (Reimann 2019). Previous expert peer reviews covered the Industrial Processes (CSD 2013), LULUCF (VTI 2011) and Waste sector (Rytec 2010). For 2020 an expert peer review concerning manure management is being planned.

Likewise, recommendations and encouragements from the UNFCCC expert review teams (ERT) are also added to the inventory development plan, discussed in the core group and implemented in future submissions. Specific actions resulting from suggestions from the ERT are listed in chp. 10 Recalculations.

Verification activities

In the energy sector, the standard verification activity carried out on an annual basis is the reference approach, as documented in chp. 3.2.1 of the NIR and CRF Table1.A(b).

In addition, the FOEN supports a long-term monitoring programme carried out by the Swiss Federal Laboratories for Materials Science and Technology (EMPA). In the frame of this programme, continuous measurements of atmospheric concentrations of various halogenated gases are made at the high-Alpine research station Jungfraujoch (3580 m asl), from which Swiss emissions of some fluorinated greenhouse gases can be estimated. These data are compared with the emissions reported in the greenhouse gas inventory. The results are briefly summarized in Annex A5.1.

Furthermore, an ongoing project is developing an independent estimate of CH_4 and N_2O emissions in Switzerland based on atmospheric measurements and inverse modelling of atmospheric transport. The results show a very good agreement between modelled emissions and emission estimates according to the greenhouse gas inventory for CH_4 and reasonable agreement within the uncertainties for N_2O. A summary of the current state of these verification activities is provided in Annex A5.2.

Treatment of Confidentiality Issues

Nearly all of the data necessary to compile the Swiss GHG inventory are publicly available. There are, however, a few exceptions:

(1) Emission data that refer to a single enterprise are in general confidential.

(2) The reporting of disaggregated emissions from F-gases is confidential (not confidential as aggregated data).

(3) In the civil aviation sub-sector one data source (FOCA 1991) has been marked confidential by the Federal Office of Civil Aviation (FOCA).

(4) Unpublished AREA land use statistics raw data have been temporarily classified confidential by the Swiss Federal Statistical Office (SFSO).

The FOEN collects the data needed for calculating emissions of HFCs, PFCs, NF_3 and SF_6 from private companies or industry associations. In the National Inventory Report, the activity data underlying emission estimates of HFCs, PFCs, NF_3 and SF_6 are only partly presented at the most disaggregated level for reasons of confidentiality. However, complete emissions are reported in aggregated tables.

Confidential data will be made available by the FOEN in line with the procedures agreed under the UNFCCC for the technical review of GHG inventories (UNFCCC 2015).

Public access to the Swiss Greenhouse Gas Inventory

FOEN operates a website (www.climatereporting.ch) where the Swiss GHG inventories (NIR, reporting tables, UNFCCC review reports), the Swiss National Communications and other reports submitted to the UNFCCC and the Kyoto Protocol may be downloaded. On this website, most papers, reports, domestic reviews, and other difficult-to-access materials (‘grey literature’) quoted in the Swiss GHG inventory are provided online. The climate reporting homepage thus provides the option for public review.

1.2.4 Changes in the national inventory arrangements since previous submission

Changes to institutional, legal and procedural arrangements (24/CP.19, 22. (a)):

No changes.

Changes in staff and capacity (24/CP.19, 22. (b)):

No changes.

Changes to national entity with overall responsibility for the inventory (24/CP.19, 22. (c)):

No changes.

Changes to the process of inventory planning (24/CP.19, 22.(d,e)/23./24.):

No changes.

Changes to the process of inventory preparation (24/CP.19, 25./26.):
No changes.

Changes to the process of inventory management (24/CP.19, 27.):
No changes.

1.3 Inventory preparation and data collection, processing, and storage

An overview over the inventory preparation is given above and is schematically shown in Figure 1-1. Each sector has an assigned sectoral expert who is responsible for conformity with the relevant reporting guidelines, selection of appropriate methods and data sources, and collection, processing and updating of data (see Figure 1-2).

For the sectors Energy, IPPU (excl. fluorinated gases) and Waste, data collection and processing is done by the Air Pollution Control and Chemicals division of the FOEN. Emissions of road and non-road transportation are provided by INFRAS, a consultancy mandated by the Traffic section of FOEN. The use of fluorinated gases and related emissions in the corresponding source categories of the IPPU sector are provided by Carbotech, a consultancy mandated by FOEN to collect and process relevant data. For Agriculture, data collection and processing is provided by Agroscope, the Federal Research Institute for Agriculture. Land-use and land use change data from the Swiss Federal Statistical Office is compiled by Meteotest/Sigmaplan, in close collaboration with the Forest division of the FOEN. The Swiss Federal Institute for Forest, Snow and Landscape Research WSL provides further input, which is processed by the Forest Division. Emission and removal estimates from forest land are calculated by the Forest division of the FOEN.

All people responsible for data collection and processing in a particular sector are preparing their data for import into the National Air Pollution Database EMIS, which compiles all inventory data, including activity data and emission factors. EMIS was originally established in the late 1980s in order to record and monitor emissions of air pollutants, but it has since been extended to cover greenhouse gases and additional emission sources. The original EMIS database underwent a full redesign and a migration to a new software platform in 2005/2006. In preparation for the submission in 2015, all processes relevant to the GHG inventory have been restructured according to the 2006 IPCC Guidelines (IPCC 2006) and the revised reporting tables (CRF). The software in use is called “Mesap”, Release 5.5.38 by Seven2one information systems (Seven2one 2014); it is running on commonly used laptops or desktop computers as client. The EMIS database is stored as SQL database on a server.

The EMIS database as well as background information on activity data and emission factors are archived by the national inventory compiler for each submission. In the sectors where data collection is made by EMIS experts (e.g. Energy, IPPU, Waste), additional background information is compiled as appropriate (e.g. interim worksheets; references; rationale for choice of methods, data sources, activity data, emission factors). Whenever such documents are cited, they are labelled as “EMIS 2020/NFR-Code” in this report.

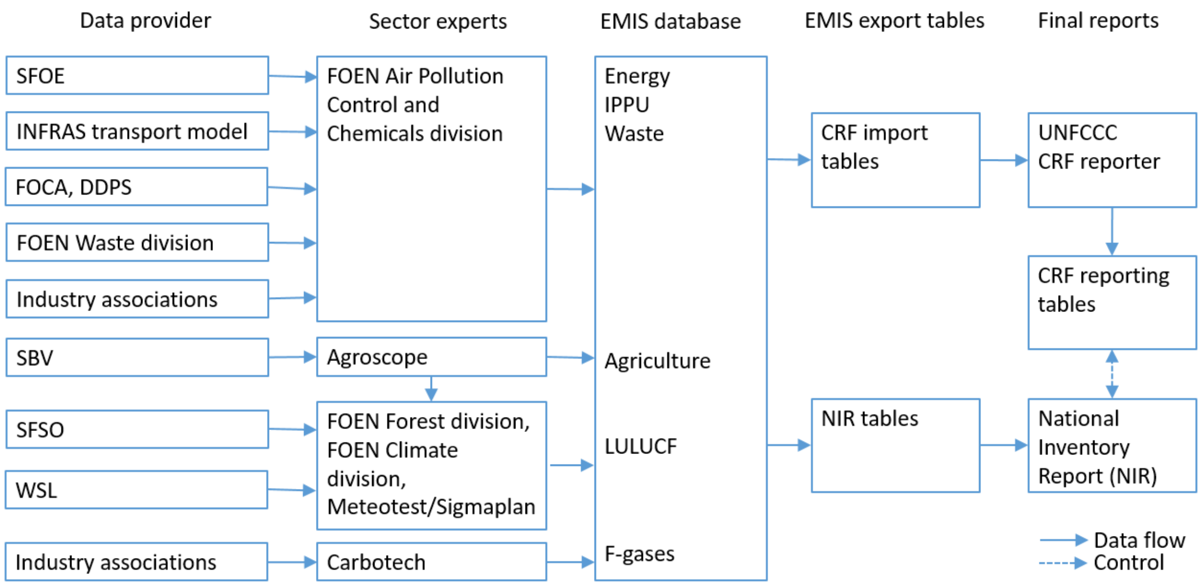


Figure 1-2 Schematic overview: Data collection and processing, compilation in EMIS database, import into CRF reporter and National Inventory Report (NIR). Abbreviations: see glossary.

1.4 Methodologies and data sources

According to the revised reporting guidelines under the UNFCCC (UNFCCC 2014a) and the Kyoto Protocol (UNFCCC 2014b), emissions are calculated based on standard methods and procedures provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) its 2019 Refinements (IPCC 2019), the 2013 KP supplement (IPCC 2014), and the 2013 wetlands supplement (IPCC 2014a). All key categories are estimated using Approach 2 or higher or country-specific methods. The methodological tier used is described in detail in the sectoral chapters of the NIR and compiled in CRF Summary3s1 and CRF Summary3s2.

Various data suppliers contribute to the greenhouse gas inventory (Table 1-3). While most data stem from official statistics either from the FOEN or from other federal offices, some data is drawn from national associations or consultancies that maintain well-established models or data-bases. Details on activity data and emission factors are provided in the sectoral chapters of the NIR.

Table 1-3 Primary data providers for the various inventory categories. Generally, statistics are updated annually. However, the on-road and non-road emission models of INFRAS, the complete area survey by the SFSO as well as the national forest inventory by the WSL require large efforts and are therefore updated every couple of years. Coloured boxes mark those sectors to which each data provider contributes. Abbreviations: see glossary.

Institution	**Subject**	**Inventory category (numbering according to reporting tables)**											
		1A1	1A2	1A3	1A4	1A5	1B	2	3	4 / KP	5	6	indir. CO2/ N2O
FOEN, Air Pollution Control and Chemicals division	EMIS database	■	■		■	■	■	■	■		■	■	■
FOEN, Climate division	Swiss ETS monitoring reports	■	■		■		■	■					
FOEN, Waste division	Waste statistics	■	■								■		
INFRAS	Road transportation emission model			■									
INFRAS	Non-road emission model		■	■	■	■							
SFOE	Swiss overall energy statistics	■	■	■	■		■				■		
SFOE	Swiss statistics of renewable energies	■	■	■	■						■		
SFOE	Swiss wood energy statistics	■	■		■								
SFOE	Energy consumption statistics in the industry and services sectors		■										
FOCA	Civil aviation			■									
Swiss Air Force Administration (DDPS)	Military aviation					■							
SGWA	Gas distribution losses						■						
Carbotech	F-gases, post-combustion of NMVOC							■					
Swissmem	National SF_6 balance							■					
SFSO	Agriculture, LULUCF								■	■			
Agroscope	Agriculture, LULUCF								■	■			
SBV	Agriculture								■				
FOEN, Forest division	Forest statistics									■			
WSL	National Forest Inventory									■			
Sigmaplan, Meteotest	LULUCF									■			

1.5 Description of key categories

The aim of the key category analysis (KCA) is to identify relevant categories that have a strong influence on Switzerland’s GHG inventory in terms of absolute emission and removal levels, trends and uncertainties (IPCC 2006, chp. 4). Data collection as well as quality assurance and control are prioritised for key categories during the inventory resource allocation.

1.5.1 GHG inventory

1.5.1.1 Methodology

The key category analysis is performed according to the 2006 IPCC Guidelines (IPCC 2006, chp. 4) and Decision 24/CP.19 (UNFCCC 2014a, Annex 1, Para. 39) for 1990 and the latest reported year 2018 including all GHG (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3). A total of 164 categories (including categories from the LULUCF sector) are used to disaggregate Switzerland’s total GHG emissions for the purpose of this key category analysis. The disaggregation level of the categories is selected based on country-specific relevance, i.e. the most important sources in Switzerland are disaggregated on a more detailed level. A table showing the key category analysis with all 164 categories is provided in Annex 1 (Table A – 1).

Both, Approach 1 (with a proposed threshold of 95%) and Approach 2 (with a proposed threshold of 90%) level and trend assessments are applied, including emissions from sector 4 LULUCF. A tool directly implemented in the software Mesap of the emissions database EMIS is used (Seven2one 2017). Indirect CO_2 emissions are included in the key category analysis, indirect N_2O emissions are not.

Uncertainty data for key category analysis Approach 2 stem from the uncertainty analysis Approach 1 (see chp. 1.6.1.2) and therefore do not incorporate any correlations.

1.5.1.2 KCA (including LULUCF categories)

Approach 1

For 2018, among the total of 164 categories, 32 are identified as **level key categories** under Approach 1 (see Table 1-4).

15 of the key categories belong to sector 1 Energy, accounting for the largest share of CO_2 equivalent emissions in 2018. The other key categories are more or less equally distributed between sectors 2 Industrial processes and product use (4 key categories), 3 Agriculture (6 key categories), 4 LULUCF (5 key categories) and 5 Waste (2 key categories).

Within the ten most relevant key categories (level contribution), only 3A Enteric fermentation and 2A1 Cement production are not part of sector 1 Energy.

Table 1-4 Switzerland's Approach 1 level key categories for the year 2018 including LULUCF categories, sorted by emission contribution to the national total.

APPROACH 1 LEVEL ASSESSMENT FOR 2018						
A	B	C	D	E	F	G
Code	IPCC Category	GHG	Ex,t (kt CO2 eq)	|Ex,t| (kt CO2 eq)	Lx,t	Cumula-tive Total
1A3b	Road transportation: Diesel	CO2	7373	7373	14.9%	14.9%
1A3b	Road transportation: Gasoline	CO2	7082	7082	14.3%	29.2%
1A4b	Residential: Liquid fuels	CO2	5016	5016	10.1%	39.4%
3A	Enteric Fermentation	CH4	3296	3296	6.7%	46.1%
1A4b	Residential: Gaseous fuels	CO2	2580	2580	5.2%	51.3%
1A1	Energy industries: Other fuels	CO2	2482	2482	5.0%	56.3%
1A4a	Commercial: Liquid fuels	CO2	2294	2294	4.6%	60.9%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	2205	2205	4.5%	65.4%
1A2	Manufacturing industries and construction: Liquid fuels	CO2	1741	1741	3.5%	68.9%
2A1	Cement production	CO2	1738	1738	3.5%	72.4%
2F1	Refrigeration and air conditioning	HFC	1410	1410	2.9%	75.3%
1A4a	Commercial: Gaseous fuels	CO2	1189	1189	2.4%	77.7%
4A1	Forest land remaining forest land	CO2	-1145	1145	2.3%	80.0%
3Da	Direct emissions from managed soils	N2O	1101	1101	2.2%	82.2%
3B1-3B4	Manure management	CH4	743	743	1.5%	83.7%
2B10	Chemical industry other	N2O	555	555	1.1%	84.9%
4A2	Land converted to forest land	CO2	-526	526	1.1%	85.9%
1A1	Energy industries: Gaseous fuels	CO2	511	511	1.0%	87.0%
1A4c	Agriculture and forestry: Liquid fuels	CO2	468	468	0.9%	87.9%
1A2	Manufacturing industries and construction: Other fuels	CO2	438	438	0.9%	88.8%
3Db	Indirect emissions from managed soils	N2O	397	397	0.8%	89.6%
1A2	Manufacturing industries and construction: Solid fuels	CO2	397	397	0.8%	90.4%
4B1	Cropland remaining cropland	CO2	-356	356	0.7%	91.1%
1A1	Energy industries: Liquid fuels	CO2	339	339	0.7%	91.8%
5A	Solid waste disposal	CH4	303	303	0.6%	92.4%
3B5	Indirect N2O emissions from manure management	N2O	272	272	0.6%	93.0%
4C2	Land converted to grassland	CO2	220	220	0.4%	93.4%
4E2	Land converted to settlements	CO2	210	210	0.4%	93.8%
1B2	Oil and natural gas energy production	CH4	191	191	0.4%	94.2%
5D	Wastewater treatment and discharge	CH4	189	189	0.4%	94.6%
2G	Other product manufacture and use	SF6	147	147	0.3%	94.9%
3B1-3B4	Manure management	N2O	135	135	0.3%	95.2%

For the **base year 1990**, 32 categories are identified as **level key categories** under Approach 1 (see Table 1-5). The following categories are key according to level in the base year 1990, but not anymore in the latest reported year:

- 1A3a Civil Aviation, Liquid Fuels, CO_2
- 1A5 Other (Military), Liquid fuels, CO_2
- 2 Indirect CO_2 emissions, CO_2
- 4G HWP Harvested wood products, CO_2 biog.

On the other hand, the following categories are key according to level in the latest reported year, but not in the base year 1990:

- 2F1 Refrigeration and air conditioning, HFC
- 2G Other product manufacture and use, SF_6
- 4C2 Land converted to grassland, CO_2
- 5D Wastewater treatment and discharge, CH_4

Table 1-5 Switzerland's Approach 1 level key categories for the base year 1990 including LULUCF categories, sorted by emission contribution to the national total.

APPROACH 1 LEVEL ASSESSMENT FOR BASE YEAR						
A	**B**	**C**	**D**	**E**	**F**	**G**
Code	**IPCC Category**	**GHG**	**Ex,0 (kt CO2 eq)**	**|Ex,0| (kt CO2 eq)**	**Lx,0**	**Cumula-tive Total of Column F**
1A3b	Road transportation: Gasoline	CO2	11334	11334	19.6%	19.6%
1A4b	Residential: Liquid fuels	CO2	10099	10099	17.4%	37.0%
1A2	Manufacturing industries and construction: Liquid fuels	CO2	3974	3974	6.9%	43.9%
1A4a	Commercial: Liquid fuels	CO2	3918	3918	6.8%	50.6%
3A	Enteric Fermentation	CH4	3585	3585	6.2%	56.8%
1A3b	Road transportation: Diesel	CO2	2633	2633	4.5%	61.4%
2A1	Cement production	CO2	2581	2581	4.5%	65.8%
1A1	Energy industries: Other fuels	CO2	1492	1492	2.6%	68.4%
1A4b	Residential: Gaseous fuels	CO2	1451	1451	2.5%	70.9%
3Da	Direct emissions from managed soils	N2O	1286	1286	2.2%	73.1%
1A2	Manufacturing industries and construction: Solid fuels	CO2	1275	1275	2.2%	75.3%
4G	HWP Harvested wood products	CO2 biog.	-1169	1169	2.0%	77.3%
4A1	Forest land remaining forest land	CO2	-1110	1110	1.9%	79.3%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	1091	1091	1.9%	81.1%
1A4a	Commercial: Gaseous fuels	CO2	920	920	1.6%	82.7%
3B1-3B4	Manure management	CH4	891	891	1.5%	84.3%
5A	Solid waste disposal	CH4	770	770	1.3%	85.6%
1A4c	Agriculture and forestry: Liquid fuels	CO2	742	742	1.3%	86.9%
1A1	Energy industries: Liquid fuels	CO2	686	686	1.2%	88.1%
3Db	Indirect emissions from managed soils	N2O	577	577	1.0%	89.1%
4A2	Land converted to forest land	CO2	-524	524	0.9%	90.0%
2B10	Chemical industry other	N2O	432	432	0.7%	90.7%
1B2	Oil and natural gas energy production	CH4	336	336	0.6%	91.3%
2	Indirect CO2 emissions	CO2	333	333	0.6%	91.9%
4E2	Land converted to settlements	CO2	255	255	0.4%	92.3%
1A3a	Civil aviation: Liquid fuels	CO2	253	253	0.4%	92.7%
3B5	Indirect N2O emissions from manure management	N2O	245	245	0.4%	93.2%
1A1	Energy industries: Gaseous fuels	CO2	243	243	0.4%	93.6%
4B1	Cropland remaining cropland	CO2	235	235	0.4%	94.0%
1A5	Other (military): Liquid fuels	CO2	218	218	0.4%	94.4%
3B1-3B4	Manure management	N2O	194	194	0.3%	94.7%
1A2	Manufacturing industries and construction: Other fuels	CO2	192	192	0.3%	95.0%

Regarding the **trend assessment** between the base year 1990 and the latest reported year, 34 categories are identified as trend key categories under Approach 1 (see Table 1-6).

Table 1-6 Switzerland's Approach 1 trend key categories between 1990 and 2018 including LULUCF categories, sorted by contribution to the trend assessment.

APPROACH 1 TREND ASSESSMENT FOR 2018							
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Code	**IPCC Category**	**GHG**	**Ex,0 (kt CO2 eq)**	**Ex,t (kt CO2 eq)**	**Trend Assess-ment**	**Contri-bution to Trend**	**Cumula-tive Total of Column G**
1A3b	Road transportation: Diesel	CO2	2633	7373	0.088%	18.6%	18.6%
1A4b	Residential: Liquid fuels	CO2	10099	5016	0.064%	13.5%	32.1%
1A3b	Road transportation: Gasoline	CO2	11334	7082	0.047%	9.9%	42.0%
1A2	Manufacturing industries and construction: Liquid fuels	CO2	3974	1741	0.029%	6.2%	48.2%
2F1	Refrigeration and air conditioning	HFC	0	1410	0.024%	5.1%	53.3%
1A4b	Residential: Gaseous fuels	CO2	1451	2580	0.023%	4.8%	58.2%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	1091	2205	0.022%	4.6%	62.8%
4G	HWP Harvested wood products	CO2 biog.	-1169	-78	0.022%	4.6%	67.3%
1A1	Energy industries: Other fuels	CO2	1492	2482	0.021%	4.3%	71.7%
1A4a	Commercial: Liquid fuels	CO2	3918	2294	0.019%	4.0%	75.7%
1A2	Manufacturing industries and construction: Solid fuels	CO2	1275	397	0.012%	2.6%	78.2%
4B1	Cropland remaining cropland	CO2	235	-356	0.010%	2.0%	80.3%
2A1	Cement production	CO2	2581	1738	0.008%	1.8%	82.1%
1A4a	Commercial: Gaseous fuels	CO2	920	1189	0.007%	1.4%	83.5%
5A	Solid waste disposal	CH4	770	303	0.006%	1.3%	84.8%
1A1	Energy industries: Gaseous fuels	CO2	243	511	0.005%	1.1%	85.9%
1A2	Manufacturing industries and construction: Other fuels	CO2	192	438	0.005%	1.0%	86.9%
1A1	Energy industries: Liquid fuels	CO2	686	339	0.004%	0.9%	87.8%
3A	Enteric Fermentation	CH4	3585	3296	0.003%	0.7%	88.5%
2	Indirect CO2 emissions	CO2	333	91	0.003%	0.7%	89.3%
2B10	Chemical industry other	N2O	432	555	0.003%	0.7%	89.9%
1A4c	Agriculture and forestry: Liquid fuels	CO2	742	468	0.003%	0.6%	90.6%
4C2	Land converted to grassland	CO2	89	220	0.002%	0.5%	91.1%
2C3	Aluminium production	CO2	139	0	0.002%	0.4%	91.5%
1A3b	Road transportation: Gasoline	N2O	160	19	0.002%	0.4%	92.0%
4A1	Forest land remaining forest land	CO2	-1110	-1145	0.002%	0.4%	92.4%
1A3a	Civil aviation: Liquid fuels	CO2	253	115	0.002%	0.4%	92.8%
3Db	Indirect emissions from managed soils	N2O	577	397	0.002%	0.4%	93.1%
2C3	Aluminium production	PFC	116	0	0.002%	0.4%	93.5%
1B2	Oil and natural gas energy production	CH4	336	191	0.002%	0.4%	93.9%
1A3b	Road transportation: Diesel	N2O	6	97	0.002%	0.3%	94.2%
1A3b	Road transportation: Gasoline	CH4	109	15	0.001%	0.3%	94.5%
5D	Wastewater treatment and discharge	CH4	131	189	0.001%	0.3%	94.8%
1A4b	Residential: Biomass	CH4	110	23	0.001%	0.3%	95.0%

Approach 2

Given that the threshold is set at 90%, the number of key categories is smaller under Approach 2 compared to Approach 1 for both, level and trend assessment.

Concerning the **level assessment**, 26 out of 164 categories are identified as key categories for the latest reported year (see Table 1-7).

Table 1-7 Switzerland's Approach 2 level key categories for the year 2018 including LULUCF categories, sorted by contribution to the uncertainty of the level assessment.

APPROACH 2 LEVEL ASSESSMENT FOR 2018						
A	**B**	**C**	**D**	**E**	**F**	**G**
Code	**IPCC Category**	**GHG**	**Ex,t (kt CO2 eq)**	**|Ex,t| (kt CO2 eq)**	**Lx,t**	**Cumula-tive Total of Column F**
3Da	Direct emissions from managed soils	N2O	1101	1101	13.8%	13.8%
4C1	Grassland remaining grassland	CO2	96	96	12.0%	25.8%
3B5	Indirect N2O emissions from manure management	N2O	272	272	9.9%	35.7%
3Db	Indirect emissions from managed soils	N2O	397	397	9.0%	44.7%
3A	Enteric Fermentation	CH4	3296	3296	6.4%	51.1%
4A1	Forest land remaining forest land	CO2	-1145	1145	5.4%	56.5%
4B1	Cropland remaining cropland	CO2	-356	356	4.8%	61.2%
3B1-3B4	Manure management	CH4	743	743	4.1%	65.3%
2B10	Chemical industry other	N2O	555	555	3.4%	68.7%
1A1	Energy industries: Other fuels	CO2	2482	2482	2.6%	71.3%
4A2	Land converted to forest land	CO2	-526	526	2.5%	73.8%
2F1	Refrigeration and air conditioning	HFC	1410	1410	2.2%	76.0%
5D	Wastewater treatment and discharge	N2O	100	100	1.6%	77.6%
1A4b	Residential: Gaseous fuels	CO2	2580	2580	1.4%	78.9%
2	Indirect CO2 emissions	CO2	91	91	1.3%	80.2%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	2205	2205	1.1%	81.4%
4E2	Land converted to settlements	CO2	210	210	1.1%	82.4%
5D	Wastewater treatment and discharge	CH4	189	189	1.0%	83.4%
4C2	Land converted to grassland	CO2	220	220	1.0%	84.4%
5A	Solid waste disposal	CH4	303	303	1.0%	85.4%
4D1	Wetland remaining wetland	CO2	65	65	0.9%	86.3%
3B1-3B4	Manure management	N2O	135	135	0.9%	87.2%
2A1	Cement production	CO2	1738	1738	0.8%	88.0%
2G	Other product manufacture and use	SF6	147	147	0.8%	88.7%
4III	Direct N2O from disturbance	N2O	36	36	0.7%	89.4%
1A3b	Road transportation: Diesel	CO2	7373	7373	0.7%	90.1%

Regarding the **trend assessment** between the base year 1990 and the latest reported year, 30 categories are identified as trend key categories under Approach 2 (see Table 1-8).

Table 1-8 Switzerland's Approach 2 trend key categories between 1990 and 2018 including LULUCF categories, sorted by contribution to the trend assessment.

APPROACH 2 TREND ASSESSMENT WITH UNCERTAINTIES FOR 2018							
A	B	C	D	E	F	G	H
Code	**IPCC Category**	**GHG**	**Ex,0 (kt CO2 eq)**	**Ex,t (kt CO2 eq)**	**Trend Assess-ment**	**Contri-bution to Trend**	**Cumula-tive Total of Column G**
4B1	Cropland remaining cropland	CO2	234	-354	1.292%	16.6%	16.6%
4G	HWP Harvested wood products	CO2 biog.	-1165	-79	1.216%	15.6%	32.3%
4C1	Grassland remaining grassland	CO2	41	99	1.214%	15.6%	47.9%
2	Indirect CO2 emissions	CO2	332	91	0.486%	6.3%	54.2%
2F1	Refrigeration and air conditioning	HFC	0	1410	0.378%	4.9%	59.0%
1A1	Energy industries: Other fuels	CO2	1493	2484	0.216%	2.8%	61.8%
3Db	Indirect emissions from managed soils	N2O	1088	747	0.211%	2.7%	64.5%
5A	Solid waste disposal	CH4	770	303	0.198%	2.5%	67.1%
2B10	Chemical industry other	N2O	433	559	0.186%	2.4%	69.5%
3B5	Indirect N2O emissions from manure management	N2O	575	635	0.162%	2.1%	71.5%
1A4b	Residential: Gaseous fuels	CO2	1451	2580	0.120%	1.5%	73.1%
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	1091	2205	0.110%	1.4%	74.5%
4C2	Land converted to grassland	CO2	89	220	0.108%	1.4%	75.9%
1A3b	Road transportation: Gasoline	N2O	160	19	0.103%	1.3%	77.2%
2F2	Foam blowing agents	HFC	0	29	0.094%	1.2%	78.4%
4A1	Forest land remaining forest land	CO2	-1106	-1144	0.094%	1.2%	79.6%
1A2	Manufacturing industries and construction: Solid fuels	CO2	1275	397	0.089%	1.1%	80.8%
2G	Other product manufacture and use	N2O	107	31	0.086%	1.1%	81.9%
5D	Wastewater treatment and discharge	N2O	80	99	0.083%	1.1%	83.0%
1A3b	Road transportation: Diesel	CO2	2633	7373	0.078%	1.0%	84.0%
5D	Wastewater treatment and discharge	CH4	130	189	0.068%	0.9%	84.8%
3A	Enteric Fermentation	CH4	3648	3353	0.064%	0.8%	85.7%
4A2	Land converted to forest land	CO2	-525	-525	0.056%	0.7%	86.4%
1B2	Oil and natural gas energy production	CH4	336	191	0.053%	0.7%	87.1%
1A2	Manufacturing industries and construction: Other fuels	CO2	192	438	0.051%	0.7%	87.7%
1A3b	Road transportation: Gasoline	CH4	108	15	0.050%	0.6%	88.4%
1A4b	Residential: Liquid fuels	CO2	10099	5015	0.044%	0.6%	88.9%
2G	Other product manufacture and use	HFC	0	63	0.041%	0.5%	89.5%
1A4b	Residential: Biomass	CH4	110	23	0.039%	0.5%	90.0%
2A1	Cement production	CO2	2581	1738	0.038%	0.5%	90.5%

Comparison of the results of KCA Approaches 1 and 2

Due to large differences in the uncertainties of specific categories, the key category analyses under Approach 1 and Approach 2 show different results. This is particularly the case for large source categories in the energy sector with relatively small uncertainties, which dominate the level assessment in Approach 1, and large source and/or sink categories in the agriculture or LULUCF sector with large uncertainties, which dominate the level assessment in Approach 2.

Several categories being key categories under Approach 1 are not key anymore when assessed with Approach 2. Nevertheless, there are nine categories only being key under Approach 2 (for the reporting year 2018):

- 2 Indirect CO_2 emissions, CO_2 (level)
- 2F2 Foam blowing agents, HFC (trend)
- 2G Other product manufacture and use, N_2O (trend)
- 2G Other product manufacture and use, HFC (trend)
- 3B5 Indirect N_2O emissions from manure management, N_2O (trend)
- 4A2 Land converted to forest land, CO_2 (trend)
- 4C1 Grassland remaining grassland, CO_2 (level and trend)
- 4III Direct N_2O from disturbance, N_2O (level)
- 5D Wastewater treatment and discharge, N_2O (level and trend)

Most of the categories listed above, which are only key under the Approach 2 assessment, are subject to rather high uncertainties (combined uncertainties according to uncertainty analysis, see Annex A2.1).

1.5.1.3 Summary of combined KCA including LULUCF categories

A summary of the key category analysis for 2018 including LULUCF categories is shown in Table 1-9, considering level and trend assessments for both, Approach 1 and Approach 2.

Table 1-9 Summary of Switzerland's combined KCA for the year 2018 including LULUCF categories, sorted by NFR code (first column). The abbreviations used in the last column indicate both, the approach and whether a certain category is identified as key because of the level or trend assessment (L1 = level according to Approach 1, T1 = trend according to Approach 1; L2 = level according to Approach 2, T2 = trend according to Approach 2).

SUMMARIES TO IDENTIFY KEY CATEGORIES			
A	**B**	**C**	**D**
Code	**IPCC Category**	**GHG**	**Identification Criteria**
1A1	Energy industries: Gaseous fuels	CO2	L1, T1
1A1	Energy industries: Liquid fuels	CO2	L1, T1
1A1	Energy industries: Other fuels	CO2	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Liquid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction: Other fuels	CO2	L1, T1, T2
1A2	Manufacturing industries and construction: Solid fuels	CO2	L1, T1, T2
1A3a	Civil aviation: Liquid fuels	CO2	T1
1A3b	Road transportation: Gasoline	CH4	T1, T2
1A3b	Road transportation: Gasoline	CO2	L1, T1
1A3b	Road transportation: Gasoline	N2O	T1, T2
1A3b	Road transportation: Diesel	CO2	L1, L2, T1, T2
1A3b	Road transportation: Diesel	N2O	T1
1A4a	Commercial: Gaseous fuels	CO2	L1, T1
1A4a	Commercial: Liquid fuels	CO2	L1, T1
1A4b	Residential: Biomass	CH4	T1, T2
1A4b	Residential: Gaseous fuels	CO2	L1, L2, T1, T2
1A4b	Residential: Liquid fuels	CO2	L1, T1, T2
1A4c	Agriculture and forestry: Liquid fuels	CO2	L1, T1
1B2	Oil and natural gas energy production	CH4	L1, T1, T2
2A1	Cement production	CO2	L1, L2, T1, T2
2B10	Chemical industry other	N2O	L1, L2, T1, T2
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFC	T1
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, T2
2F2	Foam blowing agents	HFC	T2
2G	Other product manufacture and use	HFC	T2
2G	Other product manufacture and use	N2O	T2
2G	Other product manufacture and use	SF6	L1, L2
2	Indirect CO2 emissions	CO2	L2, T1, T2
3A	Enteric Fermentation	CH4	L1, L2, T1, T2
3B1-3B4	Manure management	CH4	L1, L2
3B1-3B4	Manure management	N2O	L1, L2
3B5	Indirect N2O emissions from manure management	N2O	L1, L2, T2
3Da	Direct emissions from managed soils	N2O	L1, L2
3Db	Indirect emissions from managed soils	N2O	L1, L2, T1, T2
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T2
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2
4C1	Grassland remaining grassland	CO2	L2, T2
4C2	Land converted to grassland	CO2	L1, L2, T1, T2
4D1	Wetland remaining wetland	CO2	L2
4E2	Land converted to settlements	CO2	L1, L2
4G	HWP Harvested wood products	CO2 biog.	T1, T2
4III	Direct N2O from disturbance	N2O	L2
5A	Solid waste disposal	CH4	L1, L2, T1, T2
5D	Wastewater treatment and discharge	CH4	L1, L2, T1, T2
5D	Wastewater treatment and discharge	N2O	L2, T2

1.5.2 KP-LULUCF inventory

Switzerland identified 2 key categories for activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (Forest management and Deforestation). The approach relies on full inventory KCA (with LULUCF), KP – CRF association and qualitative assessment. A detailed description is presented in chp. 11.6.1.

1.6 General uncertainty evaluation

1.6.1 GHG inventory

This chapter presents the main results of the uncertainty evaluation concerning the GHG inventory.

1.6.1.1 Methodology

The uncertainty analyses are conducted in accordance with the 2006 IPCC Guidelines (IPCC 2006/Chapter 3 Uncertainties) and calculated using spreadsheets. Important assumptions and requirements for both approaches are described in the IPCC guidelines (IPCC 2006). Here, we only recapitulate the main aspects of both approaches:

- Approach 1: based on propagation of error, uncertainty in the emission level in the latest reported year and in the trend between the latest reported year and the base year (1990) is estimated for the inventory total and for the single source categories and gases using uncertainty ranges of corresponding activity data and emission factors.
- Approach 2: is based on Monte Carlo analysis (IPCC 2006, UNFCCC 2014a). This approach provides a detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity data, emission factors or both. The principle of Monte Carlo analysis is to select random values for emission factor and activity data from within their individual probability distributions, and to calculate the corresponding emission values. This procedure is repeated 100’000 times until an adequately stable result has been found, i.e. until the change of the simulated mean of the total GHG emissions is small. The results of all realisations yield the overall emission probability distribution.

No Approach 2 uncertainty analysis is conducted for submission 2020. Provided that the necessary resources are available, Approach 2 will be implemented in the EMIS database software and reported again in future submissions.

All uncertainties are given as half of the 95% confidence interval divided by the mean and expressed as a percentage (approximately two standard deviations) as suggested by the 2006 IPCC Guidelines (IPCC 2006).

For Approach 1 and concerning correlations across years, uncertainties have been calculated assuming no correlations for AD and assuming correlations for all EF, in accordance with previous submissions. In order to estimate the sensitivity regarding these assumptions, no/complete correlations of AD and/or EF across years were implemented in the calculation.

The following chapters present the overall results of the uncertainty evaluation. Specific information about the uncertainty estimation for activity data, emission factors or emissions of each source category is included in the respective sectoral chapters (chp. 3 to 9) below. Detailed results of the Approach 1 assessment is presented in Annex 2.

1.6.1.2 Data used

The evaluation includes uncertainties regarding activity data, emission factors and – in a few cases – emissions. Uncertainties in the GWP values are not taken into account. Uncertainties are estimated for the latest reported year only (except LULUCF). Several uncertainty values have been changed for submission 2020. For instance, in sector 3 Agriculture triangular probability distributions are assumed. Hence, in these cases the 97.5th percentile of the probability distributions is used as input for the calculation of Approach 1 uncertainties, according to the guidelines (IPCC 2006). There have also been changes of uncertainties in the energy sector (e.g. EF uncertainty for 1A3a Domestic aviation, CH_4, or EF uncertainty for 1A5 Other, liquid fuels, CH_4), in the IPPU sector (e.g. EF and AD uncertainty for 2E3 Photovoltaics, NF_3), in the agriculture sector (e.g. EF and AD uncertainty for 3B Manure management Indirect, N_2O; or EF and AD uncertainty for 3Db Indirect emissions managed soils, N_2O) and in the LULUCF sector (e.g. EF uncertainty for 4B Cropland remaining cropland, CO_2, or EF uncertainty for 4C1 Grassland remaining grassland, CO_2).

For categories with quantitative uncertainty data available, the input information from studies or from the data suppliers is used for the uncertainty evaluation. This is mainly the case for key categories. However, no explicit information on uncertainties is available for a few key categories. For these cases, authors of the NIR chapters, FOEN experts involved and several data suppliers derived estimates of uncertainties based on the 2006 IPCC Guidelines (IPCC 2006) default values and on information concerning the process of data collection for activity data and emission factors (import or sales statistics, surveys or modelling). Several experts from data suppliers were contacted for further information on some of the uncertainties. Industry associations/sources also provided published or unpublished uncertainty estimates for their data. The data sources can be found in the relevant sub-sections on “Uncertainties and time-series consistency” in each of the sectoral chapters (chp. 3 to 9) below.

For categories with no quantitative uncertainty data available, the NIR provides qualitative estimates of uncertainties. The elaboration of a quantitative uncertainty assessment for these categories would present a large effort with only limited effect on the overall uncertainty and therefore it has been decided to realize a semi-quantitative assessment. This includes the definition of a list of the combined uncertainties for all gases and three uncertainty levels: low, medium and high (see Table 1-10). These values are motivated by the comparison of uncertainty analyses of several countries carried out by de Keizer et al. (2007), as presented at the 2nd Internat. Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27-28 September 2007), and by expert judgement from sectoral experts and authors.

Table 1-10 Semi-quantitative (combined) uncertainties (U) for the emission of categories with no quantitative uncertainty data available. Note that there is no source of HFC, PFC or NF_3, for which a semi-quantitative uncertainty value is required.

Gas	Uncertainty category	Combined uncertainty
CO_2	low	2%
	medium	10%
	high	40%
CH_4	low	15%
	medium	30%
	high	60%
N_2O	low	40%
	medium	80%
	high	150%

1.6.1.3 Results of Approach 1 uncertainty evaluation

Level and trend uncertainty analyses are carried out excluding and including the LULUCF sector. Table 1-11 gives a summary for the Approach 1 uncertainties for the national total emissions and removals assuming no correlations across years for AD and assuming correlations across years for EF.

Table 1-11 Switzerland's relative uncertainties for national total GHG emission excluding and including the LULUCF sector – Approach 1: Level uncertainties 2018 and trend uncertainties 1990–2018. The uncertainty analysis is based on emissions including indirect CO_2 emissions.

Approach 1 Uncertainty Analysis		
Inventory	**Level uncertainty 2018**	**Trend uncertainty 1990-2018**
excl. LULUCF	5.48%	1.53%
incl. LULUCF	6.45%	2.73%

Concerning level uncertainty, the numbers in Table 1-11 do not change if the calculation assumes that AD or EF are correlated across years or not.

However, concerning trend uncertainty, total uncertainties slightly change depending on assumptions on correlations. Minimum (maximum) values for trend uncertainty (1990–2018) are 1.03% (6.64%) excluding LULUCF and 2.47% (7.88%) including LULUCF. Most likely, the overall uncertainty of the total inventory is within the given ranges.

Uncertainty analysis results for Switzerland's GHG inventory 2018 and including indirect CO_2 emissions with Approach 1:

- The level uncertainty 2018 is **5.48%** excluding LULUCF and **6.45%** including LULUCF.
- The trend uncertainty 1990–2018 is **1.53%** excluding LULUCF and **2.73%** including LULUCF.

Compared to the results of the previous inventory from submission 2019:

- The level uncertainty in 2017 was 3.85% excluding LULUCF and 7.14% including LULUCF.
- The trend uncertainty 1990–2017 was 1.39% excluding LULUCF and 5.37% including LULUCF.

Changes in total level and trend uncertainty are on one hand due to changes in the uncertainties of the emission factors and activity data in the different categories. On the other hand, changes in the activity data and emission factors cause changes in the contribution to the total level and trend uncertainty of each category. Contribution to level uncertainty and the uncertainty introduced to the trend in total national emissions of each category are shown in Table A – 2.

Compared to the results of the uncertainty analysis of the previous submission, the results have changed as follows:

- The level uncertainty excluding LULUCF has increased by around 1.63 percentage points. This change can mainly be attributed to increased uncertainties in the agriculture sector and to the newly introduced emissions from source category 2B10 Other (Niacin, Limestone pit). In the agriculture sector, the uncertainties for emission factors of categories 3B Manure management Indirect (N_2O) as well as 3Da Direct and 3Db Indirect emissions from managed soils (N_2O) are assumed to be much larger reflecting the non-symmetrical shape of the probability distribution.
- The trend uncertainty excluding LULUCF has slightly increased by around 0.14 percentage points. As for the level uncertainty, the reason for the increase are the increased EF uncertainties in the agriculture sector and the newly introduced source category 2B10 Other. However, these changes have less effect on the trend uncertainty than on the level uncertainty.
- The level uncertainty including LULUCF has decreased by around 0.69 percentage points. A reduction of the emission factor uncertainty for source category 4A1 Forest land remaining forest land (CO_2) is the main reason for the reduced level uncertainty of the inventory, and overcompensates for the increased uncertainties mentioned in the two points above. The reason for the strong impact on the overall uncertainty is the large absolute value of category 4A1 (net removal of -1’145.23 kt CO_2 eq).
- The trend uncertainty including LULUCF has decreased by around 2.63 percentage points. Besides the reduced emission factor uncertainty of 4A1 Forest land remaining forest land (CO_2), recalculations of net emissions and removals in category 4C1 Grassland remaining grassland (CO_2), leading to higher net emissions (lower net removals for all years, but most pronounced for 1990) attribute to the reduction of the overall trend uncertainty compared to the previous submission (see chp. 6.6.5 for further information about recalculations in category 4C).

Detailed results of the Approach 1 uncertainty analysis for GHG emissions 2018 per category are shown in Table A – 2. Details of the uncertainty estimates for specific source categories are provided in the sub-sections on “Uncertainties and time-series consistency” in each of the chapters on source categories below.

It should be noted that the results of the Approach 1 uncertainty analysis for GHG emissions do not, or not fully, take into account the following factors that may further increase uncertainties:

- correlations between source categories that are not considered by Approach 1 (e.g. production data used for industry emissions in both categories 1A2 Manufacturing industries and 2 Industrial processes and product use, or cattle numbers used for emissions related to enteric fermentation and animal manure production);
- errors due to neglected temporal variability when assuming constant parameters over time (e.g. emission factors);
- errors due to non-normal, asymmetric distribution of the uncertainties;
- errors due to methodological shortcomings, i.e. simplified approaches;
- errors due to sources not reported (these are assumed to be very small).

The Approach 2 uncertainty evaluation does explicitly take into account correlations between sources and asymmetric distributions. Note that no Approach 2 assessment is conducted for submission 2020. The latest Approach 2 uncertainty results can be seen in Switzerland's NIR 2018 (see FOEN 2018).

Based on the analysis of the predominant contributions to the uncertainty of the Swiss greenhouse gas inventory, the FOEN commissions and/or supports various projects. In line with UNFCCC (2017/ID#L.12) the soil carbon model Yasso07 will be further developed and results from various research projects will be evaluated to reduce the uncertainty in the estimates of carbon changes in mineral soil, litter and dead wood in forest land (see chp. 6.4.6 for details). A Tier 3 methodological approach for the quantification of carbon stock changes in agricultural soils (cropland remaining cropland and grassland remaining grassland) was developed at Agroscope research station and implemented in categories 4B and 4C. Together with further studies (cf. chp. 6.5.6 and chp. 6.6.6) the advancement in domestic soil carbon modelling will continue addressing the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. In the agriculture sector, a research project run by Agroscope looks into CH_4 and N_2O emissions from current pasture practices using micrometeorological measurements and modelling approaches. With regard to HFC emissions, the FOEN supports a long-term monitoring initiative at Jungfraujoch to derive independent emission estimates from atmospheric concentrations (Annex A5.1). Another, more recent verification activity addresses national total CH_4 and N_2O emissions (Annex A5.2).

1.6.2 KP-LULUCF inventory

Uncertainty estimates for KP-LULUCF activities are presented in chp. 11.3.1.5.

1.7 General assessment of completeness

1.7.1 GHG inventory

For the following categories, the notation key “not estimated” (NE) is used:

- CH_4 emissions from 1A1a iv Other / Municipal and special waste incineration plants / Other Fossil Fuels. Based on measurements of the exhaust gas (Mohn 2013), CH_4 emissions are below detection limit and thus considered insignificant (see chp. 3.2.5.2.1).
- CH_4 emissions from drainage and rewetting and other management of organic and mineral soils 4.A Forest Land/4(II), 4.B Cropland/4(II), 4.C Grassland/4(II), 4.D3 Other wetlands/4(II). Reporting for these source categories is not mandatory.
- N_2O emissions from drainage and rewetting and other management of organic and mineral soils 4.D Wetlands/4(II), 4.D.2 Flooded lands. Reporting for this source category is not mandatory.
- Carbon stock changes in living biomass for land converted to unproductive forest land (4.A.2.1, 4.A.2.2, 4.A.2.3, 4.A.2.4, 4.A.2.5). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the CRF tables; therefore the notation key NE is used.
- Net carbon stock changes in dead wood and in litter for land converted to forest land – afforestation (4.A.2.1, 4.A.2.2, 4.A.2.3, 4.A.2.4, 4.A.2.5). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the CRF tables; therefore the notation key NE is used.
- Net carbon stock changes in living biomass, in dead wood and in litter in unproductive forest land remaining unproductive forest land (4.A.1 “CC13 remaining CC13”). The Tier 1 approach assumes carbon stock change is zero, but the numerical value 0 cannot be included in the CRF tables; therefore the notation key NE is used.
- Activity data for 4.G Harvested Wood Products. The FAO database does not provide data for years prior to 1961.

For the following categories, the notation key “included elsewhere” (IE) is used:

- 1A1b Petroleum refining / Gaseous fuels: Emissions are reported under 1A1b Petroleum refining / Liquid fuels for reasons of confidentiality (see chp. 3.2.5.2.2).
- 1A2c Chemicals/Other fossil fuels: Emissions are reported under 1A2f Non-metallic minerals / Other fossil fuels for reasons of confidentiality (see chp. 3.2.6.2.4).
- 1A2d Pulp, paper and print/Biomass and 1A2e Food processing, beverages and tobacco/Biomass: Emissions are partly or totally reported under 1A2gviii due to lack of statistical data to disaggregate wood consumption in the relevant categories (see chp. 3.2.4.5.2).
- 1A2f Non-metallic minerals/Biomass: CH_4 emissions from cement production are reported under 1A2f Non-metallic minerals/Other fossil fuels, as the emission factor in the cement industry is based on direct exhaust measurements at the chimneys of the cement plants (see chp. 3.2.6.2.7).
- 1A3a Domestic aviation/Aviation gasoline and 1D International aviation/Aviation gasoline: Emissions are reported together with Jet kerosene, as only negligible amounts of aviation gasoline are consumed and no detailed modelling for aviation gasoline exists.

- 1.A(b) Reference approach, liquid fuels: Imports of refinery feedstocks are included in crude oil.
- 1.A(b) Reference approach, liquid fuels: Imports of other kerosene are included in jet kerosene.
- 1.A(b) Reference approach, liquid fuels: Carbon stored of liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 1.A(b) Reference approach, solid fuels: Import and stock change of anthracite and coke oven/gas coke are included in other bituminous coal.
- 1.A(d) Feedstock, reductants and other non-energy use of fuels, liquid fuels: fuel quantity, C excluded from reference approach and CO2 emissions for liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 2B1 Ammonia production: CO_2 emissions are reported under 2B8b Ethylene because Ammonia production is part of an integrated production chain (see chp. 4.3.2.1).
- 4D1.2 Flooded land remaining flooded land: CO_2 emissions and removals are reported for all wetlands remaining wetlands under 4D1.3 Other wetlands remaining other wetlands (unproductive wetland/surface water).
- 4.E Settlements / 4(I) Direct N_2O emissions from nitrogen inputs to managed soils: Emissions are reported together with 3.D(a) Agriculture because no data are available for a further disaggregation of fertiliser use.
- 4.A-D / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils: All carbon stock changes (CO_2 emissions and removals) are reported as carbon stock changes in tables 4.A to 4.D.
- 4.C.1 Grasslands remaining grasslands / 4(III) Direct N_2O from N mineralisation/immobilisation: N_2O emissions are reported under 3.D(a)5 Agriculture, as grasslands are considered part of the agricultural area.
- 4(IV).1 Indirect N_2O emissions from managed soils/Atmospheric deposition: Emissions are reported under 3.D(b) Agriculture because no data are available for a further disaggregation.
- 4(V) Biomass Burning: Emissions from 4.A.2 Land converted to forest land and 4.C.2 Land converted to grassland are reported under biomass burning of 4.A.1 Forest remaining forest land and 4.C.2 Grassland remaining grassland, respectively, because no data are available for a further disaggregation. CO_2 emissions from controlled burning and wildfires in 4.A.1 and 4.C.1 are covered by the carbon changes reported under 4.A and 4.C respectively.
- 5B2 Anaerobic digestion at industrial and agricultural biogas facilities: Amount of CH_4 recovered and emissions from its use in stationary motors (CHP) and boilers are reported under 1A2gviii Other / Biomass (CHP at industrial biogas plants) and 1A4ci Agriculture/forestry/fishing / Stationary / Biomass (CHP and boilers at agricultural biogas plants).
- 5C1 Waste Incineration Biogenic: Emission factors for CH_4 and N_2O cannot be separated into biogenic and non-biogenic fraction. Therefore, emissions are reported together with 5C1 Waste Incineration non-biogenic CH_4 and N_2O emissions (NIR chp. 7.4.2).
- 5D2 Industrial wastewater: CH_4 and N_2O emissions are reported under 5D1 Domestic wastewater, because industrial wastewater is merged and treated together with domestic wastewater (see chp. 7.5.1).

1.7.2 KP-LULUCF inventory

For all known sources and sinks, complete estimates are accomplished for the current submission. Notation keys for the activity coverage and the reported pools are displayed in CRF NIR-1. A detailed justification for the reported method is given in chapter 11.3.1.2.

2 Trends in greenhouse gas emissions and removals

Responsibilities for Trends in greenhouse gas emissions and removals	
Authors	Regine Röthlisberger (FOEN), Andreas Schellenberger (FOEN, for LULUCF), Nele Rogiers (FOEN, for KP-LULUCF)
Annual updates (NIR text, tables, figures)	Felix Weber (INFRAS), Beat Rihm (Meteotest), Nele Rogiers (FOEN), Dominik Eggli (Meteotest)
EMIS database operation	Anouk-Aimée Bass (FOEN)
Quality control (annual updates)	Dominik Eggli (Meteotest), Andreas Schellenberger (FOEN, for LULUCF)
Internal review	Michael Bock (FOEN), Andreas Schellenberger (FOEN), Markus Didion (WSL), Daniel Bretscher (Agroscope), Christoph Könitzer (Sigmaplan)

This chapter provides an overview of Switzerland's GHG emissions and removals in 2018 as well as trends for the period 1990–2018. Values in chp. 2.1–2.4 are relevant for reporting under the UNFCCC, values in chp. 2.5 refer to accounting under the Kyoto Protocol.

2.1 Aggregated greenhouse gas emissions 2018 (UNFCCC)

Table 2-1 shows the aggregated emissions of all greenhouse gases (GHG) 2018 for each sector and the relative shares of the sectors. Furthermore, emission data on international aviation and marine bunkers are provided. As the table indicates, CO_2 is the main contributor to total GHG emissions followed by CH_4, N_2O and F-gases. Sector 1 Energy is the main source concerning climate-related emissions followed by sectors 3 Agriculture, 2 IPPU, 5 Waste and 6 Other. In contrast, sector 4 LULUCF is a net sink regarding GHG emissions in 2018.

Table 2-1 Switzerland's GHG emissions in CO_2 equivalent (kt) by gas and sector in 2018 (without indirect emissions).

Sectors	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	Total	Share
	CO_2 equivalent (kt)								
1 Energy	34'714	275	246					35'235	76.0%
2 IPPU	2'114	3	588	1'524	36	157	0.5	4'422	9.5%
3 Agriculture	46	4'040	1'905					5'991	12.9%
5 Waste	9	521	140					671	1.4%
6 Other	12	0.7	0.6					14	0.0%
Total (excluding LULUCF)	36'895	4'840	2'880	1'524	36	157	0.5	**46'333**	100.0%
4 LULUCF	-1'375	38	45					-1'291	-2.8%
Total (including LULUCF)	35'521	4'878	2'925	1'524	36	157	0.5	**45'041**	97.2%
International aviation bunkers	5'621	0.5	46					*5'668*	
International marine bunkers	19	0.00	0.18					*19*	

A breakdown of Switzerland's total emissions by gas (excluding LULUCF) is given in Figure 2-1. Figure 2-2 charts the relative contributions of the individual sectors (excluding LULUCF) to the emissions of each GHG. Trends in GHG emissions are given in chp. 2.2 to 2.5.

The national total of 46'333 kt of CO_2 equivalent (excluding LULUCF, excluding indirect CO_2) corresponds to 5.4 tonnes of CO_2 equivalent per capita[1] (CO_2: 4.3 tonnes per capita) emitted to the atmosphere in 2018 (Table 2-1).

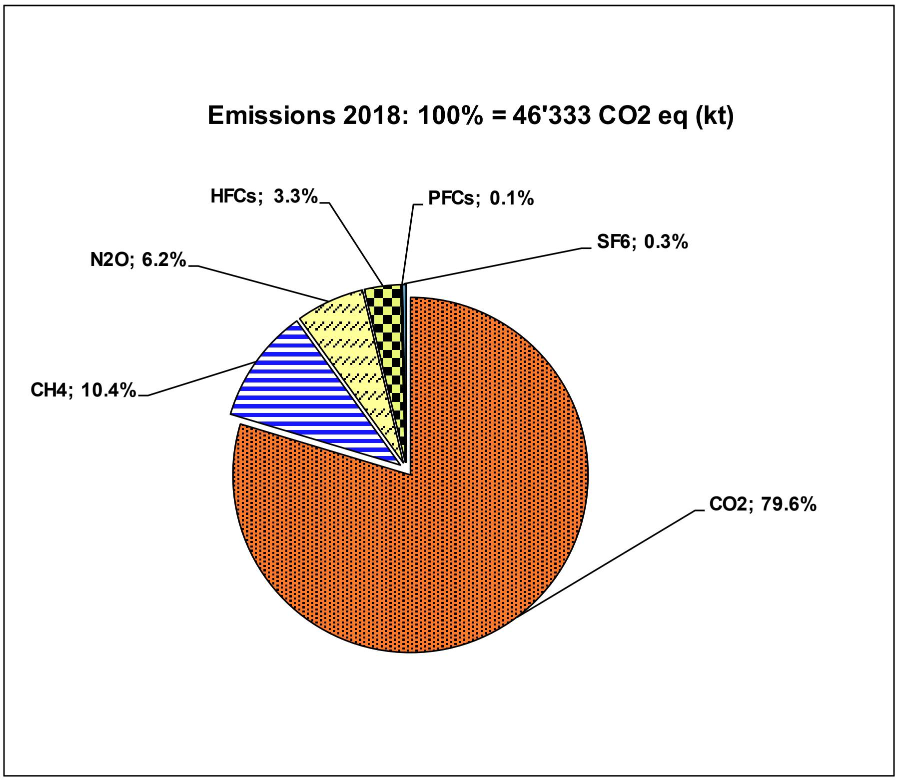


Figure 2-1 Contribution of individual gases to total greenhouse gas emissions in 2018 (excluding LULUCF, excluding indirect CO_2).

[1] Emissions per capita calculated based on population statistics from the Swiss Federal Statistical Office (SFSO).

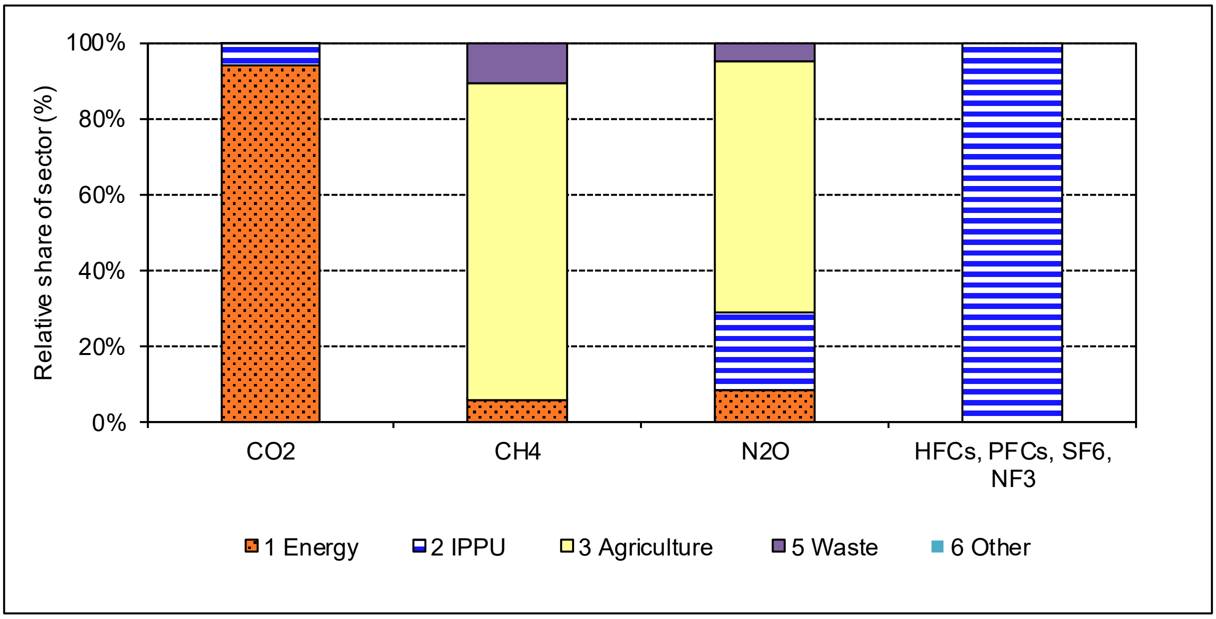


Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2018.

A clear dominance of CO_2 emissions in 2018 is related to source category 1A Fuel combustion within sector 1 Energy. CH_4 and N_2O emissions mainly originate from sector 3 Agriculture, while F-gas emissions by definition only stem from sector 2 Industrial processes and product use.

2.2 Emission trends by gas

Emission trends by gas for the period 1990–2018 are summarized in Table 2-2.

Table 2-2 Greenhouse gas emissions in CO_2 equivalent (kt) by gas. The column below on the far right indicates the percentage change in emissions in the latest year compared to the base year 1990. HFC emissions increased by more than 6 million percent when compared to 1990 levels (1990 = 0.025 kt CO_2 equivalent).

Greenhouse Gas Emissions	**1990**	**1995**	**2000**	**2005**
	CO_2 equivalent (kt)			
CO_2 emissions including net CO_2 from LULUCF	42'136	39'846	49'416	43'585
CO_2 emissions excluding net CO_2 from LULUCF	44'154	43'413	43'618	45'788
CH_4 emissions including CH_4 from LULUCF	6'074	5'749	5'321	5'218
CH_4 emissions excluding CH_4 from LULUCF	6'044	5'729	5'307	5'204
N_2O emissions including N_2O from LULUCF	3'381	3'382	3'353	3'162
N_2O emissions excluding N_2O from LULUCF	3'327	3'333	3'307	3'117
HFCs	0.02	244	636	1'048
PFCs	117	17	61	50
SF_6	137	93	152	207
NF_3	NO	NO	NO	NO
Total (including LULUCF)	**51'844**	**49'331**	**58'939**	**53'270**
Total (excluding LULUCF)	**53'779**	**52'830**	**53'081**	**55'414**

Greenhouse Gas Emissions	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2018 vs.1990**
	CO_2 equivalent (kt)										%
CO_2 emissions including net CO_2 from LULUCF	40'582	42'561	39'879	40'623	41'380	38'898	36'601	37'049	36'799	35'521	-15.7%
CO_2 emissions excluding net CO_2 from LULUCF	43'535	45'050	40'986	42'255	43'186	39'234	38'733	39'193	38'182	36'895	-16.4%
CH_4 emissions including CH_4 from LULUCF	5'194	5'167	5'114	5'084	5'020	5'017	4'987	4'946	4'882	4'878	-19.7%
CH_4 emissions excluding CH_4 from LULUCF	5'181	5'154	5'099	5'071	5'007	5'004	4'974	4'930	4'868	4'840	-19.9%
N_2O emissions including N_2O from LULUCF	2'914	3'058	2'988	3'047	2'949	2'929	2'958	2'938	3'129	2'925	-13.5%
N_2O emissions excluding N_2O from LULUCF	2'869	3'013	2'942	3'001	2'901	2'881	2'910	2'889	3'083	2'880	-13.4%
HFCs	1'272	1'308	1'380	1'453	1'432	1'469	1'508	1'480	1'504	1'524	see caption
PFCs	35	38	36	39	28	23	26	20	32	36	-69.4%
SF_6	183	151	164	218	263	266	261	213	203	157	14.7%
NF_3	7.6	12.7	9.3	0.54	0.14	0.61	0.73	0.77	0.80	0.50	-
Total (including LULUCF)	**50'189**	**52'297**	**49'571**	**50'464**	**51'071**	**48'602**	**46'341**	**46'646**	**46'551**	**45'041**	**-13.1%**
Total (excluding LULUCF)	**53'082**	**54'727**	**50'616**	**52'037**	**52'816**	**48'877**	**48'412**	**48'725**	**47'873**	**46'333**	**-13.8%**

As shown in Table 2-2, Table 2-3, and Figure 2-3, total emissions excluding LULUCF in 2018 are clearly below base year emissions. There is no discernible trend in the period 1990–2005. Only from 2005 onwards, a decreasing trend starts to develop. Compared to 2017, emissions have decreased in 2018 (by 3.2%). The emission maximum occurred in 1991. Also when including LULUCF categories, a decreasing trend is visible compared to the base year 1990, although the net CO_2 sink generated by LULUCF categories was generally smaller after 1997 (see Figure 2-8 and Figure 6-3). Total emissions reached a minimum in 2018, for both cases including and excluding LULUCF, which was 13.1% and 13.8% below base year emissions in 1990, respectively.

There is a strong correlation between CO_2 emissions and winter climatic conditions (number of heating degree days; see footnote 2, page 63 for further information) in the period 1990–2018. However, the relative developments of heating degree days and CO_2 emissions are clearly drifting apart in the years since 2002, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7).

Between 1990 and 2018, CH_4 emissions (excluding LULUCF) decreased. One major reason for this decrease was a reduction of livestock in the years 1990 to 2004 that led to a reduction of emissions from enteric fermentation in the agricultural sector (see Table 5-8).

Moreover, from 2000 onwards, a change in waste legislation banning the disposal of municipal solid waste in landfills contributed to this trend.

As a consequence of the declining livestock population and reduced input of synthetic fertilisers, N_2O emissions that mainly stem from manure management and agricultural soils decrease between 1990 und 2018 as well.

HFC emissions increased significantly in 2018 compared to the base year due to their application as substitutes for CFCs, while PFC emissions declined (mainly due to the decrease and stop of aluminium production). SF_6 emissions show relatively large fluctuations between 1990 and 2018. This effect bases on annual fluctuations of the market volumes in the production of electrical equipment as well as on changes in other applications. The recent increase of SF_6 emissions compared to 2008 is due the disposal of sound proof windows. Although soundproof windows containing SF_6 are not produced or installed in Switzerland anymore, the disposal of old windows still leads to emissions. On the other hand, the SF_6 emissions from electrical equipment (2G1) are decreasing due to the agreement of SWISSMEM and FOEN on the reduction of SF_6 emissions since 2008. Furthermore, the import of SF_6 for magnesium foundries (2C4) is prohibited in Switzerland since 2017, leading to an additional decrease of SF_6 emissions over the past couple of years. NF_3 has mainly been used only short-term in the photovoltaic industry (around 2010).

Table 2-3 Contribution of individual gases to total emissions (excluding LULUCF, excluding indirect CO_2) in CO_2 equivalent (kt) and (%).

Greenhouse Gas Emissions	**1990**		**1995**		**2000**		**2005**		**2010**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	44'154	82.1%	43'413	82.2%	43'618	82.2%	45'788	82.6%	45'050	82.3%
CH_4	6'044	11.2%	5'729	10.8%	5'307	10.0%	5'204	9.4%	5'154	9.4%
N_2O	3'327	6.2%	3'333	6.3%	3'307	6.2%	3'117	5.6%	3'013	5.5%
HFCs	0	0.0%	244	0.5%	636	1.2%	1'048	1.9%	1'308	2.4%
PFCs	117	0.2%	17	0.0%	61	0.1%	50	0.1%	38	0.1%
SF_6	137	0.3%	93	0.2%	152	0.3%	207	0.4%	151	0.3%
NF_3	NO	-	NO	-	NO	-	NO	-	12.7	0.0%
Total (excluding LULUCF)	**53'779**	**100%**	**52'830**	**100%**	**53'081**	**100%**	**55'414**	**100%**	**54'727**	**100%**

Greenhouse Gas Emissions	**2014**		**2015**		**2016**		**2017**		**2018**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	39'234	80.3%	38'733	80.0%	39'193	80.4%	38'182	79.8%	36'895	79.6%
CH_4	5'004	10.2%	4'974	10.3%	4'930	10.1%	4'868	10.2%	4'840	10.4%
N_2O	2'881	5.9%	2'910	6.0%	2'889	5.9%	3'083	6.4%	2'880	6.2%
HFCs	1'469	3.0%	1'508	3.1%	1'480	3.0%	1'504	3.1%	1'524	3.3%
PFCs	23	0.0%	26	0.1%	20	0.0%	32	0.1%	36	0.1%
SF_6	266	0.5%	261	0.5%	213	0.4%	203	0.4%	157	0.3%
NF_3	0.61	0.0%	0.73	0.0%	0.77	0.0%	0.80	0.0%	0.50	0.0%
Total (excluding LULUCF)	**48'877**	**100%**	**48'412**	**100%**	**48'725**	**100%**	**47'873**	**100%**	**46'333**	**100%**

Figure 2-3 shows Switzerland's relative GHG emission trends by gas. The base year 1990 is set to 100%.

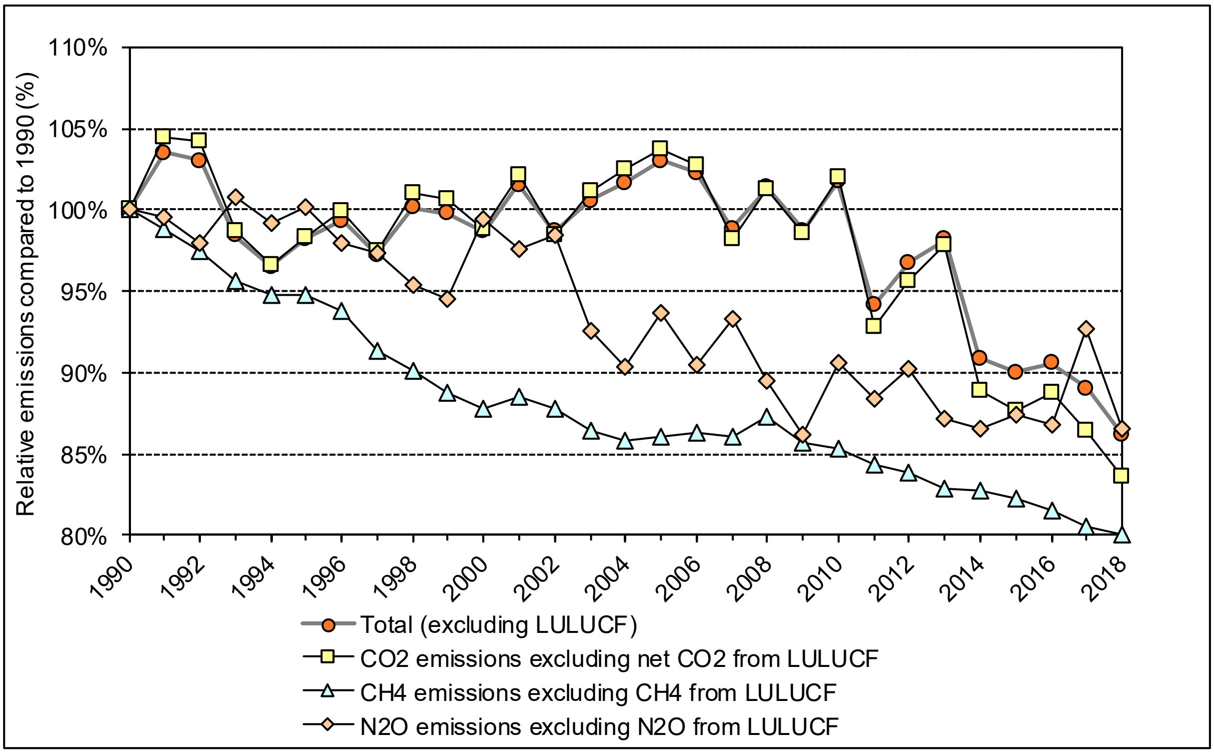


Figure 2-3 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100%. F-gases are not illustrated (see Figure 4-3).

2.3 Emission trends by sources and sinks

Table 2-4 shows the emission trends for all major sources and sink categories. As the largest share of emissions originates from sector 1 Energy, the table includes further information concerning the contributions of energy-related source categories.

2.3.1 Overview

In order to understand trends within the sector 1 Energy, the individual source categories are considered separately (see chp. 2.3.2 and Figure 2-6 below).

In line with economic development, overall emissions in sector 2 Industrial processes and product use (IPPU) show a decreasing trend in the early 1990s and a gradual increase between 1997 and 2014, except for the economically difficult year 2009. Since 2014, emissions from the sector have stagnated. The Ordinance on Chemical Risk Reduction (Swiss Confederation 2005) was put in place in 2005 and regulates the use of F-gases since then. The dominant source category of sector 2 is 2A Mineral industry although the emissions decreased by approximately one third since 1990. If sources are analysed in more detail, 2A1 Cement production is the most relevant emitter in this category. Emissions of 2F Product uses as substitutes for ozone-depleting substances (ODS), the second most important source in sector 2, increased by some orders of magnitude since 1990 due to the replacement of CFCs with HFCs. The third-most important source category from the IPPU sector is 2B Chemical industry, in particular due to N_2O emissions from category 2B10 Niacin production. Source category 2G Other product manufacture and use (in particular SF_6 and

PFC emissions from electrical equipment and other product use, as well as N_2O emissions from the application in households and hospitals) has increased by approximately factor 1.2 since 1990. Other source categories in sector 2 are of minor importance with regard to the overall greenhouse gas emissions.

GHG emissions in sector 3 Agriculture are driven by populations of cattle and swine and by fertiliser use. Both factors have been declining (see Table 5-8 and Table 5-23, respectively), thus leading to a decrease in CH_4 and N_2O emissions until 2004. Subsequently, emissions remained more or less stable with some fluctuations mainly due to the evolution of the cattle population.

Total emissions from the source category 5 Waste continuously decrease between 1990 and 2018, with a short increasing and fluctuating phase from 1999 until 2004. The main driver of the decreasing trend is the emission reduction in solid waste disposal, which was reinforced through a change of legislation in 2000 that banned disposal of combustible waste in landfills. Therefore, an increasing amount of municipal solid waste is being incinerated, with emissions reported under source 1A1 Energy industries rather than sector 5 Waste. Altogether, “waste-related” emissions (including emissions from all waste management activities reported in 1 Energy, 3 Agriculture, and 5 Waste) are increasing since 1994 and show a stagnation since 2006 (see Figure 7-3 in chp. 7.1).

The total emissions from sector 6 Other (fire damages) show fluctuations on a very low level. Emissions from sector 6 Other are not accounted for under the Kyoto Protocol and are of minor importance.

Table 2-4 Greenhouse gas emissions (excluding indirect CO_2) in CO_2 equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

Source and Sink Categories	1990	1995	2000	2005
	CO_2 equivalent (kt)			
1. Energy	41'862	41'916	42'231	43'993
1A1 Energy industries	2'519	2'643	3'172	3'816
1A2 Manufacturing industries and construction	6'571	6'295	6'007	6'041
1A3 Transport	14'676	14'305	15'977	15'858
1A4 Other sectors	17'514	18'081	16'565	17'827
1A5 Other	220	163	151	139
1B Fugitive emissions from fuels	363	430	359	312
2. Industrial processes and product use	4'014	3'420	3'775	4'429
3. Agriculture	6'826	6'612	6'232	6'132
5. Waste	1'064	870	830	846
6. Other	12	12	13	14
Total (excluding LULUCF)	53'779	52'830	53'081	55'414
4. Land use, land-use change and forestry	-1'935	-3'499	5'858	-2'145
Total (including LULUCF)	51'844	49'331	58'939	53'270

Source and Sink Categories	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. 1990*
	CO_2 equivalent (kt)										%
1. Energy	41'846	43'216	39'155	40'549	41'471	37'426	37'095	37'489	36'503	35'235	*-15.8%*
1A1 Energy industries	3'674	3'846	3'598	3'641	3'736	3'607	3'294	3'379	3'298	3'360	*33.4%*
1A2 Manufacturing industries and construction	5'759	5'864	5'435	5'432	5'498	5'100	4'980	4'986	4'950	4'820	*-26.6%*
1A3 Transport	16'447	16'337	16'158	16'275	16'185	16'079	15'344	15'178	14'916	14'918	*1.6%*
1A4 Other sectors	15'567	16'753	13'556	14'810	15'683	12'276	13'124	13'587	12'991	11'791	*-32.7%*
1A5 Other	133	137	125	132	133	139	135	139	128	127	*-42.4%*
1B Fugitive emissions from fuels	268	279	283	259	235	226	218	219	220	219	*-39.7%*
2. Industrial processes and product use	4'264	4'519	4'526	4'503	4'509	4'511	4'459	4'408	4'561	4'422	*10.2%*
3. Agriculture	6'170	6'203	6'160	6'232	6'089	6'207	6'132	6'113	6'107	5'991	*-12.2%*
5. Waste	789	776	761	739	733	722	713	703	690	671	*-36.9%*
6. Other	13	12	13	14	14	12	12	12	13	14	*10.6%*
Total (excluding LULUCF)	53'082	54'727	50'616	52'037	52'816	48'877	48'412	48'725	47'873	46'333	*-13.8%*
4. Land use, land-use change and forestry	-2'893	-2'430	-1'045	-1'573	-1'745	-276	-2'072	-2'079	-1'323	-1'291	*-33.3%*
Total (including LULUCF)	50'189	52'297	49'571	50'464	51'071	48'602	46'341	46'646	46'551	45'041	*-13.1%*

The percentage shares of source categories are shown for selected years in Table 2-5, whereas Figure 2-4 to Figure 2-6 are graphical representations of the data in Table 2-4. For the time series of the source categories of sector 1 Energy see chp. 3.

Table 2-5 Greenhouse gas emissions (excluding LULUCF, excluding indirect CO_2) in CO_2 equivalent (kt) and the relative contribution (%) of individual source categories.

Source and Sink Categories	**1990**		**1995**		**2000**		**2005**		**2010**	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1. Energy	41'862	77.8%	41'916	79.3%	42'231	79.6%	43'993	79.4%	43'216	79.0%
1A1 Energy industries	*2'519*	*4.7%*	2'643	*5.0%*	3'172	*6.0%*	3'816	*6.9%*	3'846	7.0%
1A2 Manufacturing industries and construction	*6'571*	*12.2%*	6'295	*11.9%*	6'007	*11.3%*	6'041	*10.9%*	5'864	*10.7%*
1A3 Transport	*14'676*	*27.3%*	14'305	*27.1%*	15'977	*30.1%*	15'858	*28.6%*	16'337	*29.9%*
1A4 Other sectors	*17'514*	*32.6%*	18'081	*34.2%*	16'565	*31.2%*	17'827	*32.2%*	16'753	*30.6%*
1A5 Other	*220*	*0.4%*	163	*0.3%*	151	*0.3%*	139	*0.3%*	137	*0.3%*
1B Fugitive emissions from fuels	*363*	*0.7%*	430	*0.8%*	359	*0.7%*	312	*0.6%*	279	*0.5%*
2. Industrial processes and product use	4'014	7.5%	3'420	6.5%	3'775	7.1%	4'429	8.0%	4'519	8.3%
3. Agriculture	6'826	12.7%	6'612	12.5%	6'232	11.7%	6'132	11.1%	6'203	11.3%
5. Waste	1'064	2.0%	870	1.6%	830	1.6%	846	1.5%	776	1.4%
6. Other	12	0.0%	12	0.0%	13	0.0%	14	0.0%	12	0.0%
Total (excluding LULUCF)	53'779	100.0%	52'830	100.0%	53'081	100.0%	55'414	100.0%	54'727	100.0%

Source and Sink Categories	**2014**		**2015**		**2016**		**2017**		**2018**	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1. Energy	37'426	76.6%	37'095	76.6%	37'489	76.9%	36'503	76.2%	35'235	76.0%
1A1 Energy industries	3'607	*7.4%*	3'294	*6.8%*	3'379	*6.9%*	3'298	*6.9%*	3'360	*7.3%*
1A2 Manufacturing industries and construction	5'100	*10.4%*	4'980	*10.3%*	4'986	*10.2%*	4'950	*10.3%*	4'820	*10.4%*
1A3 Transport	16'079	*32.9%*	15'344	*31.7%*	15'178	*31.2%*	14'916	*31.2%*	14'918	*32.2%*
1A4 Other sectors	12'276	*25.1%*	13'124	*27.1%*	13'587	*27.9%*	12'991	*27.1%*	11'791	*25.4%*
1A5 Other	139	*0.3%*	135	*0.3%*	139	*0.3%*	128	*0.3%*	127	*0.3%*
1B Fugitive emissions from fuels	226	*0.5%*	218	*0.5%*	219	*0.4%*	220	*0.5%*	219	*0.5%*
2. Industrial processes and product use	4'511	9.2%	4'459	9.2%	4'408	9.0%	4'561	9.5%	4'422	9.5%
3. Agriculture	6'207	12.7%	6'132	12.7%	6'113	12.5%	6'107	12.8%	5'991	12.9%
5. Waste	722	1.5%	713	1.5%	703	1.4%	690	1.4%	671	1.4%
6. Other	12	0.0%	12	0.0%	12	0.0%	13	0.0%	14	0.0%
Total (excluding LULUCF)	48'877	100.0%	48'412	100.0%	48'725	100.0%	47'873	100.0%	46'333	100.0%

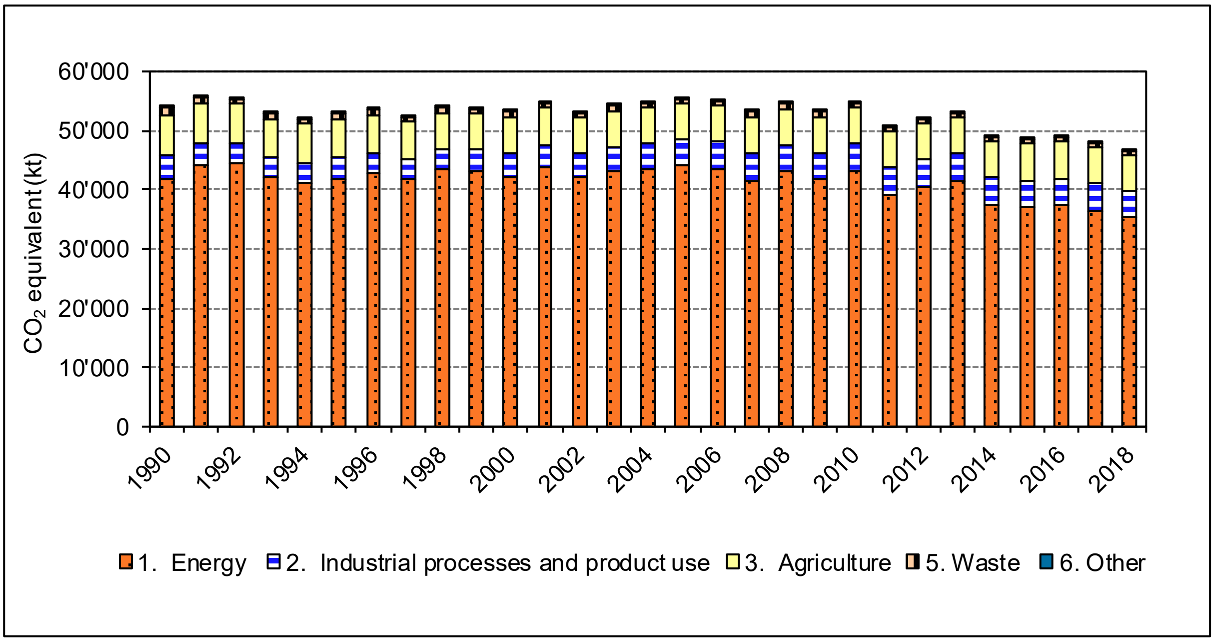


Figure 2-4 Greenhouse gas emissions in CO_2 equivalent (kt) by sectors (excluding LULUCF, excluding indirect CO_2).

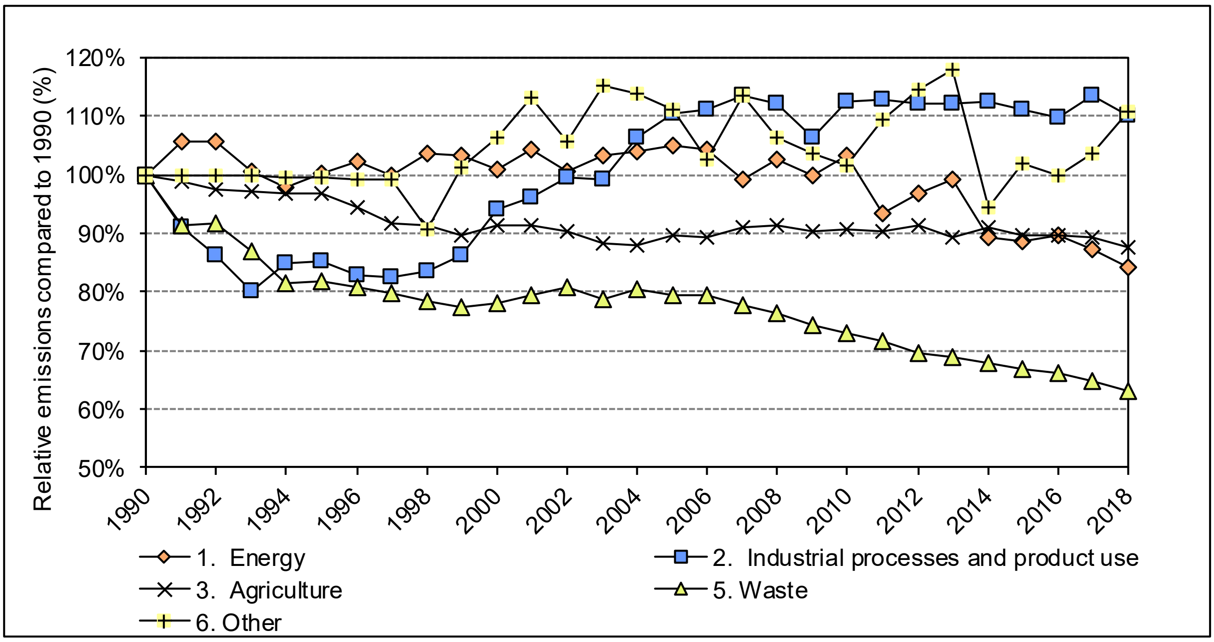


Figure 2-5 Relative emission trends (CO_2 eq) by main source categories (base year 1990 = 100%).

2.3.2 Emission trends in sector 1 Energy

The main source categories within sector 1 Energy – representing the major sources of Switzerland's GHG emissions – are shown in Figure 2-6. Values are given in Table 2-5.

It is noteworthy that due to Switzerland's electricity production structure (the most of it is generated by hydroelectric and nuclear power plants in 2018; see SFOE (2019), Table 24), category 1A1 Energy industries plays only a minor role. It does not represent thermal power stations as in many other countries, but primarily waste incineration plants. The following emission trends emerge within the sector 1 Energy:

- Despite differing trends of individual source categories, the overall emissions from the sector 1 Energy remain at a relatively constant level (orange/bold line in Figure 2-6) in the period 1990–2005. From 2006–2018, the combination of effective reduction measures and warm winters (see Figure 2-7) led to a decreasing trend in emissions (see further details below under 1A4 Other sectors).
- Overall emissions from source category 1A1 Energy industry in 2018 are higher than in 1990. The time series shows an increase until 2006 and a decreasing trend from then on, fluctuations being caused by varying combustion activities in the petroleum refinery industry, waste-to-energy, new installations of district heating and weather related forcing of heating activities (see Figure 2-6 and values in Table 2-5).
- The trend for category 1A3 Transport seems to broadly follow the overall economic development in Switzerland until approximately 2003 (gross domestic product) (SFSO 2019h). Then, emissions seem to stabilize despite further economic growth. The decrease of transport emissions since 2008 as well as the drop from 2014 to 2015 is largely caused by decreasing fuel tourism (EV 2015a) (see chp. 3.2.9.2.2).
- The trend for source category 1A4 Other sectors reflects the impact of climatic variations on energy demand for heating. The strong correlation with the number of "heating degree days"[2] – used as an index of cold weather conditions – is apparent from Figure 2-7, which shows CO_2 emissions from source category 1A4 Fuel combustion – Other sectors (only stationary sources) and the number of heating degree days. The number of heating degree days in 2018 decreased compared to 2017. CO_2 emissions caused by fuel combustion in source category 1A4 Other sectors – stationary sources decreased as well (see Figure 2-7). In the period 1990–2018, the number of buildings and apartments increased as well as the average floor space per person and workplace. Both phenomena result in an increase in the total area heated by more than one third. Over the same period, however, higher standards were specified for insulation and for combustion equipment efficiency for both new and renovated buildings, compensating for the emissions from the additional area heated.

[2] Heating degree days: Number of degrees per day calculated as the difference between 20°C (room temperature) and the daily average outdoor temperature for such days where the daily average temperature is below 12°C (e.g. daily outdoor average equals 7°C, then for that day 20–7 = 13). The number of degrees per day are summed up for a year t to yield the heating degree days of year t.

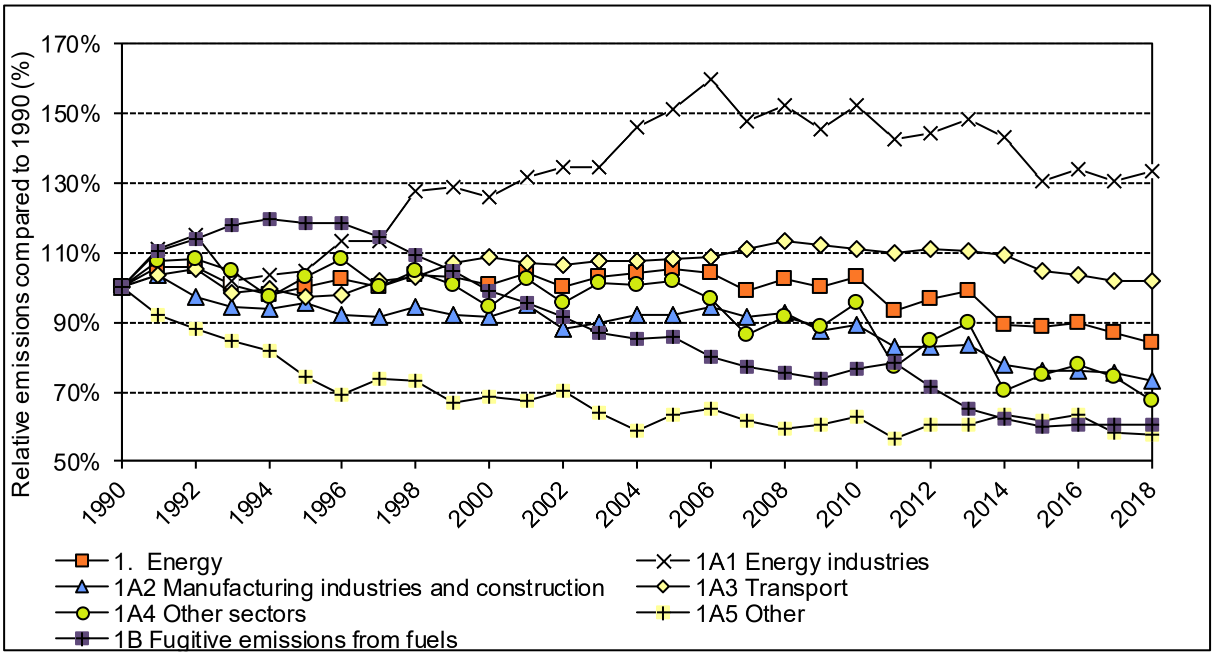


Figure 2-6 Emission trends (CO_2 eq) for the source categories in sector 1 Energy. The trend for the entire sector 1 Energy is represented by the bold line with orange squares.

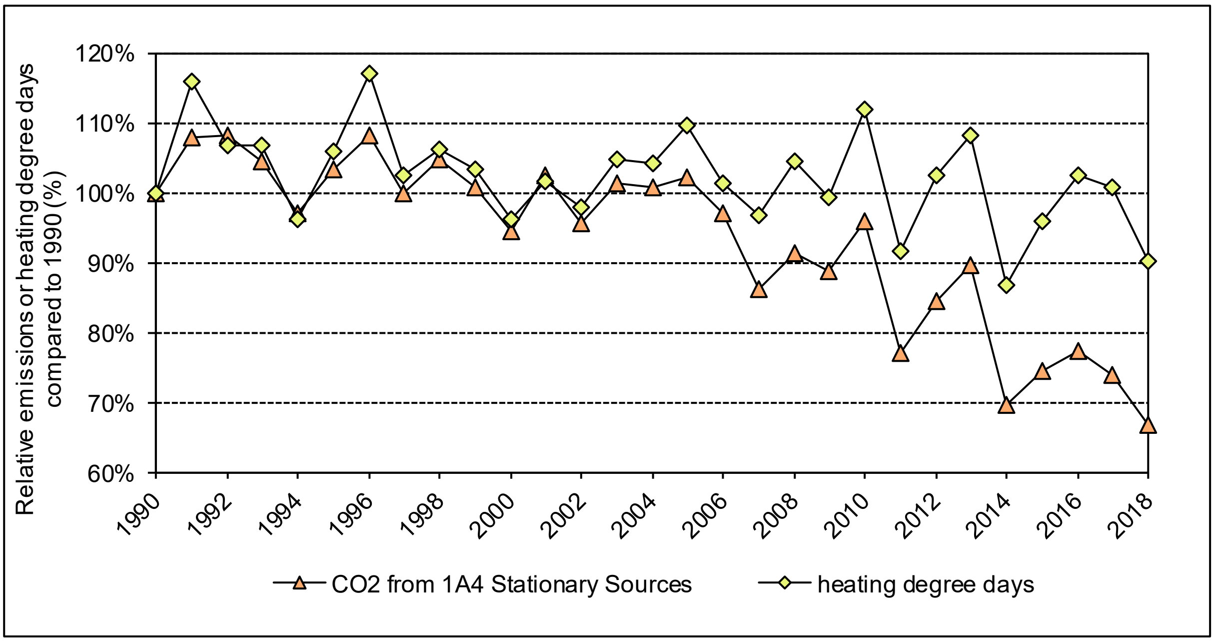


Figure 2-7 Relative trend for CO_2 emissions from 1A4 Fuel Combustion – Other Sectors (stationary sources only) compared with the number of heating degree days.

2.3.3 Emission trends in sector 4 LULUCF

Figure 2-8 illustrates the net emissions and removals in sector 4 LULUCF. Associated data are given in Table 2-4. LULUCF GHG fluxes were dominated by biomass dynamics in forests. Except for the year 2000, the net removals in sector 4 LULUCF were higher than the net emissions over the inventory period. A clear year-to-year variation is evident over the whole period. The reasons for the high net CO_2 eq emissions in 2000 (and the relatively small removals in 1990 and 2001) are the storms Vivian (February 1990) and Lothar (December 1999), respectively, which caused great damages in the forest stands and markedly increased harvesting due to salvage logging. In a medium-term perspective, harvesting rates in Swiss forests appeared to increase since 1991 and peaked in 2000 (storm Lothar, see above) and later on in 2006 and 2007, resulting in minor net removals also in both last-mentioned years. Primarily because harvesting rates started to decline in 2008 due to the international and domestic economic framework conditions, net removals from LULUCF increased again since 2008 and showed a clear year-to-year variation over the last inventory years. The relatively small net removals in 2011, 2014 and 2018 are due to comparably high harvesting rates and above-average losses in the litter pool (related to climatic circumstances). The annual contributions of CH_4 and N_2O emissions to LULUCF overall GHG net emissions over the inventory period was small compared to the CO_2 fluxes.

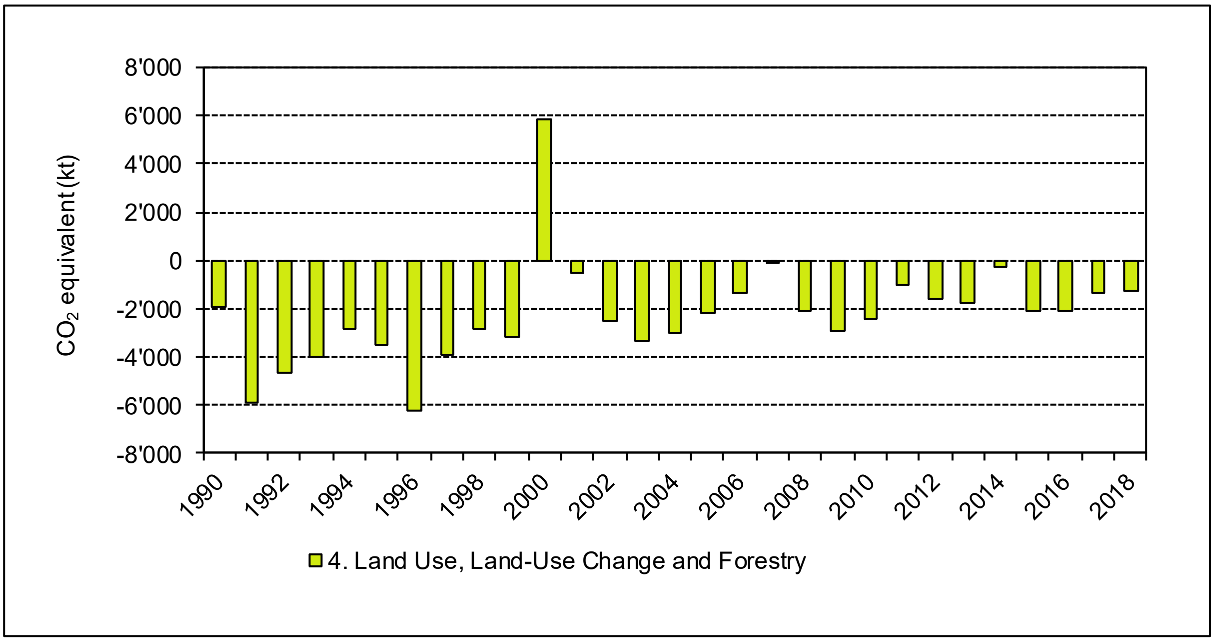


Figure 2-8 Net GHG emissions and removals of sector 4 Land use, land-use change and forestry (LULUCF), in kt CO_2 eq. Positive values refer to net emissions, negative values refer to net removals.

2.4 Emission trends for precursor gases and SO_2

Emission trends for precursor gases (IPCC 2006, Volume 1, Chapter 7) show a very pronounced decline (see Table 2-6 and Figure 2-9). A strict air pollution control policy and the implementation of a large number of emission reduction measures led to decreasing emissions of precursor gases and SO_2 over the period 1990–2018. The main reduction measures were abatement of exhaust emissions from road vehicles and stationary combustion equipment, taxation of solvents and sulphured fuels, and voluntary agreements within the industry sector.

Table 2-6 Emissions of precursor gases and SO_2 (kt) (excluding NMVOC from LULUCF).

Precursor gases and SO_2	**1990**	**1995**	**2000**	**2005**
	kt			
NO_x	144	115	102	93
CO	805	527	400	308
NMVOC	306	207	153	114
SO_2	37	26	16	14

Precursor gases and SO_2	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	***2018 vs. 1990***
	kt										*%*
NO_x	85	84	80	81	81	77	73	71	67	64	*-55%*
CO	246	238	217	210	202	183	173	169	162	156	*-81%*
NMVOC	101	98	95	93	90	86	83	81	80	79	*-74%*
SO_2	10	10	8.4	8.6	8.0	7.3	5.7	5.2	5.0	5.0	*-86%*

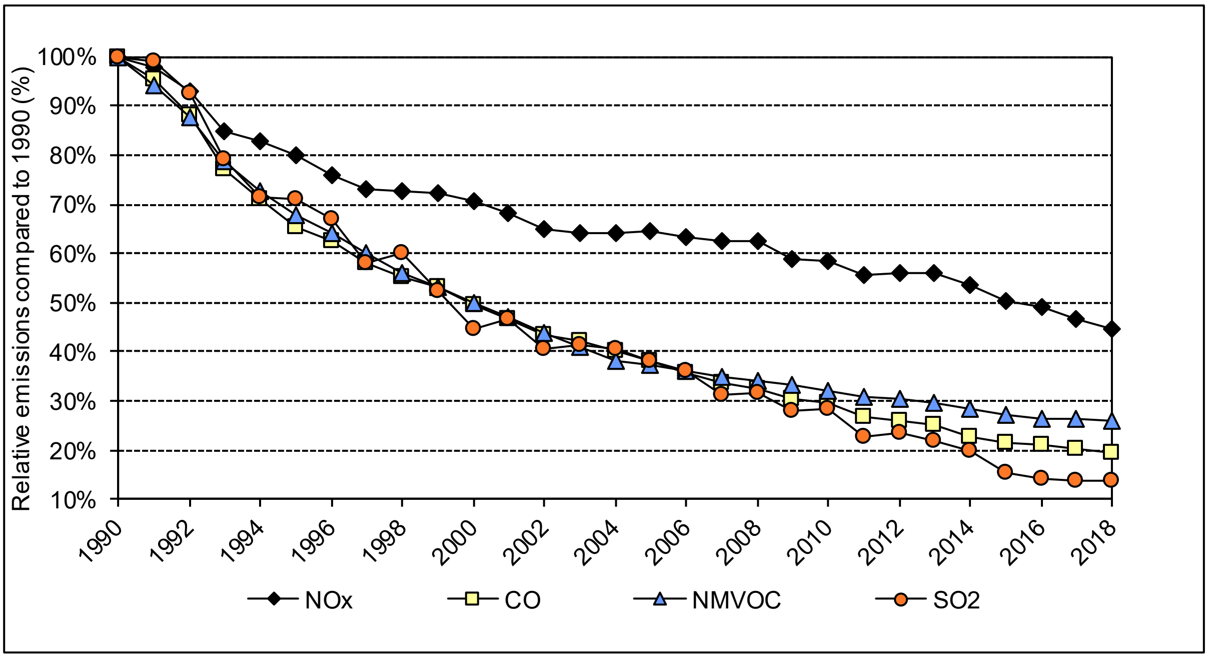


Figure 2-9: Relative trends for precursor and SO_2 emissions (excluding NMVOC from LULUCF; base year 1990 = 100%).

Sector 1 Energy is by far the largest source of precursor gas emissions (see Table 2-7), with the only exception being NMVOC, where sector 2 Industrial processes and product use is the dominant source besides NMVOC emissions from LULUCF (see Figure 2-10). The total shown in Table 2-7 includes NMVOC emissions from LULUCF, which are estimated at almost 100 kt per year according to SAEFL (1996a).

Table 2-7: Precursor and SO_2 emissions (kt) by source category in 2018.

Sectors	NO_x		CO		NMVOC		SO_2	
	kt	%	kt	%	kt	%	kt	%
1 Energy	59.83	93.0%	151.05	96.5%	17.14	11.1%	3.99	80.0%
2 IPPU	0.27	0.4%	2.59	1.7%	42.68	27.7%	0.91	18.3%
3 Agriculture	3.91	6.1%	NA	NA	17.99	11.7%	NA	NA
4 LULUCF	0.02	0.0%	0.65	0.4%	74.81	48.5%	NA	NA
5 Waste	0.17	0.3%	1.52	1.0%	1.40	0.9%	0.07	1.5%
6 Other sources	0.10	0.2%	0.75	0.5%	0.23	0.1%	0.01	0.2%
Total	**64.31**	**100.0%**	**156.56**	**100.0%**	**154.24**	**100.0%**	**4.99**	**100.0%**

Figure 2-10 shows the relative contributions of the various sectors for each individual precursor gas excluding LULUCF (data deduced from Table 2-7).

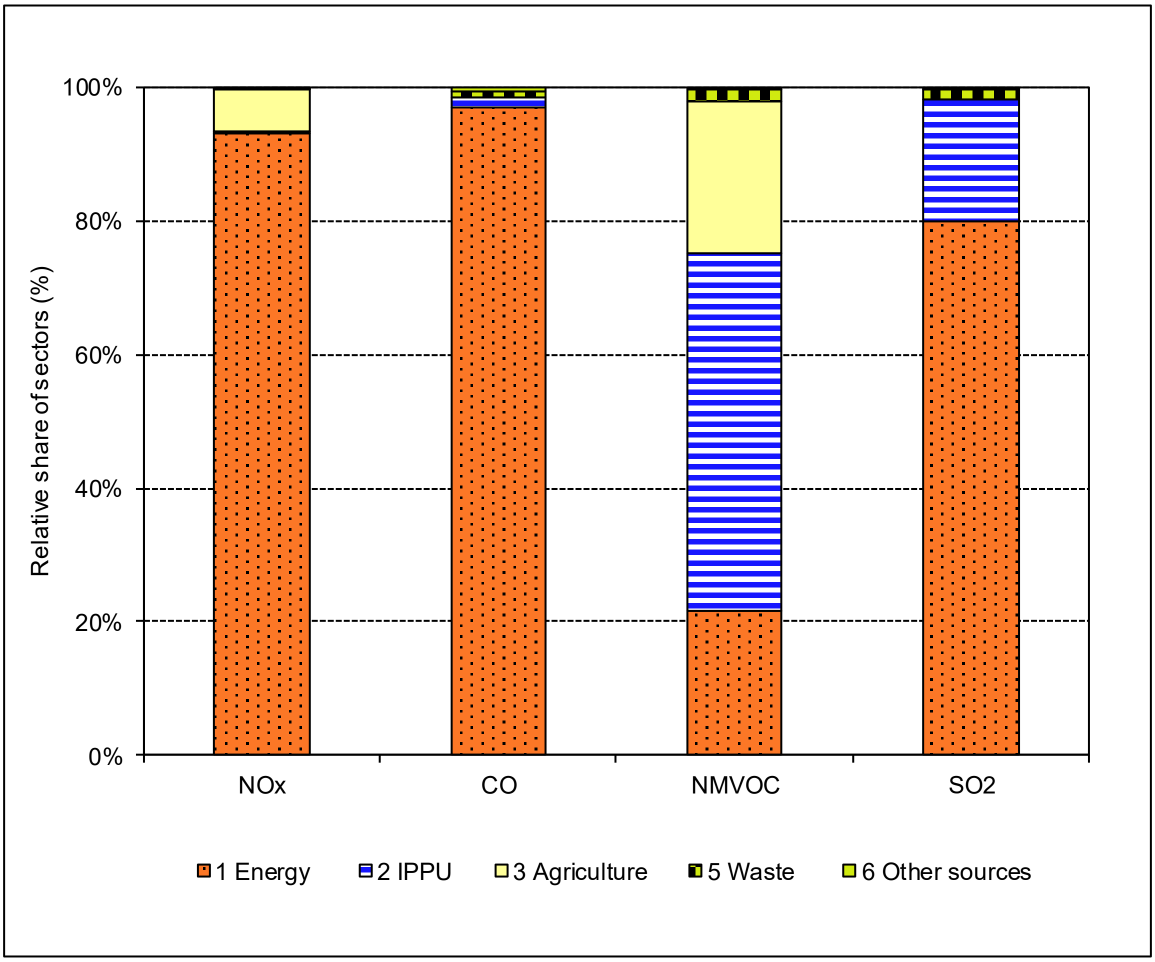


Figure 2-10: Relative contributions of individual sectors to precursor and SO_2 emissions in 2018 (excluding LULUCF).

2.5 Emission trends (Kyoto Protocol)

Relevant emissions and removals as accounted for under the Kyoto Protocol by sectors and GHG are shown in Table 2-8 and Table 2-9. Base year emissions for the second commitment period are reported in Switzerland's second Initial Report (FOEN 2016c) and the update to the report following the UNFCCC in-country review (FOEN 2016d).

Total emissions reported under the Kyoto Protocol differ from those reported under the UNFCCC because sectors 4 LULUCF and 6 Other and international bunkers are not accounted for under the Kyoto Protocol. However, activities under Article 3, paragraph 3 (Afforestation, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management, Grazing land management, and Revegetation) are taken into account. Under the activities of Article 3, paragraph 4 of the Kyoto Protocol, Switzerland only accounts for the mandatory activity Forest management.

Table 2-8 Summary of greenhouse gas emissions in CO_2 equivalent (kt) as well as emissions and removals under KP-LULUCF by sectors. Excluded are emissions and removals from sectors 4 LULUCF, 6 Other, and from International bunkers.

		Sector	Base year inital report	1990	1991	1992	1993	1994	1995	1996	1997	1998
			CO_2 equivalent (kt)									
Annex A sources		1 Energy + indirect CO_2 from this sector	41'881	41'906	44'302	44'344	42'167	41'050	41'943	42'816	41'896	43'466
		2 Industrial processes and product use + indirect CO_2 from this sector	3'887	4'348	3'968	3'746	3'482	3'649	3'648	3'540	3'504	3'529
		3 Agriculture	6'804	6'826	6'757	6'648	6'634	6'609	6'612	6'442	6'265	6'233
		5 Waste + indirect CO_2 from this sector	1'135	1'066	975	977	928	870	872	862	850	836
		Total (Annex A sources)	**53'707**	**54'146**	**56'003**	**55'715**	**53'211**	**52'178**	**53'075**	**53'660**	**52'515**	**54'064**

		Sector	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
			CO_2 equivalent (kt)									
Annex A sources		1 Energy + indirect CO_2 from this sector	43'257	42'248	43'662	42'058	43'250	43'568	44'006	43'620	41'573	42'966
		2 Industrial processes and product use + indirect CO_2 from this sector	3'630	3'936	4'005	4'133	4'109	4'390	4'542	4'580	4'661	4'608
		3 Agriculture	6'124	6'232	6'242	6'159	6'028	6'000	6'132	6'089	6'204	6'245
		5 Waste + indirect CO_2 from this sector	826	832	847	861	839	856	848	847	830	813
		Total (Annex A sources)	**53'837**	**53'247**	**54'756**	**53'210**	**54'224**	**54'815**	**55'527**	**55'135**	**53'268**	**54'632**
KP-LULUCF	Art.3.3	Afforestation & Reforestation										-25
		Deforestation										154
	Art.3.4	Forest management										-2'303
		Cropland management										NA
		Grazing land management										NA
		Revegetation										NA

		Sector	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. base year*
			CO_2 equivalent (kt)										*%*
Annex A sources		1 Energy + indirect CO_2 from this sector	41'857	43'224	39'163	40'558	41'480	37'434	37'102	37'495	36'509	35'241	*-16%*
		2 Industrial processes and product use + indirect CO_2 from this sector	4'370	4'626	4'631	4'606	4'609	4'607	4'553	4'498	4'651	4'513	*16%*
		3 Agriculture	6'170	6'203	6'160	6'232	6'089	6'207	6'132	6'113	6'107	5'991	*-12%*
		5 Waste + indirect CO_2 from this sector	791	777	762	740	734	723	714	704	691	672	*-41%*
		Total (Annex A sources)	**53'188**	**54'830**	**50'716**	**52'136**	**52'912**	**48'971**	**48'501**	**48'810**	**47'958**	**46'417**	***-14%***
KP-LULUCF	Art.3.3	Afforestation & Reforestation	-25	-24	-22	-21	-20	-18	-19	-19	-19	-16	
		Deforestation	161	165	165	166	166	147	136	129	154	165	
	Art.3.4	Forest management	-3'244	-3'198	-1'748	-2'955	-2'740	-1'435	-2'974	-2'920	-2'751	-1'278	
		Cropland management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
		Grazing land management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
		Revegetation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Table 2-9 Contribution of individual gases to total emissions (excluding 4 LULUCF, 6 Other, and International bunkers) in CO_2 equivalent (kt), as well as net emissions and removals under KP-LULUCF.

		GHG	Base year inital report	1990	1991	1992	1993	1994	1995	1996	1997	1998
			CO_2 equivalent (kt)									
Annex A sources		CO_2 + indirect CO_2	44'516	44'522	46'479	46'330	43'892	42'941	43'660	44'328	43'250	44'810
Annex A sources		CH_4	6'086	6'043	5'972	5'890	5'780	5'729	5'729	5'668	5'519	5'448
Annex A sources		N_2O	2'852	3'326	3'312	3'258	3'351	3'300	3'333	3'258	3'240	3'173
Annex A sources		HFCs	0.0	0.0	1.5	16	33	80	244	296	360	456
Annex A sources		PFCs	117	117	99	81	35	21	17	20	21	24
Annex A sources		SF_6	137	137	139	141	121	107	93	90	125	153
Annex A sources		NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Annex A sources		**Total (Annex A sources)**	**53'707**	**54'146**	**56'003**	**55'715**	**53'211**	**52'178**	**53'075**	**53'660**	**52'515**	**54'064**

		GHG	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
			CO_2 equivalent (kt)									
Annex A sources		CO_2 + indirect CO_2	44'626	43'785	45'239	43'611	44'782	45'354	45'902	45'488	43'478	44'823
Annex A sources		CH_4	5'362	5'306	5'347	5'303	5'222	5'188	5'203	5'220	5'202	5'272
Annex A sources		N_2O	3'144	3'307	3'247	3'274	3'077	3'004	3'116	3'009	3'105	2'979
Annex A sources		HFCs	533	636	736	827	910	1'010	1'048	1'160	1'253	1'275
Annex A sources		PFCs	32	61	37	36	67	69	50	62	52	45
Annex A sources		SF_6	140	152	151	161	166	190	207	197	178	239
Annex A sources		NF_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Annex A sources		**Total (Annex A sources)**	**53'837**	**53'247**	**54'756**	**53'210**	**54'224**	**54'815**	**55'527**	**55'135**	**53'268**	**54'632**
KP-LULUCF	Art.3.3	CO_2										127
KP-LULUCF	Art.3.3	CH_4										NO
KP-LULUCF	Art.3.3	N_2O										2.5
KP-LULUCF	Art.3.4	CO_2										-2'307
KP-LULUCF	Art.3.4	CH_4										2.7
KP-LULUCF	Art.3.4	N_2O										1.2

		GHG	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*2018 vs. base year*
			CO_2 equivalent (kt)										*%*
Annex A sources		CO_2 + indirect CO_2	43'642	45'154	41'087	42'355	43'283	39'329	38'823	39'278	38'268	36'981	*-17%*
Annex A sources		CH_4	5'180	5'154	5'099	5'070	5'006	5'003	4'973	4'930	4'868	4'839	*-20%*
Annex A sources		N_2O	2'868	3'012	2'941	3'001	2'901	2'881	2'910	2'889	3'082	2'879	*1%*
Annex A sources		HFCs	1'272	1'308	1'380	1'453	1'432	1'469	1'508	1'480	1'504	1'524	*see caption*
Annex A sources		PFCs	35	38	36	39	28	23	26	20	32	36	*-69%*
Annex A sources		SF_6	183	151	164	218	263	266	261	213	203	157	*15%*
Annex A sources		NF_3	7.6	12.7	9.3	0.5	0.1	0.6	0.7	0.8	0.8	0.5	*NA*
Annex A sources		**Total (Annex A sources)**	**53'188**	**54'830**	**50'716**	**52'136**	**52'912**	**48'971**	**48'501**	**48'810**	**47'958**	**46'417**	***-14%***
KP-LULUCF	Art.3.3	CO_2	132	139	141	142	143	126	114	107	133	146	
KP-LULUCF	Art.3.3	CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
KP-LULUCF	Art.3.3	N_2O	2.7	2.7	2.8	2.8	2.8	2.9	2.8	2.8	2.8	2.9	
KP-LULUCF	Art.3.4	CO_2	-3'248	-3'202	-1'754	-2'958	-2'743	-1'439	-2'977	-2'928	-2'756	-1'282	
KP-LULUCF	Art.3.4	CH_4	2.7	2.3	4.1	2.2	2.2	2.4	2.4	5.1	3.1	2.5	
KP-LULUCF	Art.3.4	N_2O	1.2	1.0	2.2	1.0	1.0	1.1	1.1	2.9	1.6	1.2	

3 Energy

Responsibilities for sector Energy	
Method updates	Anouk-Aimée Bass (FOEN)
Authors / sector experts	Anouk-Aimée Bass (FOEN; Overview, Stationary sources in 1A1, 1A4, Bunker fuels, Country-specific issues, Mobile sources in 1A2-1A5), Sabine Schenker (FOEN; Sectoral/Reference Approach, Feedstocks and non-energy use of fuels, Wood combustion, 1A2 (stationary)), Adrian Schilt (FOEN; Country-specific issues Fuel consumption, Industry Model), Theo Rindlisbacher (FOCA; Civil Aviation), Benedict Notter (INFRAS; non-road and Road transportation)
EMIS database operation	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN)
Annual updates (NIR text, tables, figures)	Felix Weber (INFRAS), Dominik Eggli (Meteotest), Beat Rihm (Meteotest), Adrian Schilt (FOEN)
Quality control (annual updates)	Felix Weber (INFRAS), Dominik Eggli (Meteotest), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Benedict Notter (INFRAS; non-road and Road transportation)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Theo Rindlisbacher (FOCA)

3.1 Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector 1 Energy. The following source categories are reported:

- 1A Fuel combustion
- 1B Fugitive emissions from fuels

In Switzerland, the sector 1 Energy is the most relevant source of greenhouse gases. The emissions of the period 1990–2018 are illustrated in Figure 3-1 and Table 3-1.

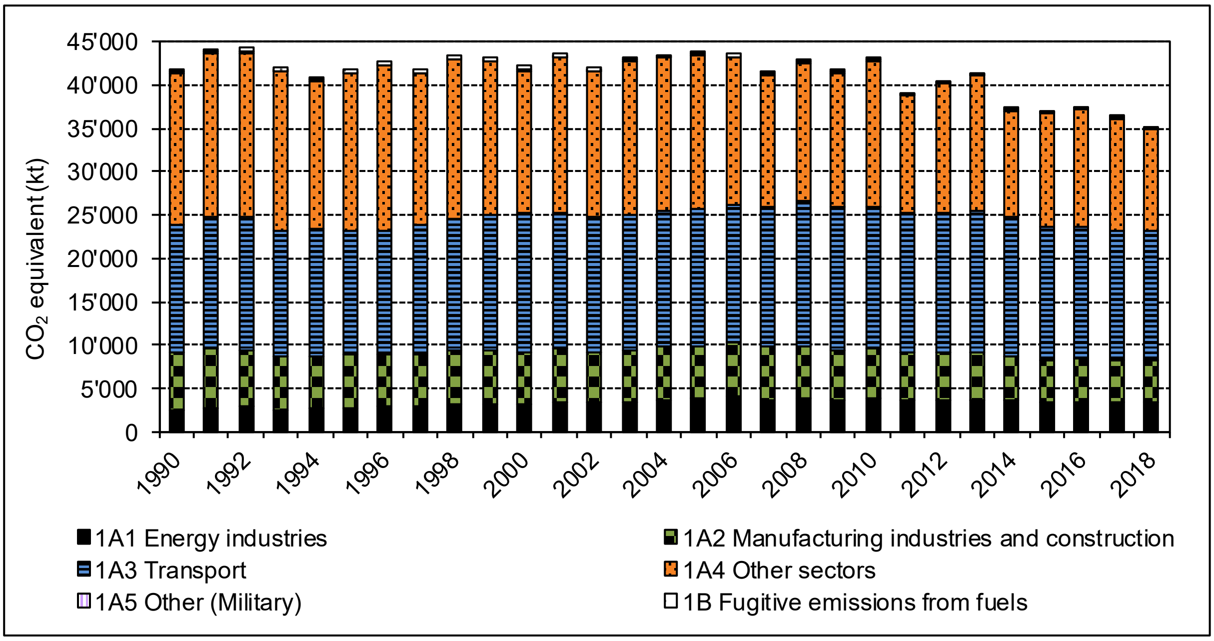


Figure 3-1 Switzerland's GHG emissions of sector 1 Energy in CO_2 equivalent (kt).

Considering total emissions of sector 1 Energy, fluctuations with no trend are observed in the period 1990–2005. From 2006 onwards, a decreasing trend can be identified, again superposed by fluctuations. The year 2018 shows the lowest value of the entire period 1990–2018. Two source categories dominate the emissions:

- 1A3 Transport and 1A4 Other sectors are the main sources of the sector 1 Energy.
- 1A1 Energy industries and 1A2 Manufacturing industries and construction contribute to total emissions as well, but are less important.
- 1A5 Other (Military) and 1B Fugitive emissions from fuels play only a minor role.

The trends of the individual gases are given in Table 3-1 and Figure 3-2:

- By far the most important gas emitted from sector 1 Energy is CO_2. Fluctuations reflect inter alia the climatic variability in Switzerland (see Figure 2-7 and related comments).
- The decreasing trend of CH_4 emissions since 1990 is the result of improved gas transmission and distribution networks, resulting in substantially lower fugitive emissions, and reduced emissions from gasoline passenger cars due to catalytic converters. Furthermore, improved combustion technologies in 1A4 Other sectors also contribute to the decreasing trend.
- The changes in N_2O emissions can mainly be explained by changes in the emission of road transportation due to changes in emission factors for diesel and gasoline combustion. The first generation of catalytic converters generated N_2O as an unintended by-product in the exhaust gases, leading to an increase in N_2O emissions until 1997. With new converter materials being used, the emission factors are decreasing since 2001 with strongest reduction during 2003 and 2004. Since 2007 the N_2O emissions are slightly increasing in line with increasing mileages (see Table 3-77). For further details, see chp. 3.2.9.2.2.

Table 3-1 GHG emissions of source category 1 Energy by gas in CO_2 equivalent (kt)

Gas	1990	1995	2000	2005
	CO_2 equivalent (kt)			
CO_2	40'900	40'916	41'345	43'343
CH_4	645	637	512	422
N_2O	318	363	374	228
Sum	41'862	41'916	42'231	43'993

Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2017 vs. 2018	1990 vs. 2018
	CO2 equivalent (kt)										%	
CO_2	42'354	41'260	42'611	38'594	39'989	40'916	36'911	36'579	36'960	35'977	-3%	-12%
CH_4	372	358	368	338	326	312	286	285	287	280	-2%	-57%
N_2O	229	229	237	223	235	243	230	232	242	246	2%	-23%
Sum	42'954	41'846	43'216	39'155	40'549	41'471	37'426	37'095	37'489	36'503	-3%	-13%

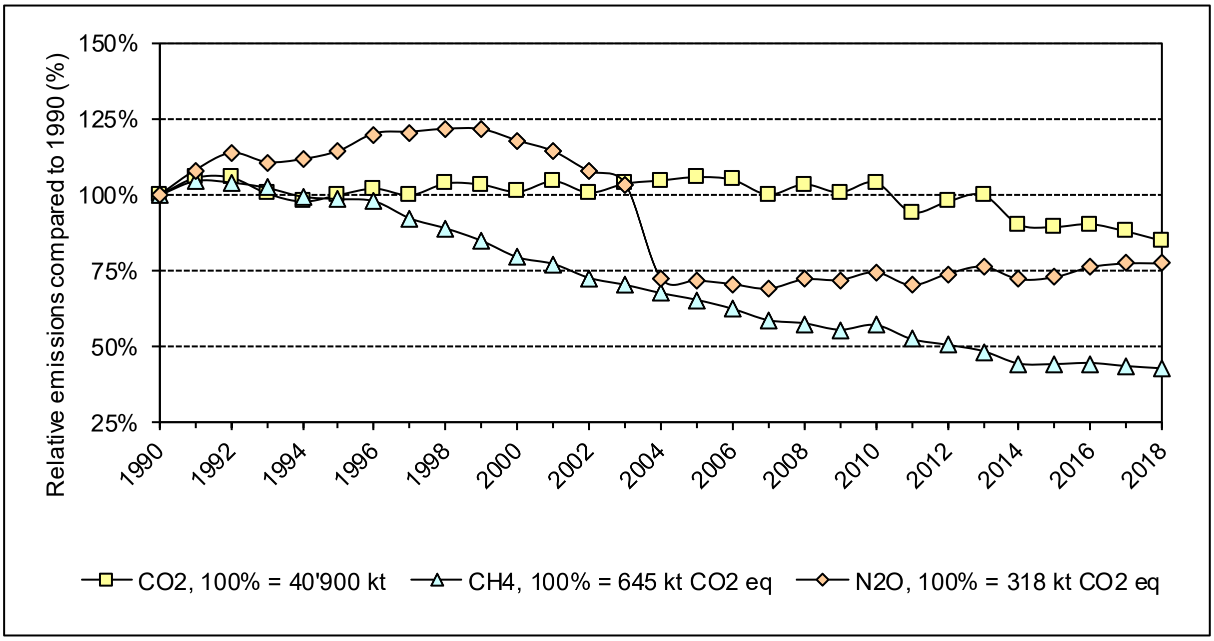


Figure 3-2 Relative trends of the greenhouse gas emissions of sector 1 Energy. The base year 1990 represents 100%.

The following table summarises the emissions of sector 1 Energy in 2018. The table also includes emissions from international bunkers (aviation and marine) as well as CO_2 emissions from biomass burning, which both are not accounted for under the Kyoto Protocol but are included in the reporting tables.

Table 3-2 Summary of sector 1 Energy, emissions in 2018 in kt CO_2 equivalent (Total: rounded values). For full biomass CO_2 emissions see Table 3-20.

Sector Energy	**CO_2**	**CH_4**	**N_2O**	***Total***
	CO_2 equivalent (kt)			
1 Energy	34'714	275.4	245.9	*35'235*
1A Fuel combustion	34'686	84.5	245.9	*35'016*
1A1 Energy industries	3'333	0.6	26.7	*3'360*
1A2 Manufacturing industries and construction	4'780	4.9	35.2	*4'820*
1A3 Transport	14'771	21.5	125.3	*14'918*
1A4 Other sectors	11'676	57.4	57.5	*11'791*
1A5b Other (mobile)	125	0.0	1.1	*127*
1B Fugitive emissions from fuels	28	190.9	0.0004	*219*
International bunkers	5'640	0.5	46.2	*5'687*
CO_2 emissions from biomass	7'526	-	-	*7'526*

In 2018, a total of 48 key source categories are identified in the Swiss greenhouse gas inventory according to level or trend (Table 1-9). Amongst these, 20 belong to the sector 1 Energy. The key categories (according to level and trend) from sector 1 Energy are shown in Figure 3-3 (Approach 1) and Figure 3-4 (Approach 2).

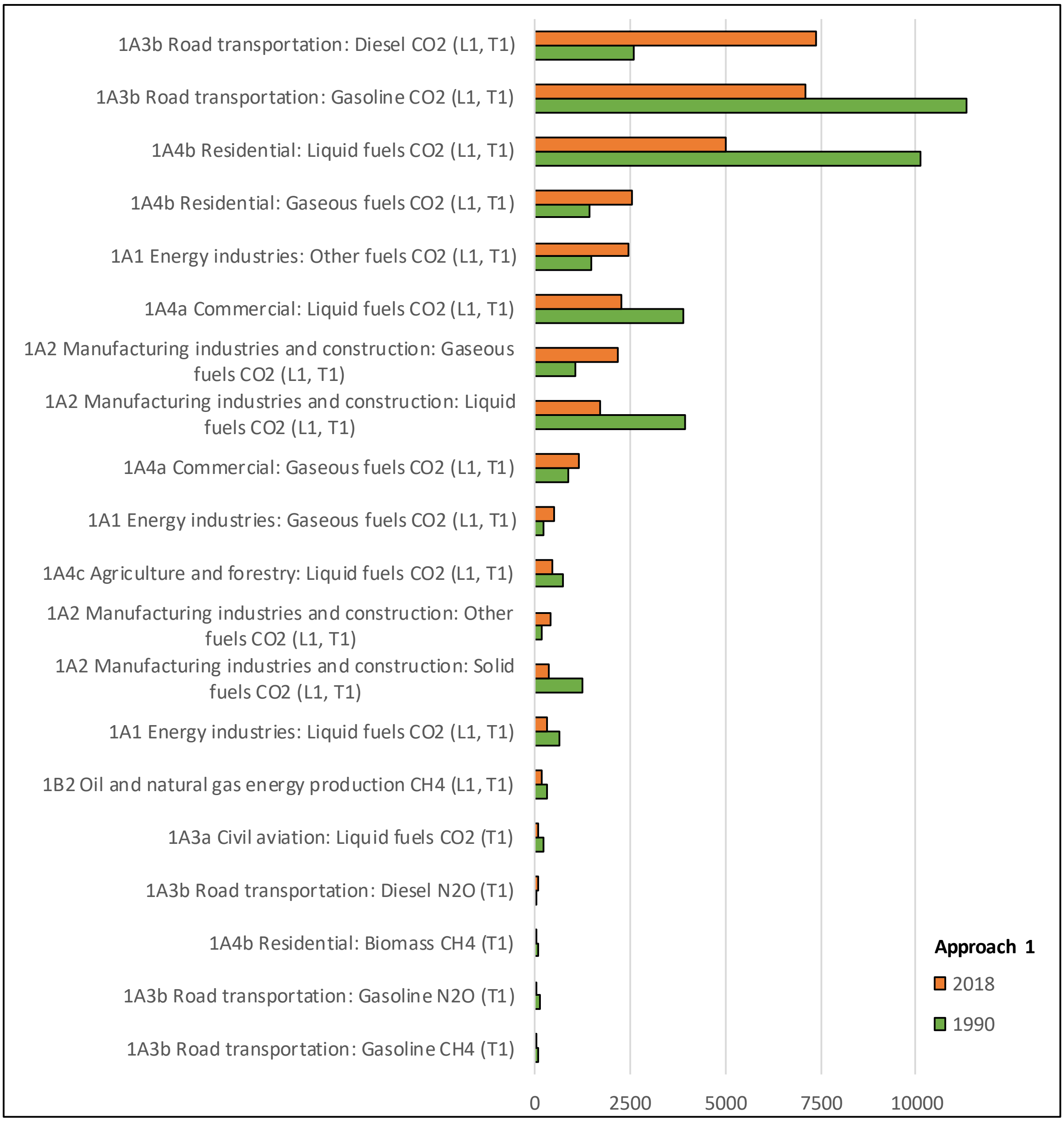


Figure 3-3 Key categories in the Swiss GHG inventory from sector 1 Energy determined by Approach 1 (L1 = key category according to Approach 1 level in 2018; T1 = key category according to Approach 1 trend 1990–2018).

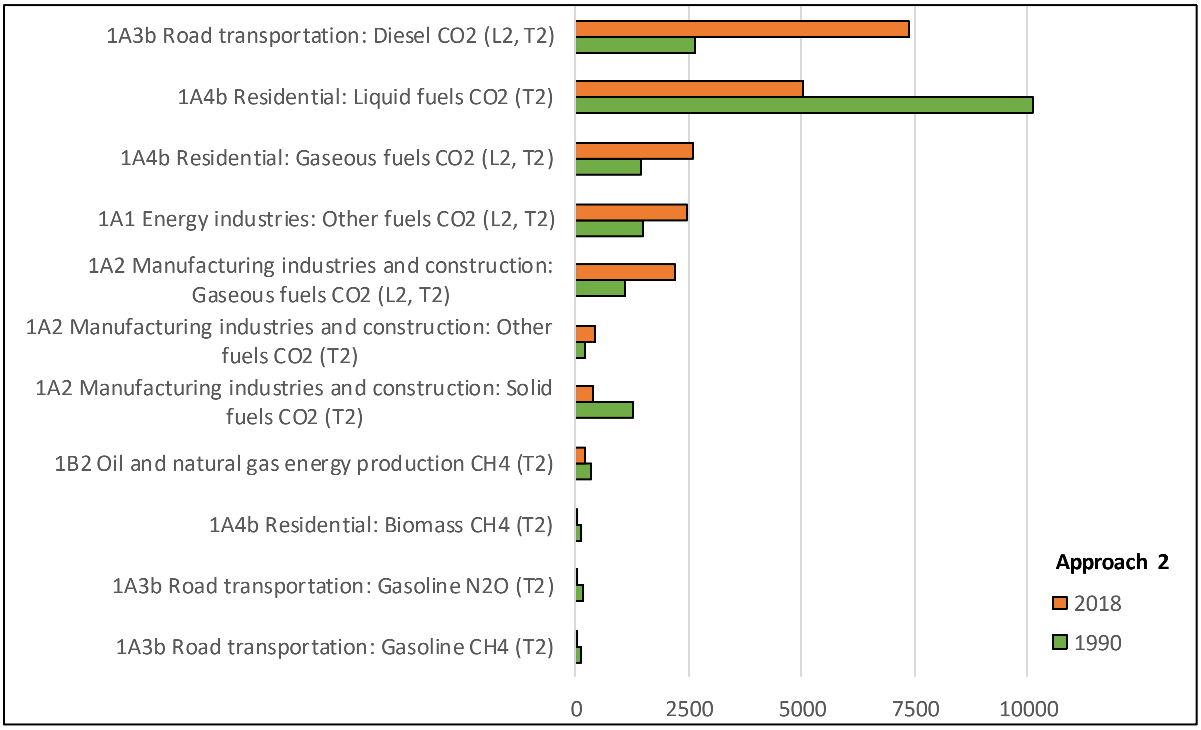


Figure 3-4 Key categories in the Swiss GHG inventory from sector 1 energy determined by Approach 2 (L2 = key category according to Approach 2 level in 2018; T2 = key category according to Approach 2 trend 1990–2018).

3.2 Source category 1A – Fuel combustion activities

3.2.1 Comparison of the Sectoral Approach with the Reference Approach

Two methods are applied for modelling CO_2 emissions from the sector 1 Energy, the Sectoral Approach and the Reference Approach. For the inventory under the Framework Convention on Climate Change and the Kyoto Protocol the Sectoral Approach is used. The Reference Approach is only used for verification purposes (quality control activity).

Figure 3-5 shows the input data used and the disaggregation of fuel types for each of the two approaches.

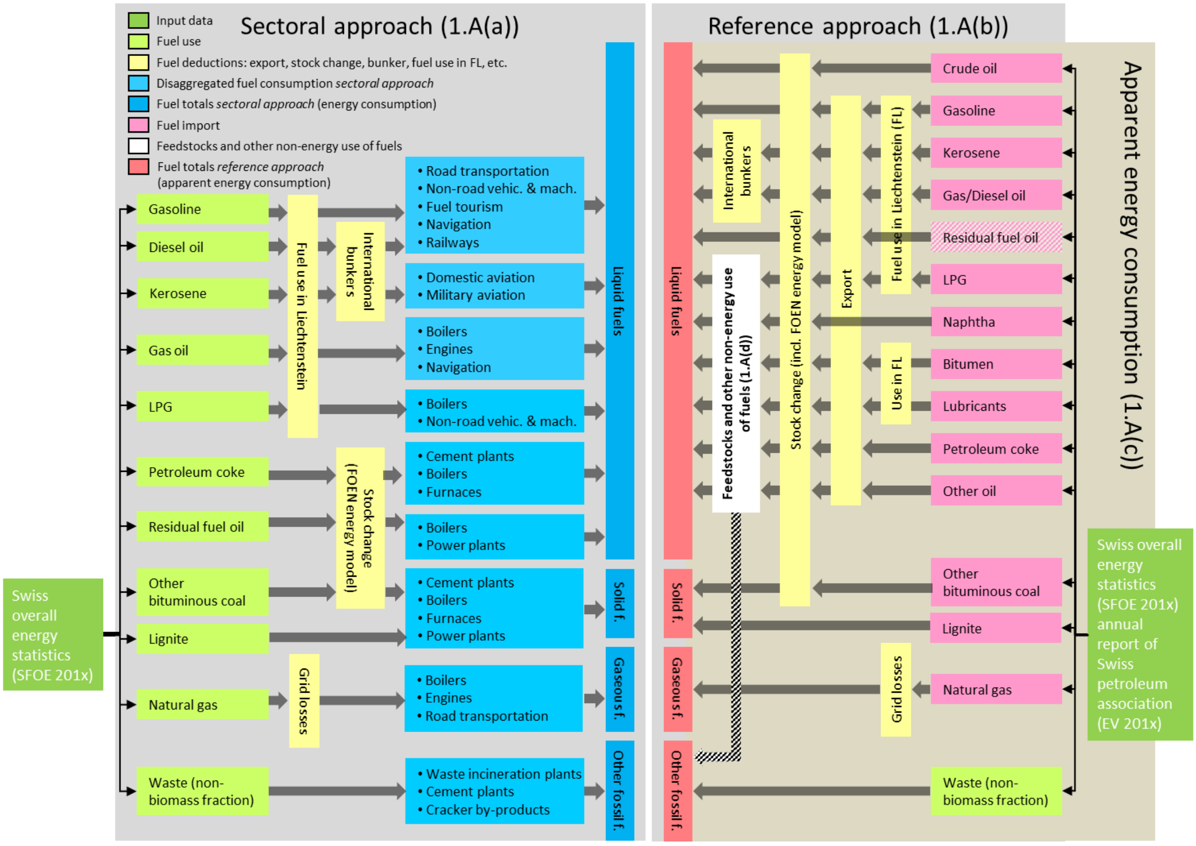


Figure 3-5 Calculation of Reference and Sectoral Approach. The input data for both approaches stem from the Swiss overall energy statistics (SFOE 2019). For the Reference Approach, additional information from Avenergy Suisse (formerly Swiss Petroleum Association) (EV 2019) is used. While the Reference Approach considers the net import/export balance, the Sectoral Approach considers the fuel consumption. The dark grey arrows represent fuel deductions where occurring. The dashed arrow from the Feedstock use to Other fossil fuels stands for the CO_2 emissions from cracker by-products (originating from feedstock use of LPG and naphtha) which are accounted for under Other fossil fuels. The graphic box of the import of Residual fuel oil is dashed since there is no more import of residual fuel oil.

The Sectoral Approach is based on sectoral energy consumption data from the Swiss overall energy statistics (SFOE 2019) and additional source-specific information. In the Sectoral Approach, fossil fuel consumption statistics are combined with bottom-up data and modelling of fuel consumption. A detailed description of the Sectoral Approach is provided in chp. 3.2.4.

The Reference Approach on the other hand corresponds to a top-down approach based on net quantities of fuel imported into Switzerland as listed in the energy supply statistics of the Swiss overall energy statistics (SFOE 2019). Apparent consumption (in tonnes) is derived from imports and exports of primary fuels (crude oil, natural gas, coal[3]), secondary fuels (gasoline, diesel oil etc.) and stock changes. For crude oil, a constant value for carbon content and net calorific value is applied for the entire time period, although these properties may vary depending on origin. For solid, gaseous, secondary liquid and other fuels, the same carbon content values and net calorific values are applied as in the Sectoral Approach (see Table 3-9 and Table 3-10, Table 3-12 and Table 3-13 in chp. 3.2.4.2 and 3.2.4.4). After the deduction of feedstocks and non-energy use of fuels (see chp. 3.2.3), the net carbon emissions and effective CO_2 emissions are calculated for the Reference Approach as shown in the reporting tables 1.A(b)–1.A(d). The oxidation factor is set to one (see chp. 3.2.4.4.1). The Reference Approach covers the CO_2 emissions of all net imported primary fuels and emissions of imported secondary fuels. In 2014, 44% of all liquid fossil fuels sold in Switzerland (without kerosene) were produced in Swiss refineries. In 2015 after closing of one refinery, the share dropped down to 30% (EV 2016). In addition, the reporting tables 1.A(b) provide information of the Reference Approach of total biomass use as well as consumption of so-called other non-fossil fuels (biogenic waste) in Switzerland.

All necessary data for calculating the Reference Approach are implemented in the EMIS database and all the data on import, export, bunkers, stock changes, apparent consumption, carbon emission factors, carbon stored and actual emissions are calculated in the EMIS database under the following conditions:

- For the Reference Approach, gas oil and diesel oil are reported together, since the reporting table template structure requires this aggregation. Accordingly, a weighted average NCV is calculated based on values given in Table 3-9. In contrast, marine bunkers consist of diesel oil only and are reported using the country-specific NCV as of Table 3-9.
- Liechtenstein's liquid fossil fuel consumption is subtracted from the input figures in SFOE (2019), as the Swiss overall energy statistics includes Liechtenstein's liquid fuel consumption as well (customs union with Switzerland) (see also chp. 3.2.4). The same holds for the non-energy use of bitumen and lubricants.

The differences in energy consumption and CO_2 emissions between Reference and Sectoral Approach are calculated within the EMIS database. For the entire period, they are below 1% for energy consumption and in the range of about 1% for CO_2 emissions, as shown in Table 3-3 and in Figure 3-6. Various effects influence the difference between Reference and Sectoral Approach. On the one hand, energy and carbon contents of crude oil may vary over time. However, no data are available to quantify this effect. On the other hand, the efficiency of Swiss refineries and the market share of secondary fuel imports potentially influence the difference between the Reference and Sectoral Approach. Apparent differences between the Reference Approach and the IEA energy statistics (IEA 2012) are discussed in Annex A4.2.

[3] Coke oven coke and anthracite are included under other bituminous coal.

Table 3-3 Differences in energy consumption and CO_2 emissions between the Reference and the Sectoral Approach. The difference is calculated according to [(RA-SA)/SA] 100% with RA = Reference Approach, SA = Sectoral Approach.

	1990	1995	2000	2005
	%			
Energy consumption	0.6	0.8	0.4	0.5
CO_2 emissions	0.8	0.9	0.7	0.8

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	%									
Energy consumption	0.6	0.5	0.5	0.4	0.4	0.4	0.1	0.5	0.2	0.1
CO_2 emissions	1.1	1.0	1.0	0.8	0.9	0.9	0.6	1.1	0.8	0.7

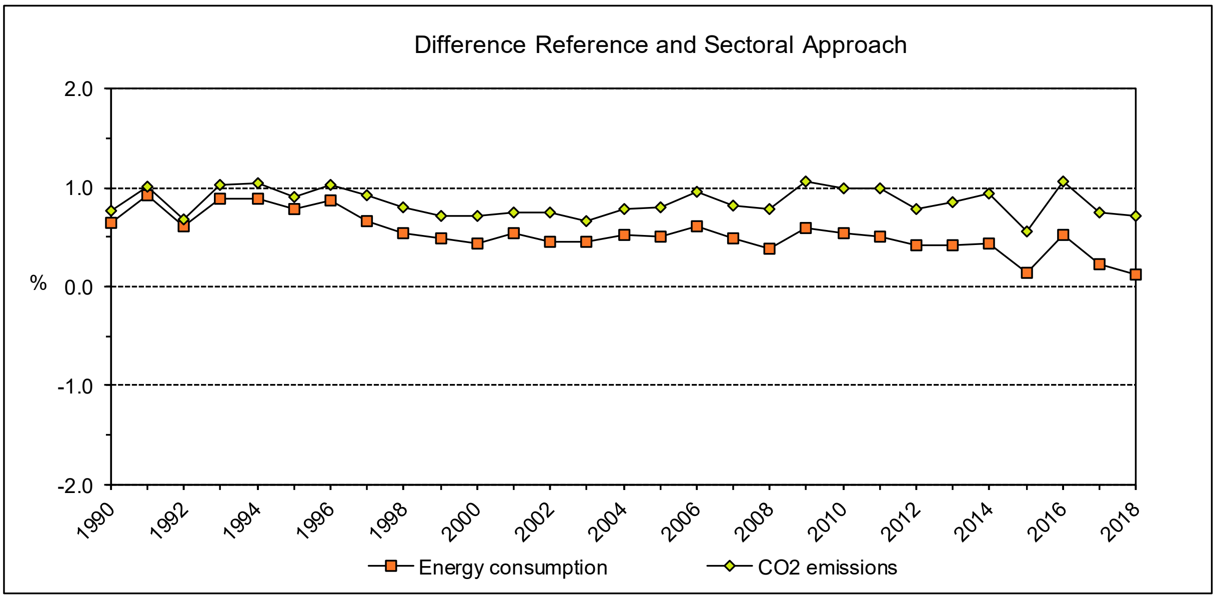


Figure 3-6 Time series for the differences between Reference and Sectoral Approach. Numbers are taken from Table 3-3. See caption there for further information.

3.2.1.1 Category-specific recalculations for the Reference Approach

No recalculations were carried out exclusively for the reference approach. Recalculations are described in the relevant chapters of the sectoral approach or the chapter on feedstock and non-energy use of fuels.

3.2.2 International bunker fuels (1D)

3.2.2.1 Source category description for 1D

With Switzerland being a landlocked country, international aviation dominates emissions from bunker fuels by far. International navigation is limited to activities on the river Rhine (Basel – Rotterdam) and navigation on Lake Geneva (bordering France) and Lake Constance (bordering Germany and Austria).

Table 3-4 Source category description of International bunkers.

1D	Source category	Specification
1D1	International aviation (aviation bunkers)	Bunker fuels include fuel used for international aviation only.
1D2	International navigation (marine bunkers)	Marine bunkers of the Rhine river and navigation on the Lake Geneva and the Lake Constance.

3.2.2.2 Methodological issues for 1D

3.2.2.2.1 International aviation / aviation bunkers (1D1)

Following the decision tree of the 2006 IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.6.1), the emissions from aviation bunkers are calculated with a Tier 3A method because of availability of data on the origin and destination of flights and also on air traffic movements delivered by the Federal Office of Civil Aviation (FOCA).

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. For international aviation (aviation bunkers), the flights departing from Switzerland to a destination abroad are selected. The emission factors are country-specific based on measurement and analyses of fuel samples. The activity data of the international aviation bunker are summarised in Table 3-6 (see also Table 3-74). Given that detailed information about activity data is available, the resulting fuel consumption is considered complete. In spite of this, there remain small differences between the fuel consumption modelled bottom-up and the total fuel sold (SFOE 2019, FOCA 2019). In 1990, the modelled consumption adds up to 1.01 million tonnes, whereas 1.05 million tonnes of fuel was sold. Such difference of 4% is considered acceptable, because discrepancies up to 10% can easily result from fuelling strategies of airlines (FOCA 2006a). Investigation showed, that airlines are calculating whether it is economically beneficial to refuel at a place with lower fuel price. In order to match the bottom-up calculation with the fuel quantity sold, any occurring difference is attributed to international bunker emissions. The factor between calculated international fuel consumption and adjusted international fuel consumption is used to scale the bunker emissions linearly. For instance in 2018, the bunker fuel consumption and the emissions had to be expanded by the factor 1.017, the correction factor was 0.983 (FOCA 2019). For the more recent years, the modelled and actual total fuel sales are listed in Table 3-5.

Table 3-5 Comparison between modelled and actual fuel sales in bunker fuel consumption for aviation.

Modelled and actual fuel sales	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Fuel consumption in t								
Modelled fuel sales domestic	39'252	42'047	43'414	42'064	44'462	43'680	44'716	37'985	36'561
Modelled fuel sales international	1'395'428	1'511'279	1'527'522	1'528'863	1'561'678	1'590'013	1'711'227	1'741'752	1'818'355
Actual fuel sales SFOE minus modelled fuel sales domestic	1'390'824	1'488'805	1'523'116	1'539'963	1'549'228	1'602'319	1'679'034	1'723'717	1'823'917
Correction factor for emission international	0.969	0.957	0.969	0.980	0.964	0.980	0.955	0.968	0.983
Overestimation emission international (modelled)	3.1%	4.3%	3.1%	2.0%	3.6%	2.0%	4.5%	3.2%	1.7%

Table 3-6 International bunker fuels (1D1): aviation bunkers. Consumption of kerosene in TJ (Liechtenstein's kerosene consumption is subtracted, see chp. 3.2.4).

1D1 International aviation	**1990**	**1995**	**2000**	**2005**
	Fuel consumption in TJ			
1D1 International aviation	41'884	49'918	63'726	47'775
1990 = 100%	100%	119%	152%	114%

1D1 International aviation	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	Fuel consumption in TJ									
1D1 International aviation	55'426	58'334	62'461	63'903	64'709	65'006	67'333	70'603	72'824	77'214
1990 = 100%	132%	139%	149%	153%	154%	155%	161%	169%	174%	184%

3.2.2.2.2 International navigation / navigation bunkers (1D2)

According to the decision tree concerning navigation bunkers (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.5.1), emissions from international navigation are calculated with a Tier 2 approach for CO_2 (with country-specific carbon contents) and with a Tier 1 approach for CH_4 and N_2O using IPCC default emission factors. On the river Rhine and on Lake Geneva and Lake Constance, some of the boats cross the border and go abroad (Germany, France). Fuels bought in Switzerland will therefore become bunker fuel. Accordingly, the amount of bunker diesel oils is reported as a memo item "International bunker / navigation".

- Only diesel oil is relevant for navigation on the river Rhine. Since there is an exemption from fuel taxation, activity data on marine river bunkers on the Rhine are well documented by the customs administration for the years 1997–2018 (SFOE 2019f).
- For navigation on two border lakes (Lake Constance, Lake Geneva), bunker fuel consumption was reported in INFRAS (2011a) after having performed surveys among the shipping companies involved. Activity data of these bunkers is summarised in Table 3-7. Data from 1995–2012 have been provided by the three navigation companies concerned as documented in INFRAS (2011a), data from 2013 onwards are constant on the 2012 level. For older data, proxies such as passenger data on a national basis had to be consulted. As marine lake bunkers provide only a minor share of the total international navigation (between 6% for the year 1990 and 23% for 2015) this approach is justified. The emission factor for CO_2 is country-specific and in accordance with Table 3-12.

Table 3-7 International bunker fuels (1D2): Navigation. Consumption of diesel oil in TJ.

1D2 International navigation	**1990**	**1995**	**2000**	**2005**
	Fuel consumption in TJ			
1D2 International navigation	813	756	526	500
1990 = 100%	100%	93%	65%	62%

1D2 International navigation	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	Fuel consumption in TJ									
1D2 International navigation	435	472	421	379	356	311	335	342	299	256
1990 = 100%	54%	58%	52%	47%	44%	38%	41%	42%	37%	32%

3.2.2.3 Uncertainties and time-series consistency for 1D

International aviation: see general remarks in chp. 3.2.4.7.

Consistency: Time series of 1D are all considered consistent.

3.2.2.4 Category-specific QA/QC and verification for 1D

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

3.2.2.5 Category-specific recalculations for 1D

No category-specific recalculations were carried out.

3.2.2.6 Category-specific planned improvements for 1D

No category-specific improvements are planned.

3.2.3 Feedstocks and non-energy use of fuels

The Swiss overall energy statistics (SFOE 2019) reports feedstocks and non-energy fuel use on an aggregated level only. Some disaggregation is provided by the petroleum balance of the annual report of Avenergy Suisse (formerly Swiss petroleum association, EV) (EV 2019). To complement this source, bottom-up data from annual monitoring reports of the Swiss emissions trading scheme (ETS) and from surveys of individual companies are used to provide a detailed breakdown into specific petroleum products and coal types. For submission 2015, a new and more differentiated breakdown of feedstocks and non-energy use of fuels was developed. The reassessment of feedstocks and other non-energy use of fuels is documented in an internal documentation (FOEN 2015g).

Feedstocks and non-energy use of fuels is reported in reporting tables 1.A(d) and differentiated in the following fuel types:

- Liquefied petroleum gas and naphtha are exclusively used in one single Swiss plant as feedstocks in the thermal cracking process for the production of ammonia and ethylene (see source categories 2B1 and 2B8b under 4.3.2.1 and 4.3.2.4, respectively). Accordingly, activity data for liquefied petroleum gas and naphtha are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Bitumen is the most important petroleum product which is used as a feedstock in Switzerland. It is mainly used for road paving with asphalt and to a lower extent in asphalt roofing (see source category 2D3 under 4.5.2.2).
- Lubricants are used in a variety of processes, including the blending with gasoline for 2-stroke engines. Two different ways of lubricant use are considered: lubricants used in 2-stroke engines are assumed to be 100% oxidised, whereas the use of all other lubricants are partly emissive. According to the 2006 IPCC guidelines (IPCC 2006), 20% of those lubricants are oxidized during use (ODU). All CO_2 emissions from use of lubricants are reported under source category 2D1, see chp. 4.5.2.1.
- Petroleum coke is used as a feedstock by two consumers only, i.e. for the production of silicium carbide and graphite as well as of anodes in primary aluminium production (up to 2006) in source categories 2B5 and 2C3, respectively (see chp. 4.3.2.3 and 4.4.2.2). Apart from bottom-up information from these two consumers, top-down information is provided by the Swiss petroleum association (EV 2019). Activity data are confidential and included in fuel type Other oil in reporting table 1.A(d).

- Paraffin waxes for non-energy use are reported under Other oil, since there is no separate category for paraffin waxes in reporting table 1.A(d). The information used stems from the statistics of the Swiss petroleum association (EV 2019). Use of paraffin waxes is considered partly emissive (see source category 2D2 under 4.5.2.1). According to the 2006 IPCC Guidelines (IPCC 2006), 20% of paraffin waxes are oxidized during use (ODU).
- Other oil comprises all other unspecified petroleum products for non-energy use. The net consumption of non-energy use of fuels reported in the Swiss overall energy statistics includes sulphur produced by the refineries. This amount of sulphur is subtracted, resulting in lower fuel quantities for non-energy use of other oil for the entire time series compared to the Swiss overall energy statistics.
- Anthracite is also used as feedstock in the Swiss production plant for silicium carbide and graphite in source category 2B5 (chp. 4.3.2.3). Accordingly, activity data for anthracite are confidential and thus denoted as “C” in reporting tables 1.A(d). Based on personal communication with the relevant experts for the Swiss overall energy statistics, the feedstock use of anthracite is included in the stock changes of other bituminous coal.

Table 3-8 This table is only available in the confidential version of this chapter. It provides a complete time series of the fuel quantity, carbon excluded and the reported CO_2 emissions from feedstocks and non-energy use of fuels.

3.2.3.1 Category-specific recalculations

There were no category-specific recalculations in 1AD.

3.2.4 Country-specific issues of 1A Fuel combustion

3.2.4.1 System boundaries: Differences between UNFCCC and CLRTAP reporting

Switzerland reports its greenhouse gas emissions according to the requirements of the UNFCCC as well as air pollutants according to the requirements of the CLRTAP. The nomenclature for both reportings is (almost) the same (NFR), but there are differences concerning the system boundaries. Under the UNFCCC, the national total for assessing compliance is based on fuel sold within the national territory, whereas under the CLRTAP, the national total for assessing compliance is based on fuel used within the territory. Thus, fuel sold in Switzerland but consumed abroad (“fuel tourism”) is accounted for in Switzerland’s GHG inventory (see chp. 3.2.9.2.2), but not in the reporting under the CLRTAP. The difference between the two approaches amounts to several percent, with considerable variation from year to year due to fluctuating fuel price differences between Switzerland and its neighbouring countries.

Also emissions from civil aviation are reported differently under the UNFCCC and the CLRTAP: Only emissions from domestic flights are accounted for under the UNFCCC, while emissions from international flights are reported as memo items. For the reporting under the CLRTAP, landing and take-off (LTO) emissions of domestic and international flights are accounted for, while emissions of international and domestic cruise flights are reported as memo items (Figure 3-7).

Differences between reporting under CLRTAP and UNFCCC concerning the accounting to the national total			CLRTAP / NFR tables			UNFCCC / CRF tables	
			accounted to				
			National total	National total for compliance	Separated information / Memo items	National total	Bunker (1D)
Road transportation (1A3b)	Fuels sold (1A3b)	Fuel used (1A3bi-v)	Yes	Yes	Yes	Yes	No
		Fuel tourism and statistical differences	Yes	No	No	Yes	No
Aviation (1A3a)	Civil and domestic aviation	Landing and Take-Off (LTO)	Yes	Yes	No	Yes	No
		Cruise	No	No	Yes	Yes	No
	International aviation	Landing and Take-Off (LTO)	Yes	Yes	No	No	Yes
		Cruise	No	No	Yes	No	Yes

Figure 3-7 Accounting rules for emissions from 1A3a Domestic aviation and 1A3b Road transportation under the CLRTAP and the UNFCCC.

3.2.4.2 Net calorific values (NCVs)

Table 3-9 summarizes the net calorific values (NCVs) which are used in order to convert from energy amounts in tonnes into energy quantities in gigajoules (GJ). More detailed explanations including information about the origin of the NCVs of the different fuels are given below.

Table 3-9 Net calorific values (NCVs) of various fuels. Where values for two years are indicated, the NCV is interpolated between these two years and constant NCVs are used before the first and after the second year (corresponding to the two indicated values). For the NCV of wood, a range covering all facility categories and years is provided. For the NCVs of natural gas and biogas see Table 3-10.

Fuel	**Data sources**	**NCV [GJ/t]**
Gasoline	EMPA (1999), SFOE/FOEN (2014)	42.5 (1998), 42.6 (2013)
Jet kerosene	EMPA (1999), SFOE/FOEN (2014)	43.0 (1998), 43.2 (2013)
Diesel oil	EMPA (1999), SFOE/FOEN (2014)	42.8 (1998), 43.0 (2013)
Gas oil	EMPA (1999), SFOE/FOEN (2014)	42.6 (1998), 42.9 (2013)
Residual fuel oil	EMPA (1999)	41.2
Liquefied petroleum gas	SFOE (2019)	46.0
Petroleum coke	SFOE (2019), Cemsuisse (2010a)	35.0 (1998), 31.8 (2010)
Other bituminous coal	SFOE (2019), Cemsuisse (2010a)	28.052 (1998), 25.5 (2010)
Lignite	SFOE (2019), Cemsuisse (2010a)	20.097 (1998), 23.6 (2010)
Natural gas	SGWA	*see caption*
Biofuel	**Data sources**	
Biodiesel	SFOE (2019)	38.0
Bioethanol	SFOE (2019)	26.5
Biogas	*assumed equal to natural gas*	*see caption*
Wood	SFOE (2019b)	8.6-14.6

Gasoline, jet kerosene, diesel oil and gas oil
For gasoline, jet kerosene, diesel oil and gas oil, the NCV for 1998 and 2013 are based on national measurement campaigns and are the same as used by the Swiss Federal Office of Energy (SFOE 2019). A first campaign was conducted by the Swiss Federal Laboratories for Materials Science and Technology (EMPA) in 1998 (EMPA 1999). Since previous data are not available, the values for 1990–1998 are assumed to be constant at the 1998 levels. A second campaign, commissioned by the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN), was conducted in 2013 (SFOE/FOEN 2014). This study was based on representative samples covering summer and winter fuel qualities from the main import streams. The sampling started in July 2013 and lasted six months. Samples were taken fortnightly from nine different sites (large-scale storage facilities and the two Swiss refineries) and analysed for carbon contents and NCVs amongst other. These updated values are used from 2013 onwards, while the NCVs for 1999–2012 are linearly interpolated between the measured values of 1998 and 2013.

Residual fuel oil
Residual fuel oil plays only a minor role in the Swiss energy supply. Therefore, this fuel was not analysed in the most recent measurement campaign in 2013 (SFOE/FOEN 2014). Thus, the respective NCV refers to the measurement campaign in 1998 (EMPA 1999). The NCV for residual fuel oil, which is the same as used by the Swiss Federal Office of Energy (SFOE 2019), is assumed to be constant over the entire reporting period. The same approach is applied for the CO_2 emission factor (see Table 3-12).

Liquefied petroleum gas
The NCV of liquefied petroleum gas is the same as used by the Swiss Federal Office of Energy (SFOE 2019) and is – as in the Swiss overall energy statistics – constant over the entire reporting period. It is assumed that LPG consists of 50% propane and 50% butane.

Petroleum coke, other bituminous coal, lignite
For the entire reporting period, the NCVs of petroleum coke, other bituminous coal and lignite are the same as used by the Swiss Federal Office of Energy (SFOE 2019). For these fuels, the Swiss overall energy statistics contains NCVs for the years 1998 and 2010. Values in between are interpolated, before the first and after the last year of available data values are held constant. The NCVs for 2010 are based on measured samples taken from Switzerland's cement plants as they are the largest consumers of these fuels in Switzerland. Samples from the individual plants were taken from January to September 2010 and analysed for NCVs by an independent analytical laboratory (Cemsuisse 2010a). For each fuel, the measurements from the individual plants were weighted according to the relative consumption of each plant.

Natural gas, biogas
The NCV of natural gas (and also the CO_2 emission factor of natural gas, see Table 3-13) is calculated based on measurements of gas properties and corresponding import shares of

individual gas import stations. Measurements of gas properties are available from the Swiss Gas and Water Industry Association (SGWA) on an annual basis since 2009 and for selected years before. The latest report is SGWA (2019). Import shares are available for 1991, 1995, 2000, 2005, 2007 and from 2009 onwards on an annual basis. Estimated import shares for the years 1991, 1995 and 2000 are taken from Quantis (2014). Values for the years in between are interpolated. The calculation procedure is documented in FOEN (2019i). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to become the same quality level including its energetic properties as natural gas.

Table 3-10 Net calorific values (NCVs) of natural gas and biogas for years with available data. Values for the years in between are linearly interpolated. Data source: Annual reports of the Swiss Gas and Water Industry Association (SGWA), the latest report is SGWA (2019). Spreadsheet to determine national averages: FOEN (2019i).

Year	NCV of natural gas and biogas [GJ/t]
1990	46.5
1991	46.5
1995	47.5
2000	47.2
2005	46.6
2007	46.3
2009	46.4
2010	46.3
2011	46.1
2012	45.8
2013	45.7
2014	45.7
2015	46.6
2016	47.1
2017	47.3
2018	47.6

Wood

The NCV of wood depends on the type of wood fuel (e.g. log wood, wood chips, pellets) and is based on the Swiss wood energy statistics (SFOE 2019b). Table 3-9 illustrates the range of the NCVs of all wood fuel types.

Bioethanol and biodiesel

The NCVs of bioethanol and biodiesel are the same as used by the Swiss Federal Office of Energy (SFOE 2019) and are – as in the Swiss overall energy statistics – constant over the entire reporting period.

3.2.4.3 Swiss energy model and final energy consumption

3.2.4.3.1 Swiss overall energy statistics

The fundamental data on final energy consumption is provided by the Swiss overall energy statistics (SFOE 2019). However, since Switzerland and Liechtenstein form a customs and monetary union governed by a customs treaty, data regarding liquid fuels in the Swiss overall energy statistics also cover liquid fuel consumption in Liechtenstein. In order to calculate the correct Swiss fuel consumption, Liechtenstein's liquid fossil fuel consumption, given by Liechtenstein's energy statistics (OS 2019), is subtracted from the numbers provided by the Swiss overall energy statistics. In all years of the reporting period, the sum of liquid fossil fuels used in Liechtenstein was less than half a percent of the Swiss consumption.

The energy-related activity data in the energy model and thus in the GHG inventory correspond to the energy balance provided in the Swiss overall energy statistics (SFOE 2019). The energy statistics are updated annually and contain all relevant information about primary and final energy consumption. This includes annual aggregated consumption data for various fuels and main consumers such as households, transport, energy industries, industry, and services (see energy balance in Annex 4).

The main data sources of the Swiss overall energy statistics are:

- The Swiss organization for the compulsory stockpiling of oil products (Carbura) and Avenergy Suisse (formerly Swiss petroleum association, EV) for data on import, export, sales, stocks of oil products and for processing of crude oil in refineries.
- Annual import data for natural gas from the Swiss Gas Industry Association (VSG).
- Annual import data for petroleum products and coal from the Federal Customs Administration (FCA).
- Data provided by industry associations (GVS, SGWA, Cemsuisse, VSG, VSTB, etc.).
- Swiss renewable energy statistics (SFOE).
- Swiss wood energy statistics (SFOE).
- Swiss statistics on combined heat and power generation (SFOE).

As can be seen in Figure 3-8, fossil fuels amount to slightly more than half of primary energy consumption. The main end-users of fossil fuels are the transport and the housing sector, as electricity generation is predominantly based on hydro and nuclear power stations. The most recent energy balance is given in Annex 4.

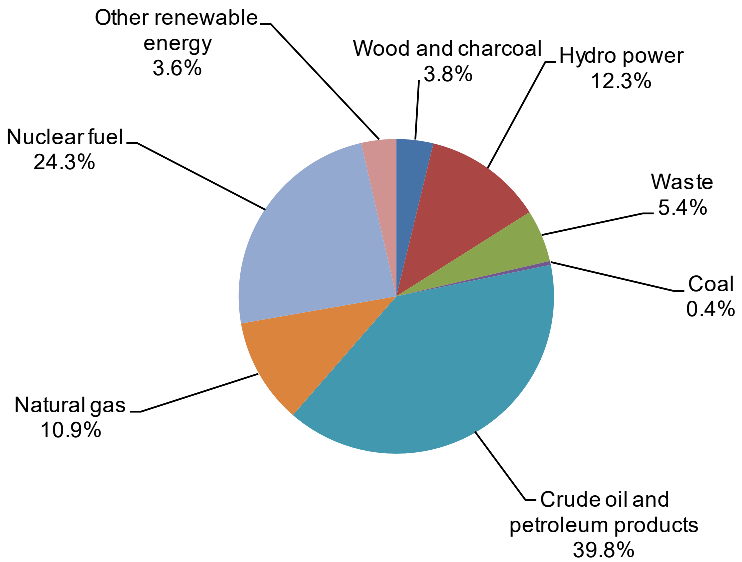


Figure 3-8 Switzerland's primary energy consumption in 2018 by fuels (see corresponding data in SFOE 2019).

Table 3-11 shows primary energy consumption excluding nuclear fuel and hydro power. On the one hand, the combined effect of decreasing consumption of gasoline and increasing consumption of kerosene and diesel led to an increasing trend until about 2010 and a stabilization thereafter in the transport sector. On the other hand, consumption of liquid fuels in the residential and services sectors (mainly gas oil) as well as in the industry sector (mainly gas oil and residual fuel oil) substantially decreased. Natural gas consumption increased since 1990, compensating to some extent the decreasing use of gas oil and residual fuel oil in the various sectors.

Table 3-11 Switzerland's energy consumption by fuel type. Only those fuels are shown that are implemented in the EMIS database (no hydro and nuclear power). The numbers are based on the fuels sold principle, thus they include consumption from fuel tourism as well as all fuels sold for domestic and international aviation.

Year	Gasoline	Kerosene	Diesel	Gas oil	Residual fuel oil	Refinery gas & LPG	Petroleum coke	Solid fuels	Natural gas	Other fuels	Bio fuels	Total
	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
1990	155'785	48'067	47'557	218'510	23'342	8'890	1'400	14'901	68'599	19'161	46'685	652'897
1991	162'225	46'562	48'154	238'602	23'590	12'437	980	12'162	76'902	18'596	48'670	688'880
1992	168'100	49'099	46'706	236'809	24'170	11'492	315	8'758	80'808	19'009	47'598	692'864
1993	155'897	50'776	44'978	225'920	17'165	12'388	1'120	7'442	84'758	19'158	47'875	667'476
1994	156'087	52'109	47'748	207'141	17'860	13'455	1'470	7'632	83'587	19'155	45'820	652'064
1995	151'290	54'947	48'604	217'523	17'278	12'756	1'260	7'962	92'123	19'688	47'817	671'249
1996	155'209	56'753	45'597	226'289	15'097	13'939	1'015	5'456	99'710	20'584	51'340	690'989
1997	161'171	58'774	47'385	212'223	12'581	14'236	280	4'590	96'260	21'655	48'206	677'361
1998	162'477	61'268	49'209	222'407	15'882	15'259	455	3'960	99'065	23'802	49'729	703'513
1999	168'025	65'244	52'184	212'349	11'058	15'805	521	4'105	102'588	24'403	50'461	706'743
2000	168'165	68'060	55'677	196'137	7'923	13'649	551	6'120	101'970	26'536	50'095	694'883
2001	163'543	64'208	56'709	213'089	9'942	14'069	410	6'233	106'132	27'068	53'250	714'654
2002	160'375	59'406	58'721	196'655	6'446	15'584	679	5'565	104'170	27'876	52'838	688'317
2003	159'636	53'438	62'251	208'040	7'061	13'642	202	5'663	110'116	27'642	55'353	703'045
2004	156'812	50'441	66'893	203'370	7'561	16'429	1'819	5'420	113'615	28'845	56'234	707'439
2005	152'062	51'101	73'065	205'729	5'805	16'432	2'906	5'940	116'646	29'236	58'276	717'197
2006	147'436	53'571	79'063	195'926	6'419	18'578	3'324	6'467	113'412	31'233	61'311	716'741
2007	146'012	57'165	84'885	171'313	5'179	15'587	2'730	7'196	110'395	30'015	60'327	690'805
2008	142'801	61'151	93'143	178'833	4'606	16'288	3'616	6'562	117'589	30'854	64'196	719'638
2009	138'968	58'665	94'569	173'219	3'575	16'301	3'254	6'193	112'807	29'811	64'093	701'454
2010	134'043	61'620	98'247	182'295	2'987	15'463	3'498	6'208	126'013	31'185	68'557	730'116
2011	128'856	65'696	100'876	143'760	2'292	14'856	2'957	5'792	111'774	30'882	64'353	672'095
2012	124'301	67'306	106'996	154'448	2'780	12'247	3'148	5'269	122'521	31'145	70'083	700'244
2013	118'634	68'068	111'824	162'532	1'959	15'053	2'735	5'567	129'027	30'925	73'488	719'811
2014	113'877	68'541	114'684	122'694	1'621	14'473	3'148	5'704	111'770	31'320	68'341	656'174
2015	105'591	70'788	113'151	129'349	892	9'822	1'145	5'205	119'420	32'084	71'677	659'123
2016	102'297	74'161	114'378	132'325	378	9'136	890	4'795	125'456	33'583	77'712	675'111
2017	99'155	75'933	114'006	123'726	350	8'770	763	4'609	125'708	33'342	80'878	667'242
2018	97'588	80'250	115'483	111'225	87	8'890	1'081	4'285	119'024	34'510	80'513	652'937

3.2.4.3.2 Energy model – Conceptual overview

For the elaboration of the greenhouse gas and air pollutants inventories, information about energy consumption is needed at a much more detailed level than provided by the Swiss overall energy statistics (SFOE 2019). Activity data in sector 1 Energy are therefore calculated and disaggregated by the Swiss energy model, which is an integral part of the emission database EMIS. The model is developed and updated annually by the Swiss Federal Office for the Environment (FOEN). It relies on the Swiss overall energy statistics and is complemented with further data sources, e.g. Liechtenstein's liquid fuel sales (OS 2019), the Swiss renewable energy statistics (SFOE 2019a), the Swiss wood energy statistics (SFOE 2019b), the energy consumption statistics in the industry and services sectors (SFOE 2019d), as well as additional information from the industry.

The Swiss overall energy statistics are not only the main data input into the energy model, but also serve as calibration and quality control instrument. The total energy consumption given by the Swiss overall energy statistics has to be equal to the sum of the disaggregated activity data of all source categories within the energy sector (including memo items/bunker). Differences are explicitly taken into account as "statistical differences" (see chp. 3.2.4.1).

As shown in Figure 3-9, the energy model consists of several sub-models, such as the industry model, the civil aviation model, the road transportation model, the non-road transportation model, and the energy model for wood combustion. A brief overview of each of these models is given below. However, depending on the scope of these sub-models, they are either described in the chapter dedicated to the corresponding source category or in an overarching chapter preceding the detailed description of the individual source categories. In chp. 3.2.4.3.3, the resulting sectoral disaggregation is shown separately for each fuel type.

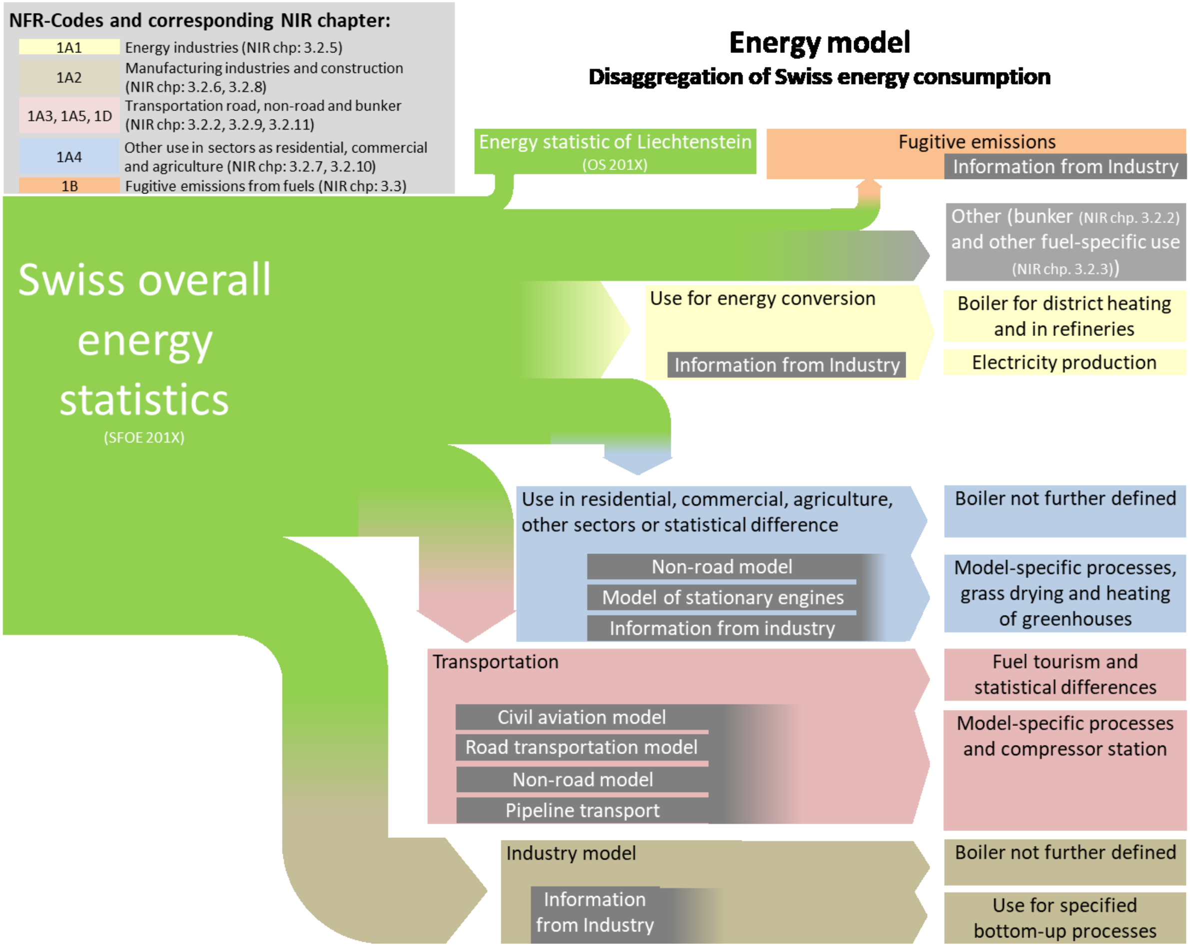


Figure 3-9 Overview of Switzerland's energy model. In the abbreviations SFOE 201X and OS 201X the "X" refers to the latest edition of the respective statistics.

Industry model (Details are given in chp. 3.2.6.2.1)
The industry model is a based on two pillars: (1) the energy consumption statistics in the industry and services sectors (SFOE 2019d), which is a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type), and (2) a bottom-up industry model (Prognos 2013) which extends fuel consumptions back to 1990. The resulting industry model provides a consistent split of energy consumption by source category and fuel type for the full reporting period. Further disaggregation is then achieved by using plant-level industry data for specific processes, as far as available.

Civil aviation model (Details are given in chp. 3.2.2.2.1 and 3.2.9.2.1)
The civil aviation model is developed and updated by the Federal Office for Civil Aviation (FOCA). It aggregates single aircraft movements according to detailed movement statistics of the Swiss airports. Differentiation of domestic and international aviation is based on the information on departure and destination of each flight in the movement database.

Road transportation model (Details are given in chp. 3.2.9.2.2)
The road transportation model is a territorial model, accounting for traffic on Swiss territory only. The model is based on detailed vehicle stock data from the vehicle registration database of the Federal Roads Office (FEDRO), mileage per vehicle category differentiated into different driving patterns, and specific consumption and emission factors. The difference between fuel sales and the territorial model (road and non-road transportation models combined) is reported as fuel tourism and statistical differences. Emissions are included in the most appropriate categories (see 3.2.9.2.2).

Non-road transportation model (Details are given in chp. 3.2.4.5.1)
The non-road transportation model covers all remaining mobile sources, i.e. industrial vehicles, construction machinery, agricultural and forestry machinery, gardening machinery as well as railways, navigation and military vehicles, except for military aviation, which is considered separately (see chp. 3.2.11.2.1). The model combines vehicle numbers, their operation hours, engine power, and load factors to derive specific fuel consumption, emission factors and resulting emissions. Data stem from surveys among producers, various user associations, and the national database of non-road vehicles run by FEDRO.

Energy model for wood combustion (Details are given in chp. 3.2.4.5.2)
Based on the Swiss wood energy statistics (SFOE 2019b), total wood consumption is disaggregated into source categories (public electricity and heat production, industry, commercial/institutional, residential, agriculture/forestry/fisheries) and into 24 different combustion installations (ranging from open fireplaces to large-scale automatic boiler or heat and power plants). Where available, industry data on wood combustion is taken into account to allocate parts of the wood consumption as given by the Swiss wood energy statistics to a specific source category.

3.2.4.3.3 Disaggregation of the energy consumption by source category and fuel types

The energy model as outlined above disaggregates total energy consumption as provided by the Swiss overall energy statistics (SFOE 2019) into the relevant source categories 1A1-1A5. Figure 3-11 to Figure 3-20 visualize for each fuel type seperately the disaggregation process of the energy model (as shown schematically in Figure 3-9), the interaction between the different sub-models as well as additional data sources.

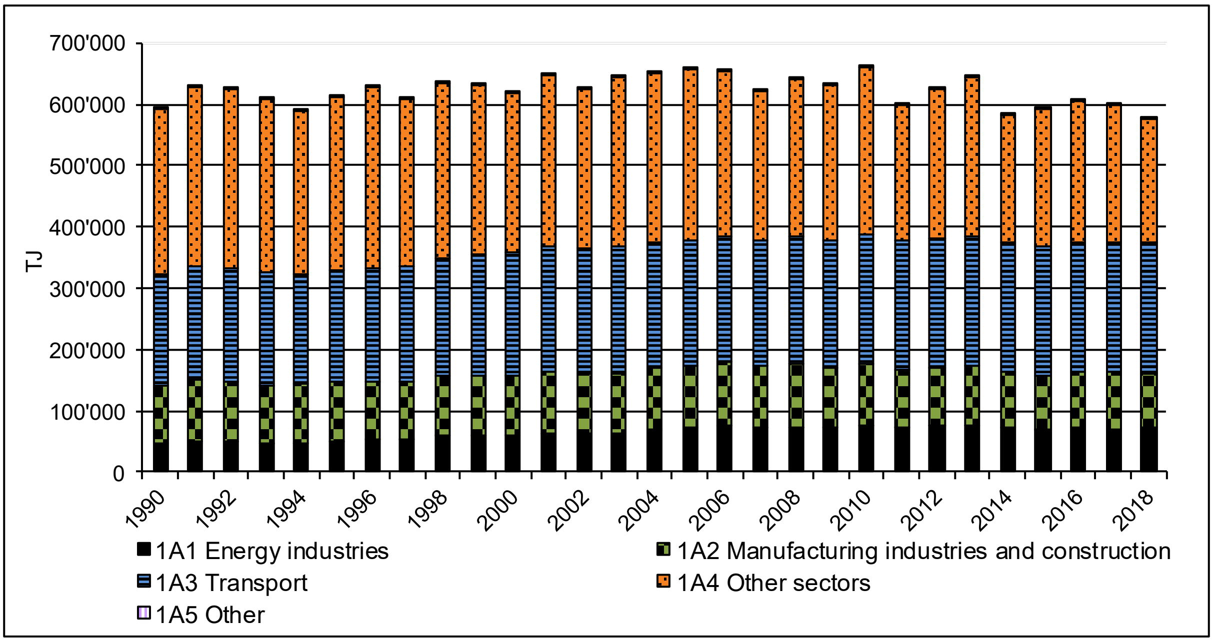


Figure 3-10 Switzerland's energy consumption by source categories 1A1-1A5 according to the Swiss energy model. Since 1990 population increased by about 27%, industrial production by more than 75% and the motor vehicle fleet by about 62% (SFOE 2019, table 43).

Starting from the total energy consumption from the Swiss overall energy statistics for each fuel type, the energy is assigned to the relevant source categories based on the various sub-models of the energy model (mentioned in chp. 3.2.4.3.2 above). In addition, the following assignments are considered as well.

Within the source categories 1A4a and 1A4b, the amount of gas oil and natural gas used for co-generation in turbines and engines is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2014c). The residual energy is then assigned to boilers which are not further specified.

For source category 1A4ci Other sectors – Agriculture/forestry/fishing, specific bottom-up industry information is available for grass drying and heating of greenhouses. The fuel consumption for grass drying is provided by the Swiss association of grass drying plants (VSTB). Further, based on annual energy consumption data from the Energy Agency of the Swiss Private Sector (EnAW) regarding agricultural greenhouses exempt from the CO_2 levy, total energy consumption of all greenhouses within Switzerland is extrapolated. The fuel consumption for grass drying and greenhouses is subtracted from the total fuel consumption of residential, commercial, agriculture and statistical differences (see Figure 3-9).

In order to report all energy consumption, the statistical differences as reported in the Swiss overall energy statistics are allocated to source category 1A4ai Other sectors – Commercial/institutional (stationary combustion) and 1A3bviii Fuel tourism and statistical differences. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

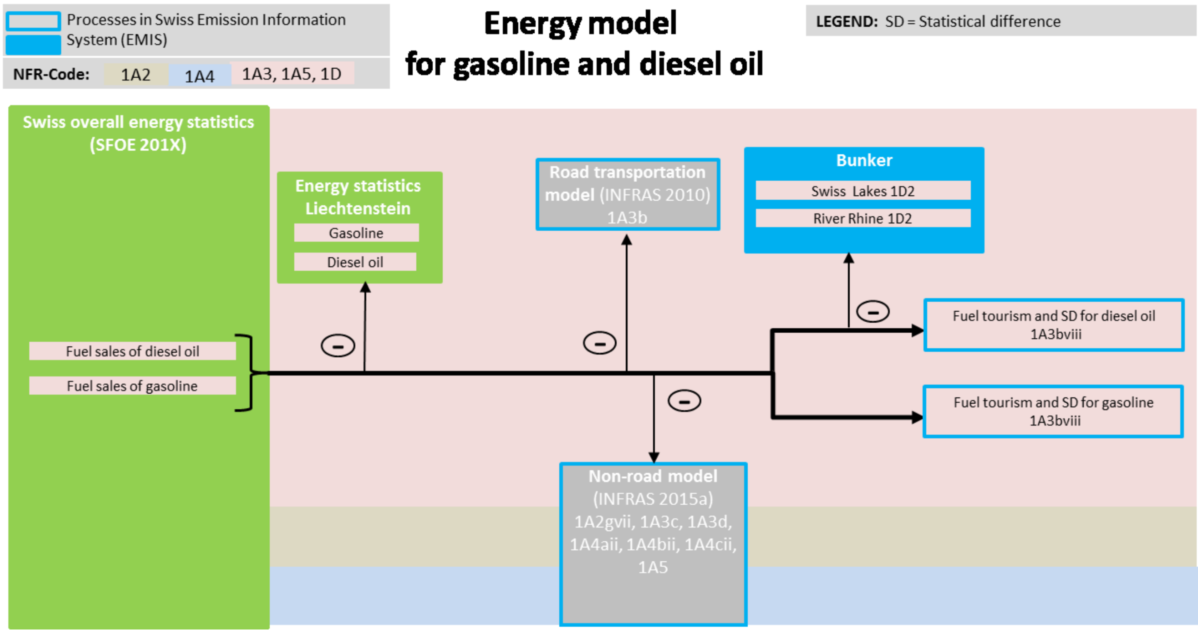


Figure 3-11 Schematic disaggregation of fuel consumption for gasoline and diesel oil. Marine bunker fuel consumption is based on the national customs statistics (see chp. 3.2.2.2.2). In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

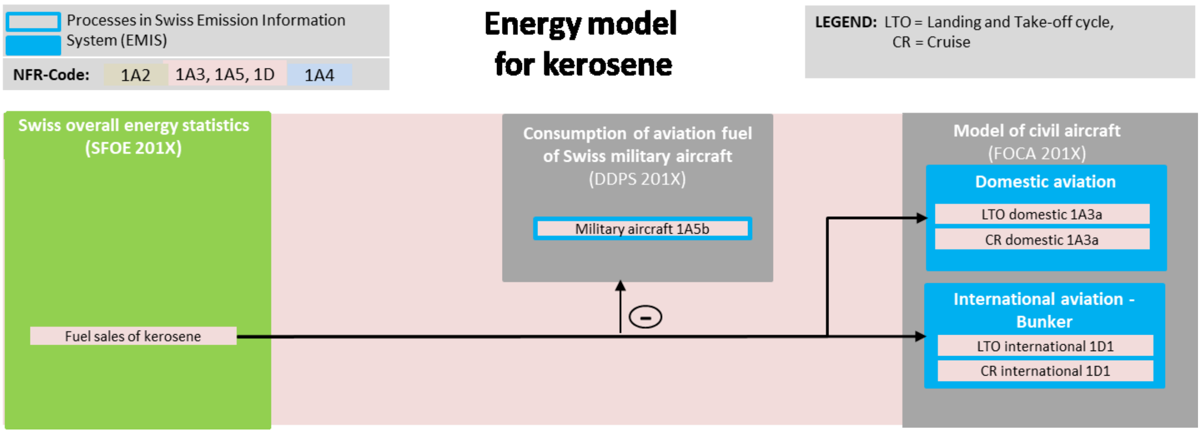


Figure 3-12 Schematic disaggregation of fuel consumption for kerosene. Fuel consumption for military aircraft is provided by the Federal Department of Defence, Civil Protection and Sport. The differentiation between domestic and international aviation as well as between CR and LTO is provided by the civil aviation model (see chp. 3.2.2.2.1).

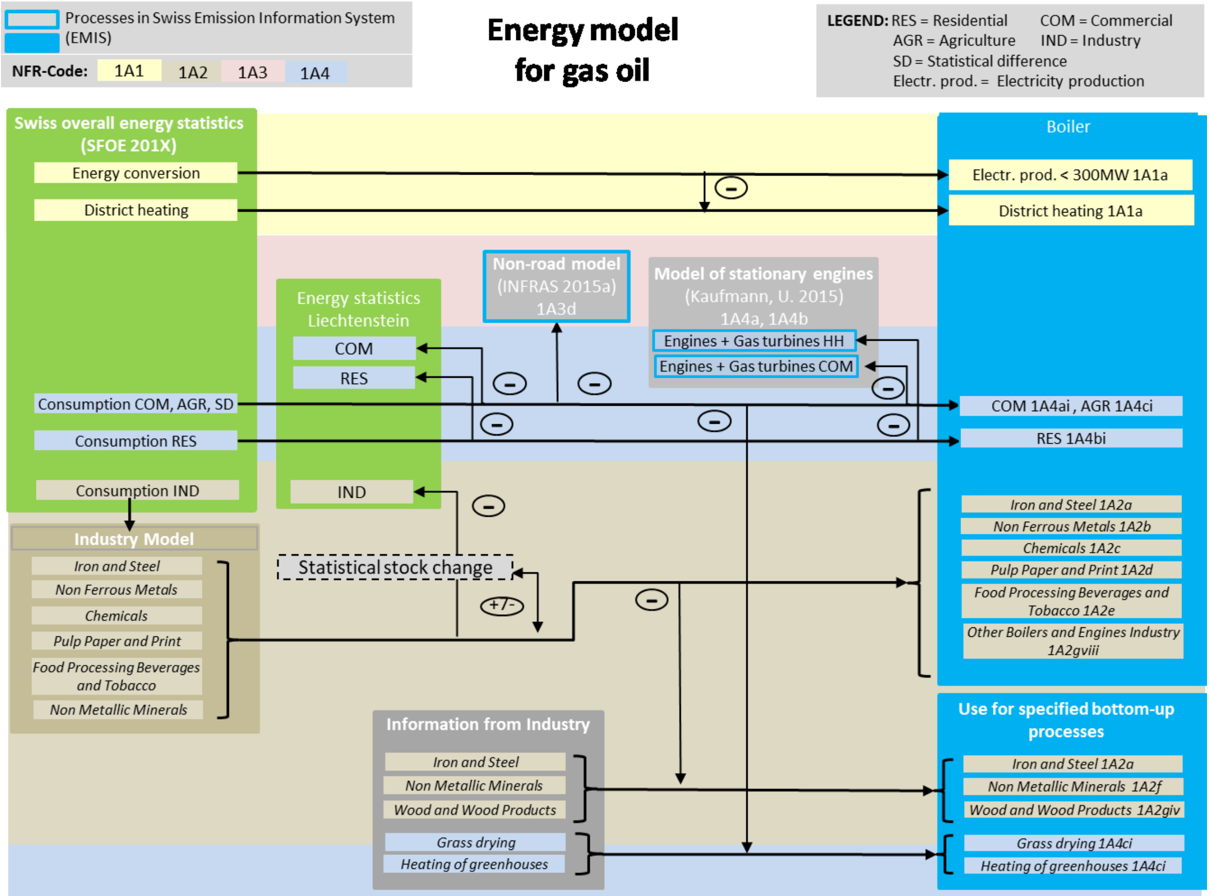


Figure 3-13 Schematic disaggregation of fuel consumption for gas oil. The Swiss overall energy statistics provides gas oil use for energy conversion and the amount thereof being used for district heating. Based on this information, gas oil use is split into 1A1ai Electricity generation and 1A1aiii Heat plants. According to the non-road model, a small amount of gas oil is consumed in source category 1A3d navigation (steam-powered vessels).

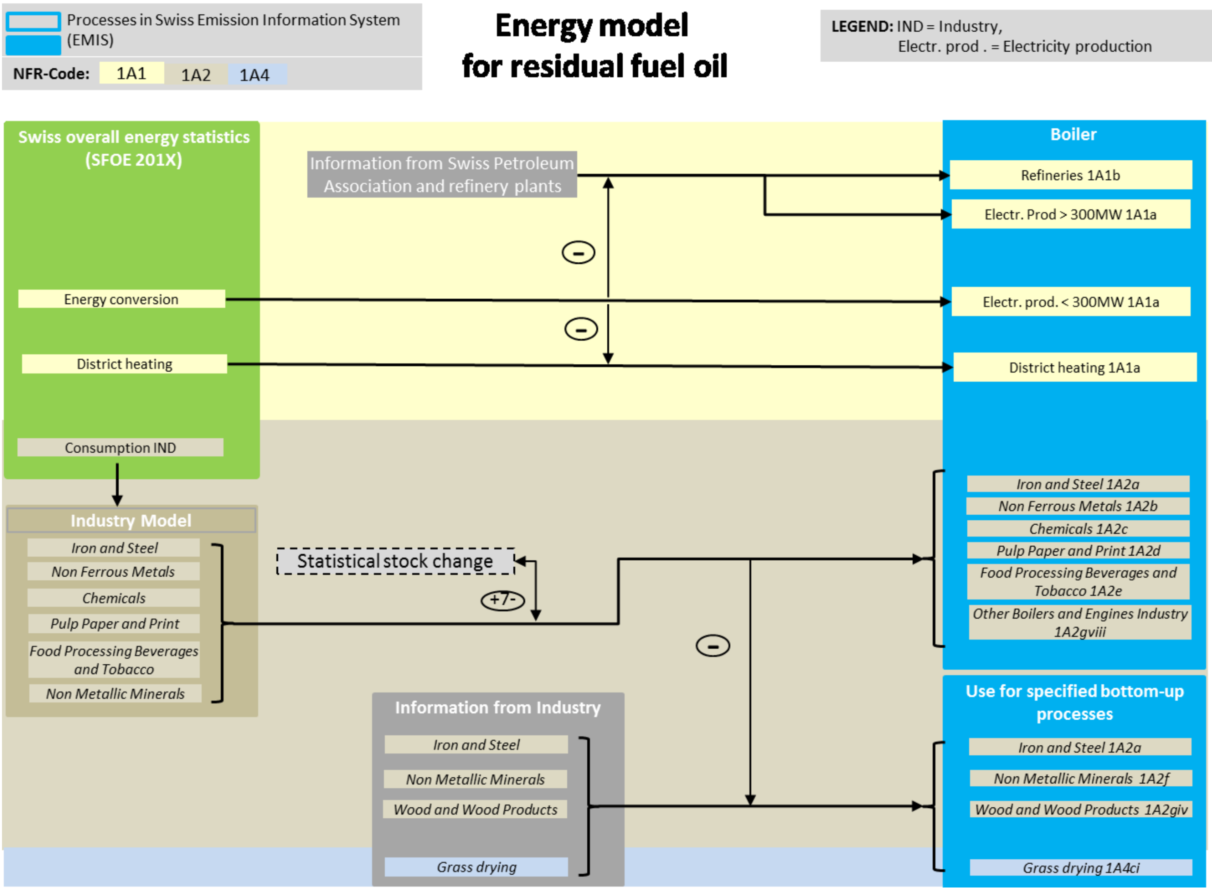


Figure 3-14 Schematic disaggregation of fuel consumption for residual fuel oil. The Swiss overall energy statistics reports residual fuel oil use in energy conversion and the amount thereof consumed in electricity production (one single fossil fuel power station, operational from 1985 to 1994), district heating, and in petroleum refineries. Based on this information, residual fuel oil use in Energy industries is split into 1A1ai Electricity generation, 1A1aiii Heat plants and 1A1b Petroleum refining.

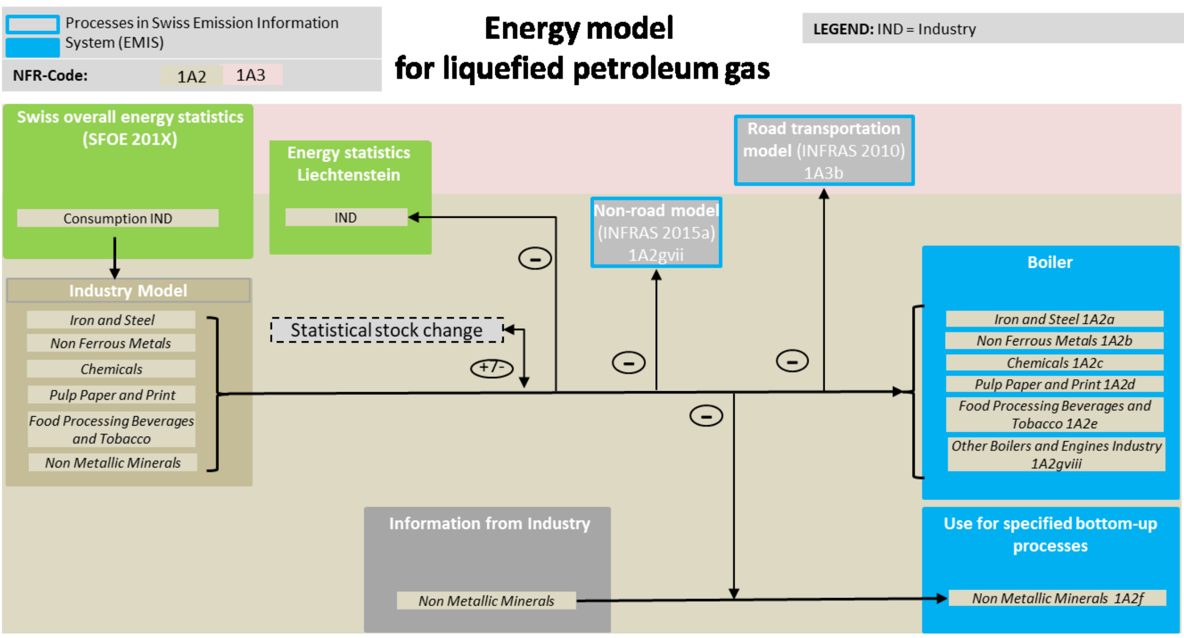


Figure 3-15 Schematic disaggregation of fuel consumption for liquefied petroleum gas (LPG).

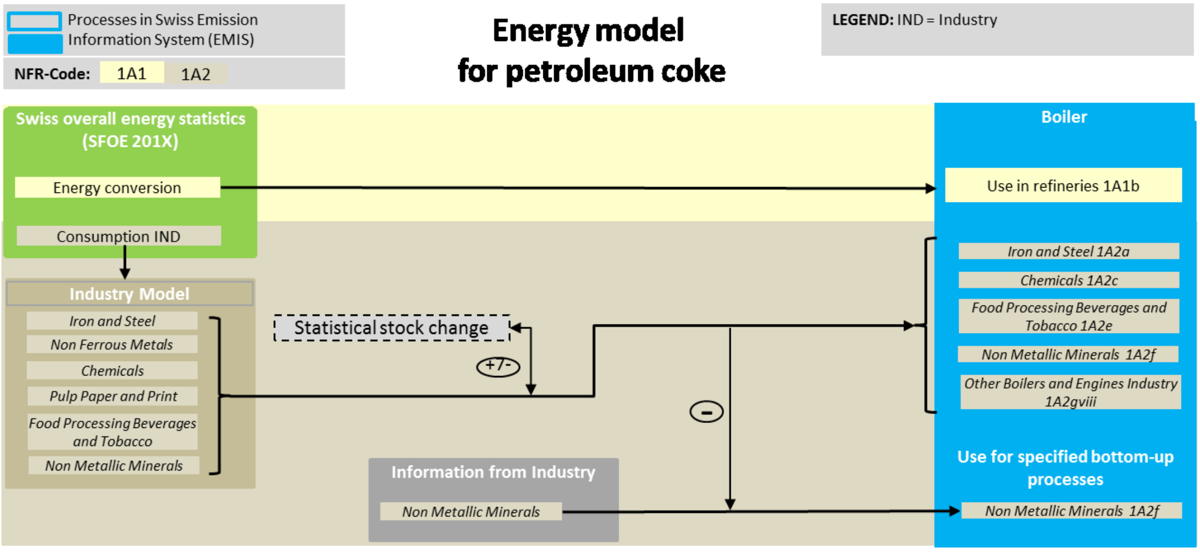


Figure 3-16 Schematic disaggregation of fuel consumption for petroleum coke.

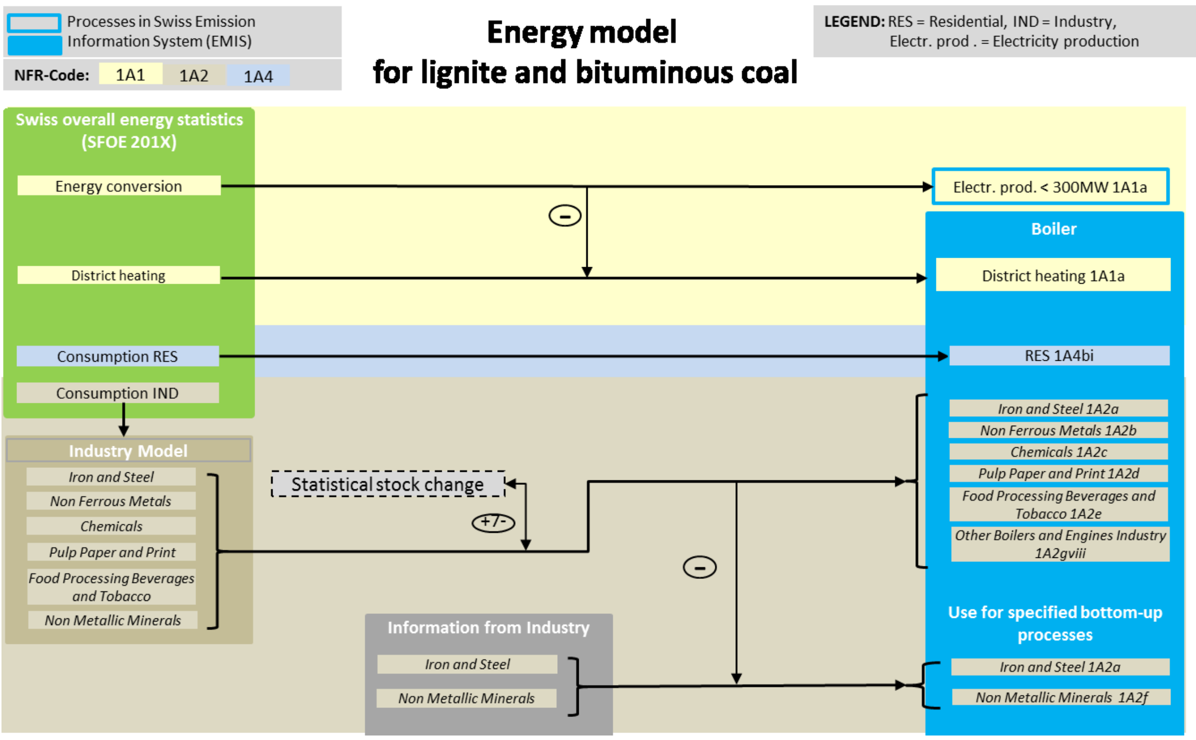


Figure 3-17 Schematic disaggregation of fuel consumption for lignite and bituminous coal. The Swiss overall energy statistics provides bituminous coal use for energy conversion and the amount thereof being used for district heating. Based on this information, use of bituminous coal in energy industries is split into 1A1ai Electricity generation and 1A1aiii Heat plants up to 1995. Coal consumption for Public electricity and heat production ceased thereafter.

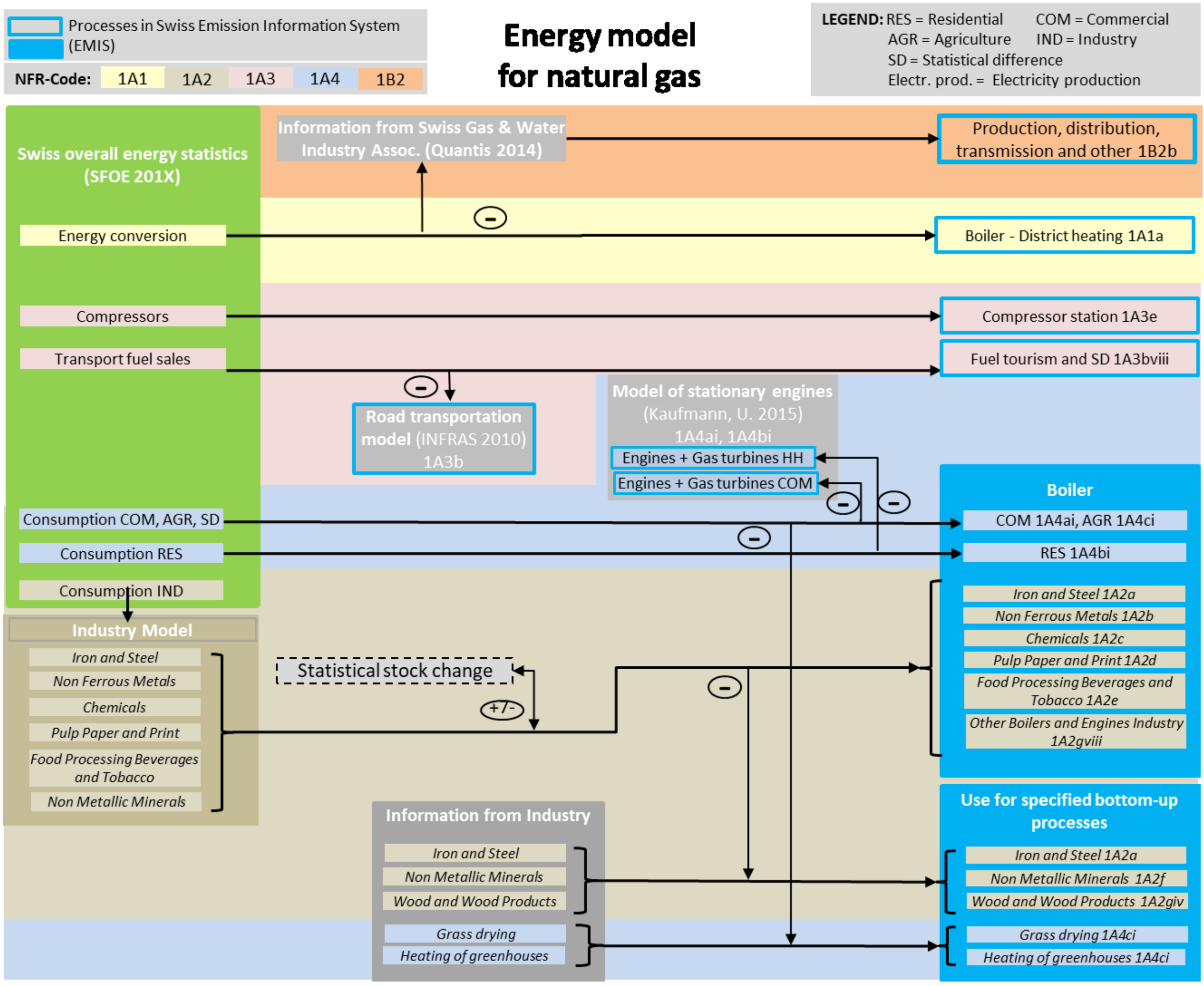


Figure 3-18 Schematic disaggregation of fuel consumption for natural gas. The Swiss overall energy statistics provides gas use in the transformation sector (energy conversion and distribution losses). Distribution losses as estimated by the Swiss Gas and Water Industry Association (SGWA) are subtracted and reported under source category 1B2 Fugitive emissions from fuels. The remaining fuel consumption for natural gas is reported under source category 1A1a Public electricity and heat production. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

A corresponding Figure 3-18b is available in the confidential version of this chapter, providing more details.

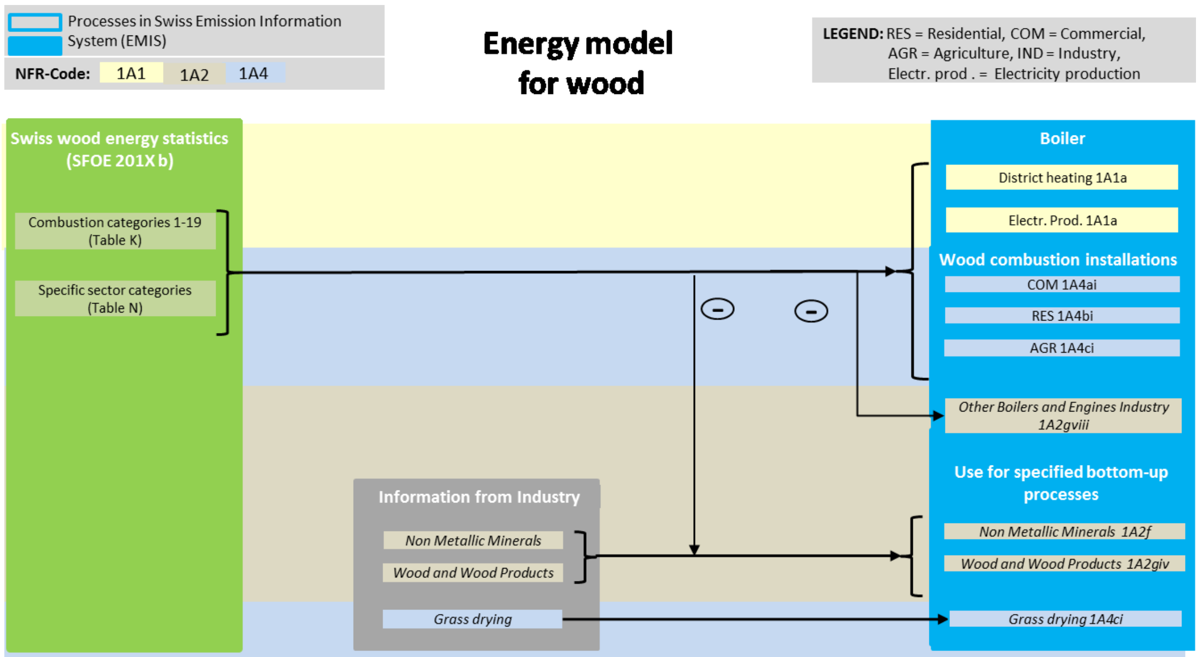


Figure 3-19 Schematic disaggregation of fuel consumption for wood (see chp. 3.2.4.5.2.)

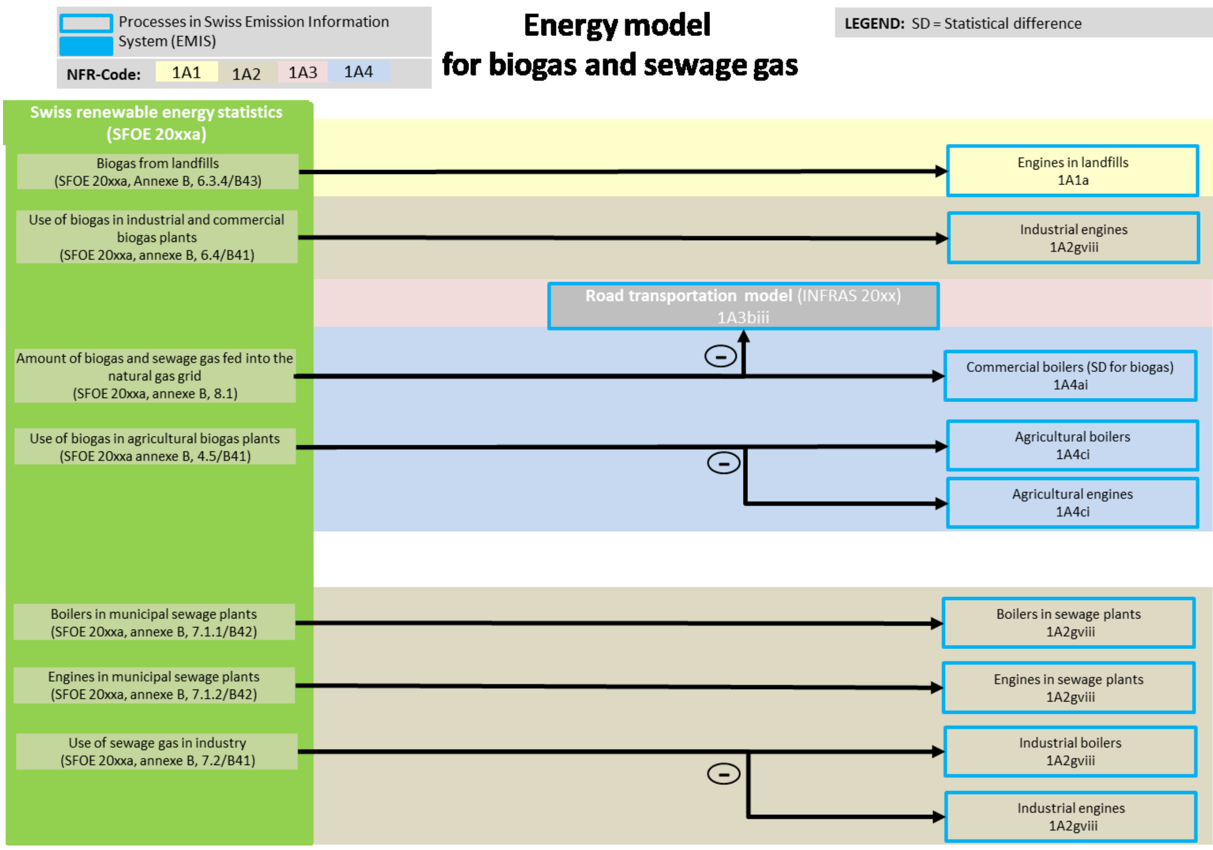


Figure 3-20 Schematic disaggregation of fuel consumption for biogas and sewage gas.

3.2.4.4 Emission factors of 1A Fuel combustion

3.2.4.4.1 Oxidation factor for 1A Fuel combustion

For the emission calculation, an oxidation factor of 100% is assumed for all fossil fuel combustion processes, since the technical standards for combustion installations in Switzerland are high and the small fraction of originally non-oxidised carbon retained in ash, particulates or soot is likely to be oxidized later. This is consistent with the 2006 IPCC Guidelines and the EU and Swiss guidelines for the Emissions Trading Scheme (ETS), where also a default oxidation factor of 100% was applied.

Because an oxidation factor of 100% is assumed, indirect CO_2 emissions from CO and NMVOC are implicitly reported as direct CO_2 emissions in sector 1A Energy and no indirect emissions are reported for sector 1A in chp. 9.

3.2.4.4.2 CO_2 emission factors for 1A Fuel combustion

General CO_2 emission factors

The CO_2 emission factors applied for the time series 1990–2018 are given in Table 3-12. Detailed information regarding the underlying data and assumptions are provided in chp. 3.2.4.2 Net calorific values (NCV), since in most cases, NCVs and carbon content were determined jointly.

Table 3-12 CO_2 emission factors 1990–1998 and years from 2013 onwards. For years between 1998 and 2013, the factors are linearly interpolated. Data source SGWA stands for annually updated reports of the Swiss Gas and Water Industry Association (SGWA).

CO_2 emission factors			1990-1998	2013-2018
Fossil fuel	**CS/D**	**Data sources**	t CO_2 / TJ	t CO_2 / TJ
Gasoline	CS	EMPA (1999), SFOE/FOEN (2014)	73.9	73.8
Jet kerosene	CS	EMPA (1999), SFOE/FOEN (2014)	73.2	72.8
Diesel oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.6	73.3
Gas oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.7	73.7
Residual fuel oil	CS	EMPA (1999)	77.0	77.0
Liquefied petroleum gas	CS	FOEN (2015d)	65.5	65.5
Petroleum coke	CS	Cemsuisse (2010a)	91.4	91.4
Other bituminous coal	CS	Cemsuisse (2010a)	92.7	92.7
Lignite	CS	Cemsuisse (2010a)	96.1	96.1
Natural gas	CS	SGWA	*see table below*	
Biofuel	**CS/D**	**Data sources**		
Biodiesel	CS	assumed equal to diesel oil	73.6	73.3
Bioethanol	CS	assumed equal to gasoline	73.9	73.8
Biogas	CS	assumed equal to natural gas	*see table below*	
Wood	CS	Cemsuisse (2010a)	99.9	99.9

CO_2 emission factors for natural gas and biogas

Table 3-13 Time series of CO_2 emission factors of natural gas and biogas. SGWA refers to annual updates of properties of natural gas that are provided by the Swiss Gas and Water Industry Association (SGWA).

CO_2 emission factors			1990	1995	2000	2005
Fuel	**CS/D**	**Data sources**	t CO_2 / TJ			
Natural gas/Biogas	CS	SGWA	56.1	55.7	56.2	56.4

CO_2 emission factors			2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fuel	**CS/D**	**Data sources**	t CO_2 / TJ									
Natural gas/Biogas	CS	SGWA	56.5	56.5	56.6	56.5	56.4	56.5	56.4	56.4	56.3	56.2

CO_2 emission factors for wood

The CO_2 emission factor for wood combustion activities is taken from Cemsuisse (2010a).

3.2.4.4.3 CH_4 emission factors for 1A Fuel combustion

General CH_4 emission factors

An overview of the general CH_4 emission factors is given in Table 3-14. These emission factors are used for most stationary combustion processes (exceptions are discussed in the detailed sectoral chapters where they occur). For stationary combustion, mainly IPCC default emission factors are used for the entire time period. For wood combustion, country-specific factors are used. Details are given below in Table 3-15. CH_4 emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-14 CH_4 emission factors for stationary combustion for the whole time period.

CH_4 emission factors			1990-2018
Fuel	**CS/D**	**Data sources**	g CH_4 / GJ
Gas oil	D	IPCC (2006)	3
Residual fuel oil	D	IPCC (2006)	3
Liquefied petroleum gas	D	IPCC (2006)	1
Petroleum coke	D	IPCC (2006)	3
Other bituminous coal	D	IPCC (2006)	10
Lignite	D	IPCC (2006)	10
Natural gas	D	IPCC (2006)	1
Biofuel	**CS/D**	**Data Sources**	
Biogas	D	IPCC (2006)	1
Wood	CS	Nussbaumer and Hälg (2015)	1.2 - 240

CH_4 emission factors for wood

There are many different combustion installations in use which have very different CH_4 emission factors. A detailed overview of all applied wood related CH_4 emission factors for the entire time series is given in Table 3-15.

The CH_4 emission factor for each combustion type is modelled based on VOC measurements at wood combustion installations (Nussbaumer and Hälg 2015), assuming a CH_4 to VOC ratio of 0.4.

The EF for the different combustion installations varies depending on the year, rated thermal input and technology used. The EF of a single category represents the emission characteristics of a large number of combustion installations with a range of technology types, maintenance and operating conditions at a given time. According to their lifespan, existing combustion installations are gradually replaced by installations of new technology with better combustion, resulting in gradually decreasing emission factors.

Table 3-15 CH_4 emission factors for wood combustion installations.

1A Wood combustion	1990	1995	2000	2005
	g CH4/GJ			
Open fireplaces	160	149	138	127
Closed fireplaces, log wood stoves	160	149	138	127
Pellet stoves	16	15	14	13
Log wood hearths	240	229	218	207
Log wood boilers	200	161	122	83
Log wood dual chamber boilers	240	229	218	207
Automatic chip boilers < 50 kW	20	17	13	10
Automatic pellet boilers < 50 kW	6.7	5.6	4.5	3.4
Automatic chip boilers 50-500 kW w/o wood proc. companies	20	16	13	8.9
Automatic pellet boilers 50-500 kW	6.7	5.4	4.1	2.8
Automatic chip boilers 50-500 kW within wood proc. companies	20	16	13	8.9
Automatic chip boilers > 500 kW w/o wood proc. companies	13	11	8.1	5.6
Automatic pellet boilers > 500 kW	6.7	5.4	4.1	2.8
Automatic chip boilers > 500 kW within wood proc. companies	13	11	8.1	5.6
Combined chip heat and power plants	13	11	8.1	5.6
Plants for renewable waste from wood products	13	11	8.1	5.6

1A Wood combustion	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	g CH4/GJ									
Open fireplaces	120	120	120	120	120	120	119	118	117	116
Closed fireplaces, log wood stoves	117	113	110	107	103	100	98	96	94	92
Pellet stoves	12	12	12	12	12	12	12	11	11	10
Log wood hearths	193	187	180	173	167	160	157	154	151	149
Log wood boilers	58	57	55	53	52	50	49	47	46	44
Log wood dual chamber boilers	193	187	180	173	167	160	154	149	143	137
Automatic chip boilers < 50 kW	8.0	8.0	8.0	8.0	8.0	8.0	7.7	7.5	7.2	7.0
Automatic pellet boilers < 50 kW	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.5	2.4	2.3
Automatic chip boilers 50-500 kW w/o wood proc. companies	6.7	6.7	6.7	6.7	6.7	6.7	6.5	6.3	6.0	5.8
Automatic pellet boilers 50-500 kW	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.8	1.7
Automatic chip boilers 50-500 kW within wood proc. companies	6.7	6.7	6.7	6.7	6.7	6.7	6.5	6.3	6.0	5.8
Automatic chip boilers > 500 kW w/o wood proc. companies	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.6	3.5
Automatic pellet boilers > 500 kW	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.8	1.8	1.7
Automatic chip boilers > 500 kW within wood proc. companies	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.6	3.5
Combined chip heat and power plants	3.6	3.1	2.7	2.2	1.8	1.3	1.3	1.2	1.2	1.2
Plants for renewable waste from wood products	3.6	3.1	2.7	2.2	1.8	1.3	1.3	1.2	1.2	1.2

3.2.4.4.4 N_2O emission factors for 1A Fuel combustion

Table 3-16 shows the general N_2O emission factors in source category 1A which are based on default values from the 2006 IPCC Guidelines (IPCC 2006) and kept constant over the whole period. N_2O emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-16 N_2O emission factors. Default emission factors are used for all fuels for the whole time period.

N_2O emission factors			**1990-2018**
Fuel	**CS/D**	**Data sources**	g N_2O / GJ
Jet Kerosene	D	IPCC (2006)	2
Gas oil	D	IPCC (2006)	0.6
Residual fuel oil	D	IPCC (2006)	0.6
Liquefied petroleum gas	D	IPCC (2006)	0.1
Petroleum coke	D	IPCC (2006)	0.6
Other bituminous coal	D	IPCC (2006)	1.5
Lignite	D	IPCC (2006)	1.5
Natural gas	D	IPCC (2006)	0.1
Biofuel	**CS/D**	**Data sources**	
Biogas	D	IPCC (2006)	0.1
Wood	D	IPCC (2006)	4

3.2.4.5 Models overlapping more than one source category

3.2.4.5.1 Non-road transportation model (excl. aviation)

Choice of method

- The GHG emissions are calculated by a Tier 3 method based on the decision tree in Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006), complemented with
- Tier 2 for railways CO_2, Fig. 3.4.1 in IPCC (2006)
- Tier 3 for railways CH_4, N_2O and precursors / SO_2, Fig. 3.4.2 in IPCC (2006)
- Tier 2 for navigation, Fig. 3.5.1 (Box 1) in IPCC (2006)

Methodology

The emissions of the non-road sector underwent an extended revision in 2014/2015, resulting in an update of GHG emissions including precursors and SO_2. Results are documented in FOEN (2015j). The non-road categories considered are listed in Table 3-17. All of them include several technologies, fuels (diesel oil, 2- or 4-stroke gasoline, LPG, gas oil), and emission standards according to the classification shown in Figure 3-21.

Table 3-17 Non-road categories as specified in FOEN (2015j) and the corresponding nomenclature in the CRF.

Non-road categories (by Corinair)	Nomenclature CRF
Construction machinery	1.A.2.g.vii Off-road vehicles and other machinery
Industrial machinery	1.A.2.g.vii Off-road vehicles and other machinery
Railway machinery	1.A.3.c. Railways
Navigation machinery	1.A.3.d. Domestic Navigation
Garden-care/professional appliances	1.A.4.a.ii Commercial/institutional, Off-road vehicles and other machinery
Garden-care/hobby appliances	1.A.4.b.ii Residental, Off-road vehicles and other machinery
Agricultural machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Forestry machinery	1A..4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Military machinery (excl. aviation)	1.A.5.b Other, mobile, Military

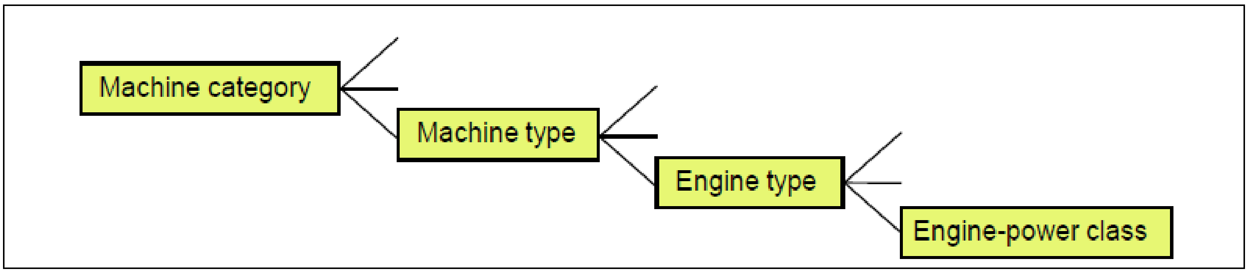


Figure 3-21 Each non-road vehicle is classified by its machine category, machine type, engine type and engine-power class (FOEN 2015j, INFRAS 2015a).

The emission modelling is based on activity data and emission factors by means of the following equation, which holds on the most disaggregated level of engine power class (Figure 3-21):

$$Em = N \cdot H \cdot P \cdot \lambda \cdot \varepsilon \cdot CF_1 \cdot CF_2 \cdot CF_3$$

with

Em	=	emission per engine type (in g/a)
N	=	number of vehicles (--)
H	=	number of operation hours per year (h/a)
P	=	engine power output (kW)
λ	=	effective load factor (--)
ε	=	emission factor (g/kWh)
CF_1	=	correction factor for the effective load (--)
CF_2	=	correction factor for dynamical engine use (--)
CF_3	=	degradation factor due to aging (--)

With this equation, the emissions of the following gases and also the fuel consumption are calculated:

- GHG: CH_4, N_2O
- precursor gases: NO_x, CO
- air pollutant: VOC
- fuel consumption: in this case, ε represents the consumption instead of emission factor (in g/kWh)

For other gases, the following method is applied:

- CO_2 is calculated as product of fuel consumption and CO_2 emission factors (according to Table 3-12)
- SO_2 is calculated as product of fuel consumption and SO_2 emission factors (according to Table A – 12)
- NMVOC is calculated as the difference between VOC and CH_4
- CO_2 emissions from the use of lubricants as an additive in gasoline for 2-stroke engines are modelled separately and the corresponding CO_2 emissions from the lubricants are reported under 2D1 Lubricant use (chp. 4.5.2.1). Non-CO_2 emissions from the combustion of lubricants in 2-stroke engines however are reported in the energy sector (1A2gvii, 1A3b, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5bii).

The total emission and consumption per non-road category is calculated by taking the sum over all engine-power classes, engine types and machine types.

Emissions are only calculated in steps of 5 years from 1980 to 2050. Emissions for years in-between (are interpolated linearly. A more detailed description of the analytical details is given in the Annex of FOEN (2015j).

Emission factors

Emission factors are taken from various sources based on measurement, modelling and literature.

- CO_2 and SO_2 emission factors are country-specific, see Table 3-12 and Table A – 12.
- For other gases, the main data sources are EPA (2010), IFEU (2010), EMEP/EEA (2016), EMEP/EEA (2019) and Integer (2013).

For a detailed description of emission factors and their origin, see tables in the annex of FOEN (2015j) and online in the database belonging to INFRAS (2015a)[4].

Activity data

Activity data were collected by surveys among producers and several user associations in Switzerland (FOEN 2015j), and by evaluating information from the national database of non-road vehicles (MOFIS) run by the Federal Roads Office (FEDRO 2014). In addition, several publications serve as further data sources:

- SBV (2013) for agricultural machinery
- SFSO (2013a) for agricultural machinery
- Jardin Suisse (2012) for garden care /hobby and professional appliances
- KWF (2012) for forestry machinery
- The national statistics on imports/exports of non-road vehicles was assessed by FCA (2015c)
- Off-Highway Research (2005, 2008, 2012) provided information on the number of non-road vehicles.
- Federal Department of Defence, Civil Protection and Sport: List of military machinery with vehicle stock, engine-power classes and operating hours (DDPS 2014a).

From these data sources, all necessary information like size distributions, modelling of the fleets, annual operating hours (age-dependent), load factors, year of placing on the market and age distribution was derived. Details are documented in FOEN (2015j). All activity data (vehicle stocks, operating hours, consumption factors) can be downloaded by query from the

[4] https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html [18.02.2020]

public part of the non-road database INFRAS (2015a), which is the data pool of FOEN (2015j). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

3.2.4.5.2 Energy model for wood combustion

Choice of method

The emissions from wood combustion in 1A Fuel combustion are calculated by a Tier 2 method based on the decision tree for stationary fuel combustion (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1 on page 2.15).

Methodology

The Swiss wood energy statistics (SFOE 2019b) provide both the annual wood consumption for specified categories of combustion installations (table K, categories 1–19, see Table 3-18), and the allocations of the combustion categories to the sectoral consumer categories (table N, household, agriculture/forestry, industry, services, electricity and district heating). This allows for assigning the annual wood consumption at the level of combustion installation categories directly to the source categories 1A1a Public electricity and heat production, 1A2gviii Other, 1A4ai Commercial/Institutional, 1A4bi Residential and 1A4ci Agriculture/forestry/fishing (EMIS 2020/1A Holzfeuerungen).

Table 3-18 Categories of wood combustion installations based on the Swiss wood energy statistics (SFOE 2019b).

1A Wood combustion, categories
Open fireplaces
Closed fireplaces, log wood stoves
Pellet stoves
Log wood hearths
Log wood boilers
Log wood dual chamber boilers
Automatic chip boilers < 50 kW
Automatic pellet boilers < 50 kW
Automatic chip boilers 50-500 kW w/o wood processing companies
Automatic pellet boilers 50-500 kW
Automatic chip boilers 50-500 kW within wood processing companies
Automatic chip boilers > 500 kW w/o wood processing companies
Automatic pellet boilers > 500 kW
Automatic chip boilers > 500 kW within wood processing companies
Combined chip heat and power plants
Plants for renewable waste from wood products

Emission factors

Emission factors are described in chp. 3.2.4.4.2 for CO_2, 3.2.4.4.3 for CH_4, and 3.2.4.4.4 for N_2O.

Activity data

Total activity data are based on the Swiss wood energy statistics (SFOE 2019b). As additional data source, specific bottom-up information from the industry is used in order to allocate wood combustion emissions directly to a particular source category. Thus, activity data of wood combustion within 1A2f, 1A2giv and 1A4ci are allocated on the basis of industry information (see Figure 3-19 and EMIS 2020/1A Holzfeuerungen):

- Wood energy consumption in source categories 1A2f Brick and tile production (2000–2012), 1A2f Cement production and 1A2giv Fibreboard are subtracted from the activity data of 1A2gviii Automatic chip boiler >500 kW without wood processing companies and 1A2gviii Plants for renewable waste from wood products, respectively.
- Since 2013, also the wood energy consumption in 1A4ci Grass drying is available and has been subtracted from the activity data in 1A4ci Automatic chip boiler >500 kW without wood processing companies.

Table 3-19 Wood energy consumption in 1A Fuel combustion.

1A Wood combustion	1990	1995	2000	2005
	TJ			
Total	28'166	29'480	27'158	30'924
Open fireplaces	226	270	195	181
Closed fireplaces, log wood stoves	7'273	7'166	6'487	7'036
Pellet stoves	0	0	7	48
Log wood hearths	8'520	7'017	4'737	4'020
Log wood boilers	5'307	5'564	5'105	5'356
Log wood dual chamber boilers	1'964	1'777	977	480
Automatic chip boilers < 50 kW	239	433	550	753
Automatic pellet boilers < 50 kW	0	0	56	804
Automatic chip boilers 50-500 kW w/o wood proc. companies	690	1'330	1'786	2'675
Automatic pellet boilers 50-500 kW	0	0	2	94
Automatic chip boilers 50-500 kW within wood proc. companies	1'283	1'729	1'759	1'898
Automatic chip boilers > 500 kW w/o wood proc. companies	310	1'055	1'674	2'337
Automatic pellet boilers > 500 kW	0	0	0	9
Automatic chip boilers > 500 kW within wood proc. companies	1'375	2'076	2'292	2'668
Combined chip heat and power plants	0	3	186	127
Plants for renewable waste from wood products	979	1'060	1'345	2'439

1A Wood combustion	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total	36'153	38'674	34'061	38'551	42'495	36'098	37'584	41'052	41'952	39'251
Open fireplaces	143	123	87	84	84	62	64	68	67	62
Closed fireplaces, log wood stoves	7'552	8'519	7'048	7'985	8'935	7'171	7'923	8'317	7'937	7'248
Pellet stoves	118	151	137	168	199	168	194	213	210	199
Log wood hearths	2'529	2'348	1'620	1'566	1'454	977	1'006	992	900	792
Log wood boilers	4'743	4'908	3'681	3'822	3'902	2'819	2'971	3'032	2'853	2'596
Log wood dual chamber boilers	288	272	194	190	182	125	119	112	88	67
Automatic chip boilers < 50 kW	860	1'008	799	866	946	739	787	798	742	667
Automatic pellet boilers < 50 kW	1'727	2'106	1'809	2'151	2'513	2'099	2'377	2'610	2'620	2'537
Automatic chip boilers 50-500 kW w/o wood proc. companies	3'258	3'744	3'227	3'789	4'293	3'536	4'060	4'483	4'511	4'307
Automatic pellet boilers 50-500 kW	425	531	507	618	722	688	877	1'075	1'232	1'251
Automatic chip boilers 50-500 kW within wood proc. companies	1'908	2'048	1'771	1'912	2'056	1'698	1'847	1'956	1'943	1'877
Automatic chip boilers > 500 kW w/o wood proc. companies	3'565	4'141	3'826	4'582	5'308	4'533	5'269	5'951	6'067	5'714
Automatic pellet boilers > 500 kW	85	93	140	165	192	185	207	240	241	237
Automatic chip boilers > 500 kW within wood proc. companies	2'597	2'856	2'437	2'638	2'820	2'359	2'518	2'645	2'539	2'360
Combined chip heat and power plants	3'422	2'756	3'900	5'010	5'421	5'325	3'792	3'936	4'856	4'633
Plants for renewable waste from wood products	2'933	3'070	2'878	3'005	3'468	3'613	3'572	4'624	5'145	4'704

3.2.4.6 Emissions from biomass (memo item)

CO_2 emissions from biomass do not count for the national total emissions and therefore are a memo item only. The CO_2 emissions from biomass as reported in the reporting tables are in-complete as the following CO_2 emissions are not foreseen for reporting in the reporting tables: 2G4 Use of tobacco, 2H2 Food and beverages, 5A Solid waste disposal, 5B Biological treatment of solid waste and 5D Wastewater treatment and discharge.

Table 3-20 provides an overview of latest effective CO_2 emissions from biomass and their reporting in the reporting tables (without land use, land-use change and forestry). For further information on the CO_2 emissions from biomass refer to the chapters of the respective source categories.

Table 3-20 Effective biomass CO_2 emissions in 2018 and their representation in the reporting tables.

Biomass CO_2 emissions	**2018**	**Note**
	kt	
1A1 Energy industries (without MSW incineration)	367	Included in CRF
1A1 Energy generation from MSW Incineration	2'307	Included in CRF
1A2 Manufacturing industries and construction	1'450	Included in CRF
thereof use of waste derived fuels in cement production	68	
thereof use of bio fuels (1A2gvii)	18	
1A3 Transport	530	Included in CRF
1A4 Other sectors (Commercial/institutional, residential)	2'873	Included in CRF
1A5 Other	0.55	Included in CRF
2H2 Food and beverages industry	14	Not included in CRF
2G Other product use (Consumption of tabacco)	10	Not included in CRF
5A Solid waste disposal on land	40	Not included in CRF
5B Biological treatment of waste (composting and anaerobic digestion)	160	Not included in CRF
5C Waste incineration (without MSW incineration)	139	Included in CRF
5D Wastewater handling	4	Not included in CRF
Total biomass combustion CO_2 emissions included in CRF	7'665	
Total energy related biomass combustion CO_2 emissions included in CRF 1A	7'526	See table "Summary 2" in CRF
Total biomass CO2 emissions in Switzerland in 2018	7'894	

3.2.4.7 Uncertainty and time series consistency for source category 1A

Basic uncertainties of AD and EF CO_2 by fuel type

Table 3-21 Uncertainties of activity data, CO_2 emission factors and CO_2 emissions for 1A Fuel combustion.

Fuel type	**Uncertainties**		
	Activity data	**CO_2 emission factors**	**CO_2 emissions**
	%		
kerosene	0.96	0.16	0.97
gasoline	0.69	0.13	0.70
diesel oil	0.88	0.068	0.88
liquid fuels	0.69	0.081	0.69
solid fuels	5	5.1	7.1
gaseous fuels	5	0.88	5.1
other fuels	5	9.2	10
biomass	10	--	--

Liquid fuels

Uncertainty of the CO_2 emission factors: In 2013, a large measurement campaign was carried out to determine the CO_2 emission factors of the dominant liquid fuels (SFOE/FOEN

2014). From the standard deviation presented in this study, the 95% uncertainties are derived and shown in Table 3-22 as lower and upper values as well as relative uncertainties.

For mobile combustion, the 2006 IPCC Guidelines provide default uncertainties for the CO_2 emission factors of 2% for kerosene, 4% for gasoline and 1% for diesel oil (IPCC 2006, vol. 2, TABLE 3.2.1). Switzerland's measurements indicate much lower uncertainties. For stationary combustion, the 2006 IPCC Guidelines give no default values but show instead a summary of an uncertainty assessment of CO_2 emission factors for selected countries (IPCC 2006, vol 2, TABLE 2.13). The values lie in the range between 0.5% and 3% and are again higher than the values derived from the Swiss measurements.

Table 3-22 Uncertainties of aggregated results of measurements of the CO_2 emission factors of selected liquid fuels (SFOE/FOEN 2014).

Fuel type	CO_2 emission factors (measurements)			95% uncertainties EF (CO_2)		no. samples
	mean	lower	upper	absolute	relative	
	t/TJ	t/TJ	t/TJ	t/TJ	%	
Kerosene	72.81	72.70	72.93	0.12	0.16%	24
Gasoline	73.80	73.71	73.90	0.10	0.13%	138
Diesel oil	73.30	73.25	73.35	0.05	0.07%	75
Gas oil	73.67	73.61	73.73	0.06	0.08%	138

Uncertainties of activity data: The values shown in Table 3-23 are based on a written message of SFOE to FOEN (SFOE 2012a). It lists two kinds of relevant sources of errors: errors of measurements and errors of the conversion from mass to energy units. For diesel oil, the transformation to other products represents a third source of errors. All these errors are multiplicative, therefore the relative uncertainties have to be summed up.

Table 3-23 Sources of errors contributing to the total uncertainty of the activity data of selected liquid fuels (SFOE 2012a).

Source of uncertainty	kerosene	gasoline	diesel oil	gas oil
	activity data uncertainty in %			
Measurement	0.39%	0.39%	0.39%	0.39%
Conversion mass to energy	0.57%	0.29%	0.29%	0.29%
Production transformation	-	-	0.20%	0.00%
Total Uncertainty	0.96%	0.69%	0.88%	0.69%

Gaseous fuels

Uncertainty of the CO_2 emission factor: The composition of the imported gas is analysed in detail at the import stations. From this information, the FOEN annually calculates the CO_2 emission factor for each import station and the weighted mean. To estimate the uncertainty of the emission factor, the weighted standard deviation is calculated and is multiplied by 1.96 to extend the standard deviation to 95% uncertainty interval. This calculation has been carried out for all years with available data (selected years between 1990 and 2009 and all years thereafter). The uncertainties fluctuate between 0.29% and 1.48% with a mean of 0.88%, which is used as the uncertainty of the CO_2 emission factor for gaseous fuels.

Uncertainty of activity data: There is no country-specific estimate of the uncertainty for the consumption of natural gas. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2%–5% for industrial combustion and 3%–5% for commercial, institutional and residential combustion. For Switzerland, an overall value of 5% is used.

Solid fuels

Uncertainty of the CO_2 emission factor: There is no country-specific uncertainty available. The 2006 IPCC Guidelines suggest a range from 0.5% to 10% (IPCC 2006, vol. 2, Table 2.13). For Switzerland, an uncertainty of 5% is chosen (medium of suggested range).

Uncertainty of activity data: There is no country-specific estimate of the uncertainty for the consumption of coal. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2%–5% for industrial combustion and 3%–5% for commercial, institutional and residential combustion. For Switzerland, an overall value of 5% is used (as for natural gas).

Other fuels (waste-to-energy)

Uncertainty of the CO_2 emission factor: There are two factors influencing the uncertainty of CO_2 emissions from municipal solid waste incineration (1A1), namely the carbon content of waste and the fossil carbon fraction of the carbon content.

- The carbon content is determined according to a study by Fellner et al. (2007). The relation between the calorific value of waste and the carbon content is derived therein, including upper and lower limits. The relation is verified by measurements. The difference between upper and lower limits (5.9%) is interpreted as 95% confidence interval for the carbon content.
- The fossil fraction of the carbon content was determined in a study by Mohn et al. (2011). The radio carbon (^{14}C) method was applied in the field to calculate the ratio of biogenic versus fossil CO_2 emissions from five waste-to-energy plants. Gas samples for $^{14}CO_2$ analysis were taken at the plants during miscellaneous seasons. Six measuring campaigns of three weeks were carried out for three plants and three campaigns, again of three weeks, were carried out for two plants, leading to a total measurement time of 72 weeks. The campaigns provided a mean and 95% confidence interval of the biogenic fraction of 52.3%±3.8% (Table 3-24). The relative uncertainty was thus 7.1%. The results fit well to a former measurement campaign on three plants, which yielded 52.0%±3.7% for the biogenic fraction (Mohn et al. 2008). For the uncertainty analysis the latest result is used (Mohn et al. 2011).
- The emission factor for fossil CO_2 results from the multiplication of the carbon content and the fossil fraction. The uncertainty of the CO_2 emission factor is thus the addition of the corresponding uncertainties by error propagation: $[(5.9\%)^2 + (3.8\%)^2]^{0.5} = 7.0\%$.

Table 3-24 Fossil and biogenic fractions of municipal solid waste measured at five different incineration plants.

Plant	Shares		Uncertainty		Measurement campaigns
	fossil	biogenic	absolute	relative	(duration)
	%	%	%	%	weeks
Buchs	47.7	52.3	3.6	7.5	6 * 3 =18
Winterthur	43.4	56.6	3.9	9.0	6 * 3 =18
Linthgebiet	50.6	49.4	3.4	6.7	6 * 3 =18
Linthgebiet	54.5	45.5	3.1	5.7	3 * 3 = 9
Zuchwil	45.9	54.1	3.7	8.1	3 * 3 = 9
Median / sum	47.7	52.3	1.8	3.8	72

Uncertainty of activity data: There is no country-specific estimate of the uncertainty for the combustion of waste. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, p. 2.40), which state: “Experts believe that the uncertainty resulting from the two errors (*systematic, random*) combined is probably in the range of ±5% for most developed countries.” In accordance with that statement, the value of 5% is used.

Biomass

Uncertainty of the CO_2 emission factor: For CO_2 emissions of biomass burning, no uncertainty is estimated (memo item).

Uncertainty of activity data: No country-specific uncertainty of the activity data is available. The 2006 IPCC Guidelines suggest 2%–5% for industrial, institutional and residential combustion and 10%–30% for biomass burning in small sources (IPCC 2006, vol. 2, Table 2.15). An average uncertainty of 10% is applied for biomass burning in all source categories.

Uncertainty of CH_4 and N_2O emission factors

Since the CO_2 emissions vastly dominate the GHG emissions of source category 1A (almost 99%), the uncertainty evaluation of the non-CO_2 emissions is carried out on a semi-quantitative level (see Table 3-25).

Only for **1A3b Road transportation**, a quantitative analysis has been performed. Following a study for the road transportation in Germany (IFEU/INFRAS 2009), where the same handbook of emission factors is used as in Switzerland, the uncertainties for the CH_4 and N_2O emission factors have been determined (see rows 1A3b gasoline and diesel oil in Table 3-25). The uncertainties of CH_4 and N_2O emissions of CNG (1A3b), which were not investigated in IFEU/INFRAS (2009), have been estimated qualitatively as “medium” according to Table 1-10. For **1A1, 1A2, 1A3a, 1A3c, 1A3d, 1A3e, 1A4a, 1A4b, 1A4c, 1A5** the uncertainties of CH_4 and N_2O emissions have similarly been estimated qualitatively (see Table 3-25).

Summary

Table 3-25 provides a summary of the uncertainties of 1A Fuel combustion as derived in the preceding sections. The uncertainty of the CO_2 emissions (“combined uncertainty”) are calculated from the uncertainties of the activity data and the emission factors by Approach 1 error propagation.

Table 3-25 Uncertainties of 1A Fuel combustion categories for activity data, emission factors and combined uncertainties. The latter are calculated by Approach 1. For 1A2/Other Fuels a mean uncertainty is assumed based on semi-quantitative estimations from Table 1-10. The emission factor uncertainty is calculated “backward”[5] from the combined and the activity data uncertainty. CH_4 and N_2O: semi-quantitative uncertainties are used (see Table 1-10).

1A Fuel Combustion Categories	Fuel type	Uncertainties				
		Activity data	CO_2 em. factors	CO_2 emissions	CH_4 emissions	N_2O emissions
		%	%	%	--	--
1. Energy industries	liquid fuels	0.69	0.081	0.69	medium	medium
1. Energy industries	solid fuels	5.0	5.1	7.1	medium	medium
1. Energy industries	gaseous fuels	5.0	0.88	5.1	medium	medium
1. Energy industries	other fuels	5.0	9.2	10	medium	medium
2. Manufacturing industries and construction	liquid fuels	0.69	0.081	0.69	medium	medium
2. Manufacturing industries and construction	solid fuels	5.0	5.1	7.1	medium	medium
2. Manufacturing industries and construction	gaseous fuels	5.0	0.88	5.1	medium	medium
2. Manufacturing industries and construction	other fuels	5.0	9.2	10	medium	medium
3a. Transport; Domestic aviation	kerosene	0.96	0.16	0.97	high	high
3b. Transport; Road transportation	gasoline	0.69	0.13	0.70	37	50
3b. Transport; Road transportation	diesel oil	0.88	0.068	0.88	20	22
3b. Transport; Road transportation	gaseous fuels	5.0	0.88	5.1	medium	medium
3c. Transport; Railways	diesel oil	0.88	0.068	0.88	medium	high
3d. Transport; Domestic navigation	liquid fuels	0.69	0.081	0.69	medium	high
3e. Transport; Other transportation	gaseous fuels	5.0	0.88	5.1	medium	medium
4a. Other sectors; Commercial/institutional	liquid fuels	0.69	0.081	0.69	medium	medium
4a. Other sectors; Commercial/institutional	gaseous fuels	5.0	0.88	5.1	medium	medium
4b. Other sectors; Residential	liquid fuels	0.69	0.081	0.69	medium	medium
4b. Other sectors; Residential	solid fuels	5.0	5.1	7.1	medium	medium
4b. Other sectors; Residential	gaseous fuels	5.0	0.88	5.1	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	liquid fuels	0.69	0.081	0.69	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	gaseous fuels	5.0	0.88	5.1	medium	medium
5. Other	liquid fuels	0.69	0.081	0.69	medium	high
1A Stationary sources	biomass	10	--	--	medium	medium
1A Mobile sources	biomass	10	--	--	high	high

Time series consistency 1A

Time series for 1A Fuel combustion are all considered consistent.

3.2.4.8 Category-specific QA/QC and verification for source category 1A

Various QA/QC activities are relevant for all source categories in 1A. Therefore, they are briefly described here and not repeated in the chapters dealing with the source categories 1A1 to 1A5.

[5] $U(EF) = \sqrt{U(EM)^2 - U(AD)^2}$

Comparison of emission estimates using different approaches
At the level of total energy-related CO_2 emissions, a quality control consists in the comparison of emissions modelled using the sectoral approach with emissions calculated based directly on fuel consumption according to the Swiss overall energy statistics (SFOE 2019). The differences in total CO_2 emissions for the entire time period are negligible, indicating the completeness of the inventory.

The cross-check of the Reference and Sectoral Approach is also used for an assessment of emissions related to the consumption of fuels in the energy sector. Again, a good agreement between the two approaches is found (see chp. 3.2.1).

Activity data checks
The SFOE constructs a national commodity balance expressed in mass and in energy units including mass balances of fuel conversion industries.

The gross carbon supply in the Reference Approach has been adjusted for fossil fuel carbon destined for non-energy use. The numbers in the Swiss overall energy statistics (SFOE 2019) are consistent with those provided by international organisations, e.g. IEA.

Emission factor check and review
Emission factors for the main fossil fuels have been reassessed for submission 2015. In 2013, the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN) launched an in-depth investigation into the NCVs and CO_2 emission factors of gas oil, diesel oil, gasoline, and kerosene (SFOE/FOEN 2014, see chp. 3.2.4.2). The most recent results differ only marginally from previously used values. The CO_2 emission factors compare well with the IPCC default values (see Table 3-26).

Table 3-26 Comparison of default CO_2 emission factors from IPCC (2006) with current country-specific values of Switzerland for selected fuels.

CO_2 emission factors	**IPCC 2006**			**Switzerland**
	lower	upper	default	CS
	t CO_2 /TJ			t CO_2 /TJ
Gasoline	67.5	73.0	69.3	73.8
Jet kerosene	69.7	74.4	71.5	72.8
Diesel oil	72.6	74.8	74.1	73.3
Gas oil	72.6	74.8	74.1	73.7

The CO_2 emission factor for gasoline is higher than the upper limit of the IPCC range. However, as the value from earlier measurements was confirmed and the new value is based on more than 100 fuel samples taken from July to December 2013, the value is considered to correctly represent national circumstances.

For natural gas, the CO_2 emission factor is annually assessed. A country-specific CO_2 emission factor is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations (see chp. 3.2.4.4). The resulting values are largely consistent with the CO_2 EF used by the countries from which gas is imported (i.e. Germany, the Netherlands, Norway, France, Italy and Denmark, with IEFs between 54.3 and 58.8 t CO_2/TJ, based on submissions 2019).

The CH_4 emission factors from combustion of wood were scrutinized and revised based on Nussbaumer and Hälg (2015). The range of country-specific values is not entirely consistent with the upper and lower IPCC default values (Table 3-27). However, as the country-specific emission factors are based on an extensive measurement campaign, they are considered representative for Swiss circumstances.

Table 3-27 Comparison of default CH_4 emission factors from the 2006 IPCC Guidelines (IPCC 2006) with country-specific values.

CH_4 emission factors	**IPCC 2006**			**Switzerland**
	lower	upper	default	CS
	kg CH_4 /TJ			kg CH_4 /TJ
Gas oil	10	100	30	1.3 - 240

Expert review

As described in chp. 1.2.3, data from source category 1A and the initial draft of the NIR were scrutinized in an external review involving national experts and stakeholders in the different fields related to emissions from stationary sources.

3.2.4.9 Planned improvements for source category 1A in general

No general improvements for 1A are planned.

3.2.5 Source category 1A1 – Energy industries (stationary)

3.2.5.1 Source category description for 1A1 (stationary)

Table 3-28 Key categories of 1A1 Energy industries. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A1	Energy industries: Gaseous fuels	CO2	L1, T1
1A1	Energy industries: Liquid fuels	CO2	L1, T1
1A1	Energy industries: Other fuels	CO2	L1, L2, T1, T2

Source category 1A1 Energy industries comprises emissions from fuels combusted by the fuel extraction and energy-producing industries. The most important source category is 1A1a Public electricity and heat production, followed by 1A1b Petroleum refining. Activities in source category 1A1c Manufacture of Solid Fuels and other energy industries are virtually not occurring in Switzerland (apart from a tiny charcoal production activity in historic trade).

Within source category 1A1a, heat and electricity production in waste incineration plants cause the largest emissions, as electricity production in Switzerland is dominated by hydroelectric power plants and nuclear power stations (SFOE 2019). Emissions from industries producing heat and/or electricity (CHP) for their own use are included in category 1A2 Manufacturing Industries and Construction.

Table 3-29 Specification of source category 1A1 Energy Industries.

1A1	Source category	Specification
1A1a	Public electricity and heat production	Main source are waste incineration plants with heat and power generation (Other fuels) and public district heating systems. The only fossil fuelled public electricity generation unit "Vouvry" (300 MWe; no public heat production) ceased operation in 1999.
1A1b	Petroleum refining	Combustion activities supporting the refining of petroleum products, excluding evaporative emissions.
1A1c	Manufacture of solid fuels and other energy industries	Charcoal production

3.2.5.2 Methodological issues for 1A1 (stationary)

3.2.5.2.1 Public electricity and heat production (1A1a)

Public electricity and heat production in Switzerland encompasses different plant types where various fuels are used (Table 3-30). Energy recovery from municipal solid waste and special waste incineration is mandatory in Switzerland (Swiss Confederation 2015, Art. 27) and plants are equipped with energy recovery systems. The emissions from municipal solid waste and special waste incineration plants are therefore reported under category 1A1a. There was a single fossil fuel power station operating with residual fuel oil in Vouvry. However, the power station closed down in 1999.

Table 3-30 Plant type and fuels used in source category 1A1a.

Plant type	Fuel type
Heat plants for renewable wastes	wood waste (biomass)
Heating boilers > 300 MW (Vouvry)	residual fuel oil
Heating boilers < 300 MW	gas oil, residual fuel oil, bituminous coal
Central heating boilers for district heating	natural gas, gas oil, residual fuel oil, bituminous coal
Wood combined heat and power generation	wood, wood waste (biomass)
Engines on landfill sites	landfill gas (biogas)
Municipal solid waste incineration plants	municipal solid waste (other, waste-to-energy)
Special waste incineration plants	special wastes (other, waste-to-energy)

Methodology (1A1a)

For CO_2 emissions in source category 1A1a Public electricity and heat production, a country-specific approach is used combining Tier 2 and Tier 3 methods (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1). For CH_4 emissions, a Tier 1 method was applied (using IPCC default emission factors), except for biomass, where country-specific emission factors are used. For N_2O IPCC default values are used (Tier 1), except for municipal solid waste and special waste incineration plants, where country-specific emission factors were used.

Emission factors (1A1a)

Table 3-31 presents the emission factors used in 1A1a. Emission factors for gas oil and natural gas (highlighted green in Table 3-31) are further explained in chp. 3.2.4.4.

Table 3-31 Emission factors for 1A1a Public Electricity and Heat Production in 2018.

1A1a Public electricity and heat production	CO_2	CO_2 bio.	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gas oil	73.7	NA	3.0	0.6	33	2	9	6.3
Residual fuel oil	NO	NA	NO	NO	NO	NO	NO	NO
Petroleum coke	NO	NA	NO	NO	NO	NO	NO	NO
Natural gas	56.3	NA	1.0	0.1	18	2	0.5	10
Other (waste-to-energy), fossil	88.9	NA	NE	1.4	32	2.4	3.6	8.3
Other (waste-to-energy), biogenic	NA	91.9	NE	1.4				
Biomass (wood, renewable waste)	NA	99.9	1.2	4.0	114	2	12	93
Biogas (co-generation from landfills)	NA	56.3	20.0	0.1	131	NE	NE	219

Emission factors for waste incineration and landfill gas use

Specific emission factors within 1A1a Public electricity and heat production apply for municipal solid waste incineration, special waste incineration and for landfill gas use. The emission factors for CO_2, NO_x, CO, NMVOC and SO_2 are country-specific and based on measurements and expert estimates. Emission factors for CH_4 and N_2O are IPCC default values, with the exception of waste and biomass as fuel, where country-specific emission factors are applied. Emission factors are documented in EMIS 2020/1A1a Kehrichtverbrennungsanlagen, EMIS 2020/1A1a Sondermüllverbrennungsanlagen and EMIS 2020/1A1a & 5A Kehrichtdeponien.

Source-specific CO_2 emission factors for municipal solid waste incineration plants

C-content of waste is calculated based on the net calorific value (NCV), which is deduced by a standard method and published on a yearly basis since 2009 by SFOE for each municipal solid waste incineration plant (MSWIP) and as a Swiss average (FOEN/SFOE/VBSA, 2019). In deviation from the general description of oxidation factors in 3.2.4.4.1, an oxidation factor of 0.99 is assumed here. The assumption is based on measurements in two MSWIPs in Zurich (AWEL 2009) and on a study in Austria (Zeschmar-Lahl 2004), where the MSWIP have the same standards as in Switzerland. The measurements in Zurich showed transfer coefficients into air of 0.96–0.99 and the ones in Austria stated a transfer coefficient into clean air of 0.989.

The fossil fraction of waste incinerated in MSWIP is based on a study conducted in the year 2014 (Rytec 2014). The study uses data from three measurement campaigns during which the waste composition has been analysed (FOEN 2014o) and measurements of the radioactive isotope carbon-14 (^{14}C) in the flue gas for calibration have been made (Mohn et al. 2011). The CO_2 emission factor in MSWIPs fluctuates over the reporting period because of gradual changes in the net calorific values of the waste (Table 3-32).

Table 3-32 Emission factor CO_2 total, share of CO_2 fossil and net calorific value (NCV) in municipal solid waste incineration plants (MSWIP).

1A1a Public electricity and heat production, Other fossil fuels	Unit	1990	1995	2000	2005
CO_2 total (MSWIP)	t/TJ	92.80	91.86	91.09	91.49
Share of CO_2 fossil (MSWIP)	1	0.497	0.505	0.513	0.505
NCV of waste (MSWIP)	TJ/t	0.0114	0.0119	0.0124	0.0121

1A1a Public electricity and heat production, Other fossil fuels	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CO2 total (MSWIP)	t/TJ	92.50	92.32	92.25	92.62	92.76	92.43	92.28	92.01	91.92	91.90
Share of CO_2 fossil (MSWIP)	1	0.489	0.486	0.482	0.478	0.478	0.478	0.478	0.478	0.478	0.478
NCV of waste (MSWIP)	TJ/t	0.0116	0.0117	0.0117	0.0115	0.0114	0.0116	0.0117	0.0118	0.0119	0.0119

Sodium bicarbonate and calcium carbonate are used in some MSWIPs for flue gas treatment. Sodium bicarbonate is used since 2013 and calcium carbonate was used between 1990 and 2005. According to IPCC 2006 the corresponding emissions are reported in source category 2A4d.

Source-specific CO_2 emission factors for special waste incineration plants

Based on detailed information regarding waste composition and estimated emission factors in the years 1992–2004, a weighted average emission factor for special waste incineration was calculated. Special waste is assumed to be of entirely fossil origin. Overall, a specific emission factor of 1.45 t CO_2/t waste results for special waste. This value is considerably higher than the one reported in SAEFL (2000). As there is no newer data on the special waste composition, the emission factor deduced as described above is used for the whole period from 1990 until today. See documentation in EMIS 2020/1A1a Sondermüllverbrennungsanlagen.

Source-specific CH_4 emission factors in municipal and special waste incineration plants

Emissions of CH_4 are not occurring in waste incineration plants because of the high temperatures and the long dwell time in the combustion chamber as confirmed by Mohn (2013). In the year 2013, EMPA assessed the N_2O and CH_4 emission factors for MSWIP (Mohn 2013). In this study, EMPA evaluated measurements that were performed in 2011 in five Swiss MSWIP with different Denox techniques (SCR, SNCR). For most of the measurements, CH_4 concentrations were below the detection limit of 0.3 ppm. The study concluded that "CH_4 emission concentrations were very low and below the background concentration of 1.8 ppm". These measurements, which showed that CH_4 concentration in the exhaust air was below the CH_4 concentration in ambient air, would point to CH_4 removal rather than emissions occurring. Therefore, CH_4 emissions from municipal waste incineration are reported as not estimated because they are considered insignificant. The same fact applies for special waste incineration.

Source-specific N_2O emission factors for municipal solid waste incineration

In 2013, a study evaluated N_2O measurements that have been performed in the years 2010–2011 in the flue gas of five Swiss municipal waste incineration plants (Mohn 2013) and derived plant-specific emission factors for Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) equipped installations.

Average Swiss emission factors have been calculated according to the state of equipment of all Swiss waste incineration plants (with two types of Denox-equipment (SCR, SNCR) and without Denox-equipment). For installations without Denox-equipment, the emission factor comes from SAEFL (2000). According to the state of equipment of all Swiss waste incineration plants in the years 1990, 1994, 1998, 2004, 2008, 2012 and 2016, weighted average N_2O emission factors have been calculated, based on the amounts of waste burnt in every plant. For the years in between, the N_2O emission factors were linearly interpolated. Since 2016, the emission factor is assumed to be constant (however the emission factor related to energy changes by reason of the conversion with the net calorific value of waste). It is planned to calculate new weighted averages for the N_2O emissions factors periodically, depending on data available; see documentation in EMIS 2020/1A1a Kehricht- und Sondermüllverbrennungsanlagen. The emission factor is therefore not constant over time.

Source-specific N_2O emission factors for special waste incineration

The emission factor of special waste for the year 1990 is based on SAEFL (2000). It is assumed that this value (3.1 g/GJ) then increases until 2003 (6.1 g/GJ) due to the installation of Denox-equipment and thereafter declines as a result of optimized installations.

Table 3-33 N_2O emission factors of 1A1a Municipal solid (MSWIP) and special waste incineration (SWIP).

1A1a Public electricity and heat production, Other fossil fuels	1990	1995	2000	2005
	kg/TJ			
N_2O (MSWIP)	5.26	2.96	2.06	1.44
N_2O (SWIP)	3.06	4.23	5.41	5.48

1A1a Public electricity and heat production, Other fossil fuels	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kg/TJ									
N_2O (MSWIP)	1.41	1.40	1.40	1.43	1.44	1.42	1.41	1.39	1.38	1.38
N_2O (SWIP)	4.21	3.89	3.57	3.25	2.94	2.62	2.30	1.98	1.67	1.35

Activity data (1A1a)

Activity data for liquid, gaseous, solid fuels and wood are based on the Swiss overall energy statistics (SFOE 2019) and additional data sources as described in 3.2.4.3. Activity data for Other fuels are based on the amount of waste incinerated in MSWIPs and special waste incineration plants (SWIPs) (FOEN 2019h, see Table 3-35). Activity data for combined heat and power generation in landfills are taken from the Swiss renewable energy statistics (SFOE 2019a).

Please note that waste-to-energy activities in CRF Table1.A(a)s1 are allocated to fuel types ‘Other fossil fuels’ and ‘Biomass’. ‘Other fossil fuels’ encompasses emissions from the fossil shares of MSWIP and SWIP. Whereas ‘Biomass’ covers emissions from wood, waste wood, landfill gas use in co-generation and biogenic share from MSWIP.

Table 3-34 Activity data in 1A1a Public Electricity and Heat Production.

1A1a Public electricity and heat production	1990	1995	2000	2005
	TJ			
Total fuel consumption	40'379	39'179	49'913	56'976
Gas oil	980	554	790	1'300
Residual fuel oil	3'214	1'813	340	290
Petroleum coke	NO	NO	NO	NO
Other bituminous coal	530	46	NO	NO
Lignite	NO	NO	NO	NO
Natural gas	4'339	5'422	8'292	9'827
Other (waste-to-energy), fossil	16'605	16'870	22'482	24'711
Biomass	14'711	14'474	18'009	20'848
Other (waste-to-energy), biogenic	14'163	13'394	16'889	19'797
Biomass (wood, renewable waste)	301	466	547	844
Biogas (co-generation from landfills)	247	614	573	207

1A1a Public electricity and heat production	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	57'798	61'740	59'796	63'402	63'334	59'366	61'381	65'016	64'743	65'292
Gas oil	540	490	400	800	670	770	660	430	490	380
Residual fuel oil	130	40	10	NO	NO	NO	NO	NO	NO	NO
Petroleum coke	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	8'073	9'926	7'512	8'213	8'449	5'082	7'080	8'956	7'927	8'141
Other (waste-to-energy), fossil	24'853	26'002	25'575	26'262	25'738	26'049	26'832	27'657	27'430	27'997
Biomass	24'202	25'282	26'299	28'127	28'476	27'464	26'809	27'973	28'896	28'775
Other (waste-to-energy), biogenic	21'249	22'275	22'272	23'051	22'489	23'112	23'716	24'765	24'886	25'100
Biomass (wood, renewable waste)	2'877	2'958	3'983	5'032	5'949	4'321	3'071	3'195	4'003	3'669
Biogas (co-generation from landfills)	76	49	44	44	39	31	21	13	6.5	6.1

Since 1990 the use of waste-derived fuels increased considerably. This is due to the fact that since 1st of January 2000, disposal of combustible wastes in landfill sites is prohibited by law, see Swiss Confederation 2015 (VVEA, Art. 25), and Swiss Confederation 1990 (the preceding Ordinance TVA, Art. 32). The increase is also partly due to municipal solid waste imported from neighbouring countries to optimize the load factor of MSWIPs. During the reporting period, the consumption of natural gas increased, and the consumption of liquid fuels decreased. This is due to a fuel shift in combined heat and power generation and the closure of the only power station located in Vouvry that has been operated with residual fuel oil in the 1990ies.

Municipal solid waste incineration and special waste incineration

Figure 7-4 in Sector 5 Waste gives an overview over the waste amounts, their treatment and their reporting in the Swiss greenhouse gas inventory. Municipal solid waste includes waste generated in households and waste of similar composition from other sources.

The amount of municipal solid waste in kt reported in Table 3-35 is the total amount of waste burnt (it includes fossil and biogenic shares). The fossil and biogenic share in TJ are given as well.

Special waste is composed of special wastes with high calorific value, wastewater and sludge with organic load, inorganic solids and dusts, inorganic sludge containing heavy metals, acids and alkalis, PCB-containing wastes, non-metallic shredder residues, contaminated soil, filter materials and chemicals residues and others.

Table 3-35 Activity data for 1A1aiv Other: Municipal solid waste and special waste incinerated with heat and/or power generation. The amount of municipal solid waste in kt is the total amount of waste burnt.

1A1aiv Public electricity and heat production, Other	**Unit**	**1990**	**1995**	**2000**	**2005**
Total fuels	TJ	30'768	30'264	39'371	44'508
Municipal solid waste fossil	TJ	13'995	13'664	17'790	20'197
Municipal solid waste biogenic	TJ	14'163	13'394	16'889	19'797
Special waste	TJ	2'610	3'206	4'692	4'514
Total waste	kt	2'603	2'433	3'040	3'527
Municipal solid waste (fossil and biogenic)	kt	2'470	2'270	2'801	3'297
Special waste	kt	133	163	239	230

1A1aiv Public electricity and heat production, Other	**Unit**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Total fuels	TJ	46'102	48'277	47'847	49'313	48'228	49'161	50'548	52'422	52'316	53'097
Municipal solid waste fossil	TJ	20'334	21'062	20'724	21'108	20'593	21'163	21'717	22'678	22'789	22'984
Municipal solid waste biogenic	TJ	21'249	22'275	22'272	23'051	22'489	23'112	23'716	24'765	24'886	25'100
Special waste	TJ	4'519	4'941	4'851	5'155	5'145	4'886	5'115	4'979	4'641	5'013
Total waste	kt	3'827	3'968	3'924	4'104	4'035	4'066	4'150	4'264	4'248	4'297
Municipal solid waste (fossil and biogenic)	kt	3'597	3'717	3'676	3'841	3'773	3'817	3'889	4'010	4'011	4'042
Special waste	kt	230	252	247	263	262	249	261	254	236	255

3.2.5.2.2 Petroleum refining (1A1b)

Methodology (1A1b)

Up to 2015, two refineries were in operation in Switzerland. Since one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request. Based on the generalised decision tree Fig. 2.1 for stationary combustion (IPCC Guidelines 2006, vol.2, chp. 2), Switzerland applies a Tier 3 approach with country-specific emission factors for CO_2 emissions. The calculations are based on measurements and data from the refining industry as documented in the EMIS database (EMIS 2020/1A1b Heizkessel Raffinerien).

Emission factors (1A1b)

CO_2 emission factors of residual fuel oil, petroleum coke and refinery gas are estimated based on measurements from the refineries for the years 2005–2011 and 2013–2018 provided in the framework of the Swiss emissions trading system. From 2005 onwards, the measured emission factors are applied. The emission factors for 2012 are interpolated between 2011 and 2013. In years before 2005, the emission factors of residual fuel oil and petroleum coke are based on the weighted mean of the available data (2005 – 2011 and 2013 – 2015). The CO_2 emission factor of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. Since 2013 the annual emission factor is derived from annual monitoring reports and the allocation report (2005–2011), which provide plant-specific data.

The resulting CO_2 emission factor of refinery gas is higher than the IPCC default value.

Table 3-36 Emission factors for 1A1b Petroleum refining in 2018.

1A1b Petroleum refining	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Residual fuel oil	C	C	C	C	C	C	C
Refinery gas	C	C	C	C	C	C	C
Petroleum coke	NO	NO	NO	NO	NO	NO	NO
Natural gas	C	C	C	C	C	C	C

Activity data (1A1b)

Activity data on fuel combustion for petroleum refining (1A1b) is provided by the Swiss overall energy statistics (SFOE 2019) and by the industry (bottom-up data). The data from the industry is collected by Carbura and forwarded to the Swiss Federal Office of Energy for inclusion in the Swiss overall energy statistics (SFOE 2019).

Refinery gas is the most important fuel used in source category 1A1b. Energy consumption, in particular use of refinery gas, has increased substantially since 1990 because one of the two Swiss refineries operated at reduced capacity in 1990 and resumed full production in later years. In 2012, one of the refineries was closed over six month due to insolvency and the search for a new buyer (EV 2014).

Net calorific values are provided by the annual monitoring reports of the refining industries for the years 2005–2011 and 2013–2018 that are required under the Swiss Federal Act and Ordinance on the Reduction of CO2 Emissions (Swiss Confederation 2011, Swiss Confederation 2012). For years with missing data (1990–2004 and 2012), the weighted mean of the net calorific value is applied for residual fuel oil and petroleum coke. The net calorific value of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. The use of a plant-specific net calorific value leads to a slight difference to the energy consumption data provided by the Swiss overall energy statistics (SFOE 2019).

Table 3-37 Activity data for 1A1b Petroleum refining.

1A1b Petroleum refining	1990	1995	2000	2005
	TJ			
Total fuel consumption	5'629	9'836	9'636	14'548
Residual fuel oil	1'259	1'786	1'908	902
Refinery gas	4'370	8'050	7'728	11'833
Petroleum coke	NO	NO	NO	1'813
Natural gas	NO	NO	NO	NO

1A1b Petroleum refining	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	14'473	14'176	13'169	11'242	13'834	14'173	7'232	6'355	6'298	6'627
Residual fuel oil	733	891	764	1'212	1'094	1'330	C	C	C	C
Refinery gas	11'706	11'282	10'720	8'249	11'055	10'935	C	C	C	C
Petroleum coke	2'035	2'003	1'685	1'781	1'685	1'908	C	NO	NO	NO
Natural gas	NO	NO	NO	NO	NO	NO	NO	NO	C	C

3.2.5.2.3 Manufacture of solid fuels and other energy industries (1A1c)

Methodology (1A1c)

In source category 1A1c Manufacture of Solid Fuels and other energy industries, only the emissions from charcoal production are reported as no other activities occur in Switzerland.

Based on the generalised decision tree in Fig. 2.1 for stationary combustion (IPCC Guidelines 2006, vol.2, chp. 2), emissions are estimated using a Tier 2 approach.

Emission factors (1A1c)

The CO_2 emission factor is based on literature (USEPA 1995) and CH_4, NO_x, CO and NMVOC emission factors are taken from the revised 1996 IPCC Guidelines (EMIS 2020/1A1c).

Table 3-38 Emission factors for 1A1c Manufacture of Solid Fuels and other energy industries in 2018. The CO_2 emission factor refers to CO_2 of biogenic origin.

1A1c Charcoal	CO_2 biog.	CH_4	NO_x	NMVOC	SO_2	CO
	kg/TJ					
Charcoal production	16'900	1'000	10	1'700	NA	7'000

Activity data (1A1c)

The annual amount of charcoal produced is based on detailed queries with the few remaining sites where charcoal is produced. The main producer is the Köhlerverein Romoos, small quantities are produced at individual traditional local trade shows (Karthause Ittingen, Freilichtmuseum Ballenberg), as documented in EMIS 2020/1A1c. The FAO database contained values that differ substantially from these detailed bottom-up data. FAO has been informed about the discrepancy and was provided with the data used in the greenhouse gas inventory.

The charcoal is not used in the industry anymore but mainly for barbecues. Production has increased between 1990 and 2016 due to two regular charcoal production sites starting operation in 2004, low wood prices and increased demand for local charcoal in Switzerland (Koehlerei 2014).

Table 3-39 Activity data for 1A1c Manufacture of Solid Fuels and other energy industries.

1A1c Charcoal	**1990**	**1995**	**2000**	**2005**
	TJ			
Charcoal production	1.25	1.43	2.20	3.37

1A1c Charcoal	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	TJ									
Charcoal production	3.60	3.63	3.74	4.06	3.26	4.26	3.75	4.08	3.93	4.25

3.2.5.3 Uncertainties and time-series consistency for 1A1 (stationary)

The uncertainty of emission estimates for source category 1A1 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A1 Energy industries are all considered consistent.

3.2.5.4 Category-specific QA/QC and verification for 1A1 (stationary)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

Concerning activity data and emission factors in the refinery sector, emissions and fuel combustion statistics are collected at large combustion plants for pollution legislation purposes. This plant-level data is used to cross-check national energy statistics from this sector for representativeness.

3.2.5.5 Category-specific recalculations for 1A1 (stationary)

The following recalculations were implemented in submission 2020. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A1a: Activity data (wood, wood waste) of all wood combustion installations have been revised for 2016–2017 due to recalculations in the Swiss wood energy statistics (SFOE 2019b).
- 1A1a: The CH_4 use from biogas in CHP from solid waste disposal sites has decreased from 2.41 GWh to 1.81 GWh due to changes in the annual statistical report by SFOE for the year 2017.

- 1A1a: Activity data for used biogas from waste disposal sites in engines has changed for all years 1990–2017. This leads to changes of 8.8% / 20 TJ in the year 1990 and -20% / -1.6 TJ in 2017.
- 1A1a: Recalculations in the Swiss energy statistics concerning use of gas oil in 1A1a Energy industries for the years 2010, 2014, 2016–2017 have been made.
- 1A1c: Activity data of 1A1c Charcoal production has been updated due to production figures from an additional charcoal pile for 2010–2017.

3.2.5.6 Category-specific planned improvements for 1A1 (stationary)

There are no category-specific planned improvements.

3.2.6 Source category 1A2 – Manufacturing industries and construction (stationary, without 1A2gvii)

3.2.6.1 Source category description for 1A2 (stationary)

Table 3-40 Key categories of 1A2 Manufacturing industries and construction. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Liquid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction: Other fuels	CO2	L1, T1, T2
1A2	Manufacturing industries and construction: Solid fuels	CO2	L1, T1, T2

[Source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emissions only. The CO_2 emissions of 1A2 from Liquid Fuels are dominated by the stationary sources, however, 37% (2018) of the CO_2 emissions stem from mobile sources 1A2gvii.]

The source category 1A2 Manufacturing industries and construction comprises all emissions from the combustion of fuels in stationary boilers and cogeneration facilities within manufacturing industries and construction. This includes use of conventional fossil fuels as well as waste-derived fuels and biomass. Use of fossil fuels as feedstocks or other non-energy use of fuels as for example bitumen and lubricants are reported in CRF Table1.A(d) and described in chp. 3.2.3.

Table 3-41 Specification of source category 1A2 Manufacturing industries and construction.

1A2	Source category	Specification
1A2a	Iron and steel	Iron and steel industry: boilers, cupola furnaces in iron foundries and electric arc furnaces and heating furnaces in steel production
1A2b	Non-ferrous metals	Non-ferrous metals industry: secondary aluminium production, copper alloys production
1A2c	Chemicals	Chemical industry: production of chemicals such as. ammonia, niacin, nitric acid, ethylene, acetic acid and sulphuric acid as well as silicon carbide (amongst others)
1A2d	Pulp, paper and print	Pulp, paper and print industry
1A2e	Food processing, beverages and tobacco	Food processing, beverages and tobacco industry: meat production, milk products, convenience food, chocolate, sugar and baby food (amongst others).
1A2f	Non-metallic minerals	Fine ceramics, container glass, glass, glass wool, lime, rock wool, mixed goods, cement, brick and tile
1A2giv	Wood and wood products	Fibreboard production
1A2gviii	Other	Industrial fossil fuel and biomass boilers and engines that do not provide heat or electricity to the public.

3.2.6.2 Methodological issues for 1A2 (stationary)

3.2.6.2.1 Methodology (1A2) and industry model

For CO_2 emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, Tier 2 and 3 methods are applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using country-specific emission factors – except for other fossil fuels (gasolio, heating gas, and synthesis gas (from 2018 onwards)) in 1A2c Chemicals, where plant-specific emission factors are used.

For all fuel combustion in 1A2f Cement production, and for wood combustion in 1A2f Brick and tile production (2000–2012), 1A2giv and 1A2gviii, CH_4 emissions are calculated by a Tier 2 approach using country-specific emission factors. For CH_4 emissions from all other fuel combustion processes in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

For N_2O emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

Overview industry model

The industry model is one sub-model of the Swiss energy model (see chp. 3.2.4.3). The industry model disaggregates the stationary fuel consumption into the source categories and processes under 1A2 Manufacturing industries and construction. The following figure visualizes the disaggregation process.

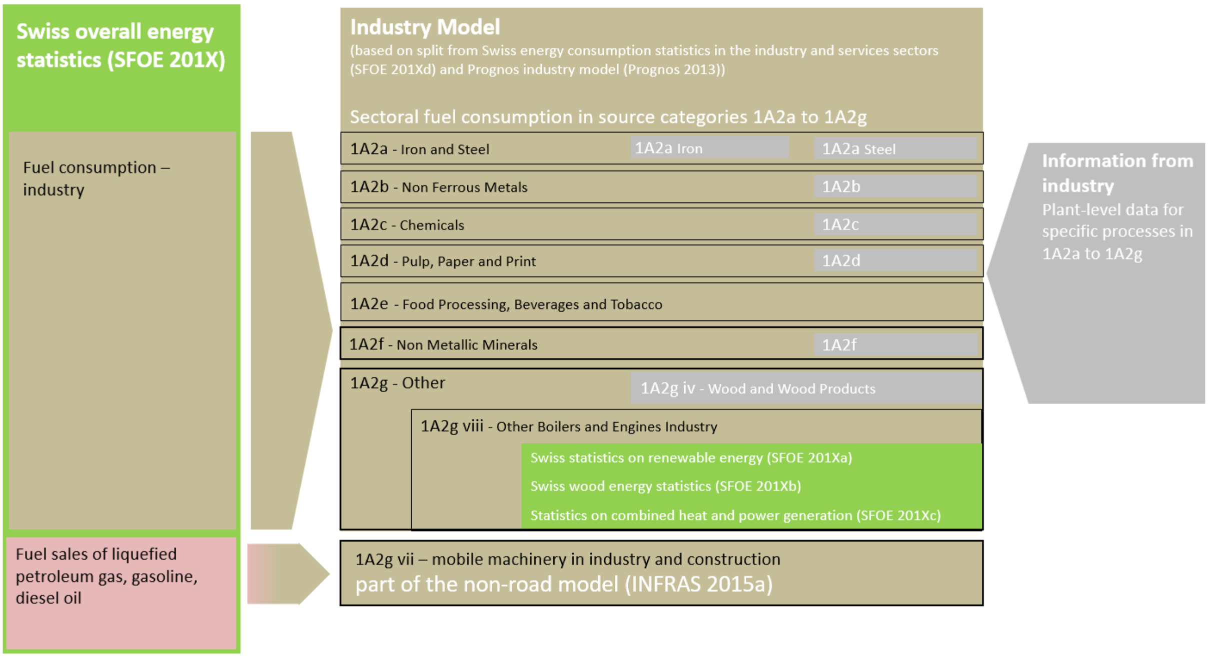


Figure 3-22 Schematic presentation of the data sources used for the industrial sectors 1A2a–1A2g. The references SFOE 201X, 201Xa, 201Xb and 201Xc refer to the 2019 edition of the corresponding energy statistics. For each fuel type, the Swiss overall energy statistics provide the total consumption for industry. The total consumption is then distributed to the different source categories based on information from industry surveys (SFOE 2019d) and the Prognos industry model (Prognos 2013). The grey boxes on the right show the specific bottom-up industry information.

The total fuel consumption regarding each fuel type in the industry sector is provided by the Swiss overall energy statistics (SFOE 2019, see also description in chp. 3.2.4.3). The energy disaggregation into the source categories 1A2a to 1A2g is carried out for each fuel type individually based on the energy consumption statistics in the industry and services sectors (SFOE 2019d). These statistics are available since 1999 for gas oil and natural gas. For all other fossil fuels (i.e. residual fuel oil, liquefied petroleum gas, petroleum coke, other bituminous coal and lignite) data are available since 2002. In order to generate a consistent time series since 1990, additional data from an industry model is applied (Prognos 2013) as described in the following paragraphs.

In addition, the share of fuel used for co-generation in turbines and engines within 1A2 is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2019c).

Energy consumption statistics in the industry and services sectors

The energy consumption statistics in the industry and services sectors (SFOE 2019d) refer to representative surveys with about 12’000 workplaces in the industry and services sectors that are then grossed up or extrapolated to the entire industry branch. For certain sectors and fuel types (i.e. industrial waste, residual fuel oil, other bituminous coal and lignite) the surveys represent a census covering all fuel consumed. The surveys are available for all years since 1999 or 2002, depending on the fuel type.

In 2015, a change in the survey method of the energy consumption statistics in the industry and services sectors was implemented (SFOE 2015d). The business and enterprise register, which forms the basis for the samples of the surveys, was revised. While previously the business and enterprise register was based on direct surveys with work places, it is now based on annual investigations of registry data (e.g. from the old-age and survivors' insurance). In the course of this revision, a comparative assessment was conducted for the year 2013. This comparison showed that the energy consumption in the source categories of 1A2 stationary are modified by less than one percent, but also that the differences between the new and the old results for 2013 are not statistically significant (SFOE 2015d). As these statistics are only used for allocation of total energy consumption to different source categories, the impact on the different source categories solely consists of a reallocation of the energy consumption and does not affect the total of the sector. Moreover, only consumption of gas oil and natural gas is affected. For all these reasons, the time series consisting of data based on the old (1990–2012) and new (since 2013) survey method are considered consistent.

Modelling of industry categories

The energy consumption statistics in the industry and services sectors (SFOE 2019d) are complemented by a bottom-up industry model (Prognos 2013). The model is based on 164 individual industrial processes and further 64 processes related to infrastructure in industry. Fuel consumption of a specific process is calculated by multiplication of the process activity data with the process-specific fuel consumption factor.

The model provides data on the disaggregation of total fuel consumption according to different industries and services between 1990 and 2012. For the time period where the two disaggregation methods overlap, systematic differences between the two time series can be detected. These two data sets have been combined in order to obtain consistent time series of the shares of each source category 1A2a–1A2g for each fuel type. For this purpose, the approach to "generate consistent time series from overlapping time series" is used according to the 2006 IPCC Guidelines (IPCC 2006, Volume 1, chp. 5, consistent overlap). To illustrate the approach, an example for gas oil attributed to source category 1A2c is provided in Figure 3-23. A detailed description for all fuel types and source categories (1A2a–1A2g), including further assumptions, is provided in the underlying documentation of the EMIS database (EMIS 2020/1A2 Sektorgliederung Industrie).

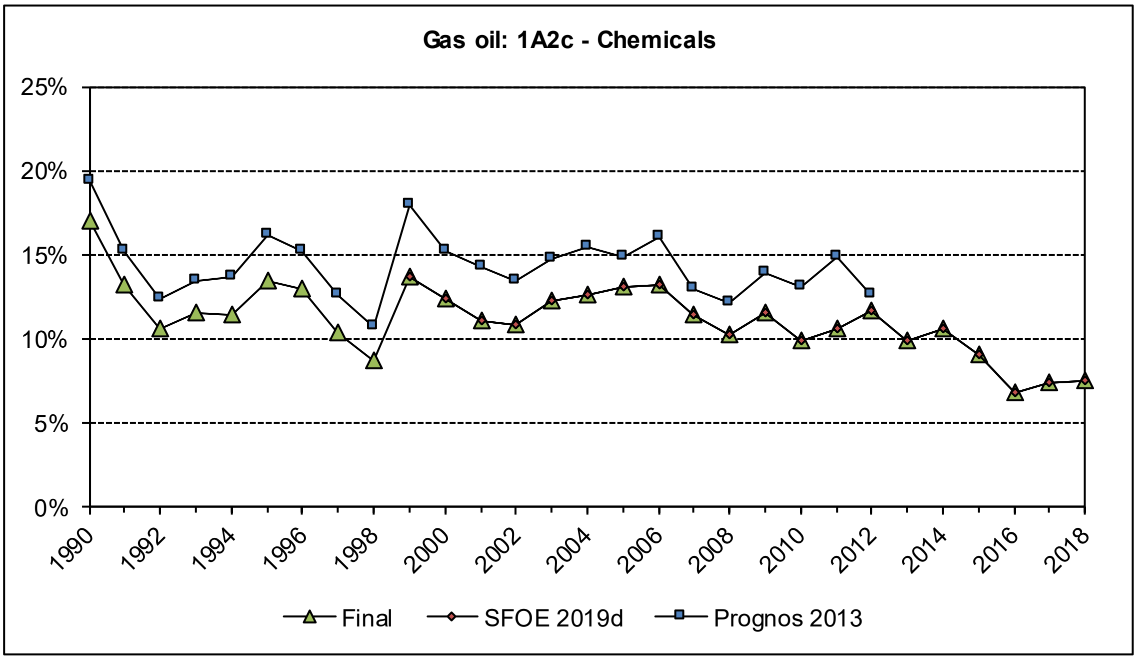


Figure 3-23 Illustrative example for combining time series with consistent overlap according to the 2006 IPCC Guidelines (IPCC 2006, Volume 1, chp. 5). The y-axis indicates the share of source category 1A2c of total gas oil consumption in the industry sector. The green triangles correspond to the share finally used to calculate the fuel consumption in 1A2c, based on the combination of the shares from the energy consumption statistics in the industry and services sectors (SFOE 2019d, orange diamonds since 1999) and the bottom-up industry model (Prognos 2013, blue squares from 1990 to 2012). Similar calculations are performed for each source category and fuel type.

Bottom-up industry data

Grey colored boxes in Figure 3-22 represent source categories, i.e. 1A2a–d, 1A2f and 1A2g for which bottom-up data from the industry are used in order to disaggregate the fuel consumption within a particular source category. These data consist of validated and verified monitoring data from the Swiss emissions trading scheme implemented under the Ordinance for the Reduction of CO_2 Emissions (Swiss Confederation 2012) and are discussed in depth in the following chapters 3.2.6.2.2 to 3.2.6.2.8.

The bottom-up information provides activity data for specific industrial production processes and forms a subset of the total fuel consumption allocated to each source category by the approach described above. Therefore, the fuel consumptions of the bottom-up industry processes are subtracted from the total fuel consumption of the respective source category and the remaining fuel consumptions are considered as fuels used in boilers of each source category. This method ensures that the sum of fuel consumption over all processes of a source category corresponds to the total fuel consumption as documented in the energy consumption statistics in the industry and services sectors (SFOE 2019d).

There is a difference in calculating the emissions of precursors from boilers and bottom-up industry processes. For boilers, fuel consumption is used as activity data whereas for bottom-up processes production data is used.

Further specific statistical data

Fuel consumption of wood, wood waste, biogas and sewage gas in manufacturing industries is based on the Swiss wood energy statistics (SFOE 2019b) as well as on data from the Swiss renewable energy statistics (SFOE 2019a) and the statistics on combined heat and power generation in Switzerland (SFOE 2019c), respectively. Emissions from these sources are reported under 1A2gviii Other due to insufficient information regarding sectoral disaggregation.

Emission factors (1A2)

The following table presents the emission factors of fuel consumption in source category 1A2 Manufacturing industries and construction (see also chp. 3.2.4.4).

Table 3-42 Emission factors for 1A2 Manufacturing industries and construction in 2018. Values that are highlighted in green are described in more detail in chp. 3.2.4.4.

1A2 Emission factors (mix of bottom-up and top-down approach (modelling)) for GHG	**CO_2 fossil**	**CO_2 bio.**	**CH_4**	**N_2O**
	t/TJ	t/TJ	kg/TJ	kg/TJ
Gas oil	73.7		3	0.6
Residual fuel oil	77.0		<3 *(lower IEF than default emission factor)*	0.6
Liquefied petroleum gas	65.5		<1 *(lower IEF than default emission factor)*	0.2
Petroleum coke	91.4		<3 *(lower IEF than default emission factor)*	0.6
Other bituminous coal	92.7		<10 *(lower IEF than default emission factor)*	1.5
Lignite	96.1		<10 *(lower IEF than default emission factor)*	1.5
Natural gas	56.2		1	0.1
Other fossil fuels (including solvents, plastics, waste tyres and rubber (see 1A2f))	70.5	5.0	2.2	3.4
Biomass (wood, biogas, biodiesel, bioethanol and other biogenic waste)		91.0	5.2	3.3

Other fossil fuels comprise various fossil waste-derived fuels used in 1A2f Cement production as well as cracker by-products, i.e. gasolio, heating gas, and synthesis gas used for steam production in a chemical plant in source category 1A2c. The emission factors of CO_2, CH_4 and N_2O are implied emission factors based on the fossil waste fuel mix. In addition, the CH_4 emission factor includes the total CH_4 emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants (see documentation in EMIS 2020/1A2f Zementwerke_Feuerung), based on industry data and emission declarations according to the Ordinance on Air Pollution Control (Swiss Confederation 1985). Implied CH_4 emission factors of source category 1A2 for residual fuel oil, petroleum coke, other bituminous coal and lignite are thus lower than the default emission factors of source category 1A documented in chp. 3.2.4.4.3 (see detailed description below in chapter Cement (1A2f)).

The emission factors of the precursors NO_x, CO, NMVOC and SO_2 for all fuels in source category 1A2 are provided in Annex A3.1.1. The emission factors for NO_x and CO for natural gas and gas oil used in boilers are derived from a large number of air pollution control measurements of combustion installations (Leupro 2012). This study analysed a large dataset from various cantons in Switzerland that was collected between 2000 and 2011. The emission factors for NO_x and CO for residual fuel oil, petroleum coke, other bituminous coal and lignite used in boilers are country-specific and documented in the Handbook on emission factors for stationary sources (SAEFL 2000). The implied emission factors for NO_x decreased significantly over the reporting period. NMVOC and SO_2 emission factors are country-specific and documented in SAEFL (2000).

In contrast to combustion in boilers, emission factors of precursors and SO_2 for fuel combustion in bottom-up industry processes are based on bottom-up industry data. Production-weighted emission factors based on various air pollution control measurements under the Ordinance on Air Pollution Control (Swiss Confederation 1985) are used to derive the corresponding process-specific emission factors.

Activity data (1A2)

The following table shows the total fuel consumption reported in source category 1A2 as described above in the industry model, and displays the fuel switch within Swiss industry over the reporting period. Since 1990, the use of residual fuel oil and other bituminous coal has decreased. In the same period, natural gas consumption has more than doubled. Currently, natural gas consumption accounts for the largest share of fuels used within Swiss industry, followed by biomass and gas oil.

Currently, source category 1A2gviii Other comprising emissions from boilers and engines is the most important category within source category 1A2 Manufacturing Industries and construction. 1A2f Non-metallic minerals and 1A2c Chemicals are the second and third most important fuel consumers, respectively.

Table 3-43 Activity data for fuel consumption in 1A2 Manufacturing industries and construction.

1A2 Manufacturing industries and constr. (stationary sources)	1990	1995	2000	2005
	TJ			
Total fuel consumption	89'922	90'461	88'992	92'380
Gas oil	22'910	24'471	25'892	25'317
Residual fuel oil	18'870	13'678	5'675	4'613
Liquefied petroleum gas	4'354	4'458	5'627	4'309
Petroleum coke	1'400	1'260	551	1'093
Other bituminous coal	13'476	7'303	5'866	4'799
Lignite	265	153	124	742
Natural gas	19'450	28'500	31'850	34'760
Other fossil fuels	2'556	2'818	4'053	4'525
Biomass	6'642	7'820	9'354	12'223

1A2 Manufacturing industries and constr. (stationary sources)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	88'645	91'257	85'024	86'170	87'731	82'311	80'823	81'901	82'266	79'841
Gas oil	21'527	21'137	17'314	17'575	18'007	12'444	12'725	12'812	11'489	10'871
Residual fuel oil	2'713	2'056	1'518	1'568	848	271	226	155	123	34
Liquefied petroleum gas	4'322	3'912	3'861	3'731	3'740	3'288	3'340	2'752	3'131	3'071
Petroleum coke	1'219	1'495	1'272	1'367	1'049	1'240	795	890	763	1'081
Other bituminous coal	4'263	4'348	3'868	3'794	3'910	2'403	1'946	1'517	1'634	1'665
Lignite	1'531	1'460	1'624	1'175	1'357	3'102	3'060	3'078	2'876	2'520
Natural gas	35'460	38'330	37'250	38'280	39'620	40'200	39'360	39'870	40'910	39'230
Other fossil fuels	4'958	5'183	5'307	4'883	5'186	5'270	5'252	5'926	5'912	6'513
Biomass	12'654	13'337	13'010	13'796	14'013	14'094	14'120	14'901	15'429	14'857

The following chapters describe the fuel consumption of the different source categories 1A2a–1A2gviii, the specific industrial production processes based directly on bottom-up industry data, and additional source-specific emission factors. Further information is documented in the respective EMIS documentation (EMIS 2020/1A2a-g).

3.2.6.2.2 Iron and steel (1A2a)

The source category 1A2a Iron and steel consists both of fuels used in boilers and specific industrial production processes, i.e. reheating furnaces in steel plants and cupola furnaces in iron foundries.

There is no primary iron and steel production in Switzerland. Only secondary steel and iron production using recycled steel scrap occurs. Iron is produced in 14 iron foundries. About 75% of the iron is processed in induction furnaces and 25% in cupola furnaces using other bituminous coal as fuel. Part of the other bituminous coal acts also as carburization material as well as reducing agent. Since other bituminous coal first of all acts as fuel in cupola furnaces it was decided to report its CO_2 emissions in source category 1A2a. Furthermore, this allows to be consistent with the fuel use of other bituminous coal provided by the Swiss overall energy statistics (SFOE 2019). Additionally, also limestone is used as flux in cupola furnaces yielding geogenic CO_2 emissions. These emissions are reported in source category 2A4d Other carbonate uses. The share of induction furnaces increased since 1990 with a sharp increase in 2009 due to the closure of at least one cupola furnace. Induction furnaces use electricity for the melting process and therefore only process emissions occur, which are reported in source category 2C1 Iron and steel production. Due to the reduced iron production and the switch from cupola to induction furnaces in iron foundries, the consumption of other bituminous coal has decreased.

Today, steel is only produced in two steel production plants after closure of two plants in 1994. Both plants use electric arc furnaces (EAF) with carbon electrodes for melting the steel scrap. In these electric arc furnaces also so-called injection coal and petroleum coke for slag formation as well as natural gas are used. These fuel consumptions are reported under source category 1A2a Electric arc furnaces of steel production based on plant-specific data from monitoring reports of the Swiss ETS for the years 2005–2011 and from 2013 onwards. In addition, emissions from the reheating furnaces are reported in source category 1A2a. Since 1995, these furnaces use natural gas only for reheating the ingot moulds prior to the rolling mills. Process emissions from steel production are included in source category 2C1 Iron and steel production. Steel production and the related natural gas consumption was significantly reduced in 1995 and the use of residual fuel oil ceased with the closure of two steel companies. Since 1995, steel production increased continuously until 2004 to reach the same production level as 1990. Since then, steel production is about constant. Only in 2009, the production was considerably lower due to the economic crisis. One steel producer switched its production to high quality steel and therefore the specific energy use per tonne of steel produced increased between 1995 and 2000. This led to higher natural gas consumption.

Today fuel consumption of source category 1A2a consists mainly of natural gas but also liquefied petroleum gas, other bituminous coal and gas oil and small amounts of petroleum coke are used.

Table 3-44 Activity data fuel consumption in 1A2a Iron and steel.

1A2a Iron and steel	**1990**	**1995**	**2000**	**2005**
	TJ			
Total fuel consumption	3'567	2'733	3'579	3'654
Gas oil	480	262	338	401
Residual fuel oil	346	131	20	39
Liquefied petroleum gas	408	193	286	217
Petroleum coke	85	46	56	72
Other bituminous coal	606	406	439	346
Lignite	NO	NO	NO	NO
Natural gas	1'642	1'695	2'439	2'578

1A2a Iron and steel	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	TJ									
Total fuel consumption	3'457	4'102	4'145	3'962	3'850	4'005	4'286	4'169	4'622	4'702
Gas oil	279	315	271	172	139	86	136	134	123	126
Residual fuel oil	39	51	1.5	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	214	219	226	438	438	388	393	327	368	358
Petroleum coke	21	47	37	42	53	81	69	78	77	71
Other bituminous coal	316	346	377	341	321	325	313	303	321	321
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	2'588	3'125	3'233	2'969	2'898	3'126	3'375	3'328	3'734	3'826

3.2.6.2.3 Non-ferrous metals (1A2b)

The source category 1A2b Non-ferrous metals consists both of fuels used in boilers and specific industrial production processes, i.e. secondary aluminium production and non-ferrous metal foundries, producing mainly copper alloys.

Until 1993, secondary aluminium production plants have been in operation using gas oil. Emissions from primary aluminium production in Switzerland are reported in source category 2C3 as induction furnaces have been used. The last primary aluminium production site closed down in April 2006.

Regarding non-ferrous metal industry in Switzerland, only casting and no production of non-ferrous metals occur. There is one large company and several small foundries, which are organized within the Swiss foundries association (Schweizerischer Giessereiverband, GVS) providing production data.

Fuel consumption of source category 1A2b represents only a small amount of the total fuel consumption in source category 1A2. Fuels consumed in 2018 are mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas. Fuel consumption within this source category decreased since 1990 due to the closing down of the secondary aluminium production and the strong reduction of the non-ferrous metal production since 2000.

Table 3-45 Activity data fuel consumption in 1A2b Non-ferrous metals.

1A2b Non-ferrous metals	1990	1995	2000	2005
	TJ			
Total fuel consumption	2'378	1'969	1'560	977
Gas oil	587	347	236	125
Residual fuel oil	NO	NO	NO	NO
Liquefied petroleum gas	27	17	15	7.1
Petroleum coke	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO
Lignite	NO	NO	NO	NO
Natural gas	1'764	1'605	1'309	845

1A2b Non-ferrous metals	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	1'006	1'218	1'177	1'746	1'593	1'916	1'792	1'683	1'640	1'743
Gas oil	167	112	76	153	128	90	78	76	78	76
Residual fuel oil	0.018	0.024	0.023	0.8	23	NO	44	NO	3.7	NO
Liquefied petroleum gas	6.9	7.7	8.2	11	11	10	10	8.3	9.3	9.0
Petroleum coke	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	833	1'098	1'093	1'581	1'430	1'816	1'660	1'598	1'549	1'658

3.2.6.2.4 Chemicals (1A2c)

In Switzerland, there are more than thirty chemical companies mainly producing fine chemicals and pharmaceuticals. Fossil fuels are mostly used for steam production and process heat. The process emissions from the production of chemicals such as ammonia, niacin, nitric acid, ethylene, acetic acid and sulphuric acid as well as silicon carbide are reported in source category 2B, see chp. 4.3.

There is one large company producing ammonia and ethylene by thermal cracking of liquefied petroleum gas and light virgin naphtha (see also descriptions in chp. 3.2.3 for feedstock use). As by-products from the cracking process, so-called heating gas and gasolio are produced, which are used thermally for steam production within the same plant. In 2018 the cracker process and the subsequent integrated production chain were modified yielding synthesis gas as additional cracker by-product. For reasons of confidentiality, fuel consumption and emissions of these by-products are included in Other fossil fuels of 1A2f in the reporting tables. The CO_2 emission factors of gasolio, heating gas and synthesis gas are plant specific based on monitoring reports of the Swiss ETS. In 2017 the fuel quality of gasolio and heating gas have been re-analysed by the production plant yielding new net calorific values and CO_2 emission factors. Due to changes in the cracker operation the composition of the heating gas has changed considerably. The further process modification in 2018 resulted again in changes of both net calorific value and CO_2 emission factor mainly for heating gas.

Since the fuel quality of gasolio and heating gas are of similar quality as residual fuel oil and gas oil, respectively, the same default IPCC emission factors are assumed for CH_4 and N_2O (see Table 3-42 and Table 3-14 (CH_4 EF of residual fuel oil)). For synthesis gas the same default IPCC emission factor as of natural gas is assumed for N_2O. Whereas no CH_4 emissions are supposed from the combustion of synthesis gas.

Table 3-46 Emission factors for 1A2c Chemicals are documented in the confidential NIR, which is available to reviewers on request.

The fuels consumed in 2018 include mainly natural gas as well as minor amounts of gas oil. Fuel consumption in this source category has slightly decreased between 1990 and 2018. Consumption of gas oil and residual fuel oil have decreased in that period, while natural gas consumption has increased.

Table 3-47 Activity data fuel consumption in 1A2c Chemicals.

1A2c Chemicals	1990	1995	2000	2005
	TJ			
Total fuel consumption	14'431	15'158	13'497	15'477
Gas oil	3'942	3'313	3'215	3'345
Residual fuel oil	1'434	693	252	36
Liquefied petroleum gas	15	13	12	10
Petroleum coke	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO
Lignite	NO	NO	NO	NO
Natural gas	9'039	11'138	10'017	12'086
Other fossil fuels	IE	IE	IE	IE

1A2c Chemicals	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	12'611	11'814	12'167	13'909	14'125	12'125	12'525	14'370	13'806	13'061
Gas oil	2'498	2'103	1'847	2'055	1'797	1'321	1'167	881	860	826
Residual fuel oil	91	66	0.16	0.16	1.2	NO	NO	NO	NO	NO
Liquefied petroleum gas	8.7	7.5	7.1	10	10	8.9	9.0	7.5	8.4	8
Petroleum coke	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	10'014	9'637	10'312	11'845	12'317	10'795	11'349	13'482	12'937	12'226
Other fossil fuels	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.5 Pulp, paper and print (1A2d)

Around half a dozen paper producers and several printing facilities exist in Switzerland. The only cellulose production plant was closed in 2008. Thermal energy is mainly used for provision of steam used in the drying process within paper production. Emissions from use of carbonate in flue gas treatment in cellulose production is reported in 2A4d Other process use of carbonates.

Fuel consumption in 1A2d consists both of fuels used in boilers and specific industrial production processes. In this source category only biomass (biogenic waste) from cellulose production (until 2008) is included, based on data from the only production site. The GHG emissions were calculated using a country-specific CO_2 emission factor (EMIS 2020/1A2d Zellulose-Produktion) and default factors for CH_4 and N_2O (IPCC 2006, vol. 2, chp.2, table 2.3, sulphite lyes). Biomass (e.g. wood and wood waste) used in paper production is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chapter 3.2.4.5.2. Therefore, from 2009 onwards, GHG emissions from biomass are reported as ”IE” in CRF Table1.A(a)s2.

The overall fuel consumption within the Swiss pulp and paper industry has considerably decreased since 1990, due to the closure of the cellulose production plant in 2008 and of several paper producers in the last years. The fuels used in 2018 are mainly natural gas as well as gas oil. Since 1990, the share of residual fuel oil and gas oil have decreased, while natural gas consumption increased.

Table 3-48 Activity data of fuel consumption in 1A2d Pulp, paper and print.

1A2d Pulp, paper and print	1990	1995	2000	2005
	TJ			
Total fuel consumption	11'760	13'700	11'577	11'379
Gas oil	1'188	1'751	1'403	1'456
Residual fuel oil	5'250	3'061	1'417	2'092
Liquefied petroleum gas	86	141	148	100
Petroleum coke	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO
Lignite	NO	NO	NO	NO
Natural gas	3'151	7'389	6'916	5'678
Biomass	2'085	1'358	1'694	2'053

1A2d Pulp, paper and print	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	6'124	6'773	6'051	5'374	5'474	4'643	3'655	2'982	2'851	2'036
Gas oil	948	852	561	623	711	297	383	410	288	278
Residual fuel oil	1'084	279	4.0	2.8	0.018	22	19	9.0	8.8	NO
Liquefied petroleum gas	62	61	62	67	67	60	60	50	57	55
Petroleum coke	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	4'030	5'581	5'424	4'681	4'696	4'264	3'193	2'513	2'498	1'704
Biomass	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.6 Food processing, beverages and tobacco (1A2e)

In Switzerland, the source category 1A2e Food, beverages and tobacco includes around 200 companies. According to the national food industry association, the major part of revenues is provided by meat production, milk products and convenience food. Further productions comprise chocolate, sugar or baby food (Fial 2013). Fossil fuels are used for steam production and drying processes. Fuel consumption in 1A2e is exclusively based on information from the energy consumption statistics in the industry and services sectors (SFOE 2019d) and Prognos (2013).

In 2018, the fuels used in this category were mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas (Table 3-49). Overall, there was a slight increase in fuel consumption between 1990 and 2018. This is due to the increased production in this sector. The consumption of residual fuel oil and gas oil ceased and has decreased, respectively, whereas natural gas and liquefied petroleum gas consumption has increased significantly.

Biomass (e.g. wood and wood waste) used in 1A2e Food processing, beverages and tobacco is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chapter 3.2.4.5.2. Therefore, activity data and GHG emissions from biomass are reported as "IE" in the CRF Table1.A(a)s2.

Table 3-49 Activity data fuel consumption in 1A2e Food processing, beverages and tobacco.

1A2e Food processing, beverages and tobacco	**1990**	**1995**	**2000**	**2005**
	TJ			
Total fuel consumption	9'858	8'784	10'437	10'239
Gas oil	7'410	5'511	5'515	4'070
Residual fuel oil	1'160	466	137	NO
Liquefied petroleum gas	204	308	535	534
Petroleum coke	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO
Lignite	NO	NO	NO	NO
Natural gas	1'085	2'500	4'250	5'635
Biomass	IE	IE	IE	IE

1A2e Food processing, beverages and tobacco	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	TJ									
Total fuel consumption	12'558	13'161	11'374	11'310	13'079	12'438	11'572	10'974	11'212	10'971
Gas oil	3'687	3'778	3'197	3'237	3'681	2'395	2'522	2'503	2'110	1'893
Residual fuel oil	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	736	659	675	935	935	828	838	699	785	763
Petroleum coke	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	8'135	8'723	7'502	7'138	8'463	9'215	8'212	7'772	8'318	8'315
Biomass	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.7 Non-metallic minerals (1A2f)

The source category 1A2f Non-metallic minerals includes several large fuel consumers within mineral industry, e.g. cement, brick and tile, glass, and rock wool production. All fuel consumption of these specific industrial production processes are based on bottom-up industry data.

The fuels consumed in this source category are very diverse, depending on the fuel use within the specific industry process (see detailed documentation below). Except for brick and tile production (from 2013 onwards) bottom-up information is also available on the amount of biomass consumed in source category 1A2f. Therefore, all emissions from biomass used in these processes are reported in source category 1A2f. Fuel consumption in 2018 comprises mainly other fossil fuels, natural gas, lignite and biomass.

Between 1990 and 2018, there has been a switch in fuel consumption from other bituminous coal and residual fuel oil to other fossil fuels, natural gas, lignite and biomass. The most important emission source within this category is cement production. Information on bottom-up data of fuel consumption and some source-specific emission factors are described in the following. Detailed data at process level cannot be provided, since they are mostly confidential. Therefore, aggregated data for 1A2f are shown in Table 3-50.

Table 3-50 Activity data fuel consumption in 1A2f Non-metallic minerals.

1A2f Non-metallic minerals	1990	1995	2000	2005
	TJ			
Total fuel consumption	25'613	19'885	18'055	17'832
Gas oil	1'871	1'629	1'642	1'389
Residual fuel oil	5'382	5'578	3'649	2'420
Liquefied petroleum gas	523	498	468	324
Petroleum coke	550	300	480	638
Other bituminous coal	12'665	6'758	5'415	4'364
Lignite	265	153	124	737
Natural gas	1'769	1'566	1'496	1'861
Other fossil fuels	2'556	2'818	4'053	4'525
Biomass	33	586	728	1'575

1A2f Non-metallic minerals	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	17'102	18'196	17'801	16'956	17'119	17'677	16'484	16'518	16'536	16'832
Gas oil	1'260	1'269	1'238	1'097	1'174	1'204	1'098	1'020	1'118	1'078
Residual fuel oil	1'374	1'519	1'403	1'456	801	209	130	139	106	31
Liquefied petroleum gas	95	102	127	108	113	45	52	44	44	45
Petroleum coke	994	1'130	1'081	920	815	1'052	622	658	574	542
Other bituminous coal	3'940	3'992	3'474	3'403	3'478	1'973	1'498	1'089	1'210	1'206
Lignite	1'379	1'348	1'493	1'081	1'283	2'912	2'856	2'881	2'694	2'367
Natural gas	1'731	2'048	1'938	2'085	2'506	3'111	3'121	2'952	2'970	2'972
Other fossil fuels	4'958	5'183	5'307	4'883	5'186	5'270	5'252	5'926	5'912	6'513
Biomass	1'371	1'604	1'739	1'923	1'764	1'901	1'856	1'809	1'908	2'078

Cement (1A2f)

Methodology

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a production capacity of 3'000 tonnes of clinker per day. All of them use modern dry process technology. Cement industry emissions stem from incineration of a wide variety of fossil and waste-derived fuels used to generate the high temperatures needed for the calcination process.

Emission factors

The CH_4 emission factor includes the overall CH_4 emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants. Therefore, these CH_4 emissions are reported under the fuel type other fossil fuels in the reporting tables.

Table 3-51 Emission factors for cement industry in 2018. Emission factors for CO_2 and N_2O are fuel specific (see Table 3-12, Table 3-16 and Table 3-52).

Cement industry (part of 1A2f)	CO_2	N_2O	CH_4	NO_x	NMVOC	SO_2	CO
	t/TJ		g/t clinker				
Cement	fuel specific		6	930	59	270	1'900

The emission factors for CO_2 and N_2O for regular fossil fuels are the same as used elsewhere (Table 3-12, Table 3-16). Regarding waste derived fuels, the NCVs and CO_2 emission factors for waste oil, solvents and residues from destillation, plastics, mix of special waste with saw dust (CSS), sewage sludge, wood waste, animal meal and saw dust are based on a study of Cemsuisse (Cemsuisse 2010a) providing measured values for the year 2010. A follow-up study of Cemsuisse (Cemsuisse 2018) provided measured values for the year 2017 for the three most relevant waste derived fuels – i.e. waste oil, solvents and residues from distillation and plastics – as well as for mix of special waste with saw dust (CSS). Emission factors between 2010 (the year of the previous assessment) and 2017 are interpolated, while constant values are used before the first and after the last year with available data.

The values for waste tyres and rubber are taken from Hackl and Mauschitz (2003). The biogenic fraction of waste tyres and rubber is based on an Austrian study and published by the German Ministry of Environment (UBA 2006). The emission factor of N_2O is the same for all waste derived fuels and is taken from the 2006 IPCC guidelines (IPCC 2006, vol 2, chp.2 table 2.3 industrial wastes).

Table 3-52 NCVs, fossil fractions as well as CO_2 (fossil and biogenic) and N_2O emission factors of waste derived fuels (Other fossil fuels and Biomass) used in the cement industry. Where data for more than one year is available, values in between are interpolated and constant values are used before the first and after the last year with available data. Waste derived fuels marked with an asterisk are classified as biomass (e.g. in Table 3-50). Entries of "NA" mean that the respective fossil or biogenic fraction is zero.

Cement industry (part of 1A2f) Waste derived fuel	Data sources	NCV	Fraction fossil	EF CO_2 fossil+biog.	EF CO_2 fossil	EF CO_2 biog.	EF N_2O
		GJ/t	%	t CO_2/TJ			kg N_2O/TJ
Waste oil	Cemsuisse (2010a, 2017)	32.5 *(2010)* 31.0 *(2017)*	100.0 *(2010)* 92.7 *(2017)*	74.4 *(2010)* 73.2 *(2017)*	74.4 *(2010)* 67.9 *(2017)*	NA *(2010)* 5.3 *(2017)*	4
Waste coke from coke filters	Vock (2001) Hackl and Mauschitz (2003)	23.7	100	97	97	NA	4
Mixed industrial waste	Cemsuisse, FOEN	18.3	100	74	74	NA	4
Other fossil waste fuels	Cemsuisse, FOEN	20.9	100	97	97	NA	4
Solvents and residues from distillation	Cemsuisse (2010a, 2017)	23.6 *(2010)* 23.5 *(2017)*	99.1 *(2010)* 89.7 *(2017)*	74.0 *(2010)* 70.7 *(2017)*	73.3 *(2010)* 63.4 *(2017)*	0.7 *(2010)* 7.3 *(2017)*	4
Waste tyres and rubber	Hackl and Mauschitz (2003) UBA (2006)	26.4	73	84	61.3	22.7	4
Plastics	Cemsuisse (2010a, 2017)	25.2 *(2010)* 23.6 *(2017)*	72.3 *(2010)* 76.6 *(2017)*	84.7 *(2010)* 84.5 *(2017)*	61.2 *(2010)* 64.7 *(2017)*	23.5 *(2010)* 19.8 *(2017)*	4
Mix of special waste with saw dust (CSS)*	Cemsuisse (2010a, 2017)	9.2 *(2010)* 9.1 *(2017)*	21.5 *(2010)* 27.0 *(2017)*	102.4 *(2010)* 112.2 *(2017)*	22.0 *(2010)* 30.3 *(2017)*	80.4 *(2010)* 81.9 *(2017)*	4
Sewage sludge (dried)*	Cemsuisse (2010a)	9.4	0	94.5	NA	94.5	4
Wood waste*	Cemsuisse (2010a)	16.3	0	99.9	NA	99.9	4
Animal meal*	Cemsuisse (2010a)	16.8	0	86.7	NA	86.7	4
Agricultural waste / other biomass*	Cemsuisse, FOEN	12.7	0	110	NA	110	4

Activity data

Data on fuel consumption is provided by the industry, for recent years based on monitoring reports of the Swiss ETS as documented in the EMIS database (EMIS 2020/1A2f Zementwerke Feuerung).

In 2018, the Swiss cement industry used about two-thirds of waste derived fuels and one-third of standard fossil fuels. Fossil fuels used in cement industry are mainly lignite, other bituminous coal and petroleum coke. In addition, also fossil and biogenic waste derived fuels are used. Fossil wastes comprise plastics, solvents and residues from distillation, waste oil and waste tyres and rubbers, whereas biogenic wastes contain mainly wood waste, sewage sludge and animal residues. The main fossil fuels used in 1990 were other bituminous coal, residual fuel oil and other fossil fuels.

Fuel consumption in cement plants has decreased between 1990 and 2018. This is partly due to a decrease in production since 1990 and an increase in energy efficiency. In the same period, the fuel mix has changed significantly from mainly fossil fuels to the above mentioned mix of fuels, including biogenic fractions of waste derived fuels.

In the reporting tables, the mainly biogenic waste derived fuels are reported under fuel type Biomass, whereas mainly fossil waste derived fuels are reported under fuel type Other fossil fuels (however, both fuel types also contain a fossil and a biogenic fraction, respectively, see Table 3-52).

Table 3-53 Activity data: Overview on fuel use in cement industry (part of 1A2f).

Cement industry (part of 1A2f)	1990	1995	2000	2005
	TJ			
Total fuel consumption	17'194	12'774	11'017	11'623
Cement fossil without waste	15'319	9'993	7'332	6'208
Gas oil	NO	NO	NO	72
Residual fuel oil	1'907	2'825	1'530	637
Petroleum coke	550	300	480	638
Other bituminous coal	12'235	6'547	5'176	4'120
Lignite	265	153	124	737
Natural gas	362	168	22	3.9
Cement, waste derived fuel	1'874	2'781	3'685	5'415
Other fossil fuels	1'842	2'196	2'997	3'931
Waste oil	1'170	1'485	1'520	1'411
Waste coke from coke filters	59	59	59	58
Mixed industrial waste	NO	NO	NO	NO
Other fossil waste fuels	NO	NO	NO	NO
Solvents and residues from distillation	283	181	426	976
Waste tyres and rubber	330	415	421	645
Plastics	NO	55	572	841
Biomass	33	586	688	1'484
Mix of special waste with saw dust (CSS)	23	135	158	133
Sewage sludge (dried)	9.4	128	333	494
Wood waste	NO	322	NO	NO
Animal meal	NO	NO	198	856
Sawdust	NO	NO	NO	NO
Agricultural waste / other biomass	NO	NO	NO	NO

Cement industry (part of 1A2f)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	11'816	12'388	12'187	11'462	11'866	12'339	11'348	11'583	11'476	11'589
Cement fossil without waste	6'127	6'278	5'859	5'406	5'512	5'847	4'917	4'544	4'354	3'965
Gas oil	NO	5.4	0.7	0.10	88	75.3	87	50	56	63
Residual fuel oil	100	112	101	297	86	58	45	90	59	NO
Petroleum coke	994	1'130	1'081	920	815	1'052	622	658	574	542
Other bituminous coal	3'650	3'662	3'167	3'097	3'203	1'713	1'267	826	938	938
Lignite	1'379	1'348	1'493	1'081	1'283	2'912	2'856	2'881	2'694	2'367
Natural gas	4.3	21	16	11	38	37	41	39	34	56
Cement, waste derived fuel	5'689	6'109	6'329	6'056	6'354	6'492	6'431	7'039	7'122	7'624
Other fossil fuels	4'394	4'580	4'685	4'225	4'599	4'596	4'582	5'234	5'219	5'550
Waste oil	1'278	1'253	1'170	839	876	923	1'142	1'567	1'311	1'336
Waste coke from coke filters	NO	NO	NO	NO	NO	NO	NO	NO	66	61
Mixed industrial waste	1	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other fossil waste fuels	137	45	55	36	25	19	12	11	5.7	5.4
Solvents and residues from distillation	1'032	1'189	1'264	1'294	1'414	1'273	1'292	1'534	1'398	1'380
Waste tyres and rubber	828	842	1'033	964	985	1'021	958	951	1'041	1'045
Plastics	1'119	1'252	1'163	1'092	1'299	1'360	1'177	1'171	1'398	1'722
Biomass	1'295	1'530	1'644	1'831	1'756	1'896	1'850	1'805	1'903	2'075
Mix of special waste with saw dust (CSS)	131	123	96	100	96	103	80	98	78	73
Sewage sludge (dried)	475	477	483	527	418	428	420	479	499	635
Wood waste	61	292	409	586	732	886	896	811	840	840
Animal meal	621	624	614	572	479	457	412	409	470	522
Sawdust	NO	5.7	24	17	32	21	42	7.9	5.6	5.4
Agricultural waste / other biomass	7.4	7.3	18	28	NO	NO	NO	NO	9.2	NO

Lime (1A2f)

In Switzerland there is only one plant producing lime. Fossil fuels are used for the burning process (calcination) of limestone. Between 1994 and 2012, fuel consumption in lime production was dominated by residual fuel oil. However in 2013, the main kiln has been switched to natural gas. Since 1995, no other bituminous coal is used anymore as it was replaced by residual fuel oil.

Container glass (1A2f)
Today, there exists only one production plant for container glass in Switzerland. Fuel consumption has drastically decreased over the reporting period due to reduction in production. Until 2003, only residual fuel oil was used. From 2004 onwards, the share of natural gas has increased, reaching a stable share between 2006 and 2012. In autumn 2013, the plant has switched its glass kiln completely to natural gas.

Tableware glass (1A2f)
Today, there exists only one production plant for tableware glass in Switzerland. Fuel consumption for tableware glass currently includes only liquefied petroleum gas, as residual fuel oil was eliminated in 1995. Since 1990, fuel consumption has strongly decreased because of the closure of one production plant in 2006.

Glass wool (1A2f)
Glass wool is produced in two plants. Currently, fuel consumption for glass wool production includes only natural gas. Production of glass wool has increased since 1990, but the natural gas consumption decreased. This can be explained by an increase in energy efficiency in the production process between 1990 and 2018.

Fine ceramics (1A2f)
In Switzerland, the main production of fine ceramics is sanitary ware produced by one big and some small companies. In earlier years, also other ceramics were produced as for example glazed ceramic tiles, electrical porcelain and earthenware. Since 2001, only sanitary ware is produced.

Until 2001, the fuel mix consisted of natural gas and gas oil. Since then, gas oil consumption decreased continuously, so that from 2010 onwards, only natural gas is consumed. Compared to the production of other fine ceramics, the production of sanitary ware is more energy-intensive. Therefore, the specific energy use per tonne of produced fine ceramics increased considerably between 1990 and 2001. This results in a lower reduction of fuel consumption compared to the reduction in production between 1990 and 2018.

Brick and tile (1A2f)
In Switzerland there are about 20 plants producing bricks and tiles. Mainly fossil fuels but also paper production residues, animal grease and wood are used for drying and burning of the clay blanks.

Emission factors

The CO_2 emission factors for wood and animal grease are based on a study of Cemsuisse (Cemsuisse 2010a), see Table 3-52, whereas the one for paper production residues is taken from a German study on secondary fuels (UBA 2006) as documented in the EMIS database (EMIS 2020/1A2f Ziegeleien).

For CH_4 and N_2O, emission factors of paper production residues and animal grease default values for wood waste and other liquid fuels, respectively, according to IPCC 2006 are used. For wood, the CH_4 and N_2O emission factors according to the energy model for wood combustion (automatic chip boiler >500 kW, w/o wood processing companies), see chp. 3.2.4.5.2, are taken.

Activity data

Since 2013, plant-specific activity data – except for biomass – are available from monitoring reports of the Swiss ETS. Fuels used in the brick and tile production in 2018 are mainly natural gas but also residual fuel oil and gas oil. Apart from a production recovery in the years around 2004, the production has gradually decreased since 1990, which is also represented in the overall fuel consumption decrease. Regarding the fuels used, there has been a considerable shift from residual fuel oil to natural gas from 1990 onwards as well as to a lesser extent, a shift from liquefied petroleum gas and gas oil to natural gas from 2004 onwards. Small amounts of paper production residues, wood and animal grease are used since 2000.

Rock wool (1A2f)
In Switzerland there is one single producer of rock wool. Cupola furnaces are used for the melting of rocks at a temperature of 1500°C.

Currently, other bituminous coal and natural gas are used in the production process. Until 2004, also gas oil and liquefied petroleum gas were used. In 2005, these fuels were substituted by natural gas.

Mixed goods (1A2f)
The production of mixed goods mainly includes the production of bitumen for road paving. A total of 110 production sites are producing mixed goods at stationary production sites. The main fuels used are gas oil and increasingly also natural gas.

3.2.6.2.8 Other (1A2g stationary)

Methodology (1A2g stationary)
Source category 1A2giv Wood and wood products includes fuel consumption of fibreboard production. Fibreboards are produced in two companies in Switzerland, where thermal energy is used for heating and drying processes.

Source category 1A2gviii Other covers fossil fuel combustion in boilers not further specified in manufacturing industries and construction, as well as combustion of wood, wood waste, biogas and sewage gas in all manufacturing industries. Methodologically, the fossil fuel consumption in boilers of 1A2gviii represents the residual entities of the industry installations that could not be allocated to any other source categories in 1A2a–f.

For more detailed descriptions on methodologies of biogas and sewage gas, see source categories 5B Biological treatment of solid waste (chp. 7.3) and 5D Wastewater treatment and discharge (chp.7.5), respectively.

This source category accounts for about one third of the overall fuel consumption in 2018 of 1A2 Manufacturing industries and construction.

Emission factors (1A2g stationary)

The CO_2 emission factors for wood waste and animal grease in 1A2giv Wood and wood products are based on a study by Cemsuisse (2010a), see Table 3-52. For wood waste, the respective CH_4 and N_2O emission factors of the energy model for wood combustion, see chp. 3.2.4.5.2, are taken, whereas for animal grease, the default values of IPCC 2006 for other liquid biofuels are used. For biogas and sewage gas in 1A2gviii Other Boilers and Engines Industry, the same emission factors as for natural gas are assumed.

Activity data (1A2g stationary)

1A2giv Wood and wood products

In source category Wood and wood products, mainly wood waste as well as natural gas are used (Table 3-54). Since 1990, the production of fibreboard and thus the fuel consumption have increased significantly. The fuel mix has strongly shifted from fossil fuels to biomass (wood waste) between 1990 and 2018. Between 2001 and 2013, also animal grease was used for fibreboard production. Since 2004, data on annual fuel consumption is taken from monitoring reports of the industry as documented in the EMIS database (EMIS 2020/1A2giv).

1A2gviii Other Boilers and Engines Industry

Activity data for wood combustion is based on Swiss wood energy statistics (SFOE 2019b) whereas sewage and biogas consumption is based on data from the Swiss renewable energy statistics (SFOE 2019a) and the Statistics on combined heat and power generation in Switzerland (SFOE 2019c). Further information on wood energy consumption is provided in chapter 3.2.4.5.2.

Since 1990, the consumption of residual fuel oil and liquefied petroleum gas decreased. Solid fossil fuel consumption also decreased, whereas biomass and natural gas consumption increased.

Table 3-54 Activity data fuel consumption in 1A2g iv Wood and wood products and 1A2gviii Other (stationary).

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	**1990**	**1995**	**2000**	**2005**
	TJ			
Total fuel consumption	22'314	28'232	30'287	32'823
Gas oil	7'431	11'657	13'542	14'531
Residual fuel oil	5'298	3'749	199	26
Liquefied petroleum gas	3'091	3'288	4'164	3'116
Petroleum coke	765	914	15	383
Other bituminous coal	205	140	12	88
Lignite	NO	NO	NO	4.7
Natural gas	1'000	2'607	5'423	6'077
Other fossil fuels	NO	NO	NO	NO
Biomass	4'524	5'877	6'931	8'596

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	TJ									
Total fuel consumption	35'786	35'993	32'310	32'912	32'491	29'507	30'508	31'206	31'600	30'496
Gas oil	12'688	12'707	10'124	10'239	10'377	7'050	7'342	7'788	6'913	6'593
Residual fuel oil	124	142	109	109	22	40	33	7.9	4.3	2.2
Liquefied petroleum gas	3'200	2'855	2'756	2'162	2'165	1'949	1'977	1'615	1'860	1'833
Petroleum coke	203	318	154	405	181	108	104	155	113	468
Other bituminous coal	6.3	11	16	50	110	105	134	125	102	138
Lignite	152	111	131	95	75	189	204	197	182	153
Natural gas	8'130	8'116	7'748	7'980	7'311	7'873	8'450	8'226	8'904	8'529
Other fossil fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biomass	11'282	11'733	11'271	11'873	12'250	12'193	12'264	13'092	13'522	12'779

3.2.6.3 Uncertainties and time-series consistency for 1A2 (stationary)

The uncertainty of emission estimates for source category 1A2 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A2 Manufacturing industries and construction are all considered consistent.

3.2.6.4 Category-specific QA/QC and verification for 1A2 (stationary)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

3.2.6.5 Category-specific recalculations for 1A2 (stationary)

The following recalculations were implemented in submission 2020. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A2/1A4: The use of gas oil and natural gas from grass drying in 1A4ci was subtracted from boilers in 1A2gviii so far. Now it is subtracted from boilers in 1A4ai. These reallocations led to changes in consumption of gas oil and natural gas in 1A2 and 1A4 for all years in the period 1990–2017. However, total amounts of gas oil and natural gas consumed remain unchanged.
- 1A2, Boilers in manufacturing industries and construction: Small recalculations concerning the distribution of gas oil (only for the year 2017) and natural gas (years 2014–2017) in source-category 1A2a-g were made. Total amounts were not affected.

- 1A2: The use of liquefied petroleum gas in 1A2b Non-ferrous metals was recalculated based on revised industry data for the year 2017 which led to a recalculation in 1A2gviii Other. This has only an effect on allocation to 1A2b and 1A2gviii, but has no impact at the aggregated level.
- 1A2c: In the previous submission, the fuel use of gasolio and heating gas was mixed up for 2017 which has been corrected now.
- 1A2gviii: Activity data (wood, wood waste) of all wood combustion installations have been revised for 1990–2017 due to recalculations in the Swiss wood energy statistics (SFOE 2019b).
- 1A2gviii: Stock changes of residual fuel oil in the year 2017–2018 lead to changes in activity data in boilers in 1A2gviii for the year 2017.
- 1A2gviii: Recalculation of use of sewage gas in the energy model for all years led to changes of 0.3% / 3 TJ in 1990 and -0.5% / -9.7 TJ in 2017.

3.2.6.6 Category-specific planned improvements for 1A2 (stationary)

There are no category-specific planned improvements.

3.2.7 Source category 1A4 – Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

3.2.7.1 Source category description for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Table 3-55 Key categories of 1A4 Other sectors. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A4a	Commercial: Gaseous fuels	CO2	L1, T1
1A4a	Commercial: Liquid fuels	CO2	L1, T1
1A4b	Residential: Biomass	CH4	T1, T2
1A4b	Residential: Gaseous fuels	CO2	L1, L2, T1, T2
1A4b	Residential: Liquid fuels	CO2	L1, T1, T2
1A4c	Agriculture and forestry: Liquid fuels	CO2	L1, T1

Each of the source categories 1A4a, 1A4b, 1A4c contain the sum of emissions of stationary and mobile sources – the above statements on key categories hold for the aggregated emissions of 1A4a etc. only. The CO_2 emissions of 1A4a and 1A4b from Liquid Fuels are vastly dominated by the stationary sources, which means that the emissions of 1A4aii and 1A4bii only play a minor role within category 1A4a and 1A4b. For 1A4c, however, the emissions of 1A4cii are of the same order of magnitude as those of 1A4ci (see also chp. 3.2.10.1.)

Table 3-56 Specification of source category 1A4 Other sectors.

1A4	Source category	Specification
1A4ai	Commercial/institutional: Stationary	Emissions from stationary fuel combustion in commercial and institutional buildings, including boilers, engines, turbines and different wood combustion installations
1A4bi	Residential: Stationary	Emissions from stationary fuel combustion in households, including boilers, engines, turbines and different wood combustion installations
1A4ci	Agriculture/Forestry/Fishing: Stationary	Emissions from stationary fuel combustion in agriculture, including different wood combustion installations, engines with biogas, heating of greenhouses and grass drying

3.2.7.2 Methodological issues for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Methodology (1A4 stationary)

CO_2 emissions from stationary combustion in source categories 1A4ai, 1A4bi and 1A4ci are estimated based on country-specific emission factors using a Tier 2 approach according to the decision tree for stationary combustion of the 2006 IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) for liquid, solid, gaseous fuels, biogas, wood consumption in bonfires and animal grease. For wood biomass, a Tier 3 approach using country-specific emission factors is applied.

A Tier 1 approach is applied with 2006 IPCC defaults EFs for CH_4 emissions of liquid fuels and gas oil for boilers and N_2O emissions of all fuels and technologies. CH_4 emissions of gas oil used in engines, gaseous fuels and biogas are calculated by a Tier 2 approach using country-specific emission factors. CH_4 emissions of wood biomass are calculated by a Tier 3 approach using country-specific emission factors.

For the calculation of the emissions from the use of gas oil and natural gas the following sources are differentiated: (a) heat only boilers, (b) combined heat and power production in turbines and (c) combined heat and power production in engines.

Emissions from 1A4ci originate from fuel combustion for the heating of greenhouses and grass drying, as well as from wood combustion for heating in agriculture and forestry. For grass drying, information is provided by the grass drying association. For greenhouses, information is provided by the Energy Agency of the Swiss Private Sector (EnAW).

Emission factors (1A4 stationary)

Table 3-57 Emission factors for stationary combustion in 1A4ai Other sectors commercial/institutional in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4ai Other sectors: Commercial/institutional	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ		kg/TJ					
Gas oil (weighted average)	73.7	NA	10	0.6	33	6	8.3	6.3
Gas oil heat only boilers	73.7	NA	10	0.6	33	6	8.3	6.2
Gas oil engines	73.7	NA	2	0.6	40	8	8.3	30.0
Natural gas (weighted average)	56.2	NA	2.3	0.1	20.1	1.9	0.5	12.5
NG heat only boilers	56.2	NA	1	0.1	16.6	2	0.5	9.4
NG turbines	56.2	NA	2	0.1	19.0	0.1	0.5	4.8
NG engines	56.2	NA	20	0.1	68.7	1	0.5	55.8
Biomass (weighted average)	NA	99.8	20.3	4.0	115.8	30.5	10.8	660.8
Biomass (wood)	NA	99.9	20.3	4	115.9	30.5	10.8	661.8
Biogas (heat only boilers)	NA	56.2	1	0.1	16.6	2.0	0.5	9.4

Table 3-58 Emission factors for stationary combustion in 1A4bi Other sectors residential in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4bi Other sectors: Residential	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ		kg/TJ					
Gas oil (weighted average)	73.7	NA	10	0.6	34	6	8.3	11
Gas oil heat only boilers	73.7	NA	10	0.6	34	6	8.3	11
Gas oil engines	73.7	NA	2	0.6	40	8	8.3	30
Natural gas (weighted average)	56.2	NA	1.2	0.1	15.8	4	0.5	12.8
NG heat only boilers	56.2	NA	1	0.1	15.6	4	0.5	12.4
NG turbines	NO	NA	NO	NO	NO	NO	NO	NO
NG engines	56.2	NA	20	0.1	31.7	1	0.5	55.8
Other bituminous coal	92.7	NA	300	1.5	65	100	350	1'400
Biomass (wood, charcoal)	NA	100.1	49.4	3.9	92.7	81.2	10.3	1'289

Table 3-59 Emission factors for stationary combustion in 1A4ci Agriculture/forestry/fishing in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4ci Agriculture/forestry/fishing	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	t/TJ		kg/TJ					
Grass drying (fossil, biogenic) (weighted average)	48.0	21.5	5.8	1.0	70	94	78	537
Gas oil	73.7	NA	3	0.6	NA	NA	NA	NA
Residual fuel oil	77.0	NA	3	0.6	NA	NA	NA	NA
Natural gas	56.2	NA	1	0.1	NA	NA	NA	NA
Biomass	NA	97.3	20.5	3.4	NA	NA	NA	NA
Heating of greenhouses (fossil, biogenic) (weighted average)	62.1	NA	1.7	0.3	23	2.0	3.1	7.2
Gas oil	73.7	NA	3	0.6	31.4	2	8.3	6.4
Natural gas	56.2	NA	1	0.1	18.6	2	0.5	7.6
Other biomass combustion (weighted average)	NA	75.0	4.8	1.8	52	7.3	5.4	174
Biogas heat only boilers	NA	56.2	1	0.1	16.6	2	0.5	9.4
Biogas engines	NA	56.2	1	0.1	16.6	2	0.5	9.4
Wood combustion	NA	99.9	9.8	4	100	14	12	392

Charcoal and bonfires

Emission factors concerning CO_2, CH_4 and N_2O emissions of charcoal use in the residential source categories (1A4bi) are taken from the 2006 IPCC Guidelines (IPCC 2006). Default emission factors according to the guidelines are also applied for CH_4 and N_2O emissions resulting from bonfires. The CO_2 emission factor for bonfires is based on the value for wood combustion; see chp. 3.2.4.4. Emission factors of precursors are taken from the EMEP/EEA Guidebook (2019) (Table 3.39).

Table 3-60 Emission factors for use of charcoal and bonfires in 1A4bi Other sectors residential in 2018.

1A4bi Other sectors: residential stationary combustion	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	t/TJ	kg/TJ					
Use of charcoal	112	200	1	50	600	11	4'000
Bonfires	100	300	4	50	600	11	6'000

Activity data (1A4 stationary)

General energy sources

Activity data about the energy sources gas oil, residual fuel oil, natural gas and biomass are calculated by the Swiss energy model (see chp. 3.2.4.3 for further information). For other energy sources such as other bituminous coal, activity data is provided directly by the Swiss overall energy statistics (SFOE 2019). Grass drying activities for source category 1A4ci are reported by the Swiss association of grass drying plants (VSTB) (as standard tonne of dried grass) as documented in the EMIS database (EMIS 2020/1A4ci Grastrocknung). Since submission 2015, the actual fuel consumption for grass drying is available and used for emission calculations. The fuel consumption for the heating of greenhouses is extrapolated from the information provided by the Energy Agency of the Swiss Private Sector (EnAW) as documented in the EMIS database (EMIS 2020/1A4ci Gewächshäuser).

Table 3-61 Activity data in 1A4a Commercial/Institutional (stationary).

1A4a Other sectors: Commercial/institutional	1990	1995	2000	2005
	TJ			
Total fuel consumption	72'345	80'065	76'712	83'246
Gas oil	52'977	54'379	48'777	51'197
Gas oil heat only boilers	52'953	54'204	48'426	50'880
Gas oil engines	24	175	351	318
Natural gas	16'399	21'843	23'552	26'732
NG heat only boilers	16'123	20'672	21'815	24'699
NG turbines	85	78	NO	28
NG engines	192	1'093	1'737	2'004
Biomass (total)	2'969	3'843	4'383	5'317
Biomass (wood)	2'929	3'812	4'355	5'270
Biogas (heat only boilers)	39	32	27	46

1A4a Other sectors: Commercial/institutional	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	72'783	78'873	64'839	71'270	76'573	60'396	66'280	69'501	66'929	60'298
Gas oil	43'231	46'525	37'088	39'750	42'727	32'998	35'158	36'440	34'221	30'879
Gas oil heat only boilers	43'078	46'406	36'983	39'656	42'640	32'916	35'076	36'358	34'139	30'797
Gas oil engines	154	119	105	94	86	82	82	82	82	82
Natural gas	22'948	25'307	21'857	24'733	26'341	20'236	23'100	24'316	23'954	21'161
NG heat only boilers	21'134	23'602	20'277	23'180	24'844	18'800	21'664	22'880	22'518	19'725
NG turbines	26	23	17	4.9	7.3	7.3	7.3	7.3	7.3	7.3
NG engines	1'787	1'681	1'564	1'548	1'490	1'429	1'429	1'429	1'429	1'429
Biomass (total)	6'604	7'042	5'893	6'788	7'505	7'162	8'021	8'744	8'753	8'258
Biomass (wood)	6'523	6'938	5'810	6'712	7'446	7'114	8'000	8'720	8'729	8'245
Biogas (heat only boilers)	82	104	83	76	59	47	21	24	24	13

Table 3-62 Activity data in 1A4b Residential (stationary).

1A4b Other sectors: Residential	1990	1995	2000	2005
	TJ			
Total fuel consumption	185'299	189'250	170'430	185'931
Gas oil	136'887	133'548	116'295	124'024
Gas oil heat only boilers	136'887	133'544	116'242	123'961
Gas oil engines	0.6	4.5	53	63
Natural gas	25'864	34'088	36'261	42'633
NG heat only boilers	25'804	33'830	35'822	42'103
NG turbines	NO	NO	NO	NO
NG engines	60	258	439	530
Other bituminous coal	630	460	130	400
Biomass	21'918	21'154	17'744	18'874

1A4b Other sectors: Residential	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	167'372	181'597	145'742	160'869	172'064	134'691	144'408	150'469	144'284	132'395
Gas oil	105'296	111'731	86'989	94'103	99'373	75'136	79'406	81'340	76'113	67'901
Gas oil heat only boilers	105'254	111'695	86'955	94'072	99'344	75'109	79'379	81'312	76'085	67'874
Gas oil engines	42	36	34	32	29	27	27	27	27	27
Natural gas	42'469	48'229	40'910	47'043	50'957	42'367	46'106	48'835	48'345	45'916
NG heat only boilers	41'931	47'723	40'440	46'577	50'509	41'937	45'676	48'405	47'915	45'486
NG turbines	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
NG engines	538	506	470	466	448	430	430	430	430	430
Other bituminous coal	400	400	300	300	300	200	200	200	100	100
Biomass	19'207	21'236	17'543	19'423	21'433	16'988	18'696	20'094	19'726	18'479

Table 3-63 Activity data in 1A4ci Agriculture/forestry/fishing (stationary).

1A4c Agriculture/forestry/fishing	**1990**	**1995**	**2000**	**2005**
	TJ			
Total fuel consumption	6'378	6'100	5'794	5'510
Drying of grass	1'895	1'544	1'223	994
Gas oil	1'156	942	746	607
Residual fuel oil	NO	NO	NO	NO
Natural gas	739	602	477	388
Biomass	NO	NO	NO	NO
Heating of greenhouses	4'000	4'000	4'000	3'735
Gas oil	3'490	3'490	3'490	3'133
Natural gas	510	510	510	601
Other biomass combustion	483	556	571	781
Biogas heat only boilers	39	32	27	46
Biogas engines	16	15	35	82
Wood combustion	428	510	509	653

1A4c Agriculture/forestry/fishing	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	TJ									
Total fuel consumption	5'326	5'617	5'144	5'758	5'252	4'871	5'084	5'609	6'166	5'669
Drying of grass	856	739	891	685	458	524	431	492	610	545
Gas oil	522	451	543	418	106	104	89	86	118	116
Residual fuel oil	NO	NO	NO	NO	17	20	22	18	25	13
Natural gas	334	288	347	267	220	264	233	279	338	296
Biomass	NO	NO	NO	NO	114	136	88	109	129	120
Heating of greenhouses	3'425	3'677	3'121	3'671	3'389	2'786	2'886	2'899	3'240	2'754
Gas oil	1'945	1'803	1'269	1'647	1'496	1'089	1'159	1'066	1'145	930
Natural gas	1'480	1'874	1'852	2'025	1'893	1'696	1'727	1'834	2'095	1'824
Other biomass combustion	1'045	1'202	1'132	1'401	1'406	1'562	1'767	2'217	2'316	2'371
Biogas heat only boilers	82	104	83	76	59	47	21	24	24	13
Biogas engines	327	394	472	599	754	880	1'020	1'168	1'248	1'390
Wood combustion	637	704	577	727	593	634	727	1'025	1'044	968

Charcoal and bonfires

Besides the main energy sources, also charcoal use and bonfires are accounted for in source category 1A4bi. The energy source charcoal is only used for charcoal grills. The total charcoal consumption under 1A4bi is very small compared to other fuels used for heating purposes. The activity data are the sum of charcoal production under 1A1c and net imports provided by the Swiss overall energy statistics (SFOE 2019).

The total wood demand for bonfires is assumed to be constant over time (for further details see documentation in EMIS 2020/1A4bi Lagerfeuer).

Table 3-64 Activity data in 1A4bi Charcoal and bonfires.

1A4bi Other sectors: residential stationary combustion	1990	1995	2000	2005
	TJ			
Use of charcoal	311	291	292	313
Bonfires	160	160	160	160

1A4bi Other sectors: residential stationary combustion	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Use of charcoal	344	344	344	344	343	354	354	334	374	354
Bonfires	160	160	160	160	160	160	160	160	160	160

3.2.7.3 Uncertainties and time-series consistency for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The uncertainty of emission estimates for source category 1A4 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A4 Other sectors are all considered to be consistent.

3.2.7.4 Category-specific QA/QC and verification for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

3.2.7.5 Category-specific recalculations for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A2/1A4: The use of gas oil and natural gas from grass drying in 1A4ci was subtracted from boilers in 1A2gviii so far. Now it is subtracted from boilers in 1A4ai. These reallocations led to changes in consumption of gas oil and natural gas in 1A2 and 1A4 for all years in the period 1990–2017. However, total amounts of gas oil and natural gas consumed remain unchanged.
- 1A4: Activity data (wood, wood waste) of all wood combustion installations in source categories 1A4ai, 1A4bi and 1A4ci have been revised for 1990–2017 due to recalculations in the Swiss wood energy statistics (SFOE 2019b).
- 1A4ai/1A4ci: The use of gas oil and natural gas for heating greenhouses in agriculture was estimated for the years 1990–2018 based on newly acquired data. This results in a shift in the consumption of gas oil and natural gas from 1A4ai commercial / institutional to 1A4ci Agriculture / forestry / fishing.
- 1A4ai and 1A4ci: Reallocation of biogas use in agricultural biogas plants in the energy model for all years led to recalculations and redistributions of biogas consumption in

1A4ai Commercial / institutional and 1A4ci Agriculture / forestry / fishing. Biogas from agricultural biogas plants is now reported in 1A4ci.

- 1A4bi: Activity data of 1A4bi Charcoal use has been updated due to revised data in 1A1c Charcoal production for 2010–2017.

3.2.7.6 Category-specific planned improvements for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

There are no category-specific planned improvements.

3.2.8 Source category 1A2 – Manufacturing industries and construction (mobile 1A2gvii)

3.2.8.1 Source category description for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Note for Key categories 1A2:

See chp. 3.2.6 and note that source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emission only. The CO_2 emissions of 1A2 from Liquid Fuels are dominated by the stationary sources. Only 37% (2018) of the CO_2 emissions of Liquid Fuels from 1A2 stem from mobile sources 1A2gvii.

Table 3-65 Specification of source category 1A2 Manufacturing industries and construction (mobile).

1A2	Source category	Specification
1A2agvii	Mobile Combustion in manufacturing industries and construction	industry sector: forklifts and snow groomers etc. construction machines: excavators, loaders, dump trucks, mobile compressors etc.

3.2.8.2 Methodological issues for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Methodology (1A2gvii)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in IPCC (2006) the emissions of industry and construction vehicles and machinery are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in source category 1A2gvii, since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A2gvii)

- The CO_2 emission factors applied for the time series 1990–2018 for diesel oil, gasoline, LPG and biofuels are country-specific and are given in Table 3-12.
- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-66 to Table 3-68 for diesel oil, gasoline and LPG engines for all emission standards.
- For SO_2, the emission factors are country-specific. See Table A – 12 in Annex A3.1.5 for diesel oil, gasoline, gas oil and LPG.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- The implied emission factors 2018 are shown in Table 3-69.

All emission factors (GHG, precursors, SO_2) can be downloaded by query from the public part of the non-road database INFRAS (2015a)[6]. They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-66 Emission factors CH_4 and N_2O for industry and construction vehicles with diesel oil engines by emission standards including the year of enforcement.

Gas	Power class	PreEU-A <1996	PreEU-B 1996	EU-I 2002/03	EU-II 2002/04	EU-IIIA 2006/08	EU-IIIB 2011/12	EU-IV 2014
	kW	g/kWh						
CH_4	<18	0.0547	0.0547	0.0384	0.0240	0.0142	0.0142	0.0142
CH_4	18–37	0.0578	0.0578	0.0221	0.0134	0.0089	0.0089	0.0089
CH_4	37–56	0.0319	0.0319	0.0156	0.0110	0.0079	0.0055	0.0058
CH_4	56–75	0.0319	0.0319	0.0156	0.0110	0.0079	0.0031	0.0031
CH_4	75–130	0.0218	0.0218	0.0108	0.0084	0.0067	0.0031	0.0031
CH_4	130–560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
CH_4	>560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
N_2O	0–3000	0.035	0.035	0.035	0.035	0.035	0.035	0.035

Table 3-67 Emission factors CH_4 and N_2O for industry and construction vehicles with gasoline engines by emission standards including the year of enforcement.

Gas	Power class	PreEU-A <1996	PreEU-B 1996	PreEU-C 2000	EU-I 2004	EU-II 2005/09
	ccm	g/kWh				
CH_4	<66	2.040	2.040	2.040	1.394	1.394
CH_4	66–100	1.360	1.360	1.360	1.088	1.088
CH_4	100–225	0.680	0.680	0.680	0.408	0.408
CH_4	>225	0.680	0.680	0.680	0.340	0.306
N_2O	0–3000	0.03	0.03	0.03	0.03	0.03

[6] https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html [29.01.2020]

Table 3-68 Emission factors CH_4 and N_2O for industry and construction vehicles with LPG engines (for all years).

Gas	without catalyst	with catalyst
	g/kWh	
CH_4	0.552	0.035
N_2O	0.05	0.05

Table 3-69 Implied emission factors 2018 for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gasoline	73.8	37.3	1.1	105	677	0.4	19'628
Diesel oil	73.3	0.6	3.3	274	24	0.5	124
Liquefied petroleum gas	65.5	0.7	2.4	101	9	NA	24
Biodiesel	73.3	0.5	2.8	234	21	0.4	106
Bioethanol	73.8	8.8	0.8	52	249	0.2	12'102

Activity data (1A2gvii)

Activity data for non-road (1A2gvii) are described in. chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-70 and in Annex A3.1.4. Detailed data can be downloaded from the online database of INFRAS (2015a). Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can also be downloaded by query from the public part of the non-road database INFRAS (2015a), see footnote 6 (p. 152). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-70 Activity data for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	1990	1995	2000	2005
	TJ			
Total fuel consumption	5'721	6'852	7'636	8'169
Gasoline	196	224	227	225
Diesel oil	5'359	6'380	7'106	7'626
Liquefied petroleum gas	165	248	294	290
Biodiesel	NO	NO	9.2	28
Bioethanol	NO	NO	NO	NO

1A2gvii Non-road vehicles and other machinery	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Total fuel consumption	8'657	8'779	8'811	8'843	8'875	8'906	8'938	8'944	8'949	8'955
Gasoline	221	220	213	206	198	191	184	180	177	174
Diesel oil	8'129	8'254	8'283	8'312	8'341	8'370	8'399	8'380	8'361	8'342
Liquefied petroleum gas	273	269	260	252	243	235	226	215	203	192
Biodiesel	34	36	54	73	91	110	128	166	205	243
Bioethanol	0.004	0.005	0.257	0.51	0.76	1.02	1.27	1.96	2.65	3.34

3.2.8.3 Uncertainties and time-series consistency for 1A2gvii (mobile)

The uncertainty of emission estimates for source category 1A2gvii (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-25.

3.2.8.4 Category-specific QA/QC and verification for 1A2gvii (mobile)

The general QA/QC procedures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

3.2.8.5 Category-specific recalculations for 1A2gvii (mobile)

No category-specific recalculations were carried out.

3.2.8.6 Category-specific planned improvements for 1A2gvii (mobile)

No category-specific improvements are planned.

3.2.9 Source category 1A3 – Transport

3.2.9.1 Source category description for 1A3

Table 3-71 Key categories of 1A3 Transport. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1A3a	Civil aviation: Liquid fuels	CO2	T1
1A3b	Road transportation: Gasoline	CH4	T1, T2
1A3b	Road transportation: Gasoline	CO2	L1, T1
1A3b	Road transportation: Gasoline	N2O	T1, T2
1A3b	Road transportation: Diesel	CO2	L1, L2, T1, T2
1A3b	Road transportation: Diesel	N2O	T1

Table 3-72 Specification of source category 1A3 Transport.

1A3	Source category	Specification
1A3a	Domestic aviation	Large (jet, turboprop) and small (piston) aircrafts, helicopters
1A3bi	Road Transportation	Passenger cars
1A3bii		Light duty trucks
1A3biii		Heavy duty trucks and buses
1A3biv		Motorcycles
1A3bv		Other
1A3c	Railways	Diesel locomotives
1A3d	Domestic navigation	Passenger ships, motor and sailing boats on the Swiss lakes and the river Rhine
1A3e	Other transportation - Pipeline compressors	Compressor station in Ruswil, Lucerne

For information on international bunker fuel emissions from international aviation and navigation, see chp. 3.2.2.

3.2.9.2 Methodological issues for 1A3

3.2.9.2.1 Domestic aviation (1A3a)

Methodology (1A3a)
The emissions of domestic aviation are modelled by a Tier 3A method (IPCC 2006, Volume 2, chp. 3 Mobile Combustion, Table 3.6.2 and figure 3.6.2) developed by FOCA (2006) and based on origin and destination of single movements by aircraft type according to detailed movement statistics. LTO emissions are modelled based on the individual engine type. The emissions of domestic aviation are modelled together with the international aviation reported in 1D1 (aviation bunker, see chp. 3.2.2.2.1).

FOCA is represented in the emissions technical working group (CAEP WG3) and in the modelling and database group (CAEP MDG) of the International Civil Aviation Organisation (ICAO). FOCA is directly involved in the development of ICAO guidance material for the calculation of aircraft emissions and in the update of the IPCC Guidelines (via the secretariat of ICAO CAEP (Committee on Aviation Environmental Protection)). The Tier 3A method applied for the emission modelling is in line with the methods developed in the working groups mentioned. The modelling scheme for domestic aviation refers to aircraft basic data, activity data and emission factors that result in calculated emissions. Respective values are ultimately imported into the EMIS database as shown in Figure 3-24.

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. The primary key for all calculations is the aircraft tail number, which allows to calculate on the most precise level, namely on the level of the individual aircraft and engine type. Every aircraft is linked to the FOCA engine data base containing emission factors for more than 800 individual engine types with different power settings. Emissions in the landing and take-off cycle (LTO) are calculated with aircraft category dependent flight times and corresponding power settings. Cruise emissions are calculated based on the individual aircraft type and the trip distance for every flight. For piston-engine powered aircraft and helicopters, to the knowledge of FOCA, it has been the only provider of publicly available engine data and a full methodology. All piston engine data and study results have been published in 2007 (FOCA 2007a). The guidance on the determination of helicopter emissions has been published in 2009 (FOCA 2009a) and updated in 2015 (FOCA 2015a).

The movement database from Swiss airports registers the departure and destination airports of each flight. With this information, all flights from and to Swiss airports are differentiated into domestic and international flights prior to the emission calculation. The emissions of domestic flights are reported under 1A3a Domestic Aviation, the emissions of international flights are reported under 1D1 international aviation (international bunkers).

The emission factors used are either country-specific or taken from the ICAO engine emissions databank, from EMEP/CORINAIR databases (EMEP/EEA 2016), Swedish Defence Research Agency (FOI) and Swiss FOCA measurements (precursors). Cruise emission factors are generally calculated from the values of the ICAO engine emissions databank, aircraft performance tables and from confidential airline data. Pollutant emission factors are adjusted to cruise conditions by using the Boeing Fuel Flow Method 2. For N_2O, the IPCC default emission factor of 2 kg/TJ is used. For the methane split of unburnt hydrocarbons, the 10% methane share for the LTO, given in IPCC 2006 is used. For cruise emissions, no methane is reported.

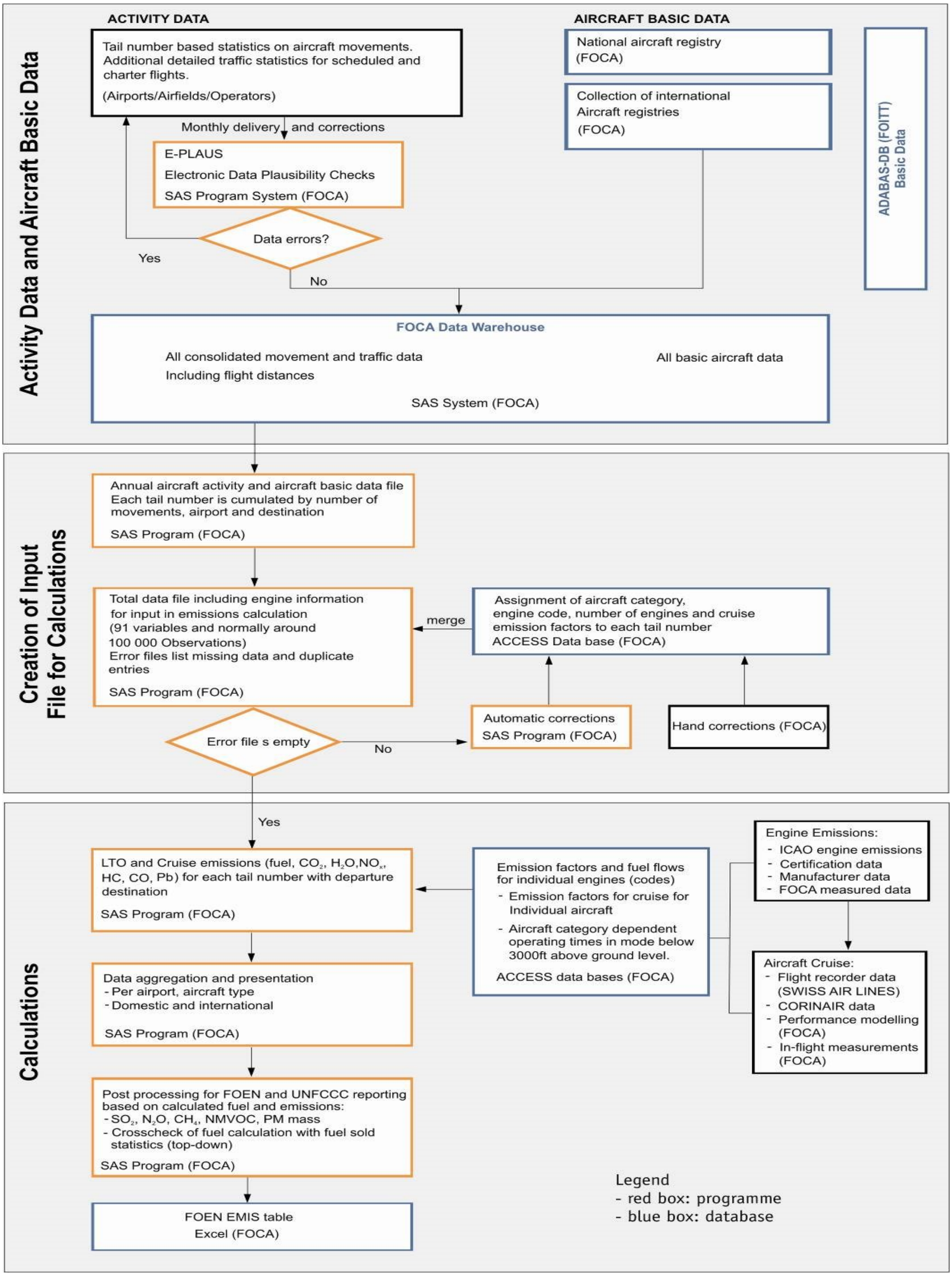


Figure 3-24 Modelling scheme (activity data, emission factors, emissions) for domestic aviation.

A complete emission modelling (LTO and cruise emissions for domestic and international flights) has been carried out by FOCA for 1990, 1995, 2000, 2002, 2004–2018. The results of the emission modelling have been transmitted from FOCA to FOEN in an aggregated form (FOCA 2006a, 2007–2019). FOEN calculated the implied emission factors 1990, 1995, 2000, 2002, 2004 and carried out a linear interpolation for the years in-between. The interpolated implied emission factors were multiplied with the annual fuel sold from Swiss overall energy statistics (SFOE in respective years), providing the missing emissions of domestic aviation for the years 1991–1994, 1996–1999, 2001 and 2003.

Details of emission factors and activity data follow below. Further tables containing more information are also given in Annex A3.1.2, more detailed descriptions of the emission modelling may be found in FOCA (2006).

Emission factors (1A3a)

LTO

The FOCA engine emissions database consists of more than 800 individual engine data sets. Jet engine factors for engines above 26.7 kN thrust (emission certificated) are identical to the ICAO engine emissions database. Emission factors for lower thrust engines, piston engines and helicopters were taken from manufacturers or from own measurements. Emission factors for turboprops could be obtained in collaboration with the Swedish Defence Research Agency (FOI).

Cruise

The fuel flows of the whole Airbus fleet (which produces a great portion of the Swiss inventory) have been modelled on the basis of real operational aircraft data from flight data recorders (FDR) of Swiss International Airlines. GHG emission factors have been modelled on the basis of the ICAO engine databank and corrected to cruise conditions using FDR engine parameters and the Boeing Fuel Flow Method 2. For older aircraft types (pre 2003), part of the cruise emission factors were taken from EMEP/CORINAIR (EMEP/EEA 2016) and from former CROSSAIR (FOCA 1991). For new aircraft type entries, the FOCA models the cruise emission factors based on the aircraft type characteristics and the engine models fitted to the aircraft. The model uses proprietary aircraft information as well as public information from the ICAO engine database. For those aircraft types, which dominate the fuel consumption in Switzerland, flight data recorder information has been used to calibrate emission factors. The factors are updated periodically to take account of flight operational improvements, as well. Calculation results for international aviation emissions are periodically compared to Eurocontrol results. For piston engine aircraft and helicopters, Swiss FOCA has produced its own data, which were taken under real flight conditions (2005 data, FOCA 2009a, FOCA 2015a).

In 2015 and 2016, the FOCA Helicopter Emissions Calculation Guidance has been updated and implemented in the emissions calculation for the 2015 and 2016 emission inventory (FOCA 2015a, 2016a). Since then, FOCA uses engine power specific emission factors for most helicopters, taking into account lower power requirement per engine, if engines are installed in a twin engine configuration. On top of the few non-public manufacturer data sources, FOCA introduced 80 individual helicopter engine models replacing most of the generic engine assignments.

Kyoto gases

- CO_2: the emission factor of 72.8 t/TJ is country-specific and is based on measurements and analyses of fuel samples (see Table 3-12 and Table 3-73)
- CH_4, NMVOC (country-specific; CORINAIR): VOC emissions (see Precursors below) are split into CH_4 and NMVOC by a constant share of 0.1 (CH_4) and 0.9 (NMVOC) for LTO. For cruise flights the VOC emissions do not consist of CH_4 emissions. The implied emission factor for CH_4 is shown in Table 3-73.
- The N_2O emission factor regarding jet kerosene is default given by the 2006 IPCC Guidelines (IPCC 2006, Table 3.6.5). It is assumed that the emission factor for international cruise is sufficient for all kind of flight periods (LTO and cruise) and remains constant over the entire time period 1990–2018 (see Table 3-73).

Precursors

- Assignment of emission factors for 1990 and 1995: The fleet that operated in and from Switzerland during those years has been analysed. The corresponding most frequent engines within an aircraft category (ICAO Code) have been assigned to every aircraft type.
- Assignment of emission factors for the year 2000, 2002 and 2004 to 2018: the actual engine of every single aircraft operating in and from Switzerland has been assigned. FOCA uses the aircraft tail number as the key variable which links activity data and individual aircraft engine information (see Annex A3.1.2 Table A – 6 Aircraft Engine Combinations).

FOCA determines the emission factors of different gases as given in Table 3-73.

Table 3-73 Implied emission factors of 1A3a in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3a Aviation	CO_2 fossil	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
Kerosene, domestic, LTO	72'800	11.8	2.0	239	106.3	20.6	2'764
Kerosene, domestic, CR	72'800	NA	2.0	267	58.8	21.9	590
Kerosene, international, LTO	72'800	3.0	2.0	317	27.2	23.2	284
Kerosene, international, CR	72'800	NA	2.0	362	8.0	23.2	41

Activity data (1A3a)

The statistical basis has been extended after 1996. Therefore, the modelling details are not exactly the same for the years 1990/1995 as for the subsequent years. The source for the 1990 and 1995 modelling are the movement statistics, which records information for every movement on airline, number of seats, Swiss airport, arrival/departure, origin/destination, number of passengers, distance. From 1996 onwards, every movement in the FOCA statistics also contains the individual aircraft tail number (aircraft registration). This is the key variable to connect airport data and aircraft data. The statistics may contain more than one million records with individual tail numbers. All annual aircraft movements recorded are split into domestic and international flights (there are 471'872 aircraft movements in the total of scheduled and charter traffic in 2018 as provided by FOCA 2019).

Non-scheduled, non-charter and general aviation (including helicopters)

- Airports and most of the airfields report individual aircraft data (aircraft registration). FOCA may therefore compute the inventory for small aircraft with a Tier 3A method, too. However, for 1990 and 1995, the emissions data for non-scheduled, non-charter and General Aviation (helicopters etc.) could not be calculated with a Tier 3A method. Its fuel consumption is estimated to be 10% of the domestic fuel consumption. Data were taken from two FOCA studies (FOCA 1991, FOCA 1991a). For 2000–2007, all movements from airfields are known, which allows a more detailed modelling of the emissions (FOCA 2007a).
- Helicopter flights which do not take off from an official airport or airfield such as transport flights, flights for lumbering, animal transports, supply of alpine huts, heli-skiing and flight trainings in alpine regions cannot be recorded with the movement data base from airports and airfields. These emissions are taken into account using the statistics of the Swiss Helicopter Association (Unternehmensstatistik der Schweizer Helikopterunternehmen). These statistics are officially collected by FOCA and updated annually (see FOCA 2004 as illustrative example for all subsequent years). In this case, emissions are calculated based on operating hours of the helicopters, with emission factors taken from the helicopter study (see FOCA 2015a).
- Since 2007, the data of these helicopter statistics are included electronically in the data warehouse of the model and undergo first some plausibility checks (E-plaus software). In order to distinguish between single engine helicopters and twin engine helicopters a fix split of 87% for single engine helicopters and 13% for twin engine helicopters has been applied for the entire commitment period until 2014 based on investigations in 2004 (FOCA 2004). Since 2015, the statistics allows to assign the individual helicopters to the helicopter companies. All emissions from helicopter flights without using an official airport or an official airfield are considered domestic emissions.

Fuel consumption: Table 3-74 summarises the activity data for domestic aviation (1A3a). It also includes international aviation, which belongs to the memo items, international bunkers/aviation (see also chp. 3.2.2). In order to split the fuel consumption for domestic and international flights, the FOCA calculates the fuel for each domestic and international flight bottom up. A first validation of this calculation can be done top down for the sum of all flights: The total annual aviation fuel sold known from robust energy statistics in a country should correspond very closely (within a few percent) to the modelled total fuel consumption of domestic and international flights together. In 2018, the modelled total fuel consumption in Switzerland was 1.7% higher than the fuel sold value, so the model showed a slight overestimation (see Table 3-5). The total fuel sold as reported in the Swiss overall energy statistics is considered the most robust value for reporting, so the modelled total fuel consumption is scaled downwards such that the sum of domestic and international fuel consumption becomes identical with the fuel sold. The scaling is only done on the international fuel for the following reasons: Eurocontrol calculations for Switzerland's international flights fuel consumption are usually a few percent lower than the FOCA result.

For domestic flights, the FOCA takes every movement including the smallest aircraft into account and applies conservative emission factors. An indication of this is the fact that Eurocontrol calculations for Switzerland's domestic flight fuel consumption is usually only around half the value reported by Switzerland. In summary, Switzerland reports the domestic fuel consumption according to the modelled value (conservative estimation), whereas the international fuel consumption (bunker) is scaled downwards so that the sum of domestic and international fuel consumption becomes identical with the fuel sold, as reported in the Swiss overall energy statistics.

Table 3-74 Fuel consumption of civil aviation in TJ separated for domestic/international and LTO/cruise. Domestic consumption and the corresponding emissions are reported under 1A3a, international consumption is reported under Memo items, international bunkers (FOCA 2007, 2007a, 2008–2019).

1A3a/1D1 Civil aviation	1990	1995	2000	2005
	Fuel consumption in TJ			
Kerosene, domestic, LTO	1'050	935	773	518
Kerosene, domestic, CR□	2'401	2'139	1'768	1'184
Kerosene, international, LTO (not part of national total)	4'277	5'097	6'507	4'878
Kerosene, international, CR (not part of national total)	37'608	44'821	57'219	42'896
Total Civil aviation	45'334	52'993	66'267	49'477
1990 = 100%	100%	117%	146%	109%

1A3a/1D1 Civil aviation	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Fuel consumption in TJ									
Kerosene, domestic, LTO	499	464	509	504	494	525	387	421	384	346
Kerosene, domestic, CR□	1'211	1'230	1'306	1'371	1'323	1'396	1'500	1'511	1'257	1'234
Kerosene, international, LTO (not part of national total)	5'468	5'643	6'041	6'226	6'208	6'142	6'459	6'529	6'728	6'953
Kerosene, international, CR (not part of national total)	49'958	52'691	56'420	57'677	58'501	58'864	60'874	64'073	66'096	70'261
Total Civil aviation	57'136	60'028	64'277	65'778	66'526	66'927	69'220	72'534	74'465	78'793
1990 = 100%	126%	132%	142%	145%	147%	148%	153%	160%	164%	174%

3.2.9.2.2 Road transportation (1A3b)

Methodology (1A3b)

Choice of method

- The CO_2 emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.2.2 in chp. 3. Mobile Combustion in IPCC (2006).
- The CH_4 and the N_2O emissions are calculated by a Tier 3 method based on the decision tree Fig. 3.2.3 in chp. 3. Mobile Combustion in IPCC (2006).
- The use of urea in urea-based catalysts is reported in chp. 4.5.2.2 under Urea use in SCR catalysts of diesel engines (2D3d) p. 247 as recommended in the reporting table's footnotes.
- CO_2 emissions from the use of lubricants as an additive in 2-stroke motorcycles are reported in chp. 4.5.2.1 under 2D1 Non-energy products from fuels and solvent use / lubricant use. Non-CO_2 emissions are reported under 1A3biv.

Connections between road model, non-road model and Swiss overall energy statistics

For the source categories related to transport, INFRAS developed a territorial emission model for road transportation (1A3b) and a model for non-road transportation (mobile sources in 1A2gvii, 1A3c, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5b excl. military aviation; (FOEN 2015j, see also “non-road transportation model” in chp. 3.2.4.5.1). The general method of the road transportation model is described in the following paragraphs and Annex A3.1.3 (INFRAS 2017c, INFRAS 2019a, Matzer et al. 2019).

Due to fluctuating fuel price differences in the vicinity of the national borders, gas stations sell varying amounts of fuels to foreign car owners. This amount of fuel is referred to as “fuel tourism”. Fuel tourism is not captured by the territorial road transportation model.

According to the reporting guidelines, emissions from road vehicles should be attributed to the country where the fuel is sold. The Swiss overall energy statistics (SFOE 2019) provide information on the total amount of fuel sold, i.e. the sum of territorial consumption **and** fuel tourism. From the amount of fuel sold, the consumption modelled by the territorial road and non-road models – i.e. fuel used – is subtracted. The resulting difference represents the amount of fuel tourism plus statistical differences[7]. Its value can be negative (in case of net fuel imports – e.g. the case for diesel in the last years since it is cheaper in the neighbouring countries) or positive (in case of net fuel exports – the case for gasoline in most years, since it is cheaper in Switzerland). It is assumed that no fuel tourism takes place with non-road vehicles.

Figure 3-25 shows how the models and the Swiss overall energy statistics are linked to determine the GHG emissions from road and non-road transportation:

- CO_2 emissions are calculated by using fuel sales and country-specific CO_2 emission factors.
- CH_4 and N_2O emissions are calculated in three steps (the same procedure also applies to precursor gases):
    - From fuel used and country-specific CH_4 and N_2O emission factors, the territorial emissions are calculated.
    - The differences between fuels sold and fuels used (territorial) are interpreted as fuel tourism and statistical differences. These amounts of gasoline and diesel oil are multiplied with implied CH_4 and N_2O emission factors, which are deduced from the territorial road transportation model (including weighted averages over all vehicle categories), to form the CH_4 and N_2O emissions resulting from fuel tourism and statistical differences.
    - CH_4 and N_2O emissions from the territorial model plus CH_4 and N_2O from fuel tourism and statistical differences are added to the total CH_4 and N_2O emissions reported to the UNFCCC.

[7] The amount of fuel tourism is regularly estimated in ex-post analysis, latest update by SFOE (2019e). The results for fuel tourism clearly show that the difference between fuels sales and fuels determined by the traffic model tend to overestimate the “true” fuel tourism. It is concluded that the difference also contains potential underestimation of the mileage and other statistical errors. Therefore, the difference between fuel sales and fuel used in the traffic model is indicated in the NIR as “fuel tourism and statistical differences”.

In the CRF tables, activity data and emissions from fuel tourism and statistical difference are reported in the most appropriate categories. In submission 2020, the CRF reporter produced an error due to negative values in some source categories for some years for CH_4. The negative values occurred because of the way the fuel tourism and statistical difference was integrated in the reporting tables (CRF Table1.A(a)s3). Therefore, the distribution of fuel tourism amongst the source categories 1A3bi, 1A3bii and 1A3biii had to be changed[8]. The new distribution is not intuitive for diesel oil and gaseous fuels, but there is currently no other solution which does not lead to an error from the CRF reporter. The distribution of fuel tourism and statistical differences does not affect total fuels sold and has no effect on the total emissions reported. The distribution is conducted as follows:

- Emissions from gasoline: fuel tourism is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.
- Emissions from diesel oil: fuel tourism is distributed amongst source categories 1A3i and 1A3iii. The distribution is conducted in proportion to annual consumption data within these two source categories, but due to negative CH_4 emission values, 5% of the fuel tourism had to be reallocated from source category 1A3biii to category 1A3bi for all years.
- Emissions from gaseous fuels: fuel tourism is completely allocated to source category 1A3biii.

[8] In previous submissions, fuel tourism and statistical difference was integrated in the reporting tables (CRF Table1.A(a)s3) as follows: Gasoline emissions were implemented in 1A3bi Cars/Gasoline, natural gas emissions in 1A3bi Cars/Gaseous fuels, and diesel oil emissions in 1A3biii Heavy duty trucks and buses/Diesel oil.

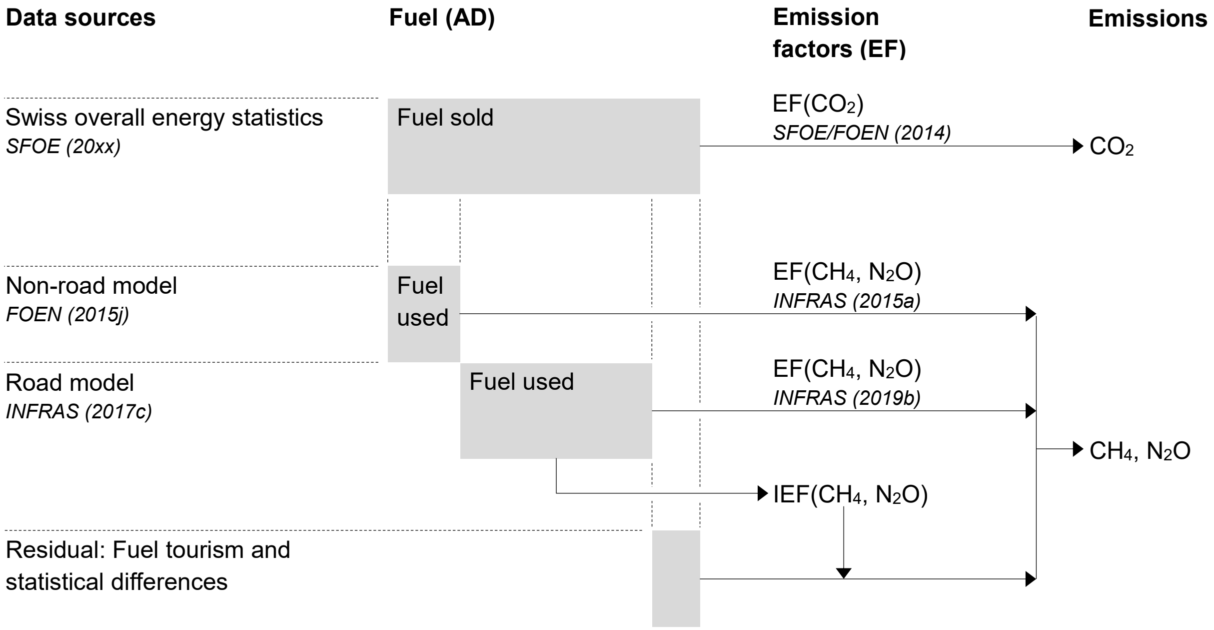


Figure 3-25 Connections between fuel sold and fuel used for road and non-road transportation. Fuel sold is provided by the Swiss overall energy statistics (minus Liechtenstein's gasoline and diesel oil consumption and bunker fuels for navigation). Fuel used results from the territorial road and non-road models. The residual fuel consists of fuel tourism and statistical differences. Its emissions are calculated by means of implied emission factors deduced from the territorial road model. The diagram holds separately for gasoline and diesel oil. SFOE (20xx) stands for the latest Swiss overall energy statistics.

Methodology of the territorial road transportation model

The emission computation is based on two sets of data:

- Emission factors: specific emissions in grams per activity data unit.
- Traffic activity data:
    - vehicle kilometres travelled (hot emissions, evaporative losses during operation)
    - number of starts/stops
    - vehicle stock (cold start, evaporative losses from gasoline passenger cars, light duty vehicles and motorcycles)
    - fuel consumption per vehicle category

Emissions are calculated as follows:

Hot emissions: $E_{hot} = VKT \cdot EF_{hot}$

Cold start excess emissions: $E_{start} = N_{start} \cdot EF_{start}$

Evaporation soak and diurnal VOC emissions: $E_{evap,i} = N_{evap,i} \cdot EF_{evap,i}$,

Evaporation running VOC losses: $E_{evap-RL} = VKT \cdot EF_{Evap-RL}$

with

- EF_{hot}, EF_{start}, $EF_{evap,i}$, $EF_{evap-RL}$: Emission factors for ordinary driving conditions (hot engine), cold start excess emissions, and evaporative (VOC) emissions (after stops, diurnal losses, and running losses)
- *VKT:* Vehicle km travelled
- N_{start}: Number of starts
- $N_{evap,i}$: Number of stops, or number of vehicles. *i* runs over two evaporation categories: a) evaporation soak emissions, i.e. emissions after stopping when the engine is still hot; and
b) evaporation diurnal emissions, i.e. emissions due to daily air temperature differences. For a) the corresponding activity is the number of stops, for b) it is the number of vehicles.
- Emission factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, LPG, bioethanol, biodiesel, gas (CNG), biogas.

CO_2 emissions from lubricant use in 2-stroke engines are calculated from the gasoline consumption of 2-stroke motorcycles, assuming a lubricant content of 2% in the gasoline. Note that the road transportation model distinguishes 2-stroke (including 2% lubricant) and 4-stroke gasoline (without lubricant). It is assumed that the whole amount of lubricant is being oxidised. The resulting CO_2 emissions are reported in source category 2D1 Lubricant use. In contrast, CH_4 and N_2O emissions from lubricant use are reported in source category 1A3biv, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines.

Cold start excess emissions for N_2O were originally not accounted for in the model described. During the in-country review in 2016, the ERT identified a potential underestimation. Switzerland therefore estimated N_2O cold start excess emissions for PC and LDV by means of emission factors from the EMEP/EEA air pollutant emission inventory guidebook, as recommended by the ERT. The corresponding emission factors per Euro class are documented in the EMEP/EEA air pollutant emission inventory guidebook 2016 on p. 78 ff. (EMEP/EEA 2016).

Emission factors (1A3b)

CO_2

- The country-specific CO_2 emission factors are described in chp.3.2.4.4.2. Values are shown in Table 3-12 (gasoline, diesel oil, biofuels) and in Table 3-13 (natural gas, biogas). The values in 2018 are also shown in Table 3-75.
- The same emission factors are also applied for the calculation of the emissions resulting from fuel tourism and statistical differences.
- Emission factors for 2-stroke gasoline: For the gasoline part of the fuel, the CO_2 emission factor for gasoline according to Table 3-12 is applied. For the lubricant part of the fuel, the IPCC default CO_2 emission factor for lubricants is applied (see Table 4-37). The resulting emissions from the gasoline part are reported under 1A3biv, the emissions from the lubricant part, however, under source category 2D1 Lubricant use (see chp. 4.5.2.1).

CH_4

- Country-specific emission factors are applied. For details including data sources see below (“*Country-specific emission factors”).* For the current submission, updated emission factors are applied based on HBEFA 4.1 (Infras 2019a).
- CH_4 emissions from fuel tourism: From the territorial model, implied emission factors for CH_4 are derived per fuel type corresponding to mean emission factors for Switzerland including all vehicle categories (see Figure 3-25). These factors are then applied to calculate the emissions resulting from fuel tourism. This approach has been verified by comparing implied emission factors with the neighbouring countries (see 3.2.9.4).
- For biofuels, no country-specific EFs for CH_4 are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel for biodiesel).

N_2O

- N_2O emissions from territorial traffic under hot operating condition: Country-specific emission factors are used, details see below (INFRAS 2019b).
- Cold start emission factors for gasoline, diesel oil, CNG and LPG vehicles are based on the EMEP/EEA 2016 Guidebook (see Annex A3.1.3 for details).
- N_2O emissions from fuel tourism: The same approach as for CH_4 is applied (see paragraph above) by means of mean emission factors (country-specific).
- For biofuels no country-specific EFs for N_2O are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel for biodiesel).

Country-specific emission factors

Emission factors for gases other than CO_2 are derived from “emission functions” which are determined from a compilation of measurements from various European countries with programmes using similar driving cycles (legislative as well as standardized real-world cycles, like “Common Artemis Driving Cycle” (CADC)). The method was developed in 1990–1995 and has been extended and updated in 2000, 2004, 2010 and latest in 2017. These emission factors are compiled in the “Handbook of Emission Factors for Road Transport” (HBEFA, see INFRAS 2019b). The latest version 4.1 – which was used for the update of the emissions in the current submission, resulting in a recalculation of the complete time series – is presented on the website (http://www.hbefa.net/) and documented in INFRAS (2019a) and Matzer et al. (2019). Further descriptions can also be found in the former publication INFRAS (2017c). The emission factors are differentiated by so-called “traffic situations”, which represent characteristic patterns of driving behaviour determined by road type, speed limit, area type (rural/urban), traffic density, and road gradient. They serve as a key to the disaggregation of the activity data. The underlying database contains dynamic fleet compositions simulating the release of new exhaust technologies and the fading out of old technologies. Further details are shown in Annex A3.1.3.

Implied emission factors for GHG, precursors and SO_2

The following Table 3-75 presents mean emission factors for GHG, precursors and SO_2 in 2018. More or less pronounced decreases of the emission factors have occurred in the last years due to new emission regulations and subsequent new exhaust technologies (optimized combustion, use of catalytic converters, particle filters, lower limits for sulphur content in diesel fuels). Early models of catalytic converters represented substantial sources of N_2O, leading to an emission increase of this gas until 1998. More recent converter technologies have overcome this problem resulting in a decrease of the (mean) emission factor.

Table 3-75 Implied emission factors in 2018 for road transportation. For more details see Annex A3.1.3. As there is no LPG consumption in 2018 based on the road transportation model, the implied emission factors for 2018 are reported as NO.

1A3b Road Transportation Gasoline / Bioethanol	**CO_2**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ						
Passenger cars	73'800	4.2	0.6	41	50	0.38	560
Light duty vehicles	73'800	10.9	2.9	145	132	0.38	3253
Heavy duty vehicles	73'800	19.5	0.8	780	558	0.38	669
Motorcycles	73'800	65	1.2	99	339	0.38	2949
Fuel tourism and statistical differences	73'800	6.3	0.7	46	84	0.38	678

1A3b Road Transportation Diesel / Biodiesel	**CO_2**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ						
Passenger cars	73'300	3.28	3.3	328	4.7	0.47	47
Light duty vehicles	73'300	0.78	2.2	377	2.4	0.47	45
Heavy duty vehicles	73'300	0.43	3.5	225	4.7	0.47	75
Motorcycles	NO	NO	NO	NO	NO	NO	NO
Fuel tourism and statistical differences	73'300	2.03	3.2	301	4.4	0.47	56

1A3b Road Transportation Gas / Biogas	**CO_2**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ						
Passenger cars	56'200	16.7	NA	43	1.45	NA	193
Light duty vehicles	56'200	7.25	NA	19	0.63	NA	1231
Heavy duty vehicles	56'200	15.2	NA	78	1.32	NA	101
Motorcycles	NO	NO	NO	NO	NO	NO	NO
Fuel tourism and statistical differences	56'200	15.6	NA	62	1.4	NA	174.5

1A3b Road Transportation Liquified petroleum gas	**CO_2**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ						
Passenger cars	NO	NO	NO	NO	NO	NO	NO
Light duty vehicles	NO	NO	NO	NO	NO	NO	NO
Heavy duty vehicles	NO	NO	NO	NO	NO	NO	NO
Motorcycles	NO	NO	NO	NO	NO	NO	NO
Fuel tourism and statistical differences	NO	NO	NO	NO	NO	NO	NO

Activity data (1A3b)

Energy-related activity data (basis for modelling the CO_2 emissions)

The Swiss overall energy statistics (SFOE 2019) provides the amount of liquid fuels (gasoline, diesel oil) and gaseous fuels (CNG) sold in Switzerland for road transportation.

From the amount of liquid fuels sold, Liechtenstein's sales, Switzerland's non-road consumption, bunker fuel emissions and fugitive emissions from transmission, storage and fuelling of gasoline (reported under 1B2av Distribution of oil products) are subtracted. Amounts of liquefied petroleum gas (LPG) used for road transportation are very small and not provided in the Swiss overall energy statistics. Therefore, the LPG consumption for road transportation is entirely based on the road transportation model.

The consumption of biofuels is based on the Swiss overall energy statistics (SFOE 2019), the Swiss renewable energy statistics (SFOE 2019a) and the Federal Customs Administrations (FCA 2019). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to reach the same quality level including its energetic properties as natural gas. (see NCV time series for natural gas and biogas in Table 3-10).

Table 3-76 shows the split of fuel sales into territorial road transportation model, the territorial non-road transportation model and fuel tourism including statistical differences.

- The relevant numbers for road transportation are given as two different contributions in the rows "on road fuel consumption (model)" and "fuel tourism and statistical differences".
- Consumption of biofuels for road transportation (biodiesel, bioethanol and biogas) starts in Switzerland in 1997.

Table 3-76 Split of fuel sales between territorial “on-road consumption (model)”, “non-road consumption (models)” and “fuel tourism and statistical differences“ (residual value to saled amounts) for gasoline, diesel oil, natural gas (CNG), liquefied petroleum gas, and biofuels (vegetable/waste oil is included in the numbers of Biodiesel) in PJ. Numbers may not add to totals due to rounding.

Activity data for on-road and non-road categories	Source category	1990	1995	2000	2005
		PJ			
Gasoline					
on-road consumption (model)	1A3b	136	134	146	136
fuel tourism and statistical differences	1A3b	17	15	20	14
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	2.4	2.4	2.3	2.1
Gasoline sold in Switzerland		156	151	168	152
Diesel oil					
on-road consumption (model)	1A3b	37	41	47	60
fuel tourism and statistical differences	1A3b	-1.7	-5.8	-5.7	-1.7
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	11	12	14	14
Diesel oil sold in Switzerland		47	48	55	73
Natural gas					
on-road consumption (model)	1A3b	NO	NO	NO	0.090
fuel tourism and statistical differences	1A3b	NO	NO	NO	0.036
non-road consumption (models)		NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		NO	NO	NO	0.13
Liquified petroleum gas					
on-road consumption (model)	1A3b	NO	NO	NO	NO
non-road consumption (models)	1A2gvii	0.17	0.25	0.29	0.29
LPG sold in on- and non-road categories in Switzerland		0.17	0.25	0.29	0.29
Biodiesel					
on-road consumption (model)	1A3b	NO	NO	0.042	0.18
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	NO	NO	0.017	0.050
Biodiesel sold in Switzerland		NO	NO	0.060	0.23
Bioethanol					
on-road consumption (model)	1A3b	NO	NO	NO	0.019
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	NO	NO	NO	NO
Bioethanol sold in Switzerland		NO	NO	NO	0.019
Biogas					
on-road consumption (model)	1A3b	NO	NO	NO	0.031
non-road consumption (models)		NO	NO	NO	NO
Biogas sold in Switzerland		NO	NO	NO	NO

Activity data for on-road and non-road categories	Source category	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
		PJ									
Gasoline											
on-road consumption (model)	1A3b	123	120	116	111	106	102	97	93	91	90
fuel tourism and statistical differences	1A3b	14	12	11	12	11	10	6.8	7.4	6.6	6.2
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	1.9	1.9	1.9	1.8	1.8	1.7	1.7	1.7	1.6	1.6
Gasoline sold in Switzerland		139	134	129	124	119	114	106	102	99	98
Diesel oil											
on-road consumption (model)	1A3b	77	81	86	90	95	99	102	106	107	106
fuel tourism and statistical differences	1A3b	3.0	1.5	-0.1	1.6	1.4	0.6	-4.2	-6.5	-7.8	-5.0
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	15	15	15	15	15	15	15	15	15	15
Diesel oil sold in Switzerland		94	98	100	107	111	114	113	114	114	115
Natural gas											
on-road consumption (model)	1A3b	0.60	0.71	0.70	0.68	0.70	0.67	0.63	0.60	0.57	0.59
fuel tourism and statistical differences	1A3b	0.1	0.16	0.31	0.29	0.31	0.27	0.24	0.21	0.18	0.16
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		0.74	0.87	1.0	0.97	1.0	0.94	0.87	0.81	0.75	0.75
Liquified petroleum gas											
on-road consumption (model)	1A3b	NO	NO	0.015	0.015	0.015	0.015	0.018	0.020	0.021	NO
non-road consumption (models)	1A2gvii	0.27	0.27	0.26	0.25	0.24	0.23	0.23	0.21	0.20	0.19
LPG sold in on- and non-road categories in Switzerland		0.27	0.27	0.27	0.27	0.26	0.25	0.24	0.23	0.22	0.19
Biodiesel											
on-road consumption (model)	1A3b	0.26	0.30	0.27	0.29	0.23	0.50	1.2	2.5	4.2	5.9
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	0.06	0.06	0.10	0.13	0.16	0.19	0.23	0.29	0.36	0.43
Biodiesel sold in Switzerland		0.32	0.37	0.37	0.42	0.39	0.70	1.5	2.8	4.5	6.3
Bioethanol											
on-road consumption (model)	1A3b	0.031	0.055	0.083	0.093	0.078	0.16	0.58	0.79	1.0	1.2
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	0.0000	0.0000	0.0022	0.0043	0.0065	0.0086	0.011	0.017	0.023	0.029
Bioethanol sold in Switzerland		0.03	0.05	0.09	0.10	0.08	0.17	0.59	0.80	1.0	1.2
Biogas											
on-road consumption (model)	1A3b	0.11	0.14	0.10	0.10	0.12	0.11	0.13	0.13	0.13	0.14
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biogas sold in Switzerland		0.11	0.14	0.10	0.10	0.12	0.11	0.13	0.13	0.13	0.14

Mileage-related activity data (basis for modelling of the non-CO_2 emissions by means of a traffic model)

The activity data are derived from different data sources:

- Vehicle stock: The federal vehicle registration database MOFIS (run by the Federal Roads Office FEDRO) contains vehicle stock data including all parameters needed for the emission modelling (vehicle category, engine capacity, fuel type, total weight, vehicle age and exhaust technology). The data are not public, but the ordinary vehicle stock numbers are published by the Swiss Federal Statistical Office (SFSO 2019e). With the help of a fleet turnover model, the vehicle categories are assigned emission standards based on age and thereby split up into "sub-segments", which are used to link with the specific emission factors of the same categorisation (vehicle category, size class, fuel type, emission standard ["Euro classes"]).
- The specific mileage per vehicle category is an input from the Swiss Federal Statistical Office (SFSO 2019e, 2019f). It is based on periodical surveys/Mikrozensus (ARE 2002, ARE/SFSO 2005, ARE/SFSO 2012, ARE/SFSO 2017). By means of the vehicle stock data (see paragraph above), the specific mileage per vehicle category can be derived (SFSO 2019e, SFOE 2019e, INFRAS 2017).
- Numbers of starts/stops: Derived from vehicle stock and periodical surveys/Mikrozensus (ARE/SFSO 2005, 2012, 2017).

The total mileage of each vehicle category is differentiated by "traffic situations" (characteristic patterns of driving behaviour) which serve as a key to select the appropriate emission factor and which are also available per traffic situation. The relative shares of the traffic situations are derived from a national road traffic model (operated by the Federal Office of Spatial Development, see ARE 2016). The traffic model is based on an origin-destination matrix that is assigned to a network of about 20'000 road segments. The model is calibrated partly bottom-up and partly top-down: bottom-up by a number of traffic counts from the national traffic-counter network, and top-down by the total of the mileage per vehicle category. The assignment of traffic situations to the modelled mileage is described in INFRAS (2017). The traffic model in combination with consumption factors (per vehicle category, size class, fuel type, emissions standard and per traffic situation) allows to calculate the territorial road traffic consumption of gasoline and diesel oil.

Table 3-77 shows the time series of the mileage per vehicle category. The total mileage has constantly been increasing since 1995. The major part of vehicle kilometres was driven by passenger cars over the whole period. In the same period, on-road fuel consumption increased less strongly, indicating improved fuel efficiency. This effect is also reflected in Table 3-78 that shows the specific fuel consumption per vehicle-km. Average consumption and the specific consumption for most of the vehicle categories have decreased in the period 1990–2018.

Table 3-77 Mileages in millions of vehicle kilometres. PC: passenger cars, LDV: light duty vehicles, HDV: heavy duty vehicles).

Veh. category	1990	1995	2000	2005
	million vehicle-km			
PC	42'649	41'324	45'613	48'040
LDV	2'600	2'746	2'957	3'228
HDV	1'992	2'107	2'273	2'120
Coaches	108	110	99	106
Urban Bus	174	192	200	229
2-Wheelers	2'025	1'563	1'700	1'785
Sum	49'548	48'043	52'841	55'507
(1990=100%)	100%	97%	107%	112%

Veh. category	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	million vehicle-km									
PC	51'112	52'066	52'696	53'721	54'695	55'641	56'620	57'737	58'735	59'039
LDV	3'432	3'502	3'635	3'776	3'874	3'998	4'129	4'269	4'382	4'430
HDV	2'164	2'226	2'258	2'229	2'243	2'236	2'235	2'235	2'229	2'253
Coaches	116	118	122	124	125	128	131	134	136	137
Urban Bus	238	244	250	254	262	267	272	281	280	286
2-Wheelers	1'846	1'852	1'877	1'899	1'904	1'920	1'937	1'976	2'008	2'019
Sum	58'909	60'009	60'838	62'003	63'102	64'188	65'324	66'631	67'770	68'163
(1990=100%)	119%	121%	123%	125%	127%	130%	132%	134%	137%	138%

Table 3-78 Specific fuel consumption of road transport, excluding fuel tourism and statistical differences. Numbers include additional fuel consumption by cold starts.

Veh. cat.	Fuel	1990	1995	2000	2005
		MJ/veh-km			
PC	Gasoline	3.13	3.21	3.27	3.20
	Diesel	3.33	3.15	3.03	2.74
	CNG	NO	NO	NO	NO
LDV	Gasoline	3.85	3.73	2.98	2.16
	Diesel	4.53	4.49	4.31	3.96
	CNG	NO	NO	NO	NO
HDV	Gasoline	NO	NO	NO	NO
	Diesel	11.1	11.6	11.6	12.2
	CNG	NO	NO	NO	10.4
Coach	Diesel	12.7	12.6	12.3	12.0
Urban Bus	Diesel	16.3	16.7	16.8	16.8
	CNG	NO	NO	NO	NO
2-Wheeler	Gasoline	1.49	9.03	1.48	1.58
Average		3.51	3.52	3.55	3.57
(1990=100%)		100%	100%	101%	102%

Veh. cat.	Fuel	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
		MJ/veh-km									
PC	Gasoline	3.10	3.06	3.01	2.94	2.87	2.80	2.72	2.64	2.56	2.51
	Diesel	2.72	2.71	2.70	2.68	2.66	2.62	2.58	2.54	2.50	2.48
	CNG	2.14	2.08	2.02	2.00	1.91	1.91	1.82	1.79	1.77	1.75
LDV	Gasoline	3.55	3.52	3.48	3.43	3.38	3.33	3.26	3.20	3.13	3.05
	Diesel	3.78	3.76	3.74	3.71	3.71	3.69	3.66	3.64	3.60	3.55
	CNG	NO	2.40	2.70	2.69	2.55	2.55	2.44	2.40	2.38	1.96
HDV	Gasoline	NO	NO	9.15	9.15	9.16	9.15	9.11	9.10	9.06	9.01
	Diesel	12.0	11.9	11.9	11.8	11.8	11.7	11.5	11.5	11.4	11.2
	CNG	13.4	13.2	13.0	13.0	12.5	12.7	12.3	12.3	12.2	11.1
Coach	Diesel	11.7	11.6	11.7	10.7	10.6	10.5	10.3	10.2	10.1	10.0
Urban Bus	Diesel	16.5	16.3	16.2	16.1	16.1	15.9	15.7	15.6	15.4	15.3
	CNG	17.3	17.0	16.6	16.7	16.0	16.0	15.4	15.3	15.3	15.2
2-Wheeler	Gasoline	1.52	1.52	1.54	1.55	1.53	1.58	1.62	1.57	1.57	1.56
Average		3.39	3.36	3.32	3.26	3.20	3.14	3.07	3.00	2.93	2.89
(1990=100%)		97%	96%	95%	93%	91%	89%	87%	86%	84%	82%

For modelling of evaporative emissions, the stock, the mileage and the number of stops of gasoline passenger cars, light duty vehicles and motorcycles are used. For modelling cold start excess emissions, also the numbers of starts of passenger cars and light duty vehicles are used as activity data. The corresponding numbers are summarised in Table 3-79. Vehicle stock figures correspond to registration data. The starts and stops per vehicle are based on specific surveys (ARE/SFSO 2005, 2012, 2017).

Table 3-79 Vehicle stock numbers (gasoline vehicles only – relevant for diurnal evaporation) and average number of starts per vehicle per day (gasoline, diesel oil, and CNG vehicles).

Veh. Category	1990	1995	2000	2005
	stock in 1000 veh. (gasoline/bioeth.)			
PC	2'838	3'048	3'303	3'265
LDV	167	164	148	112
2-Wheelers	764	688	712	746
	starts per veh. per day			
PC	2.61	2.53	2.46	2.40
LDV	1.97	1.97	1.96	1.96

Veh. Category	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	stock in 1000 veh. (gasoline/bioeth.)									
PC	3'001	2'957	2'925	2'879	2'833	2'784	2'736	2'685	2'681	2'734
LDV	81	77	73	69	64	61	58	56	54	52
2-Wheelers	767	766	775	780	793	802	805	816	836	819
	starts per veh. per day									
PC	2.35	2.34	2.34	2.33	2.33	2.32	2.33	2.32	2.31	2.30
LDV	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96

Further details are given in Annex A3.1.3.

3.2.9.2.3 Railways (1A3c)

Methodology (1A3c)

As mentioned in chp. 3.2.4.5.1, the emissions are calculated by the non-road transportation model. The following methods are used:

- Tier 2 for CO_2 (based on decision tree Fig. 3.4.1 in IPCC 2006)
- Tier 3 for CH_4, N_2O and precursors/SO_2 (based on decision tree Fig. 3.4.2 in IPCC 2006).

The entire Swiss railway system is electrified. Electric locomotives are used in passenger as well as freight railway traffic. Diesel locomotives are used for shunting purposes in marshalling yards and for construction activities only.

Emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2020 based on fuel used. For the years in-between, the emissions are interpolated linearly.

Emission factors (1A3c)

Only diesel oil is being used as fuel, therefore all emission factors refer to diesel oil.

- The CO_2 emission factor applied for the time series 1990–2018 for diesel oil is country-specific and is given in Table 3-12.
- The CH_4 and N_2O emission factors of diesel locomotives are shown in Table 3-80.
- For SO_2 the emission factors are country-specific. See also Table A – 12 (row diesel oil).
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors 2018 are shown in Table 3-81.

All emission factors (GHG, precursors, SO_2) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-80 CH_4 and N_2O emission factors for rail vehicles

Gas	Power class	Rail vehicles with diesel oil engines				
		PreEU <2000	UIC1 2000	UIC2 2003	EU3a 2006	EU3b 2012
	kW	g/kWh				
CH_4	<18	0.0547	0.0384	0.024	0.0142	0.0142
CH_4	18–37	0.0578	0.0221	0.0134	0.0089	0.0089
CH_4	37–56	0.0319	0.0156	0.011	0.0079	0.0055
CH_4	56–75	0.0319	0.0156	0.011	0.0079	0.0031
CH_4	75–130	0.0218	0.0108	0.0084	0.0067	0.0031
CH_4	>130	0.0218	0.0103	0.0072	0.0053	0.0031
N_2O	all	0.035	0.035	0.035	0.035	0.035

Table 3-81 Implied emission factors 2018 for rail vehicles. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3c Railways	CO_2 fossil	CO_2 biogen	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ							
Diesel oil	73'300	NA	1.3	3.6	994	116	0.47	533
Biodiesel	NA	73'300	1.1	3.0	849	99	0.40	455

Activity data (1A3c)

Activity data for non-road (1A3c) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-82 and in Annex A3.1.4.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-82 Activity data (diesel oil consumption) for railways.

1A3c Railways	1990	1995	2000	2005
	TJ			
Diesel oil	390	441	455	472
Biodiesel	NO	NO	0.59	1.7
Total Railways	390	441	456	474
1990 = 100%	100%	113%	117%	121%

1A3c Railways	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Diesel oil	488	492	471	451	431	410	390	388	387	385
Biodiesel	2.0	2.1	2.9	3.7	4.4	5.2	5.9	7.7	9.4	11
Total Railways	490	494	474	455	435	416	396	396	396	396
1990 = 100%	126%	127%	122%	117%	112%	107%	102%	102%	102%	102%

3.2.9.2.4 Domestic navigation (1A3d)

Methodology (1A3d)

Based on the decision tree Fig. 3.5.1 Box 1 of the 2006 IPCC Guidelines (IPCC 2006) the emissions of navigation are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

There are passenger ships, dredgers, fishing boats, motor and sailing boats on the lakes and rivers of Switzerland. The emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2020 based on fuel used. For the years in-between, the emissions are linearly interpolated.

On the river Rhine as well as on Lake Geneva and Lake Constance, some of the boats cross the border. Fuels bought in Switzerland but used for international navigation are therefore reported as bunker fuels (memo items, chp. 3.2.2.).

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported in source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use are reported in source category 1A3d, since the emission factors are deduced from measurements including 2-stroke engines.

Emission factors (1A3d)

- The CO_2 emission factor applied for the time series 1990–2018 for diesel oil, gasoline and gas oil are country-specific and are given in Table 3-12.
- The CH_4 and N_2O emission factors are country-specific and are shown below in Table 3-83 to Table 3-85 for all fuel types and emission standards.
- For SO_2 the emission factors are country-specific. See also Table A – 12 in Annex A3.1.5 rows diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).

- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- The implied emission factors 2018 are shown in Table 3-86.

All emission factors (GHG, precursors, SO_2) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-83 CH_4 and N_2O emission factors for ships with diesel engines.

Gas	Power class	Ships with diesel oil engines				
		Pre SAV (<1995)	SAV 1995	EU-I 2003	EU-II 2008	EU-IIIA 2009
	kW	g/kWh				
CH_4	<18	0.0547	0.0547	0.0384	0.0240	0.0142
CH_4	18–37	0.0578	0.0578	0.0221	0.0134	0.0089
CH_4	37–56	0.0319	0.0319	0.0156	0.0110	0.0079
CH_4	56–75	0.0319	0.0319	0.0156	0.0110	0.0079
CH_4	75–130	0.0218	0.0218	0.0108	0.0084	0.0067
CH_4	>130	0.0218	0.0218	0.0103	0.0072	0.0053
N_2O	all	0.035	0.035	0.035	0.035	0.035

Table 3-84 CH_4 and N_2O emission factors for ships with gasoline engines by emission standards including the year of enforcement.

Gas	Power class	Boats with 2-stroke gasoline engines			Boats with 4-stroke gasoline engines		
		Pre SAV <1995	SAV 1995	SAV/EU 2007	Pre SAV <1995	SAV 1995	SAV/EU 2007
	kW	g/kWh			g/kWh		
CH_4	<18	18.2	1.54	1.75	1.25	1.10	1.25
CH_4	18–37	18.2	0.84	0.91	1.00	0.60	0.65
CH_4	37–56	18.2	0.42	0.56	1.00	0.30	0.40
CH_4	56–75	18.2	0.42	0.56	1.00	0.20	0.30
CH_4	75–130	18.2	0.42	0.56	1.00	0.17	0.25
CH_4	130–560	18.2	0.42	0.56	1.00	0.10	0.25
N_2O	0–300	0.01	0.01	0.01	0.03	0.03	0.03

Table 3-85 CH_4 and N_2O emission factors for steamboats by the year of enforcement.

Gas	steamboats		
	<2000	2000-2004	>2004
	g/kWh		
CH_4	0.0218	0.0103	0.0072
N_2O	0.035	0.035	0.035

Table 3-86 Implied emission factors 2018 for navigation. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3d Navigation	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ							
Gasoline	73'800	NA	21.9	2.0	556	404	0.39	8'393
Diesel oil	73'300	NA	1.6	3.4	851	253	0.47	516
Gas oil	73'700	NA	0.2	0.7	26	1.6	8	6.9
Biodiesel	NA	73'300	1.3	2.9	727	216	0.40	441
Bioethanol	NA	73'800	12.8	1.3	349	242	0.24	5'176

Activity data (1A3d)

Activity data for navigation (1A3d) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-87 and in Annex A3.1.4.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-87 Fuel consumption of (domestic) navigation.

1A3d Navigation	1990	1995	2000	2005
	TJ			
Gasoline	701	654	616	565
Diesel oil	738	724	792	800
Gas oil	110	139	147	150
Biodiesel	NO	NO	1.0	2.9
Bioethanol	NO	NO	NO	NO
Total Navigation	1'550	1'517	1'556	1'518
1990 = 100%	100%	98%	100%	98%

1A3d Navigation	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Gasoline	854	868	870	872	874	876	878	873	867	862
Diesel oil	541	535	530	526	522	518	514	512	511	509
Gas oil	157	159	157	156	154	153	151	150	149	148
Biodiesel	3.6	3.8	5.7	7.6	9.5	11	13	17	21	25
Bioethanol	0.010	0.013	0.79	1.6	2.3	3.1	3.9	6.3	8.6	11
Total Navigation	1'556	1'565	1'564	1'563	1'562	1'561	1'560	1'559	1'557	1'556
1990 = 100%	100%	101%	101%	101%	101%	101%	101%	101%	100%	100%

3.2.9.2.5 Other transportation (1A3e)

Methodology (1A3e)

The emissions are calculated with a Tier 2 method (the 2006 IPCC Guidelines (IPCC 2006) do not contain a decision tree to determine the Tier level specifically).

Source 1A3e includes only pipeline transportation (1A3ei) from a compressor station located in Ruswil. Emissions of CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 are reported. The compressor station uses a centrifugal compressor according to Transitgas AG (the company operating the compressor station and the pipeline network).

Emission factors (1A3e)

- The CO_2 emission factor applied for the time series 1990–2018 for natural gas is country-specific and is given in Table 3-13.
- The CH_4 emission factor corresponds to the one used for gas turbines in Switzerland (SAEFL 2000) as suggested by expert judgement. The CH_4 EF is assumed to be 5 g/GJ up to 1995 and 2 g/GJ from 2000 onwards, with linear interpolation in between. This corresponds with the fact that a catalyst was fitted to the system, which reduced the CH_4 emissions of the gas turbine.
- For N_2O emission factors the IPCC 2006 default value (Table 3-16) is used as displayed in Table 3-88.
- For SO_2 the emission factors are country-specific. The emission factor 2018 is shown in Table 3-88. See also See also Table A – 12 in Annex A3.1.5 row natural gas.
- The emission factors for precursors are country-specific and are given in SAEFL (2000); see also EMIS 2020/1A3e “Gasturbinen; Erdgas”.
- The emission factors 2018 are shown in Table 3-88.

Table 3-88 Emission factors of 1A3ei Pipeline transportation / compressor station located in Ruswil in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3e Other transportation	CO_2 fossil	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
Gas	56'200	2	0.1	23	0.1	0.5	5

Activity data (1A3e)

The data on fuel consumption for the operation of the compressor station in Ruswil is based on the Swiss overall energy statistics (SFOE 2019; Table 17).

Table 3-89 Activity data of 1A3e.

1A3ei Pipeline transport	1990	1995	2000	2005
	TJ			
Natural gas	560	310	340	1'070
1990=100%	100%	55%	61%	191%

1A3ei Pipeline transport	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
Natural gas	950	830	840	810	410	830	760	340	470	490
1990=100%	170%	148%	150%	145%	73%	148%	136%	61%	84%	88%

3.2.9.3 Uncertainties and time-series consistency for 1A3

The uncertainty of emission estimates for source category 1A3 is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-25.

Time series for 1A3 Transport are all considered consistent.

3.2.9.4 Category-specific QA/QC and verification for 1A3

General

The general QA/QC measures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

Specific: Domestic aviation (1A3a)

Emissions

Total calculated emissions for domestic and international flights have been compared between different years. The development of total emissions with time is consistent with a fleet renewal of former Swissair in the early nineties, the technological improvements and changes in fleet composition.

Emission factors

- From total fuel consumption, total distance, number of passenger (without freight) per aircraft type, the fuel consumption per 100 passenger km has been calculated (backward calculation). The result of 2 to 10 kg fuel/100 passenger km is in line with expectations for 1990 passenger fleets.
- The implied emission factors were calculated for 2018 and compared with previous years.

Activity data

- In an independent Tier 3B calculation, EUROCONTROL performed a fuel calculation for Switzerland’s international flights, based on collected flight plan data and single movements. The results for the years 2004, 2005 and 2007 matched the FOCA calculations by more than 97.4%. The FOCA results were generally 1% to 2% higher but included the total number of actual flight movements of all flights, including VFR (visual flight rules) and non-scheduled flights such as helicopter movements in alpine regions.
- Comparison between total movement numbers in the calculation and in the corresponding published statistics. Example: In 1990 calculation, FOCA considered all flights for which there was a form ‘Traffic report to the airport authorities’ filled in (total heavy aircraft). The total number of movements in 1990 is 263’951 (without Basel). The published number of movements for scheduled and charter flights in 1990 is: 263’952 (without Basel).
- The bottom-up calculation of total fuel matches the total fuel sold within a few percent.

- Real-world fuel consumption was compared with modelled consumption for selected aircraft of four Swiss airlines. The difference between the two methods was smaller than 1%.

Specific: Road transportation (1A3b)

Comparison between the 2006 IPCC Guideline's default and Switzerland's emission factors

- CO_2 (see also Table 3-26): IPCC default value for gasoline is 69.3 t/TJ and for diesel oil 74.1 t/TJ (IPCC 2006, Table 3.2.1). Switzerland's emission factors vary between 73.8 and 73.9 t/TJ for gasoline – 6% higher than IPCC – and between 73.3 and 73.6 t/TJ for diesel oil – about 1% below IPCC default value.
- CH_4: The IPCC default emission factor for gasoline motors with oxidation catalysts is 25 kg/TJ with an uncertainty range from 7.5 to 86 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 25.7 kg/TJ and 4.3 kg/TJ throughout the time series and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil, the IPCC default emission factors lie in the range of 1.6-9.5 kg/TJ, whereas Switzerland's range is on a lower level (0.8-3.0 kg/TJ).
- N_2O: The IPCC default emission factor for gasoline motors with oxidation catalysts lies in the uncertainty range 2.6-24 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 5.4 kg/TJ and 0.6 kg/TJ and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil the IPCC default emission factors lies in the range of 1.3-12 kg/TJ, whereas Switzerland's range is lower (0.2-3.2 kg/TJ).

The international project for the update of the emission factors for road vehicles is overseen by a group of external national and international experts that guarantees an independent quality control. For the update of the modelling of Switzerland's road transport emissions, which has been carried out between 2015 and 2017, several experts from the federal administration have conducted the project. The results have undergone extensive plausibility checks and comparisons with earlier estimates.

The emission factors CH_4 and N_2O used for the modelling of 1A3b Road Transportation are taken from version 4.1 of the Handbook Emission Factors for Road Transport (HBEFA) (INFRAS 2019b), which is also applied in Germany, Austria, Netherlands, and Sweden. The Swiss emission factors for CH_4 and N_2O used in 1A3b were additionally compared with those shown in the CRF from Germany and a good match was found. Possible small differences might result from a varying fleet composition.

Use of implied emission factors from the territorial model to calculate emissions for fuel tourism: This approach has been verified by comparing implied emission factors with the neighbouring countries. The differences turned out to be small between Switzerland, Austria, and Germany because all three countries used the same emission factors (INFRAS 2010), whereas there were some differences when comparing with France and Italy that use other emission factors (COPERT[9]). Nevertheless, the use of the implied Swiss emission factors seemed to be the consistent approach. It must be noted, that this comparison was carried

[9] see European Environment Agency http://www.eea.europa.eu/publications/TEC05 [18.02.2020]

out with version 3.1 of the “Handbook of Emission Factors for Road Transport”, whereas the current emissions are based on version 4.1. It is expected that an update of this comparison would result in similarly low differences with the neighbouring countries, since the underlying measurement data in the inventory models are the same (given the neighbouring countries also work with an eventually updated COPERT version).

The activity data for gasoline and diesel oil of the road transportation model (consumption without tank tourism and statistical difference) is verified due to the fact that more than 90% of the gasoline and diesel oil sold 2018 in Switzerland, as reported by the Swiss overall energy statistic (SFOE 2019), is consumed by the road transportation model (see Table 3-76).

3.2.9.5 Category-specific recalculations for 1A3

The following recalculations were implemented in submission 2019. Major recalculations, which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1A3b: The Swiss road transportation model has been updated from HBEFA 3.3 to HBEFA 4.1 and N_2O emissions from starting cold engines have been included in the model. This leads to the following recalculations in emissions of greenhouse gases:
  - CO_2 biogenic: higher biogenic CO_2 emissions in the years 1997–2017 lead to 13.9% or 46.8kt more biogenic CO_2 in the year 2017.
  - N_2O: higher N_2O emissions in all years from 1990–2017 lead to 18.4% or 86t more N2O in 1990 and 25.3% or 79t in 2017.
  - CH_4: higher CH_4 emissions in all years from 1990–2017 lead to 11.6% or 460t more CH_4 in 1990 and 67.7% or 345t in 2017.

3.2.9.6 Category-specific planned improvements for 1A3

No category-specific improvements are planned.

3.2.10 Source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

3.2.10.1 Source category description for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

Key categories 1A4

See key categories mentioned in chp. 3.2.7.1, Table 3-55.

Table 3-90 Specification of source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors (1A4aii, 1A4bii, 1A4cii).

1A4	Source category	Specification
1A4aii	Commercial/ institutional	Emission from non-road vehicles (professional gardening) and motorised equipment
1A4bii	Residential	Emissions from mobile machinery (hobby, gardening) and motorised equipment
1A4cii	Agriculture/forestry	Emisions from non-road vehicles and machinery in agriculture and forestry

3.2.10.2 Methodological issues for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

Methodology (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in the 2006 IPCC Guidelines (IPCC 2006), the emissions of vehicles and machinery in 1A4 are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in the corresponding source category in 1A4 (mobile), since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

In the categories 1A4aii and 1A4bii only gasoline (and a small share of bioethanol) is being used as fuel. In category 1A4cii mainly diesel oil is consumed (more than 80%, see Table 3-92) and only a small amount of gasoline (e.g. chainsaws) or biodiesel/bioethanol (less than 20%).

- The CO_2 emission factors applied for the time series 1990–2018 are country-specific and are given in Table 3-12.
- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-66 and Table 3-67 for diesel oil and gasoline engines for all emission standards.

- For SO_2 the emission factors are country-specific. See also Table A – 12 in Annex A3.1.5 for diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors 2018 are shown in Table 3-91.

All emission factors (GHG, precursors, SO_2) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-91 Implied emission factors 2018 for 1A4 – Other non-road machinery sources in residential, commercial agriculture and forestry sectors(1A4aii – 1A4cii mobile). Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4 Non-road machinery	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ							
1A4aii Gardening professional								
Gasoline	73'800	NA	86	1.1	185	1'388	0.4	26'588
Bioethanol	NA	73'800	17	1.0	85	481	0.2	15'629
1A4bii Gardening								
Gasoline	73'800	NA	45	1.4	156	938	0.4	25'217
Bioethanol	NA	73'800	17	1.0	93	470	0.2	15'677
1A4cii Forestry and agriculture								
Gasoline	73'800	NA	83	1.1	176	1'448	0.4	24'208
Diesel oil	73'300	NA	1.3	3.0	428	50	0.5	250
Biodiesel	NA	73'300	1.1	2.6	367	43	0.4	214
Bioethanol	NA	73'800	20.4	0.9	81	580	0.2	14'842

Activity data (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Activity data are described in chp. 3.2.4.5.1 (non-road transportation model) and are shown in Table 3-92 and in Annex A3.1.4.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-92 Activity data for non-road vehicles and machinery in 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors.

1A4 Non-road machinery	1990	1995	2000	2005
	TJ			
1A4aii Gardening professional				
Gasoline	191	245	295	295
Bioethanol	NO	NO	NO	NO
1A4bii Gardening				
Gasoline	142	155	165	166
Bioethanol	NO	NO	NO	NO
1A4cii Forestry and agriculture				
Gasoline	1'160	1'070	963	824
Diesel oil	4'269	4'604	4'920	4'802
Biodiesel	NO	NO	6.4	17
Bioethanol	NO	NO	NO	NO
Total 1A4 non-road machinery	5'761	6'073	6'349	6'103
Relative values 1A4 (1990 = 100%)	100%	105%	110%	106%

1A4 Non-road machinery	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	TJ									
1A4aii Gardening professional										
Gasoline	289	287	280	273	266	260	253	251	250	248
Bioethanol	0.003	0.004	0.24	0.48	0.72	0.95	1.19	1.9	2.6	3.3
1A4bii Gardening										
Gasoline	163	163	162	160	159	158	156	155	154	153
Bioethanol	0.003	0.003	0.21	0.43	0.64	0.85	1.1	1.7	2.3	2.9
1A4cii Forestry and agriculture										
Gasoline	716	689	665	641	616	592	568	551	535	519
Diesel oil	4'866	4'882	4'876	4'870	4'864	4'859	4'853	4'835	4'817	4'800
Biodiesel	20	21	32	42	53	63	74	96	118	140
Bioethanol	0.010	0.012	0.66	1.3	2.0	2.6	3.3	4.8	6.4	8.0
Total 1A4 non-road machinery	6'054	6'042	6'015	5'989	5'962	5'936	5'909	5'898	5'886	5'874
Relative values 1A4 (1990 = 100%)	105%	105%	104%	104%	103%	103%	103%	102%	102%	102%

3.2.10.3 Uncertainties and time-series consistency for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The uncertainty of emission estimates for source category 1A4 Other sectors (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-25.

3.2.10.4 Category-specific QA/QC and verification for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The general QA/QC procedures are described in chp. 1.2.3. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

3.2.10.5 Category-specific recalculations for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

No category-specific recalculations were carried out.

3.2.10.6 Category-specific planned improvements for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

No category-specific improvements are planned.

3.2.11 Source category 1A5b – Other (mobile)

3.2.11.1 Source category description for 1A5b (mobile)

Source category 1A5b – Other (mobile) is not a key category. All of the Swiss source categories of 1A5 refer to mobile sources of military activities (1A5b). Stationary activities (1A5a) are not occurring.

Table 3-93 Specification of Swiss source category 1A5 Other.

1A5	Source category	Specification
1A5bi	Military aviation	Emissions from military aircrafts
1A5bii	Military non-road vehicles and machines	Emissions from machines like power generators, tanks, bulldozers, boats etc.

3.2.11.2 Methodological issues for 1A5b Other (mobile)

3.2.11.2.1 Military aviation (1A5bi)

Methodology (1A5bi Other, military aviation)

To calculate the emissions from military aviation, a Tier 2 method is used.

Emission factors (1A5bi Other, military aviation)

- The CO_2 emission factor applied for the time series 1990–2018 for kerosene is country-specific and is given in Table 3-12.
- CH_4: Because there is no split in LTO and cruise flights in military aviation, the CH_4 emission factor of 1A3a Civil aviation (see chp. 3.2.9.2.1) cannot be applied. Therefore, the Tier 1 emission factor from IPCC 2006, table 3.6.5 is used.
- N_2O: As for 1A3a Civil aviation, the Tier 1 IPCC default value is used (IPCC 2006, table 3.6.5).
- NO_x, NMVOC, CO: average emission factors for military aircraft are calculated by the Federal Office of Civil Aviation (FOCA) based on information from the Federal Department of Defence, Civil Protection and Sport (DDPS) concerning fuel consumption per aircraft type in the year 2016–2017 (DDPS 2018b). These emission factors stay constant for the whole time series from 1990 onwards.
- SO_2: the emission factor is taken from the EMEP/EEA Guidebook (EMEP/EEA 2019, Table 3.11, row “Switzerland/CCD”[10]) and is assumed to be constant over the period 1990–2018.

[10] CCD: climb/cruise/descent

- Implied emission factors 2018 are shown in Table 3-94.

Table 3-94 Implied emission factors 1A5bi military aviation in 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bi Military aviation	CO_2 fossil	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
Jet kerosene	72'800	0.50	2.0	232	33	23	235

Activity data (1A5bi Other, military aviation)

Fuel consumption data for 1990–2018 is available on an annual basis (DDPS 2019). A very small fraction of fuel is consumed for training abroad and might be allocated under "International aviation" (assumed to be less than 3% of total military aviation consumption). Since the exact numbers for the fuels used abroad is not known, it is not subtracted from the total consumption but included under national military aviation, as recommended by the IPCC Guidelines (2006, chp. 3.6.1.4).

Table 3-95 Activity data (fuel consumption) for military aviation.

1A5 Other Military aviation	1990	1995	2000	2005
	fuel consumption in TJ			
Jet kerosene	2'733	1'955	1'794	1'624

1A5 Other Military aviation	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	fuel consumption in TJ									
Jet kerosene	1'529	1'592	1'420	1'527	1'542	1'615	1'567	1'627	1'469	1'457

3.2.11.2.2 Military non-road vehicles (1A5bii Other, military machinery)

Methodology (1A5bii Other, military machinery)

Emissions are calculated as part of the non-road transportation model (chp. 3.2.4.5.1) corresponding to a Tier 3 according to the decision tree Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006).

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in source category 1A5bii, since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A5bii Other, military machinery)

- The CO_2 emission factors applied for the time series 1990–2018 for diesel oil, gasoline and biofuels are country-specific as shown in Table 3-12.

- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-66 and Table 3-67 for diesel oil and gasoline engines for all emission standards.
- For SO_2 the emission factors are country-specific. See Table A – 12 in Annex A3.1.5, rows diesel oil, gasoline.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors are shown in Table 3-96.

All emission factors (GHG, precursors) can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-96 Implied emission factors 1A5bii military non-road vehicles 2018. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bii Military non-road	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ							
Gasoline	73'800	NA	40.7	1.5	133	754	0.38	24311
Diesel	73'300	NA	0.76	3.0	371	31	0.47	161
Biodiesel	NA	73'300	0.65	2.6	316	27	0.40	138
Bioethanol	NA	73'800	10.7	1.0	71	298	0.24	15433

Activity data (1A5bii Other, military machinery)

Activity data for military non-road vehicles (1A5bii) are described in. chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-97 and in Annex A3.1.4.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see footnote 6, p. 152).

Table 3-97 Activity data (fuel consumption) for military non-road vehicles.

1A5bii Military non-road	**1990**	**1995**	**2000**	**2005**
	fuel consumption in TJ			
Total fuel consumption	239	248	252	257
Gasoline	19	19	19	19
Diesel	220	228	233	238
Biodiesel	NO	NO	0.30	0.86
Bioethanol	NO	NO	NO	NO

1A5bii Military non-road	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	fuel consumption in TJ									
Total fuel consumption	272	275	275	275	275	275	275	274	273	272
Gasoline	18	18	18	18	17	17	17	17	16	16
Diesel	252	256	256	255	255	254	254	252	250	248
Biodiesel	1.1	1.1	1.7	2.2	2.8	3.3	3.9	5.0	6.1	7.2
Bioethanol	0.0003	0.0004	0.023	0.046	0.069	0.092	0.11	0.18	0.25	0.31

3.2.11.3 Uncertainties and time-series consistency for 1A5b Other (mobile)

The uncertainty of emission estimates for source category 1A5b Other (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-25.

3.2.11.4 Category-specific QA/QC and verification for 1A5b Other (mobile)

The general QA/QC measures are described in chp. 1.2.3. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

The activity data of military aviation (1A5b), kerosene consumption, is provided by the Federal Department of Defence, Civil Protection and Sport. For a compatibility check with the emission database of civil aviation, they are sent to the FOCA (office of the Federal Department of the Environment, Transport, Energy and Communications).

3.2.11.5 Category-specific recalculations for 1A5b Other (mobile)

No category-specific recalculations were carried out.

3.2.11.6 Category-specific planned improvements for 1A5b Other (mobile)

No category-specific improvements are planned.

3.3 Source category 1B – Fugitive emissions from fuels

3.3.1 Source category description for 1B

Table 3-98 Key categories of 1B Fugitive emissions from fuels. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
1B2	Oil and natural gas energy production	CH4	L1, T1, T2

The only relevant source categories of fugitive emissions in Switzerland are:

- Oil (1B2a)
- Natural gas (1B2b)
- Venting and flaring (1B2c)

3.3.2 Source category 1B1 – Solid Fuels

Coal mining is not occurring in Switzerland. There are no greenhouse gas emissions from coal handling.

3.3.3 Source category fugitive emissions from 1B2a – Oil

3.3.3.1 Source category description for 1B2a

In Switzerland, oil production is not occurring. Fugitive emissions in the oil industry result exclusively from the refineries and several fuel handling stations. At the beginning of 2015, one of the two refineries ceased operation. The extents of the two existing oil pipelines in Switzerland are approximately 40 km and 70 km, respectively. The pipelines are mainly laid underground.

Table 3-99 Specification of source category fugitive emissions from 1B2a Oil in Switzerland.

1B2	Source category	Specification
1B2aiii	Fugitive emissions oil: Transport	Emissions only stem from pipeline transport
1B2aiv	Fugitive emissions oil: Refining / storage	Emissions from oil refining process
1B2av	Fugitive emissions oil: Distribution of oil products	Distribution of oil products (from gasoline storage tanks and gasoline stations) (only precursor emissions NMVOC)

3.3.3.2 Methodological issues for 1B2a

Methodology (1B2a)

According to the decision tree for crude oil transport, refining and upgrading, Switzerland estimates 1B2a fugitive emissions from oil based on a Tier 1 (1B2aiii Fugitive emissions oil: Transport) and a Tier 2 (1B2aiv Fugitive emissions oil: Refining / storage, 1B2av Fugitive emissions oil: Distribution of oil products) approach (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3 and for precursors EMEP/EEA 2016, Figure 3-1).

For source 1B2a fugitive emissions from oil, fugitive emissions of CH_4 are reported. They occur only in 1B2aiii Transport and 1B2aiv Refining/storage. Indirect CO_2 emissions resulting from NMVOC emissions in source category 1B2a are reported in chp. 9. As no CO emissions occur in source category 1B2a, no indirect CO_2 emissions from CO are reported.

Emission factors (1B2a)

For oil transport (1B2aiii), the default emission factors from the 2006 IPCC Guidelines for pipeline transportation are used to calculate emissions. Values provided in Table 3-100 are converted using a crude oil density of 0.82 t/m^3.

For oil refining and storage (1B2aiv), country-specific emission factors for CH_4 and NMVOC are used. The emission factors for CH_4 are delineated from an emission estimation project in one of the refineries in 1992 called CRISTAL (Raffinerie de Cressier 1992). The estimation from the other refinery is assumed to be twice as high, because the technology of the plant is older. Then a weighted mean based on the quantity of crude oil used in both refineries was calculated (for further details see the internal documentation of the EMIS database, EMIS 2020/1B2aiv). This emission factor is used for all the years until 1995. For the years 2007–2017, total NMVOC emissions from 1A1b, 1B2aiv and 1B2c correspond to those reported in the Swiss Pollutant Release and Transfer Register (PRTR) from the two refineries. For 2018, the emission factor is the same as for 2017, because data from PRTR is not available during data collection for the inventory. Therefore, emission factors in 1B2aiv are adapted to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register. Between the years 1995 and 2007 the emission factors are interpolated linearly. The ratio between CH_4 and NMVOC stays at 1:10 for all the years.

The emission factors for SO_2 emissions from Claus units in refineries are country-specific and based on measurements and data from industry and expert estimates.

For oil distribution from storage tanks and gasoline stations (1B2av), the NMVOC emission factor for oil distribution from tanks and gasoline stations is country-specific, based on a model which takes annual gasoline sales and technical equipment of gasoline stations and storage tanks into account (see internal database documentation in EMIS 2020/1B2av Benzinumschlag Tanklager and EMIS 2020/1B2av Benzinumschlag Tankstellen). An expert team (Weyer and Partner AG) is in charge of providing annual updates of the modelled NMVOC emissions based on their own database of Swiss storage tanks and gasoline vapour recovery systems. The model is calibrated with spot checks of the gas recovery systems of gas stations.

Table 3-100 Emission factors for fugitive emissions of source category 1B2a Oil in 2018.

Source/fuel	Unit	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
1B2a Oil								
Exploration	g/t	NO	NO	NO	NO	NO	NO	NO
Production	g/t	NO	NO	NO	NO	NO	NO	NO
Transport (crude oil in pipeline)	g/t	NA	6.59	NA	NA	65.9	NA	NA
Refining/Storage	g/t	NA	9	NA	NA	88	5	NA
Distribution of oil products: Gasoline storage tank	g/GJ	NA	NA	NA	NA	6.5	NA	NA
Distribution of oil products: Gasoline station	g/GJ	NA	NA	NA	NA	9.3	NA	NA

Activity data (1B2a)

For oil transport (1B2aiii) and oil refining and storage (1B2aiv), activity data (crude oil use in the refineries) are based on annual statistics of Avenergy Suisse (formerly Swiss petroleum association) (EV 2019). The annual amount of processed crude oil in Claus units is based on the Swiss overall energy statistics (SFOE 2019). Since 2014, data are considered confidential. However, they are documented in the confidential NIR, which is available to reviewers on request.

For oil distribution from storage tanks and gasoline stations (1B2av), gasoline sales based on the Swiss overall energy statistics (SFOE 2019), corrected for consumption of Liechtenstein, are used as activity data.

Table 3-101 Activity data for fugitive emissions from 1B2a Oil.

1B2a Oil products	Unit	1990	1995	2000	2005
Crude oil import (pipeline)	kt	3'127	4'657	4'649	4'877
Gasoline distribution	TJ	156'516	151'672	168'353	152'182

1B2a Oil products	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	*1990 vs. 2018 (%)*
Crude oil import (pipeline)	kt	4'833	4'546	4'452	3'455	4'935	4'975	2'836	3'006	2'889	3'076	*-2%*
Gasoline distribution	TJ	139'067	134'129	128'941	124'386	118'717	113'956	105'664	102'367	99'223	97'654	*-38%*

3.3.3.3 Uncertainties and time-series consistency for 1B2a

Based on expert judgement, a preliminary uncertainty assessment of all sources in source category 1B2a results in medium confidence in the emissions estimate (see Table 1-10).

Time series for 1B2a Oil are all considered consistent.

3.3.3.4 Category-specific QA/QC and verification for 1B2a

The general QA/QC measures are described in chp. 1.2.3 and partly also in chp. 3.2.4.8. No further source-specific activities undertaken for fugitive emissions from oil (1B2a).

3.3.3.5 Category-specific recalculations for 1B2a

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1B2a: NMVOC and therefore also the correlated CH_4 emission factors in 1B2aiv are adapted for the year 2017 to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register (PRTR). Data for the latest year is not available in the PRTR early enough for the data collection for the inventory. Therefore, the emissions are recalculated once the PRTR data is available.

3.3.3.6 Category-specific planned improvements for 1B2a

1B2ai Fugitive emissions from oil transport: Due to the fact that we use the tier 1 CH_4 emission factor of 5.4 * 10^{-6} Gg per 1000 m^3 oil transported by pipelines as published in the IPCC Guidelines 2006 (table 4.2.4), there is an overestimation of CH_4 emissions from oil transportation. This emission factor refers to pipelines above ground as used in North America. As in Switzerland the pipelines for oil transportation are all under ground, there is no emission of CH_4 from this process. This will be corrected for the next submission 2021.

3.3.4 Source category fugitive emissions from 1B2b – Natural gas

3.3.4.1 Source category description for 1B2b

Emissions from natural gas production (1B2bii) are only occurring for the years of operation of the single production plant in Switzerland from 1985–1994. Other emissions in this source category occur from natural gas transmission (1B2biv) and distribution (1B2bv). Emissions from accidents in the gas pipeline system are reported under source category 1B2bvi Other Leakage.

Table 3-102 Specification of source category fugitive emissions from 1B2b Natural gas in Switzerland.

1B2	Source category	Specification
1B2b	Fugitive emissions attributed to natural gas	Emissions from gas network

3.3.4.2 Methodological issues for 1B2b

Methodology (1B2b)

According to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1), Switzerland follows a Tier 1 approach for fugitive emissions concerning 1B2bii Production and a Tier 2 approach for fugitive emissions attributed to 1B2biv Transmission and storage as well as 1B2bv Distribution.

Emissions from source category 1B2 are key (see Table 3-98). However, the contribution from 1B2bii is small and therefore the use of a Tier 1 method for this source category is justified. The emissions from source category 1B2bii are calculated based on annual production data and default emission factors (IPCC Tier 1 approach). Production data under

1B2bii are only available for the years 1990–1994 because the single production site was closed in 1994.

For emission calculations from source category 1B2biv, 1B2bv and 1B2bvi country-specific emission factors and activity data are available. Emissions are calculated with a country-specific method which first assesses the losses of natural gas in the gas network including pipelines, fittings and gas devices, as these data represent the activity data. Based on the gas losses, CO_2, CH_4 and NMVOC emissions are calculated with country-specific emission factors which reflect the composition of the gas lost.

Emissions from gas transmission (source category 1B2biv) include emissions from transport pipelines including the transit pipeline and the single compressor station. Emissions comprise leakages from gas pipelines, small-scale damages, maintenance work and leakages of pipeline fittings. Gas storages are considered as components of the distribution network and the respective emissions are included in source category 1B2bv.

Source category 1B2bv Distribution covers emissions from the gas distribution pipelines and network components (e.g. control units, fittings and gas meters) as well as fugitive emissions at the end users. Emission calculations for the gas distribution network are based on the length, material and pressure of the gas pipelines. Fugitive emissions at the end users arise from on-site and indoor pipelines and the permanent leakiness of the different gas appliances in households, industry and natural gas fuelling stations. In the calculations, the number and kind of end users and connected gas appliances are considered.

Indirect CO_2 emissions resulting from NMVOC emissions in this source category are reported in chp. 9. As no CO emissions occur in source category 1B2b, no indirect CO_2 emissions from CO are reported.

Emission factors (1B2b)

For natural gas production, CO_2, CH_4 and NMVOC default emission factors are taken from the 2006 IPCC Guidelines (IPCC 2006) as documented in the internal emission database documentation (EMIS 2020/1B2b Diffuse Emissionen Erdgas).

Emission factors for transmission, distribution and other leakages (source categories 1B2biv, 1B2bv, and 1B2bvi) are calculated based on the weighted average CO_2, CH_4, and NMVOC concentrations and net calorific values of natural gas as annually reported by the Swiss Gas and Water Industry Association (SGWA) for the different import stations (see Quantis 2014 and EMIS 2020/1B2b Diffuse Emissionen Erdgas).

Table 3-103 Emission factors for fugitive emissions of source category 1B2b Natural gas in 2018.

1B2b Natural gas	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
1B2bii Production	NO	NO	NO	NO	NO	NO	NO
1B2biv Transmission	605	18'126	NA	NA	1'407	NA	NA
1B2bv Distribution	605	18'126	NA	NA	1'407	NA	NA
1B2bvi Other Leakage	NO	NO	NO	NO	NO	NO	NO

Activity data (1B2b)
Activity data for fugitive emissions from gas production (1B2bii) are the actual gas production data for the years 1990–1994 (SFOE 2019).

For gas transmission (1B2biv), distribution (1B2bv), and other leakage (1B2bvi), the activity data have been reassessed in a study by Quantis (2014) and updated in 2016 (EMIS 2020/1B2b Diffuse Emissionen Erdgas). The activity data represent the amount of natural gas lost from the gas network and are shown in Table 3-104.

For source categories 1B2biv and 1B2bv, information regarding the gas transport and distribution network from the Swiss Gas and Water Industry Association (SGWA) is used to derive the activity data (see Quantis 2014 and EMIS 2020/1B2b Diffuse Emissionen Erdgas).

For transmission pipelines a constant emission factor per pipeline length is applied accounting for losses from purging and cleaning flows, pipeline damages and leaky fittings and mountings. For the one compressor station a constant emission rate based on the physical power of the turbines is employed including emissions due to shutting down and starting of the gas turbines, leakages at regulating valves and fittings, maintenance and gasometry work.

The calculation of losses from source category 1B2bv Distribution follows a detailed country-specific approach that considers losses from the pipeline network as well as losses at the end users.

The calculated gas losses from the pipeline network depend on the length, material and pressure of the pipelines. Gas losses due to permanent leakiness, small-scale damages, network maintenance and the network components are evaluated separately. As no applicable loss rates are available for the network compounds in Switzerland (installed control units, fittings, storage systems and gas meters), a fixed percentage is applied to the permanent gas losses.

Regarding the end users, gas losses from on-site and indoor pipelines as well as gas losses due to the permanent leakiness of gas appliances are evaluated. Pipeline loss rates apply to the number of households, industrial users and gas fuelling stations separately. Regarding the gas appliances, different loss rates are assigned to the number of gas heating systems, gas cooking stoves and gas fuelling stations.

For some (earlier) years in the time series, sufficient input data are not available to calculate the gas losses. For these years, polynomial interpolations are applied to assess the activity data.

For significant emission events due to accidents the Swiss Pollutant Release and Transfer Register is considered, and emissions are attributed to source category 1B2bvi Other Leakage. So far, two events have been reported by the transit pipeline operator, one in 2010 and one in 2011.

Fugitive emissions from pipelines are the major emission source in source category 1B2b. Fugitive emissions from damages and ruptures of the pipelines, maintenance of the pipelines and the components are very small (Quantis 2014). Total CH_4 emissions from gas transmission and distribution decreased due to gradual replacement of cast-iron pipes with polyethylene pipes.

Table 3-104 Activity data (amount of gas lost) for fugitive emissions from 1B2b Natural gas.

1B2b Natural Gas	1990	1995	2000	2005
	GJ			
Total	868'472	847'902	687'838	545'527
1B2bii Production	130'000	NO	NO	NO
1B2biv Transmission	28'226	30'874	32'571	33'491
1B2bv Distribution	710'246	817'028	655'267	512'036
1B2bvi Other Leakage	NO	NO	NO	NO

1B2b Natural Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	1990 vs. 2018 (%)
	GJ										
Total	493'783	484'013	476'426	470'028	434'845	424'435	423'719	425'928	420'723	418'608	-52%
1B2bii Production	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-
1B2biv Transmission	34'586	34'595	34'569	34'483	34'852	35'125	35'468	35'743	36'185	36'003	28%
1B2bv Distribution	459'197	449'418	441'857	435'545	399'993	389'310	388'251	390'185	384'538	382'605	-46%
1B2bvi Other Leakage	NO	35'444	28'114	NO	NO	NO	NO	NO	NO	NO	-

3.3.4.3 Uncertainties and time-series consistency for 1B2b

According to the assessment by Quantis (2014), an uncertainty of 30% is estimated for fugitive CH_4 emissions from natural gas pipelines in Switzerland.

A preliminary uncertainty assessment of all other sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-10).

Time series for 1B2b Natural gas are all considered consistent.

3.3.4.4 Category-specific QA/QC and verification for 1B2b

The general QA/QC measures are described in chp. 1.2.3.

As suggested by the 2006 IPCC Guidelines (IPCC 2006) the gas industry was involved in the reassessment of fugitive emissions from the natural gas system in 2014 (Quantis 2014) and 2016 (EMIS 2020/1B2b Diffuse Emissionen Erdgas).

3.3.4.5 Category-specific recalculations for 1B2b

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences in emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1B2biv,v: As updated data on the gas network for the latest reported year are not available in time for the greenhouse inventory, a provisional value is assumed. Once the final data is available, the value is adjusted. Therefore, the data for 2017 were revised leading to smaller losses (-6 MJ) and therefore to a reduction of emissions of CO_2 (by 4t) and CH_4 (by 108t).

3.3.4.6 Category-specific planned improvements for 1B2b

No category-specific improvements are planned.

3.3.5 Source category 1B2c – Venting and flaring

3.3.5.1 Source category description for 1B2c

In Switzerland, oil production is not occurring, and only one production site for natural gas production was operational from 1985 – 1994. Therefore, emissions from flaring result primarily from the torches, which were operational at the two refineries (1B2ci Flaring). Since 2015, there is only one refinery in operation. In addition, CO_2 emissions from H_2 production in one of the two refineries are also reported under 1B2c.

Table 3-105 Specification of source category 1B2c Venting and flaring in Switzerland.

1B2	Source category	Specification
1B2c	Fugitive emissions attributed to venting and flaring.	The combustion of excess gas at the oil refinery (flaring) only. Emissions from H_2 production Emissions from gas production (1990-1994 only)

3.3.5.2 Methodological issues for 1B2c

Methodology (1B2c)

According to the decision tree for crude oil transport, refining and upgrading, Switzerland follows a Tier 2 method for emissions attributed to 1B2ci Flaring, Oil in order to estimate fugitive emissions under 1B2c fugitive emissions from venting and flaring (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3). For source category 1B2ci Flaring, Oil, emissions of CO_2 as well as CH_4, N_2O, NO_x, CO and NMVOC are considered. For emission calculations country-specific CO_2 emission factors and activity data are available from the refining industry.

Emissions from gas production are calculated by a Tier 1 method according to 1B2c fugitive emissions from venting and flaring according to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1). For source category 1B2cii Flaring, Gas, emissions of CO_2 as well as CH_4, N_2O and NMVOC are considered.

One of the refining plants produces H_2. Until 2017, butane was used for the production of H_2, leading to process emissions of CO_2. During 2017, additionally to butane, the refinery started to use natural gas in its hydrogen production unit. Emissions are estimated based on plant-specific data.

Since the CO_2 emission factors assume an oxidation of 100%, no indirect emissions need to be accounted for. Therefore, from this source category no indirect emissions are reported in chp. 9.

Emission factors (1B2c)

Emission factors concerning flaring of refinery gas during the refining process are documented in the internal emission database documentation (EMIS 2020/1B2c Raffinerie Abfackelung). The emission factor for CO2 is based on a study from Frischknecht et al. (1996), the emission factor for N2O is based on the expert estimate in the German NIR 2019, and those for the other greenhouse gases and precursors base on a study from USEPA (1995b) and data from the refining industry.

Since 2005 (with the exception of 2012), the refining industry provides annual data on the CO2 emissions from flaring under the Federal Act on the Reduction of CO2 Emissions (Swiss Confederation 2011) based on daily measurements of CO2 emission factors of the flared gases. From these data annual emission factors are derived. Since 2005, the evolution of the other emission factors (CH4, N2O, NOx, CO and NMVOC) is assumed to vary proportionally to the CO2 emission factor. Emission factors are considered confidential and are available to reviewers on request.

The emissions from flaring in the gas production facility are calculated based on default emission factors provided in the 2006 IPCC guidelines. CO_2 emission factors for H_2 production are confidential. Data are available to reviewers on request.

Table 3-106 Emission factors for 1B2c Venting and flaring in 2018.

Source/fuel	Unit	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
1B2ci Flaring Oil	g/t	C	C	C	C	C	C	C
1B2cii Flaring from gas production	g/GJ	NO	NO	NO	NA	NO	NA	NA
1B2ci: H2 production refinery (butane)	g/GJ	NO	NA	NA	NA	NA	NA	NA
1B2ci: H2 production refinery (natural gas)	g/GJ	C	NA	NA	NA	NA	NA	NA

Activity data (1B2c)

Before 2005, the amount of flared gas during the refining process is assumed to be proportional to the amount of crude oil processed in the refineries. Avenergy Suisse (formerly the Swiss petroleum association EV) provides data on the use of crude oil on an annual basis (EV 2019). Between 2001 and 2004, one of the two refineries made major changes to their installations (new cracker, new flaring installation) and their standard operation process. Therefore, emissions from flaring decreased significantly thereafter. Since 2005, the industry provides data on the amount of gas flared.

For gas production, the amount flared is estimated based on the amount of gas produced.

For H_2 production in one of the refining plants, annual data on butane and natural gas consumption are provided by the industry since 2005, when the H_2 production unit was installed. Data are confidential and they are available to reviewers on request.

Table 3-107 Activity data for 1B2c Venting/flaring.

1B2c Venting and flaring	Unit	1990	1995	2000	2005
1B2ci Flaring Oil	kt	3'127	4'657	4'649	4'877
1B2cii Flaring Gas	GJ	130'000	NO	NO	NO
1B2ci: H2 production in refinery (butane and natural gas)	GJ	NO	NO	NO	C

1B2c Venting and flaring	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1B2ci Flaring Oil	kt	4'833	4'546	4'452	3'455	4'935	C	C	C	C	C
1B2cii Flaring Gas	GJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B2ci: H2 production in refinery (butane and natural gas)	GJ	C	C	C	C	C	C	C	C	C	C

3.3.5.3 Uncertainties and time-series consistency for 1B2c

A preliminary uncertainty assessment of all sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-10).

Consistency: Time series for 1B2c Venting and flaring are all considered consistent.

3.3.5.4 Category-specific QA/QC and verification for 1B2c

The general QA/QC measures are described in chp. 1.2.3. No category-specific QA/QC activities were undertaken.

3.3.5.5 Category-specific recalculations for 1B2c

The following recalculations were implemented in submission 2020. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 3 Energy between the latest and the previous submission are presented also in chp. 10.1.2.1.

- 1B2c, flaring: The emission factor for N_2O was taken from table 4.2.5, Oil production in the IPCC 2006 Guidelines. But this emission factor refers to flaring while crude oil is produced (= oil production) and not to the flaring during refining processes. Unfortunately, the emission factors for flaring in oil refineries are not defined in the IPCC 2006 Guidelines. Therefore, the expert estimate in the German NIR 2019, table 181 for N_2O emissions for flaring in refineries is taken to calculate the one from Switzerland. This results in around 3kt lower N_2O emissions for every year 1990–2017.

3.3.5.6 Category-specific planned improvements for 1B2c

No category-specific improvements are planned.

3.4 Source category 1C – CO_2 transport and storage

CO_2 transport and storage is not occurring in Switzerland.

4 Industrial processes and product use (IPPU)

Responsibilities for sector Industrial processes and product use (IPPU)	
Method updates & authors	Sabine Schenker (FOEN), Cornelia Stettler (Carbotech; F-gases)
EMIS database operation	Sabine Schenker (FOEN), Anouk-Aimée Bass (FOEN, F-gases)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest), Cornelia Stettler (Carbotech; F-gases), Dominik Eggli (Meteotest)
Quality control (annual updates)	Felix Weber (INFRAS), Adrian Schilt (FOEN), Regine Röthlisberger (FOEN), Caroline Becker (Carbotech; F-gases)
Internal review	Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN, F-gases), Stefan Reimann (EMPA, F-gases)

4.1 Overview

This chapter provides information on the estimation of the GHG emissions from sector 2 Industrial processes and product use. The following source categories are reported:

- 2A Mineral industry
- 2B Chemical industry
- 2C Metal industry
- 2D Non-energy products from fuels and solvent use
- 2E Electronics industry
- 2F Product uses as substitutes for ozone-depleting substances (ODS)
- 2G Other product manufacture and use
- 2H Other

Emissions within this sector comprise GHG emissions as by-products from industrial processes and also emissions of F-gases during production, use and disposal. Emissions from fuel combustion in industry are reported in source category 1A2 under sector 1 Energy.

According to the 2006 IPCC Guidelines this sector provides also information on the GHG emissions from solvent and product use. CO_2 emissions from solvent and partly from product use are due to post-combustion of NMVOC in order to reduce NMVOC in exhaust gases. The disposal of solvents is reported in the waste energy sector (waste derived fuels, chp. 3.2.6).

Indirect emissions of CO_2 from fossil CO and NMVOC as well as of N_2O from NO_x and NH_3 emissions are included in CRF Table6 and reported in chapter 9. Since the CO_2 emissions from the cracker reported in source category 2B8b Ethylene, from 2C1 Secondary steel production, electric arc furnace and from 2C3 Primary aluminium production are based on carbon mass balances their emissions of CO (from source categories 2C1 and 2C3) and NMVOC (from source categories 2C1 and 2B8b) are not accounted for in the calculation of the indirect CO_2 emissions. Biogenic NMVOC and CO emissions occur in source category 2H2 Food and beverages and 2G4 tobacco consumption and are not reported as indirect CO_2 emissions.

For several industrial processes within source categories 2A Mineral industry, 2B Chemical industry and 2C Metal industry, data and information on emission factors and activity data are classified as confidential (C), because they refer to a single enterprise. For reviewers, there is an additional version of chapter 4 Industrial processes and product use (IPPU)available, including all confidential data and information.

Figure 4-1 shows the evolution of greenhouse gas emissions in sector 2 between 1990 and 2018.

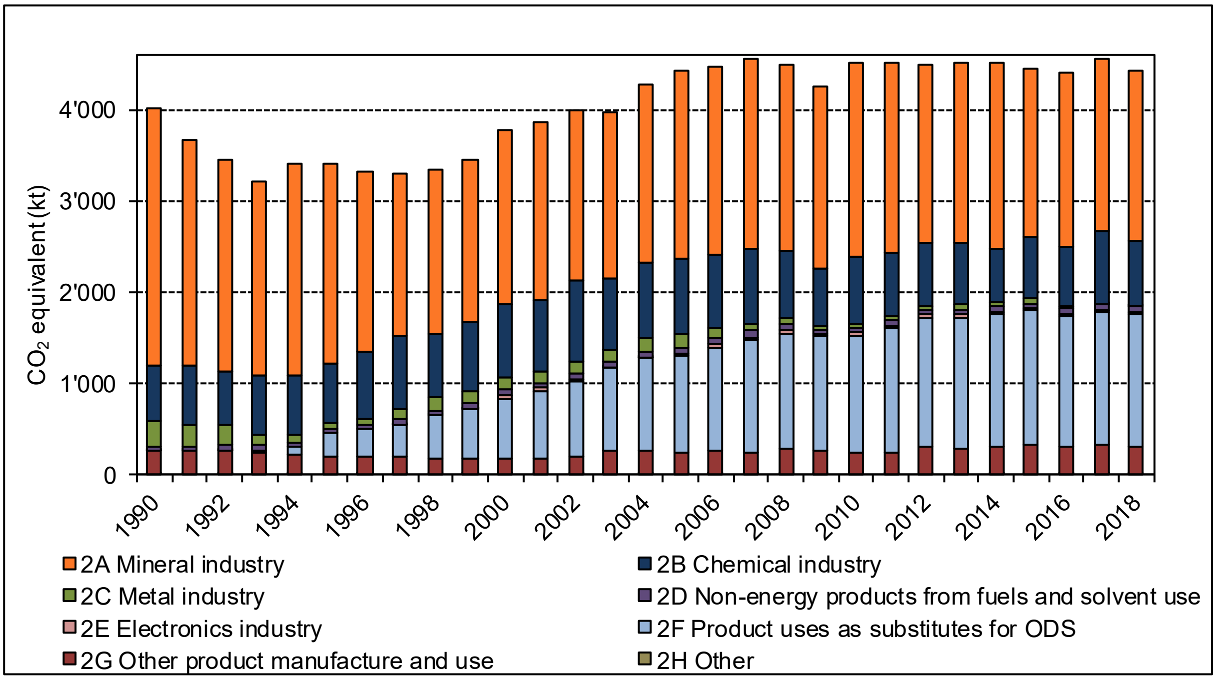


Figure 4-1 Switzerland's greenhouse gas emissions of sector 2 Industrial processes and product use.

2A Mineral industry remains the dominant source of sector 2 accounting for around 40% of the GHG emissions in 2018 although absolute emissions have decreased since 1990. 2B Chemical industry accounts for a share of around 20% and shows no clear trend since 1990. 2C Metal industry shows a strong decreasing trend and accounts only for a very small share in 2018. 2D Non-energy products have also only a minor contribution in 2018.

2F Product uses as substitutes for ozone depleting substances (ODSs) is of increasing importance: The emissions have increased since 1990 and account for almost a third of total GHG emissions in sector 2 in 2018. This is primarily due to the replacement of CFCs and other ODSs by HFCs in many technical applications. 2G Other product manufacture and use shows no clear trend since 1990. 2E Electronic industry and 2H Other are of little importance with regard to the overall GHG emissions of sector 2.

In Table 4-1, the development of GHG emissions in sector 2 Industrial processes and product use is given by gases. Dominant gases are CO_2, F-gases and N_2O in 2018 whereas CH_4 has only a minor contribution. The relative trend of these gases referring to the base year 1990 is shown in Figure 4-2 and Figure 4-3.

Table 4-1 GHG emissions of sector 2 Industrial processes and product use by gases in kt CO_2 equivalent.

Gas	1990	1995	2000	2005
	CO_2 equivalent (kt)			
CO_2	3'155	2'421	2'205	2'378
CH_4	1.8	1.8	1.7	2.6
N_2O	604	642	719	743
F-gases	254	354	849	1'306
Sum	4'014	3'420	3'775	4'429

Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	CO_2 equivalent (kt)									
CO_2	2'211	2'372	2'326	2'201	2'204	2'257	2'088	2'164	2'136	2'114
CH_4	1.9	2.7	2.8	2.8	2.1	2.1	2.2	2.7	2.9	2.8
N_2O	553	635	609	588	580	493	574	528	682	588
F-gases	1'498	1'510	1'589	1'711	1'723	1'758	1'795	1'714	1'740	1'717
Sum	4'264	4'519	4'526	4'503	4'509	4'511	4'459	4'408	4'561	4'422

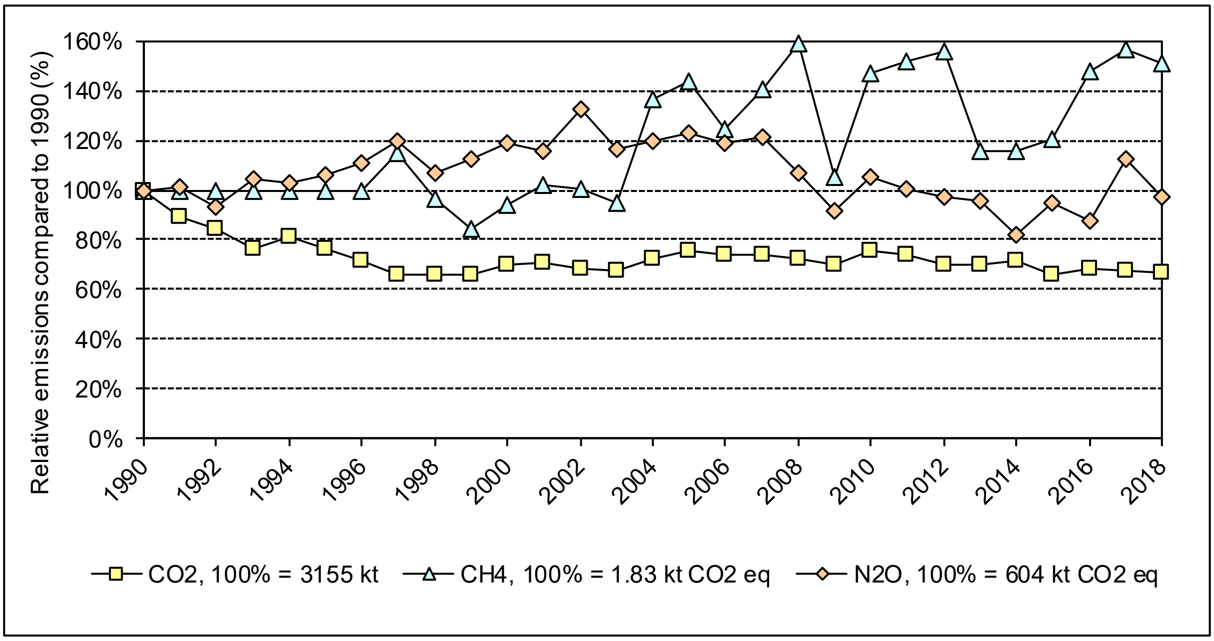


Figure 4-2 Relative trends of the greenhouse gas emissions (without F-gases, see Figure 4-3) of sector 2 Industrial processes and product use. The base year 1990 represents 100%.

Figure 4-2 shows that the emissions of CO_2 decreased between 1990 and 1998 and since then, they remain at a constant level. Emissions of N_2O from sector 2 Industrial processes and product use have increased slowly between 1990 and 2002 and decreased afterwards; in 2018 they are at a similar level as in 1990. Emissions of CH_4 have increased in the same time period with considerable interannual fluctuation. However, absolute emissions are small compared to CO_2 and N_2O.

Figure 4-3 shows a large increase in emissions of F-gases compared to the year 1990. Main contributions in the inventory 1990 result from the PFC emissions in the smeltering process of aluminium production (chp. 4.4.2.2) and from the use of SF_6 in electrical equipment and sound proof windows (chp. 4.8.2.1 and chp. 4.8.2.2). The increase between 1995 and 2012 is due to the increasing product uses of HFCs as substitutes for ODS (chp. 4.7) in refrigeration and air conditioning. Since 2012, emissions remain at a constant level. Most relevant and main source of F-gases emissions in 2018 is the use of HFC in refrigeration and air conditioning.

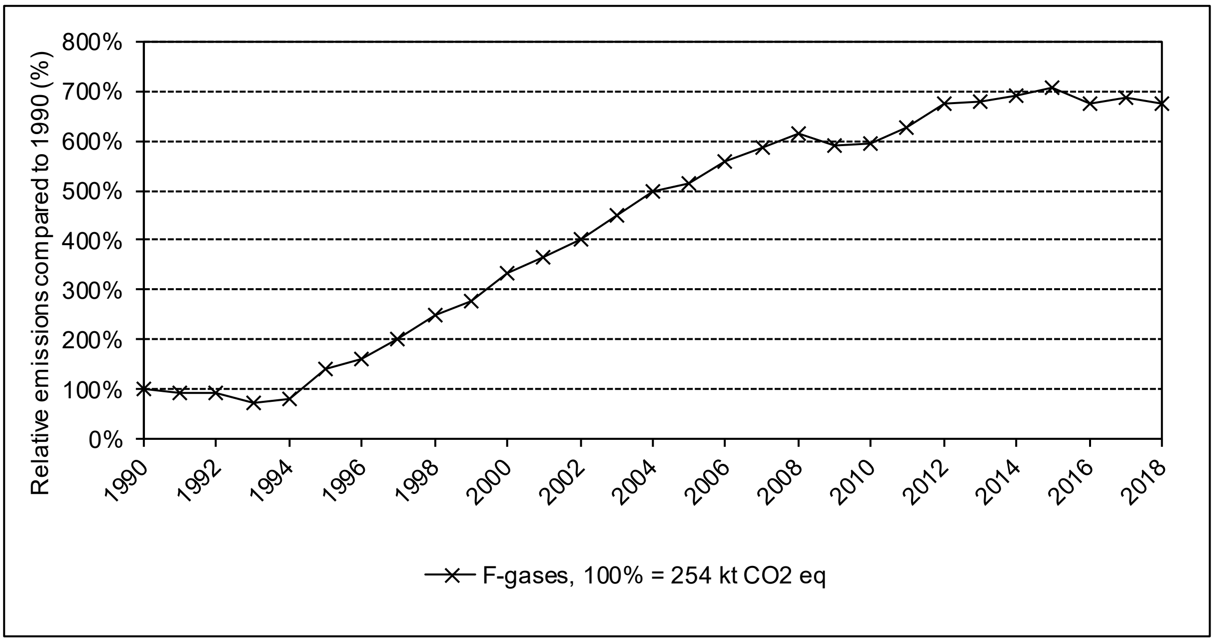


Figure 4-3 Relative trends in emissions of F-gases in sector 2 Industrial processes and product use. The base year 1990 represents 100%.

4.2 Source category 2A – Mineral industry

4.2.1 Source category description

Table 4-2 Key categories of 2A Mineral industries. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2A1	Cement production	CO2	L1, L2, T1, T2

Table 4-3 Specification of source category 2A Mineral industry.

2A	Source category	Specification
2A1	Cement production	Geogenic CO_2 emissions from calcination process in cement production; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations
2A2	Lime production	Geogenic CO_2 emissions from calcination process in lime production; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations
2A3	Glass production	Geogenic CO_2 emissions from production of container and tableware glass, and glass wool
2A4	Other process uses of carbonates	Geogenic CO_2 emissions from production of fine ceramics, bricks and tiles and rockwool; Geogenic CO_2 emissions from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants and cellulose production (ceased in 2008); Geogenic CO_2 emissions from use of sodium bicarbonate; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations in plaster production

4.2.2 Methodological issues

4.2.2.1 Cement production (2A1)

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a capacity of 3’000 tonnes of clinker per day. All of them use modern dry process technology.

Emissions of geogenic CO_2 occur during the production of clinker, which is an intermediate component in the cement manufacturing process. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is heated (calcined) to produce lime (CaO) and CO_2 as by-product. The CaO reacts subsequently with minerals in the raw materials and yields clinker. During this reaction step no further CO_2 is emitted. Clinker is then mixed with other components such as gypsum to make cement.

Blasting operations in the limestone quarries are another source of emissions for both CO_2 and precursor greenhouse gases such as NO_x, CO, NMVOC and SO_2.

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

Calcination process

The geogenic CO_2 emissions from the calcination process in cement production are determined by a Tier 2 method according to the decision tree Fig. 2.1. of 2006 IPCC Guidelines (vol. 3, chp. 2.1 Cement production).

In Switzerland, no long wet or long dry kilns are used. Only modern preheater or precalciner kilns are used and also no so-called low-alkali cement is produced. Therefore, there is no land-filling of calcined cement dust (cement kiln dust, CKD) in Switzerland. In the cement plants all the filter dust is collected in high performance electrostatic precipitator or bag filters (having an efficiency of more than 99.999%) and being recycled to the kiln feed. In some cases small portions of the CKD are added directly to the cement as filler. Due to the kiln technology used in Switzerland the degree of decarbonization of the CKD is almost equal to that of the kiln feed, meaning, that this CKD has not been decarbonised yet.

Blasting operations

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to EMEP/EEA Guidebook (EMEP/EEA 2019, chp. 2A1, Fig. 3.1) using country-specific emission factors. The CO_2 emissions from "blasting" are related only to the usage of explosives in the quarries and not to the fuel consumption of construction machinery such as bulldozers etc. The amount of used explosives is reported to be 0.13 kg/t cement[11] (EMIS 2020/2A1 Zementwerke übriger Betrieb).

Total emissions reported for the production of cement are the sum of emissions from calcination process and blasting operations. The share of CO_2 emissions from blasting operations in limestone quarries is well below one tenth of a percent of the geogenic CO_2 emissions from the calcination process.

Emission factors

Calcination process

The emission factor of CO_2 from calcination is provided per tonne of clinker. It accounts for geogenic emissions from the carbonate containing raw material, emissions from organic carbon content of the raw material and from cement kiln dust (CKD).

[11] The CO_2 emission factor for the use of blasting agents amounts to 600 kg CO_2/t of blasting agent. For the average amount on blasting agent used per kg cement measurement data for the year 2002 were taken. Measurement data were available for four Swiss cement plants, covering more than 60% of the Swiss cement production. Therefore, this information is considered representative for cement plants in Switzerland.

The base emission factor of 525 kg CO_2/t clinker used in the Swiss ETS corresponds to the value provided by the Cement Sustainability Initiative (CSI) in its report "CO_2 and Energy Accounting and Reporting Standard for the Cement Industry – The Cement CO_2 and Energy Protocol" (see method B1, p. 9 in CSI 2011). Data from the Swiss cement industry for the years 2008–2011 showed that CaO contents in clinker typically varied between 63 – 66%, while MgO contents were around 2%. This resulted in EF that varied from 529 to 532 kg CO_2/t clinker for those years (weighted average from the values of the six cement plants). However, these contents already contained fractions deriving from non-carbonate sources. Therefore, it was decided in the ETS to define the base EF as described in the CSI Protocol and then add a share for non-carbonate C and CKD. In submission 2017, the EF was revised in order to establish a consistent time series from 1990 – 2015 and also to achieve consistency between the Swiss ETS and the greenhouse gas inventory (CSI 2011).

The emissions from the organic carbon content of the raw material are assumed to be a constant share of 0.2% of the raw material (i.e. 11.37 kg CO_2/t clinker). The emission factor of CKD is estimated based on plant-specific data available for 2013–2016 that were provided by the cement industry association (cemsuisse). From this data, an average emission factor of CO_2 from CKD is calculated (0.35 kg CO_2/t clinker). As the CKD represents only an insignificant proportion of the total EF, no annual update is provided.

Based on these three partial emission factors (base, non-carbonate C and CKD) a total emission factor per ton of clinker is calculated. This results in a country-specific EF of 536.7 kg CO_2/t clinker, which represents a tier 2 approach according to the 2006 IPCC Guidelines (IPCC 2006). The emission factor is assumed constant for the entire time period. Given that the cement plants have not changed the source of their raw material, it is justified to assume a constant EF over the entire time period.

Table 4-4 CO_2 emission factor for calcination in 2A1 Cement Production 1990 to 2018.

2A1 Cement production	**1990 - 2018**
	kg/t clinker
Calcination, CO_2	536.7

Blasting operations

The emission factors are country-specific based on emission factors of civil explosives and information on the specific consumption of explosives in the quarries as documented in the Handbook on emission factors for stationary sources (SAEFL 2000) as documented in the EMIS database (EMIS 2020/2A1 Zementwerke übriger Betrieb). They are assumed to be constant over the entire time period and are given per tonne of clinker.

Table 4-5 Emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in g/t clinker from source category 2A1 Cement Production in 2018.

2A1 Cement production	**CO_2**	**NO_X**	**CO**	**NMVOC**	**SO_2**
	g/t clinker				
Blasting operations	34.1	3.3	3.3	8.6	0.1

Activity data

Since 1990, data on annual clinker production are provided by the industry association cemsuisse as documented in the EMIS database (EMIS 2020/2A1_Zementwerke Rohmaterial). From 2008 onwards they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-6 Activity data of clinker production.

2A1 Cement production	1990	1995	2000	2005
	kt			
Clinker production	4'808	3'706	3'214	3'442

2A1 Cement production	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt									
Clinker production	3'443	3'642	3'587	3'368	3'415	3'502	3'195	3'296	3'279	3'239

4.2.2.2 Lime production (2A2)

During the production of lime calcium carbonate ($CaCO_3$) is heated (calcined) yielding burnt lime (CaO) and CO_2 as by-product. In Switzerland, there is only one plant producing lime.

There is no industry in Switzerland producing lime for its own requirements, except for sugar production. A request to both sugar producing plants confirmed that indeed they produce lime from limestone in own shaft kilns. However, the CO_2 is re-captured in the sugar production process and thus no CO_2 emissions occur.

Blasting operations in quarries are another source of emissions for both CO_2 and precursor emissions such as NO_x, CO, NMVOC and SO_2.

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

Calcination process

Since 2013, the geogenic CO_2 emissions from the calcination process in lime production are determined by a Tier 3 method using plant-specific emission factors according to the decision tree Fig. 2.2. of 2006 IPCC guidelines (vol. 3, chp. 2.2 Lime production). Between 1990 and 2012, a Tier 2 method is applied.

Blasting operations

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to EMEP/EEA Guidebook 2019 (EMEP/EEA 2019, chp. 2A2, Fig. 3.1) using country-specific emission factors. The CO_2 emissions from "blasting" are related only to the usage of explosives in the quarries and not to fuel consumption of e.g. bulldozers etc.

Total emissions reported for the production of lime are the sum of emissions from calcination process and blasting operations. CO_2 emissions from blasting operations in limestone quarries account only for a small share of the total emissions.

Emission factors

Calcination process

The emission factor for CO_2 from calcination of limestone depends both on the purity of the limestone and the degree of calcination (i.e. amount of rest CO_2 remaining in the lime produced). A plant-specific value has been calculated based on industry declaration and it is assumed to be constant for the years 1990–2012 (EMIS 2020/2A2 Kalkproduktion, Rohmaterial). The value is confidential and is available to reviewers on request. Since 2013, emission factors are derived from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-7 CO_2 emission factor for calcination process in lime production in kg/t lime for 1990–2018 are documented in the confidential NIR, which is available to reviewers on request.

Blasting operations

The emission factors are country-specific as documented in EMIS 2020/2A2 Kalkproduktion, übriger Betrieb. The values are confidential and they are available to reviewers on request.

Table 4-8 CO_2 emission factor for the calcination process in lime production in kg/t lime and emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in g/t lime in 2018.

2A2 Lime production	Unit	CO_2	NO_X	CO	NMVOC	SO_2
Calcination	kg/t	C	NA	NA	NA	NA
Blasting operations	g/t	C	C	C	C	C

Activity data

Activity data on annual lime production are provided by the only existing plant in Switzerland, as documented in the EMIS database (EMIS 2020/2A2 Kalkproduktion, Rohmaterial and EMIS 2020/2A2 Kalkproduktion übriger Betrieb). Since 2009 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Detailed activity data are not reported since they are considered confidential.

Table 4-9 In the confidential NIR, the respective table with activity data on lime production are separately reported and available to reviewers.

4.2.2.3 Glass production (2A3)

Source category 2A3 Glass production comprises geogenic CO_2 emissions from the carbonate containing raw materials, i.e. soda ash, limestone and dolomite. In Switzerland, the following three glass types are produced: container glass, tableware glass and glass wool. Today, there is only one production plant remaining for container glass and tableware glass after the other plants closed in 2002 and 2006, respectively. Glass wool is produced in two plants.

Methodology

For determination of geogenic CO_2 emissions from glass production, a Tier 2 method according to the decision tree Fig. 2.3 of 2006 IPCC Guidelines (vol. 3, chp. 2.4 Glass production) is used. For glass production in Switzerland this results in the following formula:

$$CO_2 \text{ Emissions} = M_{\text{Glass type}} \bullet EF_{\text{Glass type}} \bullet (1 - \text{cullet ratio})$$

The cullet ratio describes the share of recycled glass material which is used in the production. The melting of cullet causes no geogenic CO_2 emissions.

From 2005 onwards, the geogenic CO_2 emissions from 2A3 Container glass production is determined according to a Tier 3 method based on the amount of carbonate containing raw materials used, i.e. soda, dolomite and limestone and their effective carbonate content.

Emission factors

The emission factors for glass production in Switzerland are taken from IPCC 2006 (vol.3, chp. 2.4 Glass production, Table 2.6). For the production of container glass (1990–2004), tableware glass (1990–2018) and glass wool (1990–2018) the values for glass type container, tableware and fibreglass are taken, respectively. As the emission factors are material properties, they remain constant over time.

From 2005 onwards, effective amounts of carbonate containing raw materials (soda ash, dolomite and limestone) are available from ETS monitoring reports for the container glass production and thus the corresponding default CO_2 emission factors are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-10 Geogenic CO_2 emission factor for glass production in g/t glass and g/t carbonate containing raw material (IPCC 2006).

2A3 Glass production	**Unit**	**CO_2 geogenic**	
Glass wool (fibre glass insulation)	g/t	250'000	
Glass (speciality tableware)	g/t	100'000	
		1990–2004	**2005–2018**
Container glass	g/t	210'000	
Soda use	g/t soda		414'920
Dolomite use	g/t dolomite		477'320
Limestone use	g/t limestone		439'710

Table 4-11 In the confidential NIR, a comparison of implied CO_2 emission factors based on Tier 2 and Tier 3 approaches is provided for container glass production in g/t glass for the time period 2005–2011.

Figure 4-4 In the confidential NIR, a comparison of Tier 2 and Tier 3 methods for deriving emission factors of geogenic CO2 from 2A3 Container glass production is provided for the years between 2005 and 2011.

Activity data and cullet ratios

Source category 2A3 Glass production is dominated by the emissions from the production of container glass and glass wool.

For glass wool production, activity data are based on data from the two glass wool production plants in Switzerland. Since 2008, activity data are based on plant-specific annual monitoring reports.

Activity data of tableware and container glass production are based on data from Swiss glass producers.

Detailed information on activity data for container glass production and tableware production is confidential as there is only one production plant for container glass and tableware glass, respectively. Data are available to the reviewers on request (EMIS 2020/2A3 Hohlglas Produktion, EMIS 2020/2A3 Glas übrige Produktion and EMIS 2020/2A3 Glaswolle Produktion Rohprodukt).

Table 4-12 Activity data of glass production in Switzerland and cullet ratio in % as well as consumption of carbonate containing raw materials in container glass production

2A3 Glass production	Unit	1990	1995	2000	2005
Container glass					
Production	kt	C	C	C	C
Cullet ratio	%	C	C	C	NA
Soda use	kt	NA	NA	NA	C
Dolomite use	kt	NA	NA	NA	C
Limestone use	kt	NA	NA	NA	C
Glass (speciality tableware)					
Production	kt	C	C	C	C
Cullet ratio	%	C	C	C	C
Glass wool					
Production	kt	24	24	31	37
Cullet ratio	%	21	45	69	65

2A3 Glass production	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Container glass											
Production	kt	C	C	C	C	C	C	C	C	C	C
Cullet ratio	%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Soda use	kt	C	C	C	C	C	C	C	C	C	C
Dolomite use	kt	C	C	C	C	C	C	C	C	C	C
Limestone use	kt	C	C	C	C	C	C	C	C	C	C
Glass (speciality tableware)											
Production	kt	C	C	C	C	C	C	C	C	C	C
Cullet ratio	%	C	C	C	C	C	C	C	C	C	C
Glass wool											
Production	kt	33	36	41	39	33	32	31	32	36	40
Cullet ratio	%	69	71	72	61	67	67	67	67	69	69

4.2.2.4 Other process uses of carbonates (2A4)

Source category 2A4 Other process uses of carbonates comprises geogenic CO_2 emissions from production of fine ceramics (2A4a), bricks and tiles (2A4a) and rockwool (2A4d), from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants (2A4d) and cellulose production (ceased in 2008) (2A4d), and from use of sodium bicarbonate (2A4d) as well as emissions of CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in plaster production (2A4d). The limestone use in cupola furnaces of iron foundries has been reallocated from source category 2A4d to 2C1. Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Ceramics (2A4a)

Source category 2A4a Ceramics consists of the production of fine ceramics and brick and tile.

Fine ceramics (2A4a)

In Switzerland, the main production of fine ceramics is sanitary ware. The carbonate containing raw materials limestone and dolomite as well as small amounts of soda ash are used in product glazes only. All information on the fine ceramics production is documented in EMIS 2020/2A4a Feinkeramik Produktion.

Methodology

The geogenic CO_2 emissions from fine ceramics production are determined by a Tier 2 method according to the decision tree Fig. 2.4 of 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates).

For fine ceramics production in Switzerland, this results in the following formula:

$$CO_2 \text{ Emissions} = (M_{Limestone} \bullet EF_{Limestone}) + (M_{Dolomite} \bullet EF_{Dolomite}) + (M_{Soda\ Ash} \bullet EF_{Soda\ Ash})$$

Emission factors

The CO_2 emission factors of limestone, dolomite and soda ash are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-13 Geogenic CO_2 emission factors used for fine ceramics and the production of brick and tile in g/t carbonate containing raw material and g/t product, respectively.

2A4a Ceramics	Unit	CO_2 geogenic						
Fine ceramics		1990–2018						
Limestone use	g/t limestone	439'710						
Dolomite use	g/t dolomite	477'320						
Soda use	g/t soda	414'920						
		1990–2012	2013	2014	2015	2016	2017	2018
Brick and tile production	g/t	117'000	100'000	110'000	103'000	112'000	113'000	107'000

Activity data

Activity data for carbonate containing raw materials (i.e. limestone, dolomite and soda ash) used in the glazes of the fine ceramics production are extrapolated values based on industry data from the largest production plant in Switzerland. Detailed activity data are considered confidential. They are available to the reviewers on request.

Brick and tile production (2A4a)

In Switzerland, there are about 20 plants producing bricks and tiles. The manufacturing process uses limestone containing clay as main raw material.

Methodology

The brickearth used in Switzerland for the production of bricks and tiles does not consist of pure and defined contents of clay minerals but its clay content is varying depending on the individual pit, comprising other minerals such as calcite, dolomite and quartz. Compared to other countries, the fraction of carbonate containing raw material is relatively high. Detailed data on the composition of carbonate containing raw materials from the Swiss brick and tile industry were not available before 2013. Therefore, for the period 1990 until 2012 data from a comparison of geogenic CO_2 emissions based on representative analyses of the carbonate content of the clay used for brick and tile production in a number of plants in Switzerland and the European Union are applied. This study was carried out by the Swiss association of brick and tile industry (Verband Schweizerische Ziegelindustrie, VSZ) in 2012 (see EMIS 2020/2A4a Ziegeleien).

Since 2013, the Swiss brick and tile production plants are legally obliged to report geogenic emissions from carbonate containing raw materials annually (Federal Act on the Reduction of CO_2 Emissions, Swiss Confederation 2011 and Ordinance for the Reduction of CO_2 Emissions, Swiss Confederation 2012). The emissions are estimated from analyses of the carbonate content of the raw materials and an assumed calcination factor of 100%. This procedure corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates). Between 1990 and 2012 a Tier 2 method is applied.

Emission factors

According to the above mentioned study, bricks emit a weighted average of 13.2% of geogenic CO_2 (variation range 5.4%–24%) and roof tiles have a weighted average of 8.6% (variation range 5.6%–13%). Based on the production shares of the largest Swiss brick producer, a production ratio for bricks to tiles of 2:1 was assumed for the whole period from 1990 to 2012. This resulted in an average geogenic CO_2 emission factor of 117 kg CO_2/t brick and tile, which was assumed constant for the time period 1990 to 2012.

Since 2013, a production weighted emission factor is derived based on the plant-specific monitoring data of the geogenic CO_2 emissions from the carbonate containing raw materials. For emission factors see Table 4-13.

Activity data

Activity data are based on production data from the Swiss association of brick and tile industry (VSZ). Since 2011 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-14 Activity data for the production of fine ceramics including the use of limestone, soda and dolomite in the glazes, brick and tile, rock wool and plaster as well as other use of carbonates (sodium bicarbonate).

2A4a Ceramics	1990	1995	2000	2005
	kt			
Fine ceramics production	C	C	C	C
Limestone use	C	C	C	C
Dolomite use	C	C	C	C
Soda use	C	C	C	C
Brick and tile production	1'271	1'115	959	1'086
2A4d Other				
Rock wool production	C	C	C	C
Carbonate use in waste incineration plants	0.71	0.76	0.82	0.61
Limestone use in cellulose	8.5	9.4	9.3	8.3
Other use of carbonates	5.9	5.4	7.0	7.3
Plaster production	319	304	288	327

2A4a Ceramics	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt									
Fine ceramics production	C	C	C	C	C	C	C	C	C	C
Limestone use	C	C	C	C	C	C	C	C	C	C
Dolomite use	C	C	C	C	C	C	C	C	C	C
Soda use	C	C	C	C	C	C	C	C	C	C
Brick and tile production	701	879	800	792	785	765	726	660	622	581
2A4d Other										
Rock wool production	C	C	C	C	C	C	C	C	C	C
Carbonate use in waste incineration plants	NO	NO	NO	NO	NO	NO	6.5	6.6	6.8	7.2
Limestone use in cellulose	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other use of carbonates	6.6	6.9	6.4	7.6	6.1	7.5	6.7	6.8	6.5	7.4
Plaster production	293	335	293	271	213	166	140	148	146	152

Other uses of soda ash (2A4b)

Soda ash is mainly used in the glass production, which is reported separately in source category 2A3 Glass production. A very small amount of soda ash is also applied in glazes of fine ceramics and is thus accounted for in source category 2A4a Ceramics (see Table 4-13). Based on a study investigating carbonate use in industry (INFRAS 2015), it is concluded that there are no known other uses of soda ash (2A4b) in Switzerland. No soda ash is used in flue gas or wastewater treatment.

Other (2A4d)

Rock wool production (2A4d)

In Switzerland, there is one single producer of rock wool. The plant uses carbonate containing raw materials like dolomite, basalt, cement and further additives as documented in the EMIS database (EMIS 2020/2A4d Steinwolle Produktion).

Methodology

Since 2013, rock wool manufacturers are legally obliged to report geogenic CO_2 emissions from carbonate containing raw material annually. For the years 2005–2011 and 2013 plant-specific data on raw material consumption and emission factors is available from monitoring reports of the Swiss ETS. From this information, data for the other years are interpolated for calculating an implied emission factor.

The geogenic CO_2 emissions from rock wool production are determined by a Tier 3 method according to IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Before 2004, a Tier 2 method was applied.

Emission factors

For rock wool production in Switzerland, the CO_2 emission factor is based on measurements of the oxides (CaO, MgO, Na_2O, K_2O, MnO) of the carbonate containing raw materials and the product for the years 2005 to 2011 as well as since 2013. Based on the difference in the oxide content in the raw material and the products, the total geogenic CO_2 emissions are determined. Consequently, the emission factor is specified as g/t rock wool. Since data on the carbonate content are missing for the years 1990 to 2004 and 2012 the mean value of the years 2005–2011 and 2013 is applied for these years.

The CO_2 emission factors are confidential. They are available to reviewers on request.

Table 4-15 Geogenic CO_2 emission factors used for rock wool production and other carbonate uses, CO_2 fossil, NO_x, CO, NMVOC and SO_2 emission factors for plaster production in g/t carbonate containing raw material and g/t product, respectively for 2018.

2A4d Other	Unit	CO_2 geogenic	CO_2 fossil	NO_x	CO	NMVOC	SO_2
Rock wool production	g/t	C	NA	NA	NA	NA	NA
Carbonate use in waste incineration plants	g/t	523'880	NA	NA	NA	NA	NA
Other carbonate uses	g/t	523'880	NA	NA	NA	NA	NA
Plaster production	g/t rocks	NA	144	5.6	33	14.4	0.24

Table 4-16 In the confidential NIR, the respective table with geogenic CO_2 emission factors used for rock wool production is separately reported and available to reviewers.

Activity data

Activity data are based on industry data from the single rock wool production plant in Switzerland (monitoring reports of the Swiss ETS) and are therefore confidential. They are available to reviewers on request.

Other carbonate uses (2A4d)

In 2014, an assessment was carried out in order to identify sources of CO_2 emissions from carbonate use for sulphur oxide removal and acid neutralization, which were not considered in the Swiss greenhouse gas inventory so far (INFRAS 2015). The survey among selected potentially relevant industrial plants, industry associations, Swiss cantons and the Swiss customs administration (EZV) comprised the following substances: limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), sodium bicarbonate ($NaHCO_3$) and soda ash (Na_2CO_3).

Besides applications of calcium hydroxide and sodium hydroxide in flue gas treatment also a few applications of limestone and sodium bicarbonate for sulphur oxide removal could be identified in Switzerland. Limestone had been used in the cellulose production up to 2008, when the plant was closed, and in one municipal solid waste incineration plant up to 2005. Since 2013, several waste incineration plants are using sodium bicarbonate.

In cupola furnaces of iron foundries limestone is also used as flux. The resulting geogenic CO_2 emissions are reported in 2C1 Iron and steel production. Limestone is also used to neutralize acid wastewater in one chemical production plant. These emissions are reported in source category 2B10 Limestone pit.

Additionally, it is assumed, that all other applications of sodium bicarbonate result in a complete conversion to CO_2. Since there is no production of sodium bicarbonate in Switzerland, the annual emissions can be estimated based on the net import.

Methodology

The method for calculating the geogenic CO_2 emissions from the use of limestone and sodium bicarbonate in all the source categories mentioned above – except in waste incineration plants from 1994 onwards – corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of 2006 IPCC guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates).

The method for calculating the geogenic CO_2 emissions from the use of limestone and sodium bicarbonate in waste incineration plants from 1994 onwards corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of 2006 IPCC guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates).

Emission factors

The emission factors of limestone and sodium bicarbonate are based on the stoichiometry of $CaCO_3$ (2006 IPCC Guidelines, vol. 3 chp. 2.1, table 2.1, IPCC 2006) and $NaHCO_3$ (CRC 2004), respectively, see Table 4-15. A conversion factor of 100% is assumed for all applications of both carbonates.

Activity data

Activity data on limestone use in flue gas treatment in cellulose production are based on expert estimates on the specific consumption of limestone per tonne of cellulose as documented in the EMIS database (EMIS 2020/1A2d Zellulose Produktion).

The activity data of limestone and sodium bicarbonate use in waste incineration plants are provided by the industry as documented in the EMIS database (EMIS 2020/1A1a Kehrichtverbrennungsanlagen).

The activity data of sodium bicarbonate correspond to difference between the net import of sodium bicarbonate and the amount of sodium bicarbonate used in waste incineration plants. The net import data are provided by the Swiss customs administration as documented in the

EMIS database (EMIS 2020/2A4d Karbonatanwendung weitere). For activity data see Table 4-14.

Plaster production (2A4d)

Methodology

There are two plaster production sites in Switzerland. The emissions stem mainly from blasting operations.

Emissions from blasting operations are determined by a country-specific method analogous to a Tier 2 method of EMEP/EEA Guidebook (EMEP/EEA 2019).

Emission factors

As there are no specific emission factors for gypsum mining, the emission factors for cement raw material mining are taken instead (with a rough estimate that 1.5 t of raw material are required for production of 1 t of cement). This method is documented in EMIS 2020/2A4d Gips-Produktion übriger Betrieb. For emission factors see Table 4-15.

Activity data

The activity data of the annual amount of raw material processed in the plaster production are based on industry data and expert estimates as documented in EMIS 2020/2A4d Gips-Produktion übriger Betrieb (see Table 4-14).

4.2.3 Uncertainties and time-series consistency

The uncertainty for CO_2 emissions in 2A1 Cement production, which is a key category regarding level and trend, amounts to 4.5%. The uncertainty of CO_2 emissions was calculated following the steps in Table 3.2 in 2006 IPCC Guidelines (IPCC 2006, vol. 1, chp. 3, p. 3.30–3.31). An uncertainty of 2% is assumed for activity data and 4% for the emission factor, which consists of an average emission factor per tonne of clinker for calcination of the carbonate containing raw material (FOEN 2020k, chp. G.7) and a correction for the content of organic carbon and cement kiln dust.

Combined uncertainty is estimated to be 3% for emissions from 2A2 Lime production and 4% for emissions from 2A3 Glass production (expert estimate).

For CO_2 emissions in source category 2A4 Other process uses of carbonates, an overall uncertainty of 3% is assumed. Most of the data stems from industrial plants participating in the Swiss ETS, which requires that the uncertainty in the emissions does not exceed a given limit (1.5%-7.5%, depending on the amount of emissions resulting from a given source) and from the Swiss Federal Customs Administration.

Consistency: Time series for 2A Mineral industry are all considered consistent.

4.2.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

For submission 2017, implied emission factors of 2A3 container glass production were assessed by both a Tier 2 and Tier 3 method for the years 2005–2011. This comparison provides an indication of the differences caused by the switch in the Tier level from Tier 2 (1990–2004) to Tier 3 (2005–2015).

4.2.5 Category-specific recalculations

The following recalculations were implemented in submission 2020.

Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between latest and previous submission are also presented in chp. 10.1.2.2.

- 2A4d: The limestone use in cupola furnaces of iron foundries was reallocated from source category 2A4d to 2C1.

4.2.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.3 Source category 2B – Chemical industry

4.3.1 Source category description

Table 4-17 Key categories of 2B Chemical industry. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2B10	Chemical industry other	N2O	L1, L2, T1, T2

Table 4-18 Specification of source category 2B Chemical industry.

2B	Source category	Specification
2B1	Ammonia production	Emissions of CO_2 and NMVOC are reported in 2B8b Ethylene production
2B2	Nitric acid production	Emissions of N_2O and NOx from the production of nitric acid
2B5	Carbide production	Emissions of CO_2, CH_4 and SO_2 from the production of silicon carbide
2B8	Petrochemical and carbon black production	Emissions of CO_2 and NMVOC from ethylene production. In Switzerland there is only ethylene production under this source category
2B10	Other	Emissions of CO_2, CH_4, CO and NMVOC from acetic acid production; CO_2 emissions from limestone pit; CO_2 and N_2O emissions from niacin production; NMVOC emissions from PVC production (ceased in 1996); SO_2 emissions from sulphuric acid production

4.3.2 Methodological issues

4.3.2.1 Ammonia production (2B1)

Ammonia (NH_3) is produced in one single plant in Switzerland by catalytic reaction of nitrogen and synthetic hydrogen (see Figure 4-5). Ammonia is not produced in an isolated reaction plant but is part of an integrated production chain (see Figure 4-5).

The starting production process is the thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha yielding ethylene (ethene, C_2H_4), and a series of by-products such as e.g. synthetic hydrogen and methane, which are used as educts for further production steps. According to the Swiss ammonia producer it is not possible to split and allocate the emissions of the cracking process (CO_2 and NMVOC) to every single product such as, e.g., ethylene, acetylene (ethyne, C_2H_2), cyanic acid or ammonia. Therefore, all CO_2 and NMVOC emissions of the cracking process are allocated to the ethylene production and are reported under the category 2B8b Ethylene production. Thus, for source category 2B1 Ammonia production, CO_2 and NMVOC emissions are reported as included elsewhere (IE). All information on the ammonia production and the cracking process is documented in EMIS 2020/2B1 Ammoniak-Produktion and EMIS 2020/2B8b Ethen-Produktion, respectively.

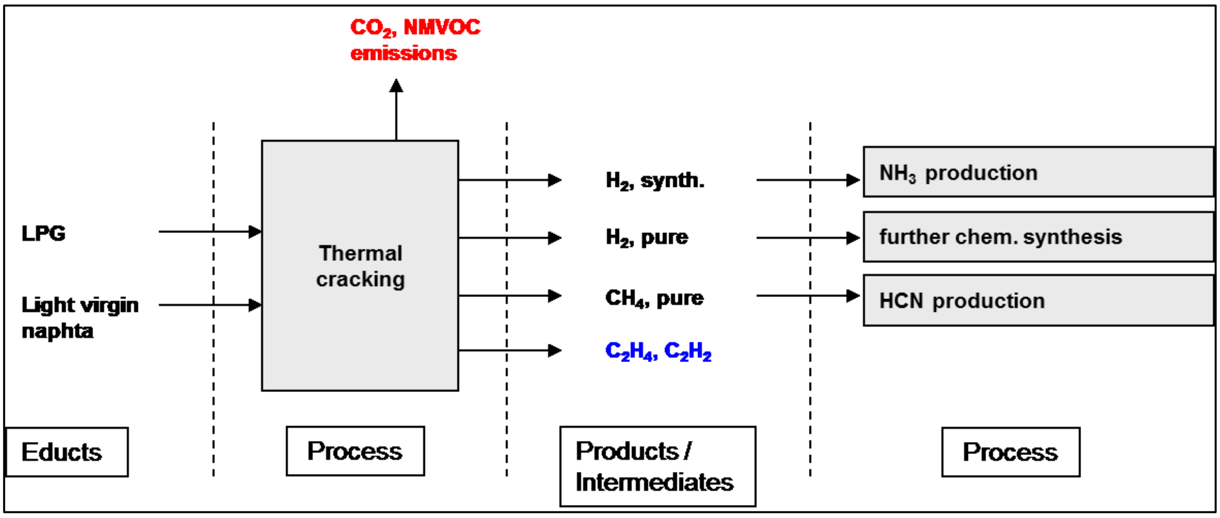


Figure 4-5 Process flow chart for the production of ethylene (C_2H_4) and acetylene (C_2H_2) by thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha. The intermediate product H_2, synth. is used as educt in the ammonia production in the same plant.

Table 4-19 Activity data for ammonia production in Switzerland are documented in the confidential NIR, which is available to reviewers on request.

4.3.2.2 Nitric acid production (2B2)

In Switzerland, there was one single plant producing nitric acid (HNO_3) which stopped production in spring 2018. Nitric acid was produced by catalytic oxidation of ammonia (NH_3) with air. At temperatures of 800°C nitric monoxide (NO) is formed. During cooling, nitrogen monoxide reacted with excess oxygen to form nitrogen dioxide (NO_2). The nitrogen dioxide reacted with water to form 60% nitric acid (HNO_3). Today, two types of processes are used for nitric acid production: single pressure or dual pressure plants. In Switzerland a dual pressure plant was installed.

During this process, nitrous oxide (N_2O) can be formed as an unintentional by-product. In addition, also some nitrogen oxide (NO_x) is produced. In the Swiss production plant abatement of NO_x was done by selective catalytic reduction (SCR, installed in 1988), which reduced NO_x to N_2 and O_2 (the SCR in this plant was also used for treatment of other flue gases and was not installed for the HNO_3 production specially). In 1990, an automatic control system for the dosing of ammonia to the SCR process was installed. A new catalyst installed in 2013 reduced the N_2O emissions.

No additional abatement technique is installed to destroy N_2O. A decomposition of N_2O occurs, to some extent, simultaneously in the NO_x reduction process.

Methodology

According to decision tree Fig. 3.2 of the IPCC 2006 guidelines (vol. 3, chp. 3.3 Nitric acid production), the N_2O emissions from nitric acid production are determined by a Tier 2 method during the time period 1990–2012 and by a Tier 3 method since 2013, based on direct measurements. The NO_x emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA (2019) (chp. 2B Chemical industry) using a plant-specific emission factor.

Emission factors

The N_2O and NO_x emission factors for nitric acid production in Switzerland are based on measurements from the single nitric acid production plant.

The measurement of N_2O was carried out in 2009 according to the guideline VDI-Richtlinie 2469/Blatt 1 (Messen gasförmiger Emissionen – Messen von Distickstoffmonoxid – Manuelles gaschromatographisches Verfahren) and is the only plant-specific measurement of N_2O emissions. The test gas is sucked in via a heated titanium sensor and then treated with a solution of potassium permanganate and hydrogen peroxide in order to remove nitrogen oxides and further disturbing components. The N_2O concentration is then measured using a gas chromatograph with an electron capture detector. The measurement uncertainty is ±20% (minimum ± 0.5 mg/m^3). On repeated enquires the plant confirmed that since a denitrification system and an automatic control system for the ammonia addition was installed in 1988 and 1990, respectively, no modifications were made in the production line until 2012. Therefore, a constant N_2O-emission factor is assumed for this time period. A new catalyst installed in 2013 reduced the N_2O emissions, which are measured online by NDIR photometry from 2013 onwards.

The NO_x emission factor is the mean value based on three plant-specific measurements in 2007, 2009 and 2012. Since no modifications were made in the production line between 1990 and 2012 a constant emission factor is assumed for this time period. In 2013, the volume of the SCR-plant was duplicated. This modification together with the new catalyst in the production line slightly reduced the NO_x emission factor. The values are documented in EMIS 20120/2B2 Salpetersäure Produktion.

Table 4-20 Emission factors for N2O and NOx for nitric acid production in Switzerland in kg/t nitric acid for 1990–2018 and for 2018 are provided in the confidential NIR, which is available to reviewers on request.

Activity data

Activity data on annual production of nitric acid (100%) are provided annually by the Swiss production plant for the entire time period 1990–2018. Since 2013, activity data of the annual nitric acid production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).The data are confidential but available to reviewers (see EMIS 2020/2B2 Salpetersäure Produktion).

Table 4-21 Activity data for the production of nitric acid (100%) in Switzerland are documented in the confidential NIR, which is available to reviewers on request.

4.3.2.3 Carbide production (2B5)

In Switzerland, there is one single plant producing carbide. The plant produces silicon carbide, which is used in abrasives, refractories, metallurgy and anti-skid flooring. The Swiss silicon carbide is produced in an electric furnace at temperatures above 2000ºC using the Acheson process. The starting materials are quartz sand (SiO_2), petroleum coke and anthracite (C) which yield silicon carbide (SiC) and carbon monoxide (CO). The CO is converted to CO_2 in excess oxygen and released to the atmosphere. Petroleum coke and anthracite – although to a lower portion – may contain volatile organic compounds, which can form methane (CH_4) as an unintended by-product. There is no abatement techniques installed which could capture the CO_2 or CH_4 emissions.

Methodology

According to decision tree Fig. 3.5 of the IPCC 2006 guidelines (vol. 3, chp. 3.6 Carbide production), the CO_2 and CH_4 emissions from silicon carbide production are determined by a Tier 2 method. The SO_2 emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA (2019) (chp. 2B Chemical industry) using plant-specific emission factors.

Emission factors

The CO_2, CH_4 and SO_2 emission factors are confidential and available to reviewers on request. The values are partly based on measurements from the single silicon carbide production plant and are documented in EMIS 2020/2B5 Graphit und Siliziumkarbid Produktion.

Table 4-22 In the confidential NIR, a respective table with emission factors of fossil CO_2 in kg/t silicon carbide are provided. Data are available to reviewers on request.

Table 4-23 Emission factors for CO2, CH4 and SO2 for carbide production in kg/t silicon carbide in Switzerland for 2018 are provided in the confidential NIR, which is available for reviewers upon request.

Activity data

Activity data on annual production of silicon carbide are provided annually from 1997 onwards by the Swiss production plant. For the time period 1990–1996 activity data are based on industry data for 1990 and 1995 and interpolated values in between.

The data are confidential but available to reviewers on request (see EMIS 2020/2B5 Graphit und Siliziumkarbid Produktion).

Table 4-24 In the confidential NIR, the respective table with activity data on silicon carbide production in Switzerland is separately reported and available to reviewers.

4.3.2.4 Petrochemical and carbon black production (2B8)

Ethylene (2B8b)

Ethylene (ethene, C_2H_4) is produced by a single plant in Switzerland by thermal cracking of liquefied petroleum gas (LPG) and virgin naphtha. Ethylene is not produced in an isolated process but is co-processed together with several other products such as H_2, CH_4, and C_2H_2 (see flow chart in Figure 4-5 in chp. 4.3.2.1). From the thermal cracking process, emissions of CO_2 and NMVOC are released. They are both allocated entirely to the production of ethylene, which is the first product within the integrated production chain. CH_4 emissions to atmosphere do not occur since CH_4 is completely used as an educt in the downstream production of cyanic acid (HCN) in the same facility (again, see Figure 4-5 and for further information see EMIS 2020/2B8b Ethen-Produktion). Therefore, CH_4 emissions are reported as NA for ethylene production and only CO_2 and NMVOC emissions are reported.

The CO_2 emissions from the cracker reported in source category 2B8b Ethylene production are based on a mass balance considering all feedstocks, products and by-products. Therefore, the NMVOC emissions are not included in the calculation of the indirect CO_2 emissions from sector 2 IPPU in order to avoid double counting.

Methodology

According to decision trees Fig. 3.8 of the IPCC 2006 guidelines (vol. 3, chp. 3.9 Petrochemical and carbon black production) and Fig. 3.1 of EMEP/EEA (2019) (chp. 2B Chemical industry), the CO_2 and NMVOC emissions, respectively, from ethylene production are determined by a Tier 2 method using plant-specific emission factors (EMIS 2020/2B8b Ethylene production).

Emission factors

The CO_2 and NMVOC emission factors for ethylene production are based on industry data from the single ethylene production plant in Switzerland. Annual emission data were only available from the year 2000 onwards. For the period 1990–1999 a constant value, i.e. the mean value of the years 2000–2009 was assumed.

The emission factors for ethylene production are considered confidential; however, they are available to reviewers on request.

Table 4-25 Emission factors for CO_2 and NMVOC in ethylene production, NMVOC in acetic acid production, CO_2 in limestone pit, CO_2, N_2O, NO_x and CO in niacin production and SO_2 in sulphuric acid production for 2018 in kg/t product.

	Unit	CO_2	N_2O	NO_x	CO	NMVOC	SO_2
2B8 Petrochemical and carbon black production							
2B8b Ethylene	kg/t	C	NA	NA	NA	C	NA
2B10 Other							
Acetic acid production	kg/t	NA	NA	NA	NA	C	NA
Limestone pit	kg/t	C	NA	NA	NA	NA	NA
Niacin production	kg/t	C	C	C	C	NA	NA
Sulphuric acid production	kg/t	NA	NA	NA	NA	NA	C

Table 4-26 CO_2 fossil emission factors in 2B8b Ethylene are documented in the confidential NIR, which is available to reviewers on request.

Activity data

Activity data on the annual production of ethylene are provided annually by the single ethylene production plant in Switzerland. Since 2013, activity data are taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).The data are considered confidential but available to reviewers on request.

Table 4-27 Activity data for the production of ethylene, acetic acid, niacin, PVC and sulphuric acid as well as for limestone pit in Switzerland in kt.

	Unit	1990	1995	2000	2005
2B8 Petrochemical and carbon black production					
2B8b Ethylene	kt	C	C	C	C
2B10 Other					
Acetic acid production	kt	30	27	24	8
Limestone pit	kt	C	C	C	C
Niacin production	kt	C	C	C	C
PVC production	kt	43	43	NO	NO
Sulphuric acid production	kt	C	C	C	C

	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2B8 Petrochemical and carbon black production											
2B8b Ethylene	kt	C	C	C	C	C	C	C	C	C	C
2B10 Other											
Acetic acid production	kt	28	20	18	12	C	C	C	C	C	C
Limestone pit	kt	C	C	C	C	C	C	C	C	C	C
Niacin production	kt	C	C	C	C	C	C	C	C	C	C
PVC production	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sulphuric acid production	kt	C	C	C	C	C	C	C	C	C	C

4.3.2.5 Other (2B10)

Source category 2B10 Other comprises emissions from production of acetic acid, sulphuric acid, niacin and PVC (ceased in 1996) as well as from limestone pits.

Acetic acid production (2B10)

In Switzerland, there is only one plant producing acetic acid (CH_3COOH) remaining after the other one stopped its production by the end of 2012. The still existing plant emits NMVOC only whereas from the latter one also emissions of CO_2, CH_4 and CO occurred.

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

In order to determine emissions of CO_2 and CH_4 from acetic acid a country-specific method analogous to a Tier 2 method according to the IPCC 2006 guidelines (vol. 3) is used. The CO and NMVOC emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA (2019) (chp. 2B Chemical industry).

Emission factors

The emission factors for CO_2, CH_4, CO and NMVOC from acetic acid production in Switzerland are plant-specific and based on data from industry and expert estimates documented in EMIS 2020/2B10 Essigsäure-Produktion.

In the plant which ceased production by the end of 2012 process emissions had been treated in a flue gas incineration. Thus, the reported emissions of CH_4, CO and NMVOC only occurred in case of malfunction, which resulted in strongly fluctuating plant-specific emission factors. In addition, the resulting implied emission factors based on the emissions of both plants are modulated by considerable production fluctuations of one of the plants from 2000 onwards.

The emission factors for acetic acid production are confidential but available to reviewers on request.

Table 4-28 In the confidential NIR, the respective table with emission factors for CO_2 and CH_4 in acetic acid production are separately reported and available to reviewers.

Activity data

The annual amount of produced acetic acid is based on data from industry and from the Swiss industry association for the chemical, pharmaceutical and biotech industry (scienceindustries) documented in EMIS 2020/2B10 Essigsäure-Produktion (see Table 4-27).

The data for acetic acid production since 2013 are confidential, since there is only one manufacturer remaining. The data are available for reviewers on request.

Limestone pit (2B10)

In one chemical plant acids are neutralized in a so-called limestone pit yielding geogenic CO_2 emissions.

Methodology

According to decision tree Fig. 2.4 of the IPCC 2006 guidelines (vol. 3, chp. 2.5 Other process uses of carbonates), the CO_2 emissions from the limestone pit are determined by Tier 2 method using plant-specific emission factors..

Emission factors

The CO_2 emission factor is considered confidential but available to reviewers on request.

Activity data

Activity data of annual consumption of calcium carbonate are provided by the chemical plant from 1999 onwards as documented in EMIS 2020/2B10 Kalksteingrube. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS. Since no data are available of the limestone pit for the time period 1990–1998, the annual activity is derived from the average annual consumption between 1999 and 2015.

Activity data is considered confidential but available to reviewers on request.

Niacin production (2B10)

So far CO_2 emissions from niacin production of the single manufacturer in Switzerland were reported only based on monitoring reports of the Swiss ETS. CO_2 is released in the last reaction step of the niacin production. From submission 2020 onwards, also emissions of N_2O as well as of the precursors NO_x and CO are included in the inventory. In the production process nitric acid is used as oxidizing agent. Since the nitric acid production plant was closed in spring 2018 the required nitric acid is directly produced within the niacin production plant using a so-called ammonia burner.

Methodology

In order to determine emissions of CO_2 and N_2O from niacin production, a country-specific method analogous to a Tier 2 method according to the IPCC 2006 guidelines (vol. 3) is used. The NOx and CO emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2B Chemical industry in EMEP/EEA (2019) using plant-specific emission factors.

Emission factors

The emission factors of CO_2, N_2O, NO_x and CO are plant-specific based on measurement data from industry. For CO_2 and CO, they are based on measurements in 2018 before and after the production process was modified (i.e. including the ammonia burner). For N_2O, the emission factor is derived from measurements in 2018 after the modification of the production process but with and without operating the ammonia burner. For NO_x, the emission factor is based on measurements in 2017 and 2018 (after process modification). Due to lack of emission measurements in previous years, constant emission factors are assumed between 1990 and 2017 as documented in the EMIS database (EMIS 2020/2B10 Niacin-Produktion. The emission factor is considered confidential but available to reviewers on request.

Table 4-29 In the confidential NIR, the respective table with emission factors for CO_2 and N_2O emission factors for 2B10 Niacin production are separately reported and available to reviewers.

Activity data

Activity data of annual niacin production were provided by the Swiss production plant for the entire time period as documented in EMIS 2020/2B10 Niacin-Produktion. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS.

Activity data are considered confidential but available to reviewers on request.

PVC and sulphuric acid production (2B10)

Sulphuric acid (H_2SO_4) is produced by one plant only in Switzerland. From this production process SO_2 is emitted. Until 1996, also PVC was produced in Switzerland releasing NMVOC emissions.

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology

In order to determine SO_2 and NMVOC emissions from sulphuric acid and PVC production, respectively, a Tier 2 method according to the decision tree Fig. 3.1 of EMEP/EEA (2019) (chp. 2B Chemical industry) with plant-specific emission factors is used.

Emission factors

The emission factor for SO_2 from sulphuric acid production in Switzerland is plant-specific and based on measurement data from industry and expert estimates documented in the EMIS database (EMIS 2020/2B10 Schwefelsäure-Produktion).

The SO_2 emission factor is confidential but available to reviewers on request.

For PVC production the NMVOC emission factor was based on industry information and expert estimates (EMIS 2020/2B10 PVC-Produktion).

Activity data

The annual amount of sulphuric acid and PVC produced is based on data from industry and expert estimates documented in EMIS 2020/2B10 Schwefelsäure-Produktion and EMIS 2020/2B10 PVC-Produktion (see Table 4-27). The activity data for sulphuric acid production are confidential but available to reviewers on request.

4.3.3 Uncertainties and time-series consistency

For N_2O emissions from 2B2 Nitric acid production, the uncertainty is assumed to be 7.5% (from 2013 onwards) since the Swiss ETS requires that an uncertainty of 7.5% is not exceeded for continuous N_2O measurements. For 1990 an uncertainty of 60% is assumed based on the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on a single N_2O emission measurement in 2009.

The uncertainties for CO_2 in source categories 2B5 Silicon carbide production, 2B8b Ethylene and 2B10 Acetic acid production (up to 2012) are estimated to be medium, (see Table 1-10 Semi-quantitative uncertainties for non-key categories) resulting in a relative uncertainty of 10%. For CH_4 from 2B5 Silicon carbide production a combined uncertainty of 20% is estimated.

The uncertainties for CO_2 and N_2O emissions from 2B10 Niacin production are assumed to be 60% according to the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on (spot) measurement data from industry in 2014 and 2018 only.

Consistency: Time series for 2B Chemical industry are all considered consistent.

4.3.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

4.3.5 Category-specific recalculations

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between latest and previous submission are also presented in chp. 10.1.2.2.

- 2B10: The CO_2 and N_2O emission factors from 2B10 Niacin production have been revised and newly included in the inventory, respectively, for 1990–2017 based on measurements and information from the production plant.

4.3.6 Category-specific planned improvements

No category-specific improvements are planned.

4.4 Source category 2C – Metal industry

4.4.1 Source category description

Table 4-30 Key categories of 2C Metal industry. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFC	T1

Table 4-31 Specification of source category 2C Metal industry.

2C	Source category	Specification
2C1	Iron and steel production	Emissions of CO_2, NOx, CO, NMVOC and SO_2 from the production of iron and steel; Geogenic CO_2 emissions from use of limestone in iron-foundries (cupola furnaces)
2C2	Ferroalloys production	Production is not occuring in Switzerland
2C3	Aluminium production	Emissions of PFC, CO_2, NOx, CO, NMVOC, and SO_2 from the production of primary aluminium (ceased in 2006); Emissions from use of SF_6 in aluminium foundries
2C4	Magnesium production	Emissions from use of SF_6 in magnesium foundries
2C7	Other	Emissions of CO and NMVOC from non-ferrous metal foundries; Emissions of CO_2, NOx, CO and SO_2 from battery recycling

4.4.2 Methodological issues

4.4.2.1 Iron and steel production (2C1)

There is no primary iron and steel production in Switzerland. Only secondary steel production occurs, which is steel production from recycled steel scrap. After closing down of two steel plants in 1994, there remain two plants in Switzerland. Both plants use electric arc furnaces (EAF) with a carbon electrode for melting the steel scrap. During the melting process CO_2 emissions occur mainly from scrap, electrodes and carburization coal whereas the produced steel, filter dust and slag act as carbon sinks. Emissions of precursors such as NO_x, CO, NMVOC and SO_2 occur as well.

In Switzerland, no production of pig iron occurs but iron is processed in foundries only. Today, there exist about 14 iron foundries in Switzerland. About 75% of the iron is processed in induction furnaces and 25% in cupola furnaces. From induction furnaces only precursors are emitted. In cupola furnaces also CO_2 emissions from other bituminous coal and limestone occur. Other bituminous coal acts first of all as fuel but also as carburization material and reductant. Therefore it was decided to report those CO_2 emissions in source category 1A2a. This ensures consistency with the reported use of other bituminous coal as fuel in the Swiss overall energy statistics (SFOE 2019). In cupola furnaces of iron foundries limestone is also used as flux as documented in the EMIS database (EMIS 2020/1A2a 2C1 Eisengiessereien Kupolöfen). The resulting geogenic CO_2 emissions are reported in 2C1.

The CO_2 emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of CO and NMVOC are not included in the calculation of the indirect CO_2 emissions from sector 2 IPPU in order to avoid a double counting.

Methodology

For determination of CO_2 emission from EAF in secondary steel production a mixture of a Tier 2 (before 2005 and for 2012) and a Tier 3 method (2005–2011 and since 2013) according to decision tree Fig. 4.7 IPCC 2006 (vol. 3, chp. 4.2 Iron & steel and metallurgical coke production) is used. For the years 2005–2011 and from 2013 onwards plant-specific data on the carbon mass balance is available from monitoring reports of the Swiss ETS, since under the Ordinance for the Reduction of CO_2 Emissions (Swiss Confederation 2012) the plants are required to report their emissions annually (Tier 3). From this information, data for the other years are interpolated for calculating an implied emission factor. In Switzerland, no CH_4 emissions occur in the EAF process.

The method for calculating geogenic CO_2 emissions from limestone use in cupola furnaces of iron foundries corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of 2006 IPCC guidelines (IPCC 2006, vol. 3, chp. 2.5 Other process uses of carbonates).

Emissions of all precursors are determined by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2C1 in EMEP/EEA (2019) using country-specific emission factors (EMIS 2020/2C1).

Emission factors

The emission factors for EAF in secondary steel production in Switzerland are country-specific and are based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2020/2C1 Eisengiessereien Elektroschmelzofen/übriger Betrieb, EMIS 2020/2C1 Stahl-Produktion Elektroschmelzöfen and EMIS 2020/2C1 Stahlwerke Walzwerke).

The electrode consumption in the two Swiss plants differs. For the calculations all carbon sources (graphite electrodes, steel scrap, alloy coal, etc.) and carbon sinks (steel, filter dust and slag) for the years 2005–2011 and from 2013 onwards were taken into account. Based on these carbon mass balances, a mean plant-specific CO_2 emission factor results. The reported CO_2 emission factor for Swiss steel industry is the production-weighted average. Consequently, there are no indirect CO_2 emissions to be accounted for in chp. 9 Indirect CO_2 and N_2O emissions for source category 2C1.

The plant-specific data are confidential but available to reviewers on request.

Table 4-32 CO_2 emission factor of electric arc furnaces in 2C1 Steel production in kg/t.

2C1 Steel production	Unit	1990	1995	2000	2005
CO_2	kg/t	8.3	8.0	7.7	8.8

2C1 Steel production	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CO_2	kg/t	6.8	7.6	7.1	7.9	8.5	8.2	8.6	8.8	9.2	9.1

Emission factors for all precursors emitted from steel production are based on air pollution control measurements of the steel plants. For submission 2016, emission factors of NO_x, NMVOC, SO_2, and CO have been revised based on air pollution control measurements at the electric arc furnaces of the two plants in 1999, 2005 and 2010 and in 1998, 2009 and 2014, respectively.

The emission factor of geogenic CO_2 from limestone use in cupola furnaces of iron foundries is based on the stoichiometry of $CaCO_3$ (2006 IPCC Guidelines, vol. 3 chp. 2.1, table 2.1, IPCC 2006), see Table 4-33. A conversion factor of 100% is assumed. The emission factors of the precursors from induction furnaces of iron foundries are provided by the Swiss foundry association (GVS).

Table 4-33 Emission factors for CO_2, NO_x, CO and NMVOC in iron production, for CO_2, NO_x, CO, NMVOC and SO_2 in steel production, for CO and NMVOC in non-ferrous metal production and for CO_2, NO_x, CO and SO_2 in battery recycling for 2018.

2C Metal industry	Unit	CO_2	NO_x	CO	NMVOC	SO_2
2C1 Iron production	kg/t	NA	0.01	4.1	4	NA
2C1 Limestone use in iron foundries (cupola furnaces)	kg/t	439.71	NA	NA	NA	NA
2C1 Steel production	kg/t	9.1	0.14	0.7	0.1	0.014
2C7a Non-ferrous metals	kg/t	NA	NA	0.24	0.05	NA
2C7c Battery recycling	kg/t	C	C	C	C	C

Activity data

Activity data on annual production of iron and steel are provided annually by the Swiss foundry association (Giesserei-Verband Schweiz, GVS) and the steel plants, respectively. Since 2009, activity data of the annual steel production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

The amount of limestone used as flux in iron foundries (cupola furnaces) is estimated by GVS to be in the range of 30 – 50% of the coal consumed. Therefore, an average share of 40% is assumed to calculate the activity data of limestone use (EMIS 2020/1A2a_2C1 Eisengiessereien Kupolöfen).

Table 4-34 Production of iron, steel, aluminium and non-ferrous metals as well as amount of batteries recycled in Switzerland in kt.

2C Metal industry	Unit	1990	1995	2000	2005
2C1 Iron production	kt	170	130	120	67
2C1 Limestone use in iron foundries (cupola furnaces)	kt	6.2	4.1	3.8	2.3
2C1 Steel production	kt	1'108	716	1'022	1'159
2C3 Aluminium production	kt	87	21	36	45
2C7a Non-ferrous metals	kt	55	60	70	33
2C7c Battery recycling	kt	C	C	C	C

2C Metal industry	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2C1 Iron production	kt	49	53	61	46	45	43	37	34	35	34
2C1 Limestone use in iron foundries (cupola furnaces)	kt	1.1	1.0	1.1	0.86	0.86	0.82	0.70	0.65	0.67	0.65
2C1 Steel production	kt	935	1'218	1'322	1'252	1'231	1'315	1'296	1'238	1'270	1'291
2C3 Aluminium production	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2C7a Non-ferrous metals	kt	15	20	12	18	6.8	7.4	6.8	6.6	5.9	5.7
2C7c Battery recycling	kt	C	C	C	C	C	C	C	C	C	C

4.4.2.2 Aluminium production (2C3)

Methodology

The last production site for primary aluminium in Switzerland closed down in April 2006. According to the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 4.4, fig. 4.11), CO_2 emissions are calculated by a Tier 2 method using a country-specific emission factor. For PFC emissions, a more specific Tier 3 method with facility-specific data according to the 2006 IPCC Guidelines (IPCC 2006) was used. Operating smelter emissions have been monitored periodically by the industry for selected years.

FOEN import statistics indicate in the year 2003 part of the SF_6 imports to be related to the aluminium industry, referring to cleaning processes in foundries. The 2006 IPCC Guidelines mention use of SF_6 in aluminium production for magnesium alloys on a low scale but do not provide further information for evaluation. Accordingly, the same evaluation methodology as for magnesium foundries with an emission factor based on a Tier 2 method is applied.

Emission factors

The emission factor for CO_2 of 1.6 tonnes per tonne of aluminium is country-specific. It is based on measurements and data from industry and expert estimates, documented in the EMIS database (EMIS 2020/2C3 Aluminium Produktion). CO_2 emissions from aluminium production stem from the oxidation of the anode in the electrolysis process. In Switzerland, only prebake anode technology was used. For the anode consumption, a constant mean value of 0.43 tonnes per tonne of aluminium was applied. It is assumed that the anode consisted completely of carbon and that it was fully oxidized during the process. Therefore, there are no indirect CO_2 emissions to be accounted for in chp. 9 Indirect CO_2 and N_2O emissions from CO emissions of primary aluminium production. But as the NMVOC emissions originate solely from the production of the electrodes at the plants they have to be considered for the calculation of the indirect CO_2 emissions in chp. 9. Indirect CO_2 emissions are not included in CO_2 emissions in CRF Table2, but exclusively reported in CRF Table6.

Before the close down of the only Swiss primary aluminium factory in 2006, PFC emission factors of operating smelters have been monitored periodically. Measurements made in 1990, 1999 and 2000 reported EFs in kg per tonne of 0.17, 0.06 and 0.04, respectively, for those three years (Alcan 2003). This was reported to be lower than the European averages, by factors of 3.9, 4.7 and 5.1, respectively. For other years no measurements have been made; thus, European Union (EU) average EFs have been used, multiplied by a factor of 0.25 (Alcan 2002). Figure 4-6 shows the resulting development of the EF for PFC over time. The European average has been decreasing over 60% from 0.68 kg PFC per tonne of aluminium to 0.16 kg PFC per tonne of aluminium between 1990 and 2000.

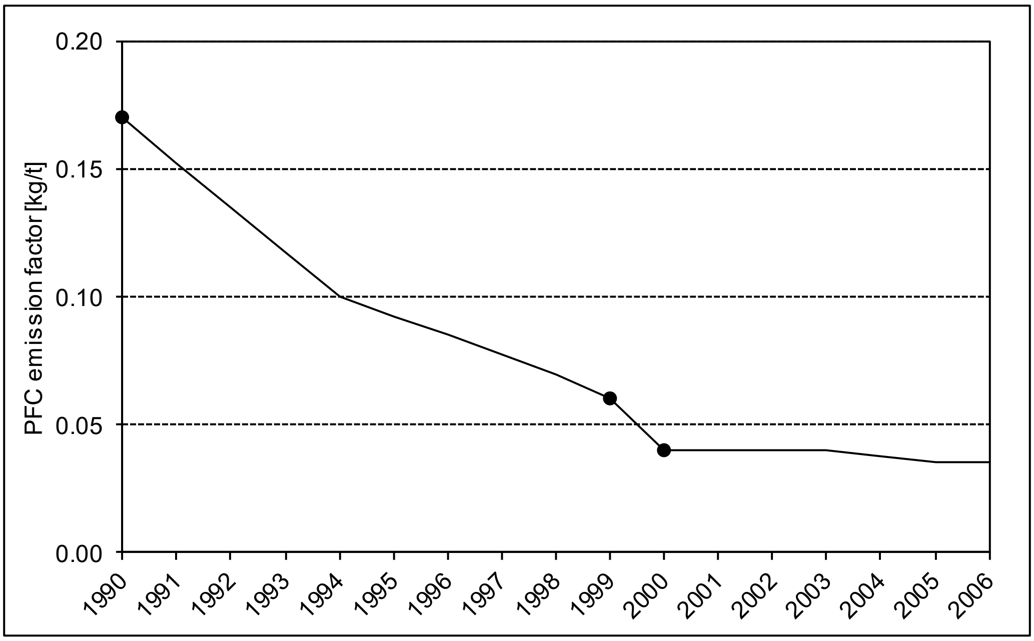


Figure 4-6 Extrapolation of PFC emission factor based on measurements in 1990, 1999 and 2000. The path for the reduction between measurements and the stagnation after the last measurements reflects the observed development of average EFs in the European Union.

There is no documentation of the measurements. Due to the close down in 2006 it is not possible to redo any measurements or to collect any information about the process details retroactively. Measurement results and development of EFs are assumed to be plausible because the factory used point feed prebake (PFPB) technology which is known for the lowest emissions per tonne of aluminium. The resulting emission factors for Switzerland are within the uncertainty range according to the 2006 IPCC Guidelines (variations by a factor of 10 using same technologies). The comparison with data from IAI (2005) on global PFC emissions from aluminium production showed that the monitored emissions from the smelter in Switzerland were lower by a factor of about 4.

Table 4-35 PFC emission factors for aluminium production in Switzerland. Aluminium production in Switzerland ceased in 2006.

Gas	Unit	1990	1995	2000	2005
CF_4	kg/t	0.1530	0.0833	0.0360	0.0315
C_2F_6	kg/t	0.0170	0.0093	0.0040	0.0035

Gas	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CF_4	kg/t	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
C_2F_6	kg/t	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

There are no measurements of SF_6 emissions available from aluminium foundries to identify the fraction of SF_6 destroyed or transformed in the cleaning process. For SF_6 used in aluminium foundries (2C3) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1000 kg per tonne of imported substance) of the 2006 IPCC Guidelines (IPCC 2006).

Activity data

In 2006, the last primary aluminium production site in Switzerland was closed. Activity data on aluminium production from 1997 to 2006 are based on annual data published by the Swiss Aluminium Association. For earlier years, data were provided directly by the aluminium industry. Activity data for aluminium production in Switzerland are given in Table 4-34.

Activity data on SF_6 used in aluminium foundries (2C3) is derived from import data from FOEN statistics. Import companies indicated in the year 2003 a portion of SF_6 imports for foundries to be used for aluminium cleaning. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2004 the mean value of 2003 and 2004 import data are used). In 2011, a study was carried out among members of the Swiss Foundry Association (GVS), confirming that SF_6 is not used any more in aluminium foundries. As no details on the imported amount are available for the time period 2003–2011, a steady decrease of the import amount of SF_6 is assumed from 2003 until the final elimination of SF_6 for aluminium cleaning in 2011. This assumption is based on the above-mentioned survey and on information obtained on applications within the category ‘others’ from FOEN import statistics.

4.4.2.3 Magnesium production (2C4)

Use of SF_6 in magnesium foundries (2C4)

SF_6 was used in Swiss magnesium foundries in the time period 1997 to 2016. There have been two magnesium foundries known to be using SF_6. In 2007 one of them closed down. A survey carried out 2011 among members of the Swiss Foundry Association (GVS) confirmed that only one company is using SF_6.

The import of SF_6 for magnesium foundries is prohibited in Switzerland since 2017.

Methodology

SF_6 was used in magnesium foundries in the cleaning process as inert gas to fill casting forms. The Swiss Foundry Association (GVS) has not provided information on emission factors and hence a Tier 2 method is used.

Emission factors

There are no measurements of SF_6 emissions available to identify the fraction of SF_6 destroyed or transformed in the process. For SF_6 used in magnesium foundries (2C4) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1000 kg per tonne of imported substance) of the 2006 IPCC Guidelines (IPCC 2006).

Activity data

Activity data on SF_6 used in magnesium foundries (2C4) are based on import data from FOEN statistics. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2016 the mean value of 2015 and 2016 import data are used). The import of SF_6 ceased in 2016. Part of the import of the preceding year were considered for the phase-out 2016.

One of the magnesium foundries reported on the SF_6 consumption between 2008 to 2015 to the SWISSMEM statistics. The information is in accordance with import data obtained for FOEN statistics.

4.4.2.4 Other (2C7)

Battery recycling and non-ferrous metal foundries (2C7)

There is one battery recycling plant in Switzerland. The recycling is done by applying the Sumitomo process. The batteries are first pyrolised at temperatures of 700°C in a reducing atmosphere in a shaft kiln. The gas with the carbonised components then goes to a post-combustion step where it is completely oxidised at temperatures of 1000°C. The flue gas is then directed to a flue gas treatment installation. The metal fraction from the pyrolysis goes to a melting furnace where it is reduced by addition of coal and magnesium oxide. As reducing agent coke and Carburit is used.

In Switzerland, there are one large company and several small plants operating non-ferrous metal foundries producing mainly copper alloys. During the melting process emissions of CO and NMVOC occur.

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Methodology
To determine emissions of CO_2, NO_x, CO and SO_2 from battery recycling and of CO and NMVOC from non-ferrous metal foundries, Tier 2 methods according to EMEP/EEA Guidebook 2016 (EMEP/EEA 2019, chp. 2C7c and 2C7a) with country-specific emission factors are used.

Emission factors
The emission factors of CO_2, NO_x, SO_2, CO from battery recycling between 1990 and 2002 are based on measurements in 2003 as well as mass balances of the single recycling site and are assumed constant. Since 2003 they are based on air pollution control measurements from 2003 and 2012 and are assumed constant during this time period. Emission factors of NMVOC are also based on air pollution control measurements from 2003 and 2012 and are assumed constant for the entire time period (EMIS 2020/2C7 Batterie-Recycling).

Emission factors of CO and NMVOC from non-ferrous metal foundries in Switzerland are country-specific and based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2020/2C7 Buntmetallgiessereien Elektroöfen) (see Table 4-33). Emission factors are confidential. They are available to reviewers on request.

Activity data
The annual amount of recycled batteries and produced non-ferrous metals in Switzerland is reported from industry and the foundry association as documented in the EMIS database (EMIS 2020/2C7 Batterie-Recycling and /2C7 Buntmetallgiessereien Elektroöfen). Activity data are confidential. They are available to reviewers on request.

4.4.3 Uncertainties and time-series consistency
The uncertainty of CO_2 emissions in 2C1 Iron and steel production amounts to 5.4%. Production data of the steel industry have a high confidence and its uncertainty is estimated at 2%. The uncertainty for the CO_2 emission factor is estimated at 5%. Since the geogenic CO_2 emissions from the limestone use in cupola furnaces (iron foundries) are comparatively small their contribution to the uncertainty calculation was neglected.

For the emission of CO_2 and PFC from 2C3 Aluminium production, which is a key category for both gases, combined uncertainties of 20.6% and 9%, respectively, are determined. The emission factor uncertainty for CO_2 and PFC are estimated to be 20% and 6.4%, respectively. The uncertainty in the activity data is estimated to be 5% for CO_2 emissions and 6.4% for PFC emissions.

For the emissions of SF_6 from the use in 2C4 Magnesium the combined uncertainty is estimated at 27.7%.

The uncertainty of CO_2 emissions from source category 2C7 Other is estimated to be 20% (expert estimate).

Consistency: Time series for 2C Metal industry are all considered consistent.

4.4.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

4.4.5 Category-specific recalculations

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between latest and previous submission are also presented in chp. 10.1.2.2.

- 2C1: The limestone use in cupola furnaces of iron foundries was reallocated from source category 2A4d to 2C1.

4.4.6 Category-specific planned improvements

No category-specific improvements are planned.

4.5 Source category 2D – Non-energy products from fuels and solvent use

4.5.1 Source category description

Source category 2D – Non-energy products from fuels and solvent use is not a key category.

Table 4-36 Specification of source category 2D Non-energy products from fuels and solvent use in Switzerland.

2D	Source category	Specification
2D1	Lubricant use	Emissions of CO_2 from primary usage of lubricants in machinery and vehicles and from fully oxidised lubricants blended into gasoline for 2-stroke engines
2D2	Paraffin wax use	Emissions of CO_2 from primary usage of paraffin waxes
2D3a	Solvent use	Emissions of NMVOC from coating applications, degreasing, dry cleaning and chemical products as well as emissions of CO_2 resulting from post-combustion of NMVOC in exhaust gases of these sources
2D3b	Road paving with asphalt	Emissions of NMVOC from road paving with asphalt
2D3c	Asphalt roofing	Emissions of CO and NMVOC from asphalt roofing
2D3d	Urea use in SCR catalysts of diesel engines	Emissions of CO_2 from urea use in SCR catalysts of diesel engines

4.5.2 Methodological issues

4.5.2.1 Lubricant use (2D1) and Paraffin wax use (2D2)

Lubricants are mostly used in industrial and transportation applications. They can be subdivided into motor oils, industrial oils and greases, which differ in terms of physical characteristics, commercial applications and environmental fate. Lubricants in engines of road and non-road vehicles are primarily used for their lubricating properties and associated GHG emissions are therefore considered as non-combustion emissions reported in 2D1 Lubricant use. Only lubricants blended into gasoline for 2-stroke engines are assumed to be fully oxidised.

The source category 2D2 Paraffin wax use includes products such as petroleum jelly, paraffin waxes and other waxes, including mixtures of saturated hydrocarbons, solid at ambient temperature. Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Emissions from the use of waxes occur primarily when the waxes or derivatives of paraffins are combusted during use (e.g. candles).

Methodology

CO_2 emissions from the use of lubricants in 2-stroke engines (road and non-road vehicles) are calculated by a Tier 1 method and default emission factor according to the decision trees in IPCC 2006, vol 2, chp. 3, Figure 3.2.2 and Figure 3.2.3) assuming that the lubricants are fully oxidised (as described in chp. 3.2.9.2.2). Please note that CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in sector 1 Energy since these emissions are included in the CH_4 and N_2O emission factors of the respective 2-stroke engines (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b).

CO_2 emissions from oxidation of all other lubricants and paraffin wax are calculated by a Tier 1 method according to the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.2 and 5.3) applying the IPCC default oxidation fraction of 0.2.

Emission factors

The CO_2 emission factor for lubricants used in 2-stroke vehicles is based on the default emission factor and the net calorific value from 2006 IPCC Guidelines (vol. 2, chp. 2 Stationary combustion, Table 2.2 and chp.1, Table 1.2, respectively), see Table 4-37 and EMIS 2020/2 D 1_Schmiermittel-Verbrauch B2T. Non-CO_2 emissions from lubricant use in 2-stroke engines are included in the road and the non-road transportation model, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines (see chp. 3.2.9.2.2).

The emission factors of CO_2 from all other lubricant and paraffin wax use in Switzerland are based on default IPCC values for NCV, carbon content and oxidation fraction documented in vol. 2, chp.1 and vol. 3, chp. 5.2 and 5.3, respectively, of IPCC 2006, see also EMIS 2020/2D1 Lubricant use and EMIS 2020/2D2 Paraffin wax use.

Table 4-37 CO_2 emission factor of 2D1 Lubricant use and 2D2 Paraffin wax use for 2018.

	Unit	CO_2
2D1 Lubricant use		
in two-stroke engines	kg/t	2'947
unspecified	kg/t	590
2D2 Paraffin wax use	kg/t	590

Activity data

The annual amount of lubricant and paraffin wax used in Switzerland is derived from Avenergy Suisse (formerly Swiss petroleum association) (EV 2019). The consumption of lubricants of Liechtenstein, which forms a customs union with Switzerland, is subtracted from the consumption reported by Avenergy Suisse. The resulting amount is further differentiated between application in 2-stroke engines and unspecified use. The amount of lubricants corresponds to 2% of total gasoline consumption of all 2-stroke engines based on the road and non-road transportation models (INFRAS 2019b, INFRAS 2015a).

Table 4-38 Use of lubricants.

	Unit	1990	1995	2000	2005
2D1 Lubricant use					
in two-stroke engines	kt	0.61	0.42	0.49	0.37
unspecified	kt	79	61	62	72
2D2 Paraffin wax use	kt	11	10	12	10

	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2D1 Lubricant use											
in two-stroke engines	kt	0.30	0.30	0.28	0.27	0.26	0.23	0.22	0.24	0.24	0.23
unspecified	kt	51	55	53	51	53	53	51	51	50	45
2D2 Paraffin wax use	kt	5.8	5.0	4.6	3.3	3.8	4.5	3.8	3.4	4.0	4.2

4.5.2.2 Other (2D3)

Solvent use (2D3a)

Since the 2006 IPCC Guidelines (vol. 3, chp. 5.5) refer to the EMEP/EEA Guidebook 2019 regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. In the following sections, the NMVOC emissions from coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) are reported. The source categories paint application in construction, paint application on wood, industrial and non-industrial paint application, production of fine chemicals and cleaning of parts in metal processing account for the largest share of NMVOC emissions from 2D3a in 2018. Indirect CO_2 emissions resulting from NMVOC emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO_2 emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2019a).

Post-combustion of NMVOC (2D3a)

Methodology

The CO_2 emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of industrial plants (Carbotech 2019a). Post-combustion facilities are applied in source categories 2D3a Solvent use (industrial paint applications (2D3d NFR), metal degreasing (2D3e NFR) and chemical products, manufacture and processing (2D3g NFR)) and 2G4 Other. For submission 2019, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 60% of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents are updated annually whereas all the others every five years. If no information of the solvent composition is available, mean source category-specific values are applied for the carbon content.

Source categories coating applications (2D3d NFR) and degreasing (2D3e NFR) comprise ten facilities each, whereas chemical products, manufacture and processing (2D3g NFR) comprise about 70 facilities. Not all facilities have been in use for the entire period 1990–2018. There was a significant increase in total number of facilities from 33 in the year 1990 to 119 in 2002. Since then, the number fluctuates around 120.

The amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus, not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

Emission factors

CO_2 emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed are updated annually whereas for all others at least every five years. In between, the values are kept constant (see Table 4-39). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-39 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc. For example, the NMVOC quantity of the largest facility within chemical products, manufacture and processing with a rather high carbon content (CO_2 emission factor of 2.444 t CO_2/t NMVOC) has doubled in the last ten years and thus, contributes importantly to the observed increase in the implied emission factor.

Table 4-39 CO_2 emission factors for post-combustion of NMVOC in 2D3a Solvent use.

2D3a Solvent use	Unit	CO_2			
Post-combustion of NMVOC		**1990**	**1995**	**2000**	**2005**
Coating applications (2D3d NFR)	t/t NMVOC	2.57	2.45	2.45	2.57
Degreasing (2D3e NFR)	t/t NMVOC	2.44	2.63	2.63	2.63
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	1.88	1.67	1.88	1.90

2D3a Solvent use	Unit	CO_2									
Post-combustion of NMVOC		**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Coating applications (2D3d NFR)	t/t NMVOC	2.57	2.56	2.56	2.56	2.56	2.56	2.01	2.01	2.01	2.01
Degreasing (2D3e NFR)	t/t NMVOC	2.64	2.65	2.65	2.65	2.65	2.41	2.38	2.36	2.36	2.35
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	1.94	2.21	2.24	2.31	2.31	2.34	2.28	2.31	2.31	2.31

Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry. For the ten most important installations (within 2D3a and 2G4), they are updated annually whereas for all others at least every five years.

Table 4-40 Activity data of NMVOC post-combustion in 2D3a Solvent use.

2D3a Solvent use	Unit	1990	1995	2000	2005
Post-combustion of NMVOC					
Coating applications (2D3d NFR)	t NMVOC	443	720	773	942
Degreasing (2D3e NFR)	t NMVOC	5.2	754	754	576
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	1'170	4'472	6'037	8'454

2D3a Solvent use	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Post-combustion of NMVOC											
Coating applications (2D3d NFR)	t NMVOC	942	1'170	1'174	1'171	1'147	1'117	1'297	1'339	1'365	1'365
Degreasing (2D3e NFR)	t NMVOC	1'294	903	1'008	988	988	678	669	868	837	1'003
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	7'323	5'520	5'366	4'925	5'135	5'298	4'575	5'342	5'542	5'542

Coating applications (2D3d NFR)

Methodology

For the determination of NMVOC emissions from coating applications a Tier 2 method according to the EMEP/EEA Guidebook 2019 is used based on the consumption of paints, lacquers, thinners etc. and their solvent content.

Emission factors

Emission factors for NMVOC are derived from the solvent contents of the paints and thinners based on data from the Swiss association for coating and paint applications (VSLF) the biggest industrial users (incl. surveys of VOC balances), paint producers, and all major Swiss DIY (do it yourself) companies as documented in the EMIS database (EMIS 2020/2D3d NFR). The emission factors for all commercial and industrial coating applications declined significantly between 1990 and 2004 as a result of both a reduction of the solvent content and replacing of solvent based paint by water based paint due to increasingly strict NMVOC regulations by the EU directive (EC 2004). In addition, powder coatings, which are far more efficient, replaced in this time period the conventional paint (rough estimate: 1 t of powder coating replaces 3 t of conventional paint). Since 2004, the mean solvent content of paint applied in construction and on wood has remained about constant with some fluctuations whereas a decrease has been observed for paints in industrial and non-industrial applications. For paint application, wood and paint application, car repair, even a slight increase in solvent content has been observed in the last few years. Paint application, households is based on a comprehensive study including all major Swiss DIY companies.

Table 4-41 NMVOC emission factors of coating applications, degreasing, dry cleaning, chemical products, manufacture and processing in 2D3a Solvent use for 2018.

2D3a Solvent use	Unit	NMVOC
Coating applications (2D3d NFR)		
Paint application, construction	kg/t paint	61
Paint application, households	kg/t paint	64
Paint application, industrial	kg/t paint	180
Paint application, wood	kg/t paint	318
Paint application, car repair	kg/t paint	550
Degreasing (2D3e NFR)		
Cleaning of electronic components	kg/t solvent	500
Degreasing of metal	kg/t solvent	460
Other industrial cleaning	kg/t solvent	610
Dry cleaning (2D3f NFR)	kg/t solvent	900
Chemical products, manufacture and processing (2D3g NFR)		
Fine chemicals production	t/production index	3.5
Glue production	kg/t glue	0.8
Handling and storing of solvents	t/production index	1.7
Ink production	kg/t ink	5.0
Paint production	kg/t paint	3.0
Pharmaceutical production	kg/t pharmaceutical	7.4
Polyester processing	kg/t polyester	50
Polystyrene processing	kg/t polystyrene	34
Polyurethane processing	kg/t polyruethane	3.3
PVC processing	kg/t PVC	4.0
Rubber processing	kg/tyres	0.14

Activity data

The activity data correspond to the annual consumption of paints which are estimated according to data and information from VSLF, the biggest industrial users (incl. VOC balances), Swiss paint producers, foreign trade statistics and all major Swiss DIY companies for paint applications in households (EMIS 2020/2D3d NFR). Between 1990 and 1998, the total consumption of paint decreased considerably, increased continuously from 2004 onwards and dropped again after 2013. This trend results from the opposing trends in the different source categories:

- Paint application, construction: As a consequence of the comprehensive assessment of all coating applications and the paint production in the course of the previous and the latest submission, the amount of paint applied in construction was adjusted considerably downwards. It seemed that the total amount of all paint applied in Switzerland in 1990 was attributed erroneously to construction. Still, the paint consumption in construction shows a substantial reduction compared to 1990 levels. The increasing tendency in paint application between 2001 and 2013 and the drop afterwards can be explained to a certain extent by the evolution in the construction activity in Switzerland. Before 2001, there was a decline in construction activity, which explains the decreasing tendency in paint application.
- Paint application, wood: The paint consumption for applications on wood increased moderately between 1990 and 1998. But from 2001 onwards it shows a comparable development as the paint application in construction.

- Paint application, industrial & non industrial: Between 1990 and 2016, the activity of industrial and non-industrial paint application decreased significantly. There was a clear decrease between 2001 and 2004 due to structural changes in the industrial sectors and a widespread application of powder coatings from 2004 onwards. Since 2004, the activity data show a moderate decrease.

Table 4-42 Activity data of coating applications, degreasing, dry cleaning and chemical products, manufacture and processing.

2D3a Solvent use	Unit	1990	1995	2000	2005
Coating applications (2D3d NFR)					
Paint application, construction	kt	81	50	33	42
Paint application, households	kt	12	13	13	12
Paint application, industrial	kt	20	21	21	8.8
Paint application, wood	kt	6.0	6.3	6.5	7.7
Paint application, car repair	kt	2.7	2.2	2.0	1.9
Degreasing (2D3e NFR)					
Cleaning of electronic components	kt	0.90	0.56	0.35	0.64
Degreasing of metal	kt	16	10	5.9	2.6
Other industrial cleaning	kt	0.6	0.6	0.6	1.4
Dry cleaning (2D3f NFR)	kt	1.30	0.77	0.23	0.10
Chemical products, manufacture and processing (2D3g NFR)					
Fine chemicals production	prod. index	70	100	163	224
Glue production	kt	19	32	44	60
Handling and storing of solvents	prod. index	70	100	163	224
Ink production	kt	20	29	36	55
Paint production	kt	104	84	72	77
Pharmaceutical production	kt	16	21	20	28
Polyester processing	kt	11	7.0	6.5	6.9
Polystyrene processing	kt	20	19	19	24
Polyurethane processing	kt	17	35	45	54
Production of adhesive tape	kt	1.5	NO	NO	NO
PVC processing	kt	94	94	78	64
Rubber processing	tyres	120'000	119'375	103'667	67'000
Tanning of leather	employees	110	108	102	88

2D3a Solvent use	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coating applications (2D3d NFR)											
Paint application, construction	kt	51	54	56	59	61	42	42	40	41	41
Paint application, households	kt	11	11	11	11	11	10	10	10	10	10
Paint application, industrial	kt	8.6	8.3	8.2	8.0	7.9	7.8	7.6	7.5	7.5	7.5
Paint application, wood	kt	9.3	10	10	10	10	7.2	6.7	6.3	6.3	6.3
Paint application, car repair	kt	1.7	1.7	1.5	1.4	1.2	1.1	0.97	0.85	0.85	0.85
Degreasing (2D3e NFR)											
Cleaning of electronic components	kt	0.63	0.67	0.70	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Degreasing of metal	kt	2.2	2.1	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Other industrial cleaning	kt	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dry cleaning (2D3f NFR)	kt	0.086	0.081	0.076	0.074	0.072	0.072	0.071	0.071	0.070	0.070
Chemical products, manufacture and processing (2D3g NFR)											
Fine chemicals production	prod. index	295	314	299	302	305	307	310	313	316	319
Glue production	kt	64	63	63	63	62	62	62	61	61	61
Handling and storing of solvents	prod. index	295	314	299	302	305	307	310	313	316	319
Ink production	kt	65	65	63	62	60	52	43	35	37	39
Paint production	kt	78	78	79	79	80	73	67	60	60	60
Pharmaceutical production	kt	30	30	30	30	30	31	31	31	31	31
Polyester processing	kt	4.8	3.4	3.5	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Polystyrene processing	kt	28	35	36	34	30	29	27	23	24	22
Polyurethane processing	kt	52	54	40	40	38	38	37	37	36	36
Production of adhesive tape	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
PVC processing	kt	62	52	55	40	38	37	36	35	34	32
Rubber processing	tyres	75'000	77'500	80'000	80'000	81'000	82'000	83'000	84'000	85'000	86'000
Tanning of leather	employees	76	65	54	44	33	22	11	NO	NO	NO

Degreasing and dry cleaning (2D3e NFR, 2D3f NFR)

Methodology

Source category 2D3e NFR comprises emissions from degreasing of electronic components, metal and other industrial cleaning. For the determination of NMVOC emissions from degreasing and dry cleaning a Tier 2 method according to the EMEP Guidebook (EMEP/EEA 2019) is used based on the consumption of solvents. Switzerland's Informative Inventory

Report contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from 2D3e NFR Degreasing and 2D3f NFR dry cleaning (FOEN 2020b).

Emission factors

Emission factors for NMVOC emissions from degreasing are based on data from the association of Swiss mechanical and electric engineering industries (swissmem) including VOC balance evaluations in 2004, 2007 and 2012 and expert estimates as documented in the EMIS database (EMIS 2020/2D3e NFR). For emission factors see Table 4-41.

NMVOC emission factors for dry cleaning are estimated based on information from the emission control authority and analysis of about 170 VKTS (Swiss supervising association of textile cleaning) inspection protocols from the four biggest Swiss cantons (AG, BE, VD and ZH) of 2017 as documented in the EMIS database (EMIS 2020/2D3f NFR).

Activity data

Activity data of degreasing correspond to the annual consumption of solvents used for degreasing. Data are based on data from the association of Swiss mechanical and electric engineering industries (swissmem) in 2004, 2007 and 2012, VOC balances, import statistics and expert estimates, documented in the EMIS database (EMIS 2020/2D3e NFR)). A comparison between the surveys and the evaluations of VOC balances showed an underestimation of the survey data by about 6%. Thus, the emissions based on survey data from the industry association (swissmem) have been corrected by +10%. Activity data is provided in Table 4-42.

For dry cleaning, activity data is the amount of tetrachloroethylene (PER) and non-halogenated solvents used. The activity data from 2001 onwards has been calculated based on the (annual) number of dry-cleaning facilities in Switzerland according to VKTS and SFSO (business census) and the mean solvent consumption per facility based on an analysis of about 170 VKTS inspection protocols from the four biggest Swiss cantons (AG, BE, VD and ZH) of 2017. Activity data for 1990 are based on net imports of PER. For the years in between, data are interpolated linearly as documented in the EMIS database (EMIS 2020/2D3f NFR).

Chemical products, manufacture and processing (2D3g NFR)

Methodology

Based on the decision tree Fig. 3.1 in chapter 2D3g in EMEP/EEA (2019), for source category 2D3g NFR Chemical products a Tier 2 method using country-specific emission factors is used for calculating the NMVOC emissions. Switzerland's Informative Inventory Report contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from 2D3g NFR Chemical products, manufacture and processing (FOEN 2020b).

Emission factors

Emission factors for NMVOC are mainly provided by industry associations, i.e. for:

- Fine chemicals production, pharmaceutical production and handling and storing of solvents: Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries)
- Paint and ink production: Swiss association for coating and paint applications (VSLF) and the Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV)
- Polyurethane processing: Swiss plastics association
- Polyester processing: Swiss polyester association
- Tanning of leather: Swiss leather tanning association.

For all other processes data are based on information from the industry (e.g. ink and paint production)), surveys of VOC balances (e.g. ink production**),** emission control authorities (e.g. polystyrene processing) and expert estimates as documented in the EMIS database.(EMIS 2020/2D3g). For emission factors see Table 4-41.

Activity data

The activity data are mainly production or consumption data provided by industry associations and by the Swiss Federal Office of Statistics and Swiss foreign trade statistics, i.e. for:

- Fine chemicals production and handling and storing of solvents: Swiss Federal Office of Statistics.
- Pharmaceutical production: Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries).
- Paint and ink production: Swiss association for coating and paint applications (VSLF) and Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV).
- Polyurethane processing: Swiss plastics association.
- Polyester processing: Swiss polyester association.
- Polystyrene processing: Swiss foreign trade statistics (annual net import figures)
- Tanning of leather: Swiss leather tanning association. The last Swiss tannery ceased production at the beginning of 2015.

For all other processes data are based on information from the industry and expert estimates as documented in the EMIS database. Since 1994 no production of adhesive tape is occurring in Switzerland anymore.

For activity data see Table 4-42.

Road paving with asphalt (2D3b)

Methodology

Asphalt road surfaces are composed of compacted aggregate and asphalt binder. From road surfacing operations only NMVOC emissions occur. Based on the decision tree Fig. 3.1 in chapter 2D3b in EMEP/EEA (2019), the NMVOC emissions from 2D3b Road paving with asphalt are determined by a Tier 2 method based on country-specific emission factors as documented in EMIS 2020/2D3b NFR.

Emission factors

The emission factor for NMVOC emissions from 2D3b Road paving with asphalt comprises NMVOC emissions from the use of prime coatings and from the bitumen content in asphalt products (about 5%). The NMVOC content in the bitumen has decreased considerably between 1990 and 2010. The values are based on industry data from 1990, 1998, 2007, 2010 and 2013. All other years are interpolated and complemented with expert estimates documented in the EMIS database.

Table 4-43 Emission factors of 2D3b Road paving with asphalt and 2D3c Asphalt roofing for 2018.

	Unit	CO	NMVOC
2D3b Road paving	kg/t asphalt concrete	NA	0.54
2D3c Asphalt roofing	kg/t asphalt sealing sheeting	0.01	5.3

Activity data

Activity data on the amount of asphalt products (so-called mixed goods) used for road paving is based on annual data from the association of asphalt production industry (SMI) for 1990 and from 1998 onwards and expert estimates for the years between.

Table 4-44 Activity data for road paving with asphalt, asphalt roofing and urea use in SCR catalysts.

	Unit	1990	1995	2000	2005
2D3b Road paving with asphalt					
Asphalt concrete	kt	5'500	4'800	5'170	4'780
2D3c Asphalt roofing					
Asphalt sealing sheeting	kt	54	56	58	51
2D3d Urea use in SCR catalysts					
AdBlue	kt	NO	NO	NO	0.26

	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2D3b Road paving with asphalt											
Asphalt concrete	kt	5'200	5'250	5'300	4'770	4'770	5'260	4'850	4'710	5'260	5'180
2D3c Asphalt roofing											
Asphalt sealing sheeting	kt	61	68	74	74	73	73	73	72	72	72
2D3d Urea use in SCR catalysts											
AdBlue	kt	15	19	21	23	25	25	26	26	27	27

Asphalt roofing (2D3c)

Methodology

This source category comprises emissions from production and use of asphalt roofing materials (saturated felt, roofing and siding shingles, roll roofing and sidings). These products are used in roofing and other building applications. From 2D3c Asphalt roofing only precursors such as CO and NMVOC arise. CO is emitted during the production process of asphalt roofing materials whereas NMVOC emissions are released during the entire production and laying processes (primers included). Based on the decision tree Fig. 3.1 in chapter 2D3c in EMEP/EEA (2019), the emissions of NMVOC from Asphalt roofing are determined by a Tier 2 method based on country-specific emission factors as documented in the EMIS database (EMIS 2020/2D3c Dachpappen Produktion und Verlegung). Emissions of CO are determined based on a Tier 1 method using the default emission factor (EMEP/EEA 2019).

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Emission factors

The NMVOC emission factors from asphalt roofing are based on information from the industry association, literature and expert estimates as documented in the EMIS database. Tier 1 emission factor of CO is taken from the EMEP/EEA Guidebook 2019 (EMEP/EEA 2019) (see Table 4-43).

Activity data

Activity data is based on data from industry and expert estimates as documented in the EMIS database (see Table 4-44).

Urea use in SCR catalysts of diesel engines (2D3d)

This source category encompasses CO_2 emissions from the use of urea containing AdBlue in diesel engines with SCR-catalysts in road transportation (Euro V/VI and Euro 5/6).

Methodology

In accordance with the 2006 IPCC Guidelines the consumption of Ad Blue is reported in this submission following a methodology suggested in the EMEP/EEA guidebook 2016 (EMEP/EEA 2016; part B, chp. 1.A.3.b.i-iv, page 48). A specific percentage of the fuel consumption of SCR-vehicles in road transportation according to their Euro class is applied for Ad Blue consumption estimates. Emissions are calculated according to following formula:

CO_2 Emissions = EF • FC • Share of SCR vehicles mileage • Specific urea share

“FC” relates to the fuel consumption in tonnes of the entire vehicle category. “Share of SCR vehicles mileage” implies the mileage share of SCR-vehicles in the entire vehicle category and “Specific urea share” comprises the percentage of fuel consumption, which relates to AdBlue (urea solution) consumption.

Emission factors

The emission factor for CO_2 emissions from urea use in SCR-catalysts in vehicles is a default value (EMEP/EEA 2016) considering the molecular mass conversion of urea into CO_2 during the reaction with water and the content of 32.5% of the aqueous AdBlue urea solution.

Activity data

Activity data on AdBlue consumption as well as annual mileage are provided by INFRAS (INFRAS 2017, INFRAS 2019b) on a yearly basis as documented in EMIS 2020/2D3d NFR Urea (AdBlue) Einsatz Strassenverkehr. For activity data see Table 4-44.

4.5.3 Uncertainties and time-series consistency

The uncertainty of total CO_2 emissions from the entire source category 2D – Non-energy products from fuels and solvent use is estimated to be 14% (expert estimate).

Consistency: Time series for 2D Non-energy products from fuels and solvent use are all considered consistent.

4.5.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

4.5.5 Category-specific recalculations

The following recalculations were implemented in submission 2019.

Major recalculations which contribute significantly to the total differences in direct and indirect CO_2 emissions of sector 2 IPPU between latest and previous submission are presented also in chp. 10.1.2.2.

- 2D1: The gasoline use in 1A3biv 2-stroke engines of motorcycles has been revised for the entire time series which resulted in revised activity data of 2D1 Lubricant use in 2-stroke engines as well as 2D1 Lubricant use unspecified. In addition, the emission factor for lubricant use in 2-stroke engines has been revised for the entire time series based on 2006 IPCC guidelines.
- 2D3a: The activity data and NMVOC emission factor of 2D3a Postcombustion of NMVOC in chemical products, manufacture and processing (2D3g) have been revised for 2015–2017 based on surveys of VOC balances.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3d NFR) Coating applications, industrial & non-industrial have been revised for 2002–2017 and 2005–2017, respectively, based on new data and information from the industry association and companies.
- 2D3a: The activity data of 2D3a (2D3d NFR) Coating applications, construction has been corrected for 1990 based on data on the industry association and expert judgement yielding revised values between 1990 and 1997.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3g NFR) Production of polystyrene have been revised for 1990–2017 based on annual net import figures of the Swiss foreign trade statistics and information from the industry association and emission control authorities, respectively.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3g NFR) Paint production have been revised for 1990–2017 and 1993–2017, respectively, based on data and information from paint manufacturers.
- 2D3a: The activity data and NMVOC emission factor of 2D3a (2D3g NFR) Ink production have been revised for 1991–2017, 1991–2003 and 2014–2017, respectively, based on the Swiss foreign trade statistics, surveys of the VOC balances as well as additional data and information from ink manufacturers.

2D3d: Use of urea in SCR catalysts was recalculated 2005–2017 due to recalculations in the road transportation model. CO_2 emissions from urea were calculated separately until the previous submission, although these emissions were already included in the CO_2 measurements used for the road transportation model. Accordingly, this was a double counting which has been eliminated.

4.5.6 Category-specific planned improvements

There are no planned improvements.

4.6 Source category 2E – Electronics industry

4.6.1 Source category description

Source category 2E Electronics industry is not a key category.

Source category 2E Electronics industry comprises HFC, PFC, NF_3 and SF_6 emissions from consumption of the applications listed in Table 4-45.

Table 4-45 Specification of source category 2E Electronics industry in Switzerland.

2E	Source category	Specification
2E1	Integrated Circuit or Semiconductur	Etching and cleaning processes in the production of IC and semiconductors (similar cleaning services for printed wiring boards included in the evaluation)
2E2	TFT flat panel display	No production of TFT flat panel displays in Switzerland, activities contained in the production of displays for watches
2E3	Photovoltaics	Emissions from photovoltaic manufacturing
2E4	Heat transfer fluids	No application in Switzerland assumed*
2E5	Other	Test activities (for example related to printed wiring boards), research activities

* Heat transfer fluids subject of research, for example ORC systems. Alternative products available with low GWP as for example Novec 649 and 7000

4.6.2 Methodological issues

Emission calculations are based on import data from FOEN statistics for etching and cleaning processes of the electronics industry, covering different source categories as listed in Table 4-45 (until 2010 import declarations for electronic industry under solvents). Process-specific transformation and emission rates are used. A survey within the electronics industry was carried out for the submission in 2015 to distribute the imported substances to the different source categories of electronic industry and to obtain information on waste air treatment. Information was obtained on the type of substance used in different source categories, but no information on emission factors and type of efficiency of exhaust treatment. More information are available from Carbotech (2020).

Methodology

A Tier 2a approach with specific parameters for each gas is used for emission calculations. IPCC default values for the gas-specific transformation rate of different processes and general values for the exhaust treatment efficiency are applied.

Imports of electronics industry were included in FOEN statistics under solvents until 2010. For the inventory report 2011 (FOEN 2011) interviews were conducted with the industry to get in-depth information on allocation of imported PFC volumes to different applications and to obtain process-specific information from consumers. Until 2010, most PFC imports declared as 2F5 Solvents or 2F6 Other were related to the electronics industry (2E). Since 2011, PFC import declarations have been improved and information is provided for the source category 2E separately. A survey was carried out for the submission in 2015 to determine contributions of different source categories 2E1–2E5 in Table 4-45 (Carbotech, 2020). As a result, the peak of NF_3 imports (and corresponding emissions) between 2009 and 2011 was found to be related to photovoltaic manufacture.

Emission factors

Default emission factors according to the 2019 refinement of the 2006 IPCC Guidelines are used for production and waste-air treatment (IPCC 2019). An exhaust treatment is assumed probable for most applications due to the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) and given limit of 5% for the emission factor in semiconductor use. For some large users the presence of exhaust treatment was confirmed in a survey.

Activity data

Activity data are based on FOEN import statistics and industry information.

4.6.3 Uncertainties and time-series consistency

The uncertainty for the emissions from the use of HFC, PFC, SF_6 and NF_3 in 2E Electronics industry is estimated at 50% (HFC), 79% (PFC), 61% (SF_6), 50% (NF_3) based on a Monte Carlo simulation. More information is available from Carbotech (2020).

Consistency: Time series for 2E Electronics industry are all considered consistent.

4.6.4 Category-specific QA/QC and verification

The entire time series are compared between the current and the previous submissions. The general QA/QC measures are described in chp. 1.2.3.

4.6.5 Category-specific recalculations

Recalculations reported in submission 2020:

- 2E: New default emission factors from the refinement of the 2006 IPCC Guidelines (IPCC 2019).

4.6.6 Category-specific planned improvements

No category-specific improvements are planned.

4.7 Source category 2F – Product uses as substitutes for ozone depleting substances

4.7.1 Source Category Description

Table 4-46 Key categories of 2F Product uses as substitutes for ozone depleting substances. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, T2
2F2	Foam blowing agents	HFC	T2

Source category 2F Product uses as substitutes for ozone depleting substances comprises HFC and PFC emissions from consumption of the applications listed in Table 4-47.

Table 4-47 Specification of source category 2F Product uses as substitutes for ozone depleting substances in Switzerland.

2F	Source category	Specification
2F1	Refrigeration and air conditioning	Emissions from refrigeration and air conditioning (inclusive heat pumps and tumble dryers)
2F2	Foam blowing agents	Emissions from foam blowing, incl. polyurethan spray;
2F4	Aerosols	Emissions from use as aerosols, incl. metered dose inhalers
2F5	Solvents	Emissions from use as solvents

The following graph shows HFC and PFC emissions from different applications in source category 2F. In 2018, stationary and mobile refrigeration and air conditioning equipment accounted by far for the highest emissions with a share of 96% of the total emissions in source category 2F. Further, emissions are dominated by HFCs and only a minor contribution comes from PFCs (generally less than 1%).

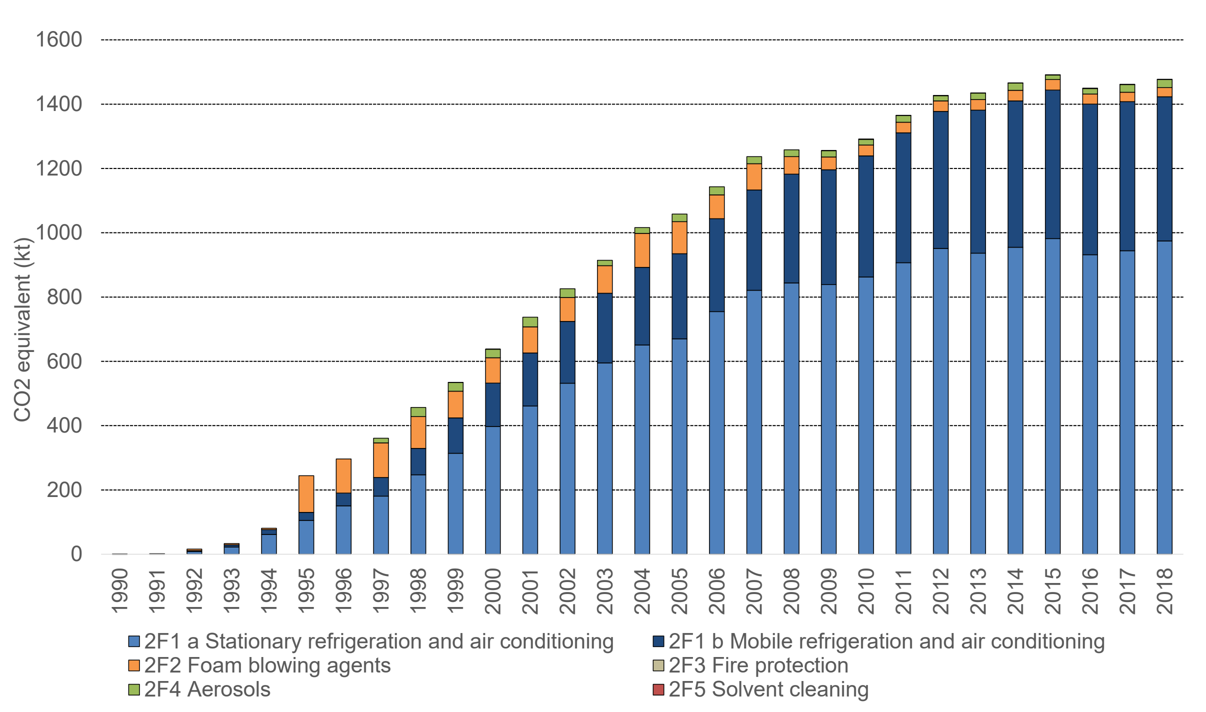


Figure 4-7 Development of emissions under source category 2F Product uses as substitutes for ozone depleting substances. HFC and small amounts of PFC are used as substitutes for ozone depleting substances. Most relevant today are emissions from the built up refrigerant stock in refrigeration and air conditioning equipment.

4.7.2 Methodological issues

The data models used for source category 2F are complex and therefore a comprehensive documentation of all relevant model parameters is not possible within the NIR. Most relevant is the contribution of 2F1 refrigeration and air conditioning. Calculations are carried out for different applications separately.

2F1a Stationary refrigeration and air conditioning

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Stationary air conditioning, heat pumps and tumble dryers

2F1b Mobile refrigeration and air conditioning

- Mobile air conditioning in different vehicle types
- Transport refrigeration for different vehicle types

Annex A3.2 shows an illustrative example of the model structure and parameters used for calculating emissions from mobile air conditioning in cars. Where possible, the most important assumptions for the data model are documented in Table 4-48. More information of the individual data and models is available from Carbotech (2020) as well as related background documents. This information is FOEN internal due to confidentiality of data, but is open for consultation by reviewers.

4.7.2.1 Refrigeration and air conditioning (2F1)

Methodology

The inventory under source category 2F1 includes different applications and equipment types. For each individual emission, models are used for calculating actual emissions as per the 2006 IPCC Guideline’s Tier 2a approach (emission factor approach). In order to obtain the most reliable data for the calculations, two different approaches are applied to get the stock data needed for the model calculations. For the following applications a ‘bottom up’ approach is applied relying on statistics, product information and expert estimations:

- Domestic refrigeration
- Mobile air conditioning for different vehicle types
- Transport refrigeration for different vehicles types
- Stationary air conditioning (direct and indirect systems)
- Heat pumps
- Tumble dryers

On the other hand, a ‘top down’ approach is applied for the calculation of the stock in commercial and industrial equipment starting with the total imported amount of refrigerant. To determine the portion used for commercial and industrial refrigeration, the refrigerant consumption of other applications is subtracted from the import amount (consumption for the production and maintenance based on the bottom up calculations of stock as given in the example of mobile air conditioning in Annex A3.2).

Commercial and industrial refrigeration have been evaluated together in former years. Since the submission 2018 calculations are carried out separately. The total bulk refrigerant for commercial and industrial application is split considering typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2020). Parameters for commercial and industrial applications are given in Table 4-48. HFC-245fa included under commercial and industrial refrigeration was found to be used for organic rankine cycles (ORC).

The combination of ‘bottom up’ with ‘top down’ calculations leads to more comprehensive results than using just one approach. Noteworthy, in the hypothetical but possible case of incomplete ‘bottom up’ evaluations, remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be a reason why the resulting refrigerant stock of commercial and industrial refrigeration, which serves as the residual, tends to be higher than in neighbouring countries.

The import data as reported to FOEN are adjusted for imported substances to be used in Liechtenstein. This is to eliminate double counting with the inventory data of Liechtenstein.

The split factor is based on the proportion of employees in the industrial and service sector (share of import for Liechtenstein <1%). The adjustment does not affect the bottom up calculations and leads to an adjustment of commercial and industrial refrigeration mainly.

Figure 4-8 shows the required data for the model calculation of refrigeration and air conditioning.

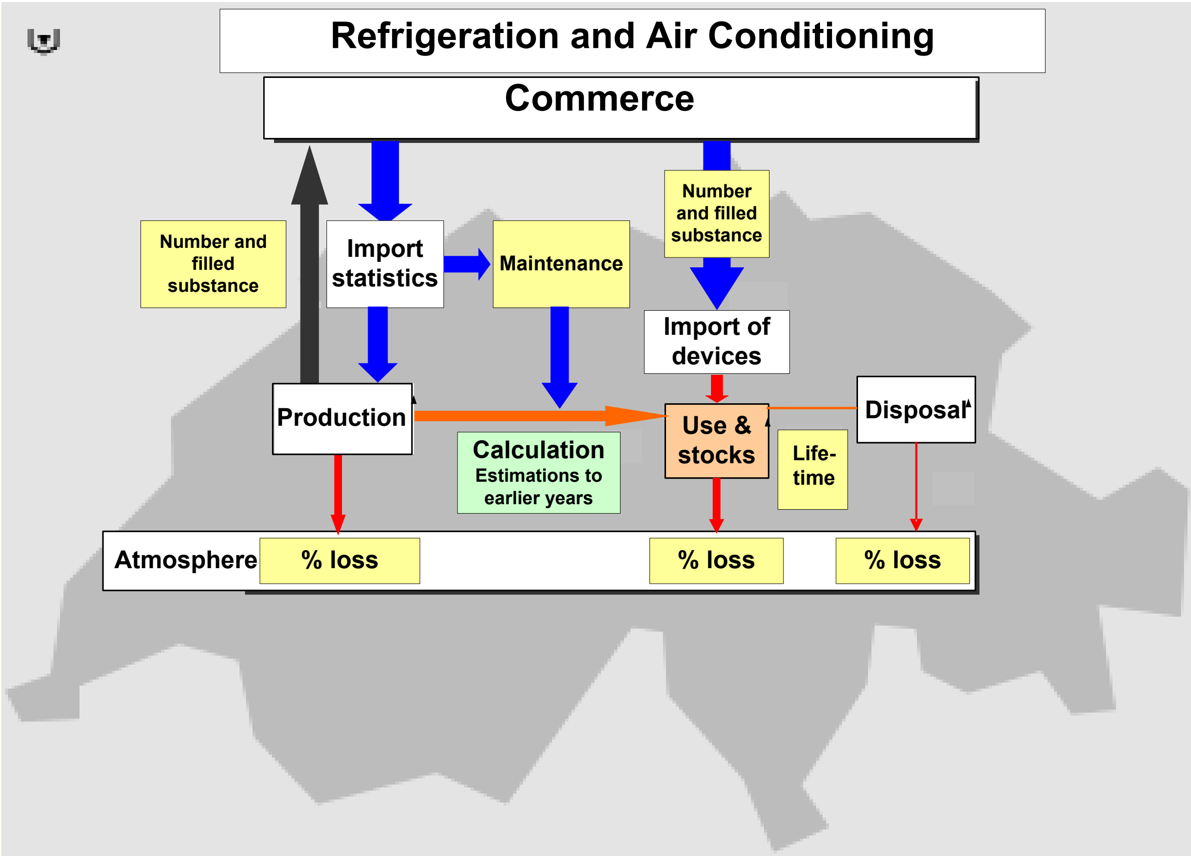


Figure 4-8 Required data for the model to calculate emissions from refrigeration and air conditioning in Switzerland.

Since 2008, there is an obligation for operators handling equipment containing more than 3 kg of HFCs to provide information to FOEN on the date of operation start, type of equipment, type and amount of refrigerant and date of disposal was introduced. This data source provides valuable information and has been used to improve the estimates used for modelling emissions under source category 2F and for the split of commercial and industrial equipment. However, it does not allow to directly draw the stock data or emission factors for the national inventory.

Emission factors

Emission factors for manufacturing, product life and disposal as well as average product lifetime are established on the basis of expert judgement and literature. Direct monitoring of the product life emission factors is only done at the company level for internal use and has been used partly for the verification of quality (confidential data from retailers and other type of industry). The product life factors and further parameters (i.e. re-filling frequency, handling losses and reuse of refrigerant) are used to allocate imported F-gases to new products and maintenance activities.

Table 4-48 displays the detailed model parameters used for the present submission. Changes of model parameters within the period 1990 to 2018 are indicated with values in brackets. The parameters in brackets are applied for the inventory 2018. For product life emission factors of some equipment types, a dynamic model is applied, which implies that emission decrease linearly between 1995 and 2015 due to improved production technologies and the continuous sensitisation of service technicians. The start/end values are based on expert statements (UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). The charge at end of life for different applications has been analysed considering the technical minimal charge of equipment and the expected frequency of maintenance (UBA/Ökorecherche 2012). Disposal losses are calculated based on expert assumptions on the portion of broken equipment (100% loss) and on assumptions on disposal losses for professional recovery at site or waste treatment by specialized companies.

Table 4-48 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2018 for refrigeration and air conditioning equipment. Changes of model parameters within this time period are indicated with the new value in brackets (for example a charge of 4.7–7.5 kg was applied for heat pumps until 2000 and a lower charge of 2.8–4.5 kg from 2000 onwards). A linear interpolation is applied for the product life emission factor of commercial and industrial refrigeration, stationary air conditioning and for the emission factor of mobile air conditioning within the given time period.

Equipment type	Product life time	Initial charge of new product	Manufacturing emission factor	Product life emission factor	Charge at end of life *)	Export of retiring equipment **)	Disposal loss emission factor ***)
	[a]	[kg]	[% of initial charge]	[% per annum]	[% of initial charge of new product]	[% of retiring equipment]	[% of remaining charge]
Domestic refrigeration	16	0.1	NO	0.5	92	0-5	19 ****)
Commercial refrigeration	8	NR	0.5	Sinking from 12.5 in 1990 to 7.8 in 2015	80-90	NE	21
Industrial refrigeration	15	NR	0.5	Sinking from 10 in 1990 to 5 in 2015	75-90	NE	15
Transport refrigeration: trucks/vans	10	1.8-7.8	1.5	15	86	90	28
Transport refrigeration: wagons	16	NR	NO	10	100	NE	28
Stationary air conditioning: direct cooling systems	15	NR	3 (2005: 1)	Sinking from 10 in 1995 to 4 in 2010	74-89	NE	28
Stationary air conditioning: indirect cooling systems	15	NR	1	Sinking from 6 in 1995 to 4 in 2010	85-89	NE	19
Stationary air conditioning: heat pumps	15	4.7-7.5 (2000: 2.8-4.5)	3 (2005: 1)	2	86	NE	19
Stationary air conditioning: tumble dryers	15	0.4	0.5	2	74	NE	19
Mobile air conditioning: cars	15	Sinking from 0.84 1990 to 0.55 in 2014	NO	8.5	58	31-72 (2016: 48)	50
Mobile air conditioning: truck/van cabins	12	1.1	NO	10 (2010: 8.5)	69-73	90 trucks 50 vans	50
Mobile air conditioning: buses	12	7.5	NO	20 (2001: 15)	100	50	50
Mobile air conditioning: trains	16	20	NO	5.5	100	50	20

*) Calculated value taking into account annual loss and portion refilled over the whole product life where applicable.

**) Allocation of disposal losses to export country (export for reselling and secondhand use)

***) Calculated value taking into account share of total refrigerant loss and emission factor of professional disposal. Disposal losses of HFC and PFC occur from 2000 onwards (introduction of HFCs and PFCs starting 1991 and 8 to 16 years lifetime of equipment). The value of 50% for mobile air conditioning is based on UBA 2005 and expert assumptions on share of total refrigerant loss, e.g. due to road accident.

****) Takes into account HFC-134a content in foams, based on information from the recycling organisation SENS.

NR = Not relevant as only aggregate data is used

NO = Not occurring (only import of charged units)

NE = Not estimated

Activity data
Activity data are taken from industry information and national statistics such as for admission of new cars, buses, vans and trucks. Stock data is modelled dynamically. Due to the large number of sub-models used for modelling the total emissions for source category 2F1, no table on time series of activity data is provided here. For illustration, Annex A3.2 shows the detailed calculation model for car air conditioning including the time series for the activity data for this particular sub-model. Mobile air conditioning accounts for approx. 30% of the total emissions (CO_2 eq) of source category 2F1 Refrigeration and air conditioning in the inventory 2018.

For the NIR 2012 (FOEN 2012) a cross check has been performed for results from model calculation and FOEN statistics on disposal and recycling of HFCs. This has indicated a significant gap with higher disposal values in model calculations compared to the FOEN disposal statistics. Some of the gap is explained by the onsite reuse and recycling of refrigerants, which is not reflected in the FOEN statistics and by other factors as e.g. the not accounted export of refrigeration equipment for second-hand use. Export rates used in model calculations are given in Table 4-48.

The registered refrigerant import is assumed to cover the consumption of Switzerland and Liechtenstein. To avoid double counting with the inventory data of Liechtenstein, the activity data for the equipment type commercial and industrial refrigeration is reduced by 0.9%, based on the share of imports of substances to be used in Liechtenstein. The reduction factor is based on the proportion of employees in the industrial and service sector in these two countries. For other equipment types no scope for double counting with the inventory of Liechtenstein was identified and therefore no correction factor is applied.

4.7.2.2 Foam blowing agents (2F2)

Methodology
In Switzerland no production of open cell foam based on HFCs is reported by the industry. Therefore, only closed cell PU and XPS foams, PU spray applications and further closed cell applications as sandwich elements are relevant under source category 2F2.

The emission model (Tier 2a) for foam blowing has been developed 'top down' based on import statistics for products, industry information and expert assumptions for market volumes and emission factors. Emissions from further not specified have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.

Emission factors
For the emission factors and the lifetimes of XPS and PU foams, expert estimates and default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. For PU sprays, expert estimates and specific default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. Unknown applications are evaluated following the Gamlen model recommended in the 2006 IPCC Guidelines (IPCC 2006). First-year losses are allocated to the country of production.

Table 4-49 Typical values on lifetime, charge and emission factors used in model calculations for foam blowing

Product	Product lifetime	Charge of new product	Manufacturing emission factor	Product life emission factor	Charge at end of life
Foam type	years	% of product weight	% of initial charge	% per annum	% charge of new product
PU foam	50	4.5	NR	NR	Calculated charge minus emissions over lifetime (so far not relevant, products still in use)
XPS foam HFC-134a	50	6.5	NR	NR / 0.7**	
XPS foam HFC-152a				100 / 0**	
PU spray all HFC	50	13.6 / 0 *	<1%	95 / 2.5 **	
Unknown use:					
HFC 134a, HFC 227ea, HFC 365 mfc	20	NR	10	10 / 4.5 **	
HFC 152a			100	100 / 0 **	

* The first value represents the charge of HFC 1995 (start of HFC use as substitutes for ozone depleting substances). The HFC amount was reduced continuously between 1995 and 2008. Since 2009 the production of PU spray is HFC free in Switzerland.

** Data for 1st year / following years (HFC-152a all emissions allocated to production)

NR Not relevant (PU foam: no substances according to this protocol have been used; XPS foam: emissions occur outside Switzerland; unknown use: calculations are based on the remaining propellant import amount).

Activity data

HFCs have been used until 2008 in the Swiss production of PU spray. The export rate of PU spray from Swiss production was about 96.5% of total production volume in the time period of HFC use. About one third of PU spray sold in Switzerland originates from local production, the rest is imported. For PU rigid foams no HFCs are used as foam blowing agent (only pentane and CO_2). There has been no production of XPS in Switzerland with HFCs. XPS foams were 100% imported until 2010. In 2011 a new production facility was started which, however, does not use HFCs. The HFC import not related to the main applications above has been allocated to further unknown applications (possible use in the production of sandwich elements mentioned by an import company of foam blowing agents has not been confirmed).

Detailed activity data for this source category are available from Carbotech (2020) as well as related background documents at FOEN, but not reported due to confidentiality.

4.7.2.3 Fire protection (2F3)

No emissions occur in source category 2F3 within Switzerland. The application of HFCs, PFCs and SF_6 in fire extinguishers is prohibited by law.

4.7.2.4 Aerosols (2F4)

Methodology

The Tier 2a emission model for Aerosol / MDI is based on a 'top-down' approach using import statistics for HFCs.

Emission factors

A manufacturing emission factor of 1% is applied. The model then assumes prompt emissions, i.e. 50% of the remaining substance is emitted in the first year and the rest in the second year, in line with the 2006 IPCC Guidelines.

Activity data

In most aerosol applications, HFCs have been replaced already in the past years. According to the information of companies filling aerosol bottles for use in households, e.g. cosmetics, cloth care and paint, no HFC is being used. For special technical applications – especially metered dose inhalers (MDI) – HFC is still in use. Compared to the total amount of aerosol applied, the HFC use for MDI is considered to be irrelevant.

Activity data are based on import statistics. The export and import of filled products is unknown, but assumed to be in a similar range.

4.7.2.5 Solvents (2F5)

Methodology

HFCs and PFCs are used as solvents. Emissions are calculated according to a Tier 1a method according to the 2006 IPCC Guidelines on basis of a 'top-down' approach using import statistics and industry information on allocation of the imported HFC and PFC amounts to different applications.

The import data as reported to FOEN cover imported substances to be used in Switzerland and Liechtenstein, and are therefore split in proportion of inhabitants of the two countries to avoid double counting.

Emission factors

In line with the 2006 IPCC Guidelines prompt emissions are assumed, i.e. half of the initial amount is emitted in the first year, the other half in the second year.

Activity data

Activity data are based on import statistics. Imports before 2011 were included under solvents. Therefore, the model for allocation of imported PFC volumes was adjusted accordingly for substances related to the electronics industry. Since 2011 imports for semiconductors manufacturing and further etching processes of electronics industry are registered as separate category in FOEN import statistics.

To avoid double counting with the inventory data of Liechtenstein, the import data reported to FOEN which is assigned to source category 2F5 in the inventory of Switzerland is reduced by 0.5%. The reduction factor is based on the proportion of inhabitants in these two countries.

4.7.2.6 Other applications (2F6)

There are no further applications of substitutes for ozone depleting substances in Switzerland.

4.7.3 Uncertainties and time-series consistency

For refrigeration equipment, air conditioning equipment as well as for foam blowing, a Monte Carlo analysis according to IPCC Good Practice Guidance for the evaluation of uncertainties of model calculations according to Tier 1 and 2 has been carried out. The Monte Carlo analysis was performed on the inventory data of the current GHG inventory (submission 2018). For the purpose of the Monte Carlo analysis, the uncertainty of all relevant parameters (e.g. initial appliance charge, product life emission factor, import and export volumes, etc.) used in the emission models for the applications as per Table 4-50 below has been characterised using the following statistical distributions:

- Triangular distribution (defined by the three parameters minimum, maximum and most likely value)
- Uniform distribution (same probability for the whole spectrum)
- Normal or lognormal distribution

The analysis was carried out with 10'000 cycles. Details on the distributions of parameters used (i.e. type of distribution, minimum, maximum, most likely value) are available from background documents at FOEN (Carbotech, 2019).

For the submission 2006 the uncertainty for the import statistic data had been estimated for the first time. Discussions with the persons responsible for data collection in the years 1997–2015 led to the estimations of standard deviation and minimal and maximal values given in Table 4-50. A normal distribution is used in the Monte Carlo analysis and the standard deviation, minimal and maximal values applied to define the probability ranges.

Table 4-50 Estimated uncertainty for the data of the imported substances.

Year	Std. Dev.	Minimal	Maximal	Remarks
Up to 1999	20%	15%	50%	Assumed that the data is not complete
2000 – 2003	20%	20%	20%	Data can be incomplete or possible double declaration
2004 – 2018	10%	20%	20%	Data can be incomplete or possible double declaration

The probability range of parameters applied in the model calculation is defined based on the variation given in expert interviews and the literature. Table 4-51 illustrate the definition of ranges for the example of commercial refrigeration.

Table 4-51 Assumptions on probability ranges for the example of commercial refrigeration.

Parameter	applied "likeliest"	Minimal	Maximal	Remarks
Initial charge of product	NR	NR	NR	Not relevant, calculated value
Manufacturing emission factor	0,5%	0,1%	3%	Triangular distribution
Prefilled import	25%	10%	40%	Normal distribution, StdDev5%
Product life emission factor 1990	12,5%	5%	20%	Normal distribution, StdDev5%
Product life emission factor 2018	7,8%	5%	15%	Lognormal distribution, StdDev2%
Recharge of product life emissions	80%	70%	100%	Triangular distribution
Product lifetime	8	7	15	Triangular distribution
Charge at end of life	NR	NR	NR	Not relevant, calcualted value
Disposal loss emission factor (professional disposal)	10%	1%	40%	Normal distribution, StdDev10%
Professional disposal	85%	45%	95%	Normal distribution, StdDev5%

Table 4-52 summarises the results for the application-specific emission models. The “value 2018” represents the reported emissions in kt CO_2 eq for the specific application for the year 2018. The uncertainty values stem from the Monte Carlo analysis. Detailed data are available from background documents at FOEN (Carbotech 2020).

The uncertainty of the resulting total emissions from source category 2F Product uses as substitutes for ODS is about 15%. Higher values result for the contributions of sub-categories and for single applications evaluated under 2F1. The calculated refrigerant amount for commercial and industrial refrigeration depends on the consumption of further refrigerant applications. Higher consumption for those applications lead to lower consumption in commercial and industrial applications and vice versa.

Relevant parameters for the building of stock in foam are the PU foam import and export rate of past years and the PU spray first year emission factor. The data base for PU sprays has been significantly improved with effect from the 2007 submission (FOEN 2007). This is attributed to improved models which have been elaborated by the main producer and its blowing agent import firm. However, the following three factors lead to a small amount remaining in the stock with a relative high uncertainty: high import and export rate of PU spray, lacking information on import of PU spray and on propellant used in import products and high uncertainty regarding the emission factor of the first year.

Table 4-52 Summary of results for model parameter “emissions” from Monte Carlo analysis for 2018 data on selected emission sources.

Application	Model para-meter	Value 2018 kt CO_2 eq.	Average kt CO_2 eq.	Median kt CO_2 eq.	min. kt CO_2 eq.	max. kt CO_2 eq.	Uncer-tainty %
2F1 Refrigeration and air conditioning	Emissions in kt CO_2 eq.	1'412	1'460	1'451	1'165	1'946	15
2F2 Foam blowing agents		28.3	42.1	36.6	10.8	219.3	148
2F4 Aerosols		20.5	21.2	21.1	8.9	35.0	42
2F5 Solvents		0.7	0.7	0.7	0.3	1.4	57
Total 2F Product use as substitutes for ODS		1'461	1'524	1'509	1'185	2'202	18

Consistency: Time series for 2F are all considered consistent.

4.7.4 Category-specific QA/QC and verification

The entire time series are compared between the current and the previous submission. Recalculations were identified and correspond to applied changes and improvements in model calculations.

The assumptions of decreasing emission factors for the different equipment types under source category 2F1 Refrigeration and air conditioning have been cross-checked with the inventories of Austria and Germany and have been found to be in line with the assumptions made for these inventories.

The emission factor of category 2F used in the Swiss inventory was compared to the corresponding emission factors of other countries (UNFCCC: http://unfccc.int/di/FlexibleQueries.do) and to the IPCC default value if available (INFRAS 2012). Concerning ODS substitutes the following sources of emissions are deemed most relevant: HFC-125, HFC-134a, HFC-143a and HFC-32 from stationary and commercial refrigeration as well as mobile air conditioning. The product life factor is relevant, since there is no production of halocarbons in Switzerland. For all these sources Switzerland’s emission factors lie in the midfield of the range of other countries except for the life factor in mobile air conditioning and commercial and industrial refrigeration. However, when compared to neighbouring countries such as Germany, very similar values are used. The Swiss product life factors are often lower than the average for the following reasons. First, since 2005 the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) is in place that ensures the proper handling and disposal of halocarbons and SF_6. Second, the decommissioning sector is well-organized by the SENS foundation and recycling is taxed in advance. Third, servicing staff is well-trained to proper handling and disposal of respective appliances. And fourth, the good economic conditions allow a higher renewal frequency and higher equipment standard (export of old vehicles and equipment for second-hand use).

The FOEN supports a monitoring campaign at the high-altitude research station Jungfraujoch, where various greenhouse gases are measured continuously. The location of the research station normally provides analyses of tropospheric background concentrations. However, under special meteorological conditions, an estimate of Swiss emissions can be derived from the measurements. For five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and for SF_6 a comparison of the inventory data with the inferred emissions is presented in Annex A5.1. Estimated emissions based on measurements at Jungfraujoch agree fairly well with the emission estimates of HFC-134a, HFC-125, HFC-143a, HFC-32 and of SF_6 of the Swiss greenhouse gas inventory. Larger differences result for less relevant contributions of HFC-152a. The allocations of first year emissions of foam blowing agents to the country of production might be the reason for the observed differences.

4.7.5 Category-specific recalculations

Recalculations reported in submission 2020:

- 2F1 mobile air-conditioning: Vehicles statistics for trucks were harmonized with data on the time period 1990 to 2018 provided by SFSO/Astra.
- 2F1 mobile air-conditioning: HFC-134a model calculation have been adapted considering higher service activities and on the other hand no recycling of HFC-134a at the disposal of vehicles (use of filtration equipment for service activities in garages only).
- 2F1 stationary air-conditioning: Split of refrigerants was adapted for stationary air-conditioning and heat pumps with data from the Swiss Registration Office for Refrigeration Systems and Heat Pumps (SMKW) covering the years 2015–2018. New refrigerants added to the evaluation.

4.7.6 Category-specific planned improvements

Gradual improvement of the data quality in co-operation with industry is ongoing. As in the past years, methodologies and emission models will be updated during the yearly process of F-gas inquiry. The focus will be on:

- Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO_2 compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).

4.8 Source category 2G – Other product manufacture and use

4.8.1 Source category description

Table 4-53 Key categories of 2G Other product manufacture and use. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2G	Other product manufacture and use	HFC	T2
2G	Other product manufacture and use	N2O	T2
2G	Other product manufacture and use	SF6	L1, L2

Table 4-54 Specification of source category 2G Other product manufacture and use.

2G	Source category	Specification
2G1	Electrical equipment	Emissions of SF_6 from use in electrical equipment
2G2	SF_6 and PFCs from other product use	Emissions of SF_6 and PFC not accounted in other source categories (i.e. for particle accelerators, soundproof windows, leakage detection, research and laboratory use)
2G3	N_2O from product uses	Emissions of N_2O from the use of N_2O in hospitals; Emissions of N_2O from the use of aerosol cans
2G4	Other	Emissions of NMVOC from domestic solvent use, printing, other solvent and product use as well as emissions of CO_2 resulting from post-combustion of NMVOC in exhaust gases of these sources; Emissions of CO_2, NO_x, CO, NMVOC and SO_2 from use of fireworks; Emissions of NO_x, CO and NMVOC from use of tobacco; Emissions of HFC not accounted in other source categories

4.8.2 Methodological issues

4.8.2.1 Electrical equipment (2G1)

Methodology

Under an agreement with FOEN, the industry association SWISSMEM is reporting actual emissions of SF_6 on basis of a mass-balance approach (Tier 3a). The mass balance includes mainly data for the production, installation, operation and disposal of electrical equipment, but included in past years also small amounts of SF_6 for other applications (i.e. research, magnesium foundry). SWISSMEM is collecting data from its members and is crosschecking the reported SF_6 consumption data with data from importers of SF_6. Installations in operation with electrical equipment containing SF_6 are periodically inspected for leakage, and losses are refilled (topping up). The refilled quantities and any SF_6 charge required during repair are reported as emissions at the time of filling. A product lifetime of 35 years is assumed.

Emission factors
Emission factors for source category 2G1 are based on industry information and are calculated values based on the mass-balance data. The discontinuity in emission factor from 2005 to 2006 data is due to the inspection intervals, optimised data collection and technical optimisation of equipment. The trend for reduced emission factors can be linked to the existing agreement of SWISSMEM and FOEN on the reduction of SF_6 emissions.

Activity data
Activity data are based on industry information. The wide annual fluctuation of SF_6 emissions from electrical equipment is related to the annual fluctuation of market volumes for such equipment as well as variations in inspection intervals and equipment break-down requiring topping up of SF_6 charge in the equipment. Import declarations obtained for FOEN import statistics are cross-checked regularly in order to eliminate double counting between SWISSMEM data and other import declarations.

4.8.2.2 SF_6 and PFCs from other product use (2G2)

Methodology
The emissions reported under 2G2 are related to the use of SF_6 for industrial particle accelerators (2G2b), the use of SF_6 for soundproof windows (2G2c) and other PFC and SF_6 use (2G2e). 2G2e summarizes research/analytics and further applications (including the unallocated difference in SF_6 emissions based on the FOEN import statistics and the SWISSMEM mass balance).

Under an agreement with FOEN, the industry association SWISSMEM is reporting actual emissions of SF_6 from industrial particle accelerators on the basis of a mass-balance approach (Tier 3a).

For 2G2c soundproof windows and 2G2e Other a Tier 2 approach is applied. Therefore, the unallocated amount of SF_6 under 2G2e has been assigned as application of cables and electrical control systems. Further evaluations of applications under 2G2e are based on FOEN import statistics and industry data, including applications with direct emissions and applications with banks. No further details are provided due to confidentiality. They are available in the confidential NIR for reviewers on request.

Emission factors
For the unallocated amount of SF_6 assigned to cables and electrical control systems, the emission factor is assumed to be 4% for manufacturing and 1% per year during the product life. The remaining charge is completely emitted at the time of disposal after a lifetime of 40 years. Because of the long lifetime, the disposal emissions are not yet relevant for the results.

For soundproof windows an emission rate of 1% per year is assumed, including the portion of broken windows. For the manufacturing an emission factor of 33% is assumed. However, since 2008, there is no production of windows with SF_6 in Switzerland.

Activity data

Activity data are based on import statistics and industry information. For the unallocated amount of SF_6 assigned to cables and electrical control systems an export rate of 80% is assumed similar to electrical equipment 2G1. For the inventory report submitted in 2015 (FOEN 2015), the split factors for allocation of imported amounts to different applications was checked through industry interviews and in-depth analysis in order to eliminate double counting between SWISSMEM data and other import declarations. Interviews with industry were carried out for the present inventory to identify applications of substances related to research under source category 2G2e Other.

4.8.2.3 N_2O from product uses (2G3)

Methodology

Emissions of N_2O from the source category 2G3 occur from the anaesthesia use in hospitals (2G3a Medical applications) and from the use of aerosol cans in households and restaurants (2G3b Other). For both categories a Tier 2 method based on country-specific emission factors for the production/consumption of N_2O is used (IPCC 2006 (vol. 3 chp. 8.4)).

Emission factors

For source category 2G3a Medical applications the emission factor is calculated based on the amount of N_2O sold for anaesthesia purpose in Switzerland divided by the number of inhabitants. The amount of N_2O sold is derived from annual sales data from the main suppliers from 2005 onwards (EMIS 2020/2G3a Lachgasanwendung Spitäler).

Source category 2G3b Other includes N_2O emissions from whipped-cream makers using gas capsules for private households and restaurants. The emission factor is calculated based on sales data and N_2O content of gas capsules sold in Switzerland divided by the number of inhabitants (EMIS 2020/2G3b Lachgasanwendung Haushalt).

Table 4-55 N_2O emission factors for the source categories 2G3a Medical applications and 2G3b Other.

2G3a Use of N_2O for anaesthesia	Unit	1990	1995	2000	2005
N_2O	g/inhabitant	43	30	17	12
2G3b N_2O from aerosol cans					
N_2O	g/inhabitant	9.6	10	11	11

2G3a Use of N_2O for anaesthesia	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
N_2O	g/inhabitant	7.0	7.0	6.0	5.7	3.5	3.8	3.3	2.5	2.4	2.3
2G3b N_2O from aerosol cans											
N_2O	g/inhabitant	12	12	12	12	11	11	11	10	10	10

Activity data

As the emission factors are expressed in g N_2O per capita, the corresponding activity data for the source categories 2G3a Medical applications and 2G3b Other are the Swiss population (SFSO 2019c).

Table 4-56 Activity data for the source categories 2G3a Use of N_2O for anaesthesia and 2G3b N_2O from aerosol cans.

2G3 N_2O from product uses	Unit	1990	1995	2000	2005
2G3a, 2G3b	inhabitants	6'796'000	7'081'000	7'209'000	7'501'000

2G3 N_2O from product uses	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2G3a, 2G3b	inhabitants	7'801'000	7'878'000	7'912'000	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000	8'514'000

4.8.2.4 Other (2G4)

Since the 2006 IPCC Guidelines (vol. 3, chp. 5.5) refer to the EMEP/EEA Guidebook 2019 regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. In the following sections the NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) as well as other product use (2G NFR) are reported. From other product use (2G NFR) also CO_2, NO_x, CO and SO_2 as well as CO from the use of fireworks and tobacco, respectively, are emitted. Switzerland's Informative Inventory Report 2020 contains a detailed description of the methods and country-specific data used for estimating the NMVOC emissions from the most important sources within source category 2G4 Other (FOEN 2020b). Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO_2 emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2019a).

Emissions of HFC not accounted for in other source categories are reported under 2G4.

Post-combustion of NMVOC (2G4)

Methodology

The CO_2 emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of more than 100 industrial plants (Carbotech 2019a). Post-combustion facilities are applied in source categories 2D3a Solvent use and 2G4 Other (printing (2D3h NFR), other solvent use (2D3i NFR)) and other product use (2G NFR)). For submission 2019, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 60% of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents are updated annually whereas all the others every five years. If no information of the solvent composition is available, mean source category-specific values are applied for the carbon content.

Not all facilities have been in use for the entire period 1990–2018. There was a significant increase in total number of facilities from 33 in the year 1990 to 119 in 2002. Since then, the number fluctuates around 120.

These amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

Emission factors

CO_2 emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed are updated annually whereas for all others at least every five years. In between the values are kept constant (see Table 4-57). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-57 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-57 CO_2 emission factors for post-combustion of NMVOC in 2G4 Other.

2G4 Other	Unit	CO_2			
Post-combustion of NMVOC		**1990**	**1995**	**2000**	**2005**
Printing (2D3h NFR)	t/t NMVOC	2.25	2.20	2.17	2.14
Other solvent use (2D3i NFR)	t/t NMVOC	2.06	2.04	2.02	2.01
Other product use (2G NFR)	t/t NMVOC	1.30	1.56	1.61	1.68

2G4 Other	Unit	CO_2									
Post-combustion of NMVOC		**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Printing (2D3h NFR)	t/t NMVOC	2.15	2.13	2.13	2.13	2.13	2.13	2.08	2.09	2.09	2.08
Other solvent use (2D3i NFR)	t/t NMVOC	2.01	2.02	2.02	2.02	2.02	2.01	2.28	2.28	2.28	2.28
Other product use (2G NFR)	t/t NMVOC	1.68	1.89	1.70	1.72	1.72	1.69	1.72	1.72	1.65	1.67

Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry. For the ten most important installations (within 2D3a and 2G4), they are updated annually whereas for all others at least every five years.

Table 4-58 Activity data of NMVOC post-combustion in 2G4 Other.

2G4 Other	Unit	1990	1995	2000	2005
Post-combustion of NMVOC					
Printing (2D3h NFR)	t NMVOC	2'188	9'357	11'276	12'933
Other solvent use (2D3i NFR)	t NMVOC	317	503	559	405
Other product use (2G NFR)	t NMVOC	412	935	1'118	953

2G4 Other	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Post-combustion of NMVOC											
Printing (2D3h NFR)	t NMVOC	12'865	13'331	15'083	14'249	14'488	14'286	14'294	14'872	16'204	16'240
Other solvent use (2D3i NFR)	t NMVOC	377	573	573	573	573	543	382	382	382	382
Other product use (2G NFR)	t NMVOC	953	622	866	833	833	850	872	871	1'016	972

Domestic solvent use (2D3a NFR)

Methodology

The source category 2G4 Domestic solvent use including fungicides (2D3a NFR) comprises mainly the use of cleaning agents and solvents in private households for building and furniture cleaning and cosmetics and toiletries but also the use of spray cans and pharmaceuticals. These products contain solvents, which evaporate during use or after the application. Among the numerous NMVOC emission sources, the use of household cleaning agents is the largest single source in source category 2G4.

Based on the decision tree Fig. 3.1 in chapter 2D3a in EMEP/EEA (2019), the emissions are calculated by a Tier 2 method (EMIS 2020/2D3a NFR) using country-specific emission factors. All emissions related to domestic solvent use are calculated proportional to the Swiss population.

Emission factors

Household cleaning agents: This source category includes the use of cosmetics, toiletries, cleaning agents and care products. Its resulting emission factor bases thus on a multitude of products, their NMVOC contents, emission fractions and consumption numbers. About 80% of the NMVOC emissions stem from the use of cosmetics and toiletries whereas the rest arises from the use of cleaning agents and care products. Available data sources consist of surveys of the use of household cleaning agents, cosmetics and toiletries in Switzerland (1990) and information from the Swiss association of cosmetics and detergents (SKW 2010) as well as surveys from Germany (1998, 2005). From 2001 until 2010 a constant EF is assumed for domestic use of cleaning agents. The value is based both on information from the Swiss association of cosmetics and detergents (SKW 2010) and from a German study on NMVOC emissions from solvent use and abatement possibilities by Theloke (2005). There were no significant improvements in the solvent compositions of the employed detergents. In a study conducted in 2013/2014 in Switzerland better data of household cleaning agents, cosmetics and toiletries was collected based on comprehensive surveys at retailers, producers, industry associations and experts as well as analysis of import statistics (Hubschmid 2014). As a result of this study, the emission factor of household cleaning agents was adjusted in 2013. The study indicates again an increase in the NMVOC emission factor in 2013.

Domestic use of spray cans: Emission factors of domestic use of spray cans are based on surveys in Switzerland (1990) and a Swiss study conducted in 2013/2014. This study provided better data of domestic spray cans based on comprehensive surveys at retailers, producers, industry associations and experts as well as analysis of import statistics (Hubschmid 2014). As a result of this study, the emission factor of spray cans was adjusted. It is assumed constant for the time period since 1998.

Domestic use of pharmaceutical products: Emission factors of domestic use of pharmaceutical products are available from surveys in Switzerland (1990) and Germany (1998) and from the Swiss business association for the chemical, pharmaceutical and biotech industry (scienceindustries) for 2011, as documented in the EMIS database. For years with no survey data, emission factors are interpolated.

Table 4-59 Emission factors for NMVOC for source category 2G4 Other: domestic solvent use, printing, other solvent use, other product use in 2018.

2G4 Other	Unit	NMVOC
Domestic solvent use (2D3a NFR)		
Domestic use of spray cans	g/inhabitant	360
Domestic use of pharmaceuticals	g/inhabitant	30
Household cleaning agents	g/inhabitant	971
Printing (2D3h NFR)		
Printing	kg/t ink	280
Package printing	kg/t ink	130
Other solvent use (2D3i NFR)		
Production of cosmetics	kg/employee	63
Production of paper and paperboard	g/t	35
Production of perfume and flavour	kg/employee	37
Production of textiles	kg/employee	7.9
Production of tobacco	kg/employee	12
Removal of paint and lacquer	kg/t removal agent	350
Scientific laboratories	kg/employee	15
Other product use (2G NFR)		
Application of glues and adhesives	kg/t solvent	735
Commercial & industrial use of cleaning agents	g/employee	421
Cosmetic institutions	kg/employee	28
De-icing of airplanes	kg/t de-icing agent	54
Glass wool enduction	g/t glass wool	134
Hairdressers	kg/employee	14
Health care, other	kg/employee	8.4
Medical practices	kg/employee	7.6
Preservation of wood	kg/t preservative	110
Rock wool enduction	g/t rock wool	350
Underseal treatment & conservation of vehicles	kg/t underseal agent	450
Use of antifreeze agents in vehicles	kg/Mio vehicle km	8
Use of concrete additives	g/t additive	740
Use of cooling lubricants	kg/t lubricant	6
Use of lubricants	kg/t lubricant	340
Use of pesticides	kg/t pesticide	116
Use of tobacco	kg/Mio cigarette eq.	4.8

Activity data

As described in the methodology chapter, the activity data used for calculating the NMVOC emissions from domestic solvent use corresponds to the Swiss population (SFSO 2019c), see Table 4-60.

Table 4-60 Activity data for source category 2G4 domestic solvent use, printing, other solvent use, other product use.

2G4 Other	**Unit**	**1990**	**1995**	**2000**	**2005**
Domestic solvent use (2D3a NFR)	inhabitants	6'796'000	7'081'000	7'209'000	7'501'000
Printing (2D3h NFR)					
Printing	kt ink	13	13	14	12.0
Package printing	kt ink	5.9	5.9	5.5	9.1
Other solvent use (2D3i NFR)					
Fat, edible & non-edible oil extraction	kt	40	38	12	NO
Production of cosmetics	employees	2'200	2'200	2'267	2'100
Production of paper and paperboard	kt	1'510	1'560	1'780	1'750
Production of perfume and flavour	employees	2'200	2'325	2'567	3'200
Production of textiles	employees	25'200	26'763	24'300	17'067
Production of tobacco	employees	3'300	2'988	2'733	2'700
Removal of paint and lacquer	t	700	600	502	405
Scientific laboratories	employees	10'194	18'604	23'217	23'000
Vehicles dewaxing	vehicles	200'000	166'250	72'667	NO
Other product use (2G NFR)					
Application of glues and adhesives	kt	4.0	3.0	2.0	1.5
Commercial & industrial use of cleaning agents	employees	3'950'000	3'867'500	3'954'667	4'133'667
Cosmetic institutions	employees	2'600	3'100	3'533	3'800
De-icing of airplanes	kt	1.2	2.4	1.8	2.5
De-icing of airport surfaces	kt	0.34	0.39	0.32	0.41
Fireworks	kt	0.8	1.0	1.5	1.4
Glass wool enduction	kt	24	24	31	37
Hairdressers	employees	20'553	22'826	23'530	22'200
Health care, other	employees	113'000	129'250	145'667	161'667
Medical practices	employees	27'625	42'047	50'833	55'357
Preservation of wood	kt paint	6.0	7.9	8.7	7.2
Rock wool enduction	kt	38	40	51	46
Underseal treatment & conservation of vehicles	kt	0.06	0.06	0.08	0.12
Use of antifreeze agents in vehicles	Mio vehicle km	47'523	46'479	51'142	53'723
Use of concrete additives	kt	24	25	29	36
Use of cooling lubricants	kt	5.0	5.2	5.8	4.5
Use of lubricants	kt	1.3	1.3	1.3	3.7
Use of pesticides	kt	2.4	2.4	2.3	2.3
Use of tobacco	Mio cigarette eq.	16'192	15'774	15'381	13'369

2G4 Other	**Unit**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Domestic solvent use (2D3a NFR)	inhabitants	7'801'000	7'878'000	7'912'000	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000	8'514'000
Printing (2D3h NFR)											
Printing	kt ink	8.4	8.3	8.2	8.1	8.0	7.8	7.7	7.5	7.6	7.6
Package printing	kt ink	13	13	13	13	13	13	13	13	13	13
Other solvent use (2D3i NFR)											
Fat, edible & non-edible oil extraction	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Production of cosmetics	employees	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100	2'100
Production of paper and paperboard	kt	1'540	1'540	1'380	1'372	1'363	1'355	1'346	1'338	1'329	1'321
Production of perfume and flavour	employees	3'450	3'475	3'500	3'521	3'542	3'563	3'583	3'604	3'625	3'646
Production of textiles	employees	14'200	13'800	14'800	14'768	14'737	14'705	14'674	14'642	14'611	14'579
Production of tobacco	employees	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200	3'200
Removal of paint and lacquer	t	327	307	288	268	249	229	210	190	190	190
Scientific laboratories	employees	23'000	23'000	23'000	23'083	23'167	23'250	23'333	23'417	23'500	23'583
Vehicles dewaxing	vehicles	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other product use (2G NFR)											
Application of glues and adhesives	kt	1.2	1.1	1.0	1.9	1.0	1.0	1.0	1.0	1.0	1.0
Commercial & industrial use of cleaning agents	employees	4'363'667	4'404'000	4'333'333	4'262'667	4'192'000	4'236'000	4'280'000	4'324'000	4'368'000	4'412'000
Cosmetic institutions	employees	4'600	4'800	5'000	5'111	5'222	5'333	5'444	5'556	5'667	5'778
De-icing of airplanes	kt	4.0	3.3	2.6	3.8	3.1	2.3	2.3	2.3	2.3	2.4
De-icing of airport surfaces	kt	0.004	0.018	NO	NO	NO	NO	NO	NO	NO	NO
Fireworks	kt	2.0	1.7	2.0	1.9	2.3	1.8	1.6	1.2	1.7	1.8
Glass wool enduction	kt	33	36	41	39	33	32	31	32	36	40
Hairdressers	employees	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000	23'000
Health care, other	employees	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000	163'000
Medical practices	employees	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700	58'700
Preservation of wood	kt paint	5.3	4.5	3.6	2.8	2.0	2.0	2.0	2.0	2.0	2.0
Rock wool enduction	kt	53	56	57	57	54	53	47	52	52	57
Underseal treatment & conservation of vehicles	kt	0.15	0.16	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17
Use of antifreeze agents in vehicles	Mio vehicle km	56'376	57'039	58'007	58'976	59'944	60'913	61'881	62'260	62'638	63'017
Use of concrete additives	kt	34	41	44	38	38	37	37	36	36	35
Use of cooling lubricants	kt	3.1	3.9	4.4	4.1	4.1	4.1	4.1	4.1	4.0	4.0
Use of lubricants	kt	0.29	0.35	0.49	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Use of pesticides	kt	2.2	2.1	2.3	2.2	2.3	2.2	2.2	2.2	2.0	2.1
Use of tobacco	Mio cigarette eq.	13'667	12'443	11'856	12'705	12'162	10'628	10'284	10'731	10'731	10'342

Printing (2D3h NFR)

Methodology

The source category 2G4 Printing (2D3h NFR) comprises package printing and other printing industry. A Tier 2 method according to the EMEP/EEA Guidebook 2019 is applied using country-specific emission factor for calculating the NMVOC emissions from ink applications.

Emission factors

Emission factors for NMVOC are based on data from industry associations (Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector (SOLV)), Swiss organisation for the print and media industry (viscom)), surveys on the VOC balances, emission control authorities, German studies on NMVOC emissions from solvent use (Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2020/2G4). For emission factors see Table 4-59.

Activity data

The activity data used for calculating the NMVOC emissions correspond to the annual consumption of printing ink. This data stem from industry associations (SOLV, viscom), surveys on the VOC balances, Swiss Federal Office of Statistics, emission control authorities and expert estimates, documented in the EMIS database (EMIS 2020/2G4). For activity data see Table 4-60.

Other solvent use (2D3i NFR)

Methodology

Source category 2G4 Other solvent use (2D3i NFR) consists of a number of solvent uses in various production processes and services. Based on the decision tree Fig. 3.1 in chapter 2D3i in EMEP/EEA (2019), a Tier 2 method using country-specific emission factors is applied for calculating the NMVOC emissions from the different solvent applications (EMIS 2020/2G4). For the source category 2G4 Other solvent use (2D3i NFR) Not-attributable solvent emissions so-called direct emission data is available only.

Emission factors

Emission factors for NMVOC are country-specific based on data from industry and services, industry associations, German studies on NMVOC emissions from solvent use (Theloke et al. 2000 and Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2020/2G4). For emission factors see Table 4-59.

Activity data

For the majority of production processes and services – such as production of perfume and flavour and production of textiles – the activity data correspond to the respective number of employees (SFSO 2019d). The quantity of NMVOC emission per employee originates from the bottom-up approach in these industrial sectors and the decentralized political structure in Switzerland. The determined NMVOC emissions of representative production sites or service institutions are referred to the number of employees in order to calculate the Swiss total.

For production of paper and paperboard and fat, edible and non-edible oil extraction, the activity data are based on production volumes. Annual production volumes of paper and paperboard are provided by the Swiss association of pulp, paper and paperboard industry (ZPK). For the removal of paint and lacquer the activity data correspond to the amount of removal agent based on information from producers and retail trade.

For activity data see Table 4-60.

Other product use (2G NFR)
Methodology

Within source category 2G4 Other product use (2G NFR), the major NMVOC emission sources in 2018 are commercial and industrial use of cleaning agents and health care, other.

Based on the decision tree Fig. 3.1 in chapter 2G in EMEP/EEA (2019), for source category 2G4 Other product use (2G NFR) Tier 2 methods using country-specific emission factors are applied for calculating the emissions from the different product applications and the use of fireworks and tobacco (EMIS 2020/2G).

For the source categories 2G4 Renovation of corrosion inhibiting coatings (2G NFR) and 2G Use of aerosol cans in commerce and industry (2G NFR) so-called direct emission data is available only.

Indirect CO_2 emissions from CO and NMVOC emissions from tobacco use are of biogenic origin and are therefore not reported in chp. 9 Indirect CO_2 and N_2O emissions.

Emission factors

Emission factors for NMVOC are based on data from industry, services and Swiss airports, industry associations, survey on co-formulants in pesticides, German studies on NMVOC emissions from solvent use (Theloke et al. 2000 and Theloke 2005) and expert estimates, as documented in the EMIS database (EMIS 2020/2G4). For emission factors see Table 4-59.

Emission factors for pollutants other than NMVOC from use of fireworks and tobacco are displayed in Table 4-61. Emission factors of fireworks are documented in FOEN (2014p). Emission factors for use of tobacco are according to the EMEP/EEA Guidebook 2019 (EMEP/EEA 2019).

Table 4-61 Emission factors for CO_2, NO_x, CO, SO_2 for source category 2G4 Fireworks and Use of tobacco in 2018.

2G4 Other	**Unit**	**CO_2**	**NO_x**	**CO**	**SO_2**
Other product use (2G NFR)					
Fireworks	kg/t	43	0.26	7.4	4.1
Use of tobacco	kg/Mio cigarette eq.	NA	1.8	55	NA

Activity data

For the production processes, such as enduction of glass and rock wool and part of the applications in services or agriculture, such as preservation of wood, pesticides and application of glues and adhesives the activity data are based on production volume or employed agents. For the other part of applications in services, such as house cleaning in services, commerce and industry and medical practices the activity data correspond to the respective number of employees. The quantity of NMVOC emission per employee originates from the bottom-up approach in these service sectors and the decentralized political structure in Switzerland. The determined NMVOC emissions of representative production sites or service institutions are referenced to the number of employees in order to calculate the Swiss total.

The activity data stem from industry, services, Swiss airports (since 2011 no VOC-containing agents are used for de-icing of airport surfaces anymore), industry associations, Swiss federal statistical office, Swiss Federal Office for Agriculture (sales statistics of pesticides) and expert estimates. They are documented in the EMIS database. Activity data for annual tobacco consumption and the annual firework sales are provided by the Swiss addiction prevention foundation ("Sucht Schweiz") and the statistics of the Swiss federal office for police (FEDPOL 2018), respectively.

For activity data see Table 4-60.

HFC not accounted in other source categories

Emissions of HFC not accounted for in any other source categories are reported under 2G4 Other. For confidentiality reasons, no further details are provided here. Information is documented in the confidential NIR.

Methodology

A Tier 2 approach is applied for HFCs with prompt emissive applications based on import statistics.

Emission factors

Prompt emissions of HFC are calculated following the 2006 IPCC Guidelines assuming a total loss of product within two years (50% loss in the first and 50% in the second year).

Activity data

HFC activity data under 2G4 are based on FOEN import statistic and company data.

4.8.3 Uncertainties and time-series consistency

The uncertainty of total CO_2 emissions from the entire source category 2G4 is estimated at 14% (expert estimate).

The uncertainty of N_2O emissions from source category 2G3, which is a key category for this gas regarding trend according to Approach 2, is estimated at 80% (expert estimate, see Table 1-10).

The uncertainty of SF_6, HFC and PFC emissions in source category 2G is estimated at 47%, 36% and 34% respectively based on a Monte Carlo analysis. Further details are available from background documents, confidential/internal excel calculations and the respective report (Carbotech, 2020).

Time series is consistent, with exception of the source category 2G2 Electrical equipment where from 2000 onwards the data are based on a Tier 3a approach instead of model calculations according to Tier 2 as applied for data before 2000. Due to lack of basic information it is not possible to provide a consistent time series for category 2G2 Electrical equipment retroactively.

4.8.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

For SF_6, measurements at Jungfraujoch are used to estimate Swiss emissions for verification purposes (see 4.7.4 and Annex 5). Estimated emissions based on measurements at Jungfraujoch agree well with the emissions from the inventory.

4.8.5 Category-specific recalculations

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between latest and previous submission are presented also in chp. 10.1.2.2.

- 2G4: The activity data and NMVOC emission factor of 2G4 Postcombustion of NMVOC in printing (2D3h NFR) and other product use (2G NFR) have been revised for 2017 and 2016–2017, respectively, based on surveys of VOC balances.
- 2G4: The NMVOC emission factors of 2G4 (2G NFR) Rock wool enduction have been updated for 2016 and 2017 based on industry data.
- 2G4: The activity data and NMVOC emission factor of 2G4 (2D3h NFR) Package printing have been revised for 2011–2017 and 2014–2017, respectively, based on surveys of the VOC balances of the printing companies.
- 2G4: The activity data and NMVOC emission factor of 2G4 (2D3h NFR) Printing have been revised thoroughly for 2002–2017, 2002–2012 and 2014–2017, respectively, based

on the Swiss foreign trade statistics, the ink production, data and information of the industry association and emission control authorities as well as the statistics of the employees (SFSO 2019c).

- 2G4: The activity data and NMVOC emission factor of 2G4 (2D3i NFR) Removal of paints and lacquer have been revised for 1997–2017 based on data and information from companies, paint manufacturers as well as retail trade.
- 2G4: The activity data and NMVOC emission factor of 2G4 (2G NFR) Use of pesticides have been revised thoroughly for 1991–2017 based on the sales statistics of pesticides of the Swiss federal office for agriculture and a recent survey on co-formulants in pesticides, respectively.
- 2G4: In the previous submission, the updated NMVOC emission factors for 2016 and 2017 of 2G4 (2G NFR) Underseal treatment and conservation of vehicles were forgotten to include in the inventory. This has been corrected yielding revised values from 2013 onwards.

4.8.6 Category-specific planned improvements

No category-specific improvements are planned.

4.9 Source category 2H – Other

4.9.1 Source category description

Source category 2H Other is not a key category.

Table 4-62 Specification of source category 2H Other in Switzerland.

2H	Source category	Specification
2H1	Pulp and paper	Emissions from NMVOC from pulp and paper including chipboard, fibreboard and cellulose production (ceased in 2008)
2H2	Food and beverages industry	Emissions of CO and NMVOC from production of food and drink
2H3	Other	Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting and shooting

4.9.2 Methodological Issues

4.9.2.1 Pulp and paper (2H1)

Methodology

In 2018, the production of chipboard and fibreboard are the relevant industrial processes in the source category 2H1 Pulp and paper. In Switzerland, chipboard and fibreboard are produced in one and two plants, respectively. The cellulose production was closed down in 2008 and is not occurring anymore in Switzerland. The NMVOC emissions are calculated by a Tier 2 method according to EMEP/EEA (2019) using country-specific emission factors.

Indirect CO_2 emissions resulting from NMVOC emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Emission factors

The emission factor for NMVOC emissions from pulp and paper production in Switzerland is country-specific and based on measurements and data from industry and expert estimates documented in EMIS 2020/2H1. The implied emission factor given in Table 4-63 is production-weighted and related to chipboard and fibreboard production.

Table 4-63 Emission factors for CO and NMVOC in pulp and paper production and food and beverages industry, CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting for 2018.

2H Other	Unit	CO_2	NO_x	CO	NMVOC	SO_2
2H1 Pulp and paper	g/t	NA	NA	NA	530	NA
2H2 Food and beverage industry (exc. beer, wine, spirits)	g/t	NA	NA	250	2'200	NA
2H2 Food and beverage industry (beer, wine, spirits)	g/m^3	NA	NA	NA	340	NA
2H3 Blasting and shooting	kg/t	400	35	310	60	0.5

Activity data

The annual amount of pulp and paper produced in Switzerland is based on data from industry and expert estimates documented in EMIS 2020/2H1.

Table 4-64 Pulp and paper production, food and beverages production and amount of explosives used.

2H Other	Unit	1990	1995	2000	2005
2H1 Pulp and paper	kt	604	593	641	693
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'254	2'116	2'301	2'138
2H2 Food and beverage industry (beer, wine, spirits)	m3	560'972	516'519	492'208	452'877
2H3 Blasting and shooting; blasting agent and powder	kt	2.6	1.3	1.9	0.79

2H Other	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2H1 Pulp and paper	kt	544	602	564	533	510	516	519	503	507	502
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'467	2'400	2'525	2'491	2'413	2'533	2'473	2'428	2'424	2'414
2H2 Food and beverage industry (beer, wine, spirits)	m3	465'753	467'699	461'453	454'903	449'070	446'567	447'709	439'556	435'426	457'265
2H3 Blasting and shooting; blasting agent and powder	kt	2.1	2.4	2.9	2.3	2.2	2.1	2.1	0.67	0.73	0.81

4.9.2.2 Food and beverages industry (2H2)

Methodology

Production of beverages comprises wine, beer and spirits and food industry comprises production of bread, sugar, smoked meat, roasting of coffee and the milling industry. The CO and NMVOC emissions from food and beverages industry are calculated by a Tier 2 method according to EMEP/EEA (2019) using country-specific emission factors. Since these CO and NMVOC emissions are of biogenic origin, they are not considered for calculation of indirect CO_2 emissions.

Emission factors

The emission factors for CO and NMVOC emissions from food and beverages industry are country-specific and based on measurements and data from industry and expert estimates as documented in the EMIS database (EMIS 2020/2H2). The implied emission factors are production-weighted (Table 4-63).

Activity data
The annual amount of food and beverages produced is based on data from industry and the farmers' association (SBV) and expert estimates as documented in EMIS 2020/2H2 (Table 4-64).

4.9.2.3 Other (2H3)

Methodology
For determination of emissions of CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting, an analogous Tier 2 method with country-specific emission factors is used as documented in the EMIS database (EMIS 2020/2H3 Sprengen und Schiessen).

Indirect CO_2 emissions resulting from NMVOC and CO emissions in this source category are only included in CRF Table6 and reported in chp. 9.

Emission factors
The emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting activities are country-specific and based on measurements and data from industry and expert estimates (see Table 4-63).

Activity data
The annual amount of used explosives is based on the Federal statistics on explosives (FEDPOL 2018) (Table 4-64).

4.9.3 Uncertainties and time-series consistency

The uncertainty for CO_2 emissions from 2H3 Other is estimated to be 8% (expert judgement) since activity data are taken from customs statistics.

Consistency: Time series for 2H Other are all considered consistent.

4.9.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

4.9.5 Category-specific recalculations

The following recalculations were implemented in submission 2020. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between latest and previous submission are presented also in chp. 10.1.2.2.

- 2H2 Bread production: Activity data for bread consumption had previously been derived from the annual grain harvest statistics due to lacking direct statistical data as of 2010. The Swiss Bread Association has provided a direct value for 2017 of bread consumption. Values between 2010 and 2017 have been linearly interpolated.

- 2H2 Smoked meat: Activity data for 2017 has been updated in the annual statistical report by the SFSO.
- 2H3 Blasting and shooting: For 2014 the value for activity data of detonation cords has been corrected by the FEDPOL.

4.9.6 Category-specific planned improvements

No category-specific improvements are planned.

5 Agriculture

Responsibilities for sector Agriculture	
Overall responsibility for sector	Daniel Bretscher (Agroscope)
Author	Daniel Bretscher (Agroscope)
Sector experts	Chloé Wüst (Agroscope, QC), Christoph Ammann (Agroscope)
EMIS database operation	Sabine Schenker (FOEN)
Technical contributor	Dominik Eggli (Meteotest)
Annual updates (NIR text, tables, figures)	Daniel Bretscher (Agroscope)
Internal review	Michael Bock (FOEN)

5.1 Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector Agriculture. The following source categories are reported:

- 3A Enteric fermentation, CH_4 emissions from domestic livestock,
- 3B Manure management, emissions of CH_4, N_2O and NO_x,
- 3D Agricultural soils, emissions of N_2O, NO_x and NMVOC,
- 3G Liming, emissions of CO_2
- 3H Urea application; emissions of CO_2

No emissions are reported for 3C Rice cultivation as in Switzerland only a small area is cultivated with upland rice. The categories 3E Prescribed burning of savannahs and 3F Field burning of agricultural residues do not occur in Switzerland and are therefore not reported.

CO_2 emissions from soils are reported under 4 Land use, land-use change and forestry (LULUCF). CO_2 emissions from energy use in agriculture are reported under 1A4c Agriculture/forestry/fishing.

Total greenhouse gas emissions from the agriculture sector in 2018 were 5'991 kt CO_2 equivalents which is a contribution of 12.9% to the total of Swiss greenhouse gas emissions (excluding indirect CO_2, excluding LULUCF, Table 2-5, Table 5-1). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting 55% of all agricultural greenhouse gases, followed by 3D Agricultural soils with 25% and 3B Manure management with 19% (Figure 5-1). 3G Liming and 3H Urea application contributed 0.5% and 0.2% respectively.

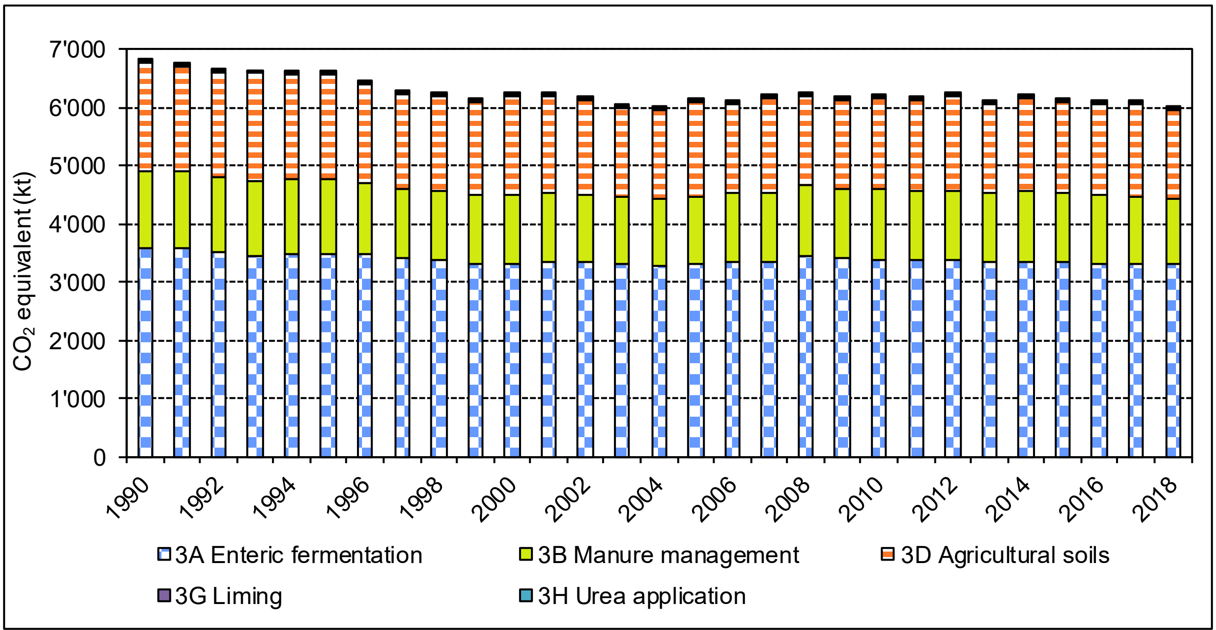


Figure 5-1 Greenhouse gas emissions of the agricultural sector in kt CO_2 equivalents.

Table 5-1 Greenhouse gas emissions of the agricultural sector in kt CO_2 equivalents.

Gas	1990	1995	2000	2005
	CO_2 equivalent (kt)			
CO_2	49	42	39	42
CH_4	4'476	4'348	4'093	4'067
N_2O	2'302	2'222	2'100	2'023
Sum	6'826	6'612	6'232	6'132

Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	CO_2 equivalent (kt)									
CO_2	41	44	43	42	42	46	44	47	48	46
CH_4	4'172	4'151	4'143	4'144	4'107	4'141	4'127	4'090	4'048	4'040
N_2O	1'956	2'008	1'974	2'047	1'940	2'020	1'961	1'976	2'011	1'905
Sum	6'170	6'203	6'160	6'232	6'089	6'207	6'132	6'113	6'107	5'991

CH_4 and N_2O emissions generally declined from 1990 until 2004 (Figure 5-2). Subsequently CH_4 emissions increased slightly until 2008 and decreased again afterwards. N_2O emissions remained more or less on a constant level since 2004. This general development can be explained by the development of the cattle population and the input of mineral fertilisers. Use of mineral fertiliser declined due to the introduction of the “Proof of Ecological Performance (PEP)” in the early 1990s (Agroscope 2019a, Leifeld and Fuhrer 2005), while the cattle population was influenced by the market situation, the milk quotation system (suspended in 2009) and the general agricultural policy- and subsidy-system (OECD 2013). Most emission factors did not change significantly over the inventory years. CO_2 emissions display high year to year variability due to variability of urea application, which depends among others on the relative price levels of different industrial fertilisers.

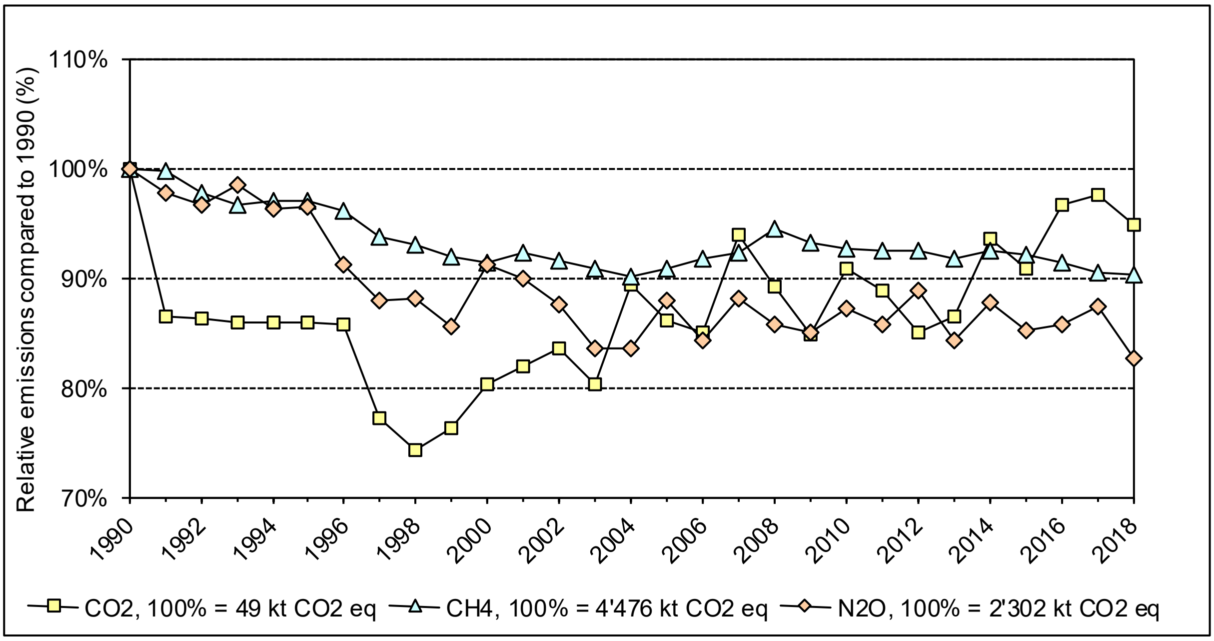


Figure 5-2 Relative trends of the greenhouse gas emissions of sector 5 Agriculture. The base year 1990 represents 100%.

Among the key categories of the Swiss inventory, six are from the agricultural sector (Figure 5-3).

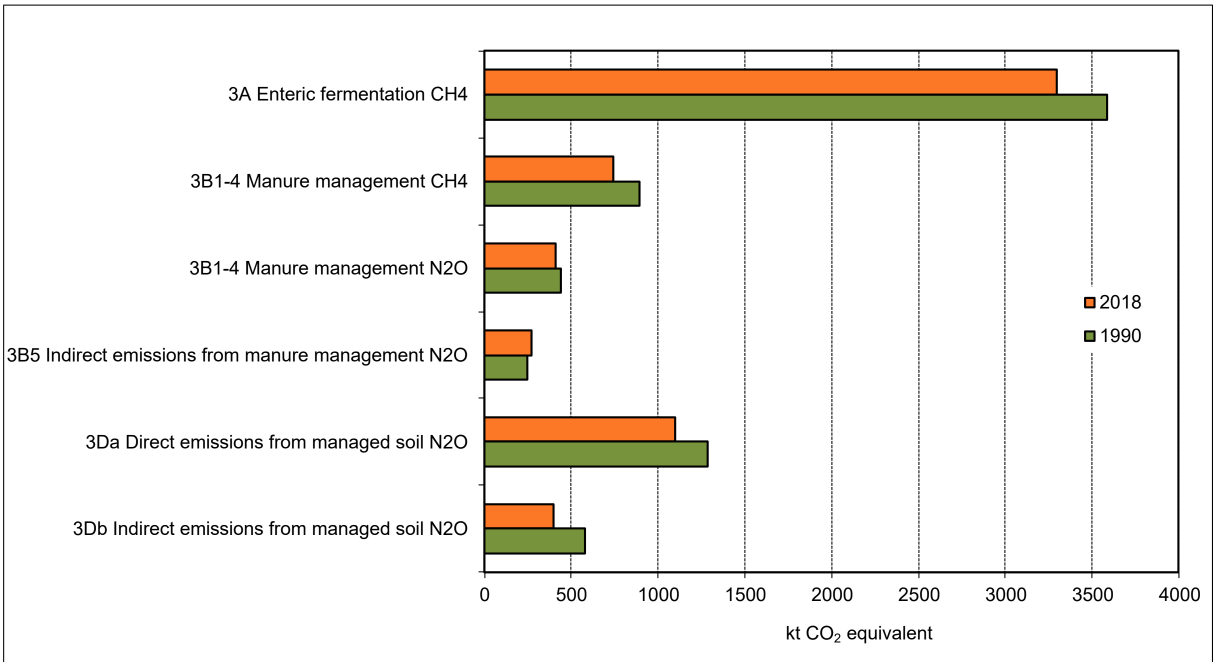


Figure 5-3 Key categories (Approach 1 and Approach 2) in the agricultural sector.

5.2 Source category 3A – Enteric fermentation

5.2.1 Source category description

Table 5-2 Key categories of 3A Enteric fermentation. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
3A	Enteric Fermentation	CH4	L1, L2, T1, T2

This emission source comprises the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by the agricultural census (livestock NCAC) (Table 5-3).

Emissions from 3A Enteric fermentation declined from 1990 until 2004, mainly due to a reduction in the number of cattle. However, between 2004 and 2008 cattle livestock numbers and subsequently CH_4 emissions increased, whereas since 2008 they were decreasing again.

Cattle contribute over 94% to the overall emissions from 3A Enteric fermentation and the contribution of mature dairy cattle is more than 62%.

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss animal protection law (Swiss Confederation 2003). This is true for the whole inventory time period as the first version of the law dates back to 1978. Consequently, fur farming is not economically viable in Switzerland. In addition, fur animals (other than rabbits) are not included in national livestock data.

Table 5-3 Specification of source category 3A Enteric fermentation.

3A	Source	Specification
3A1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year, Fattening Cattle (Fattening Calves 0-4 months[2], Fattening Cattle 4-12 months))
3A2	Sheep	Lambs < 1 year
		Mature Sheep
3A3	Swine	
3A4a	Buffalo	Bisons < 3 years[3]
		Bisons > 3 years[3]
3A4b	Camels	Llamas < 2 years
		Llamas > 2 years
		Alpacas < 2 years
		Alpacas > 2 years
3A4c	Deer	Fallow Deer
		Red Deer
3A4d	Goats	
3A4e	Horses	Horses < 3 years
		Horses > 3 years
3A4f	Mules and Asses	Mules
		Asses
3A4g	Poultry	
3A4h i	Rabbits	
3A4h ii	Livestock NCAC	Sheep
		Goats
		Horses < 3 years
		Horses > 3 years
		Mules
		Asses

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

5.2.2 Methodological issues

5.2.2.1 Methodology

For mature dairy cattle a detailed Tier 3 model approach is applied, predicting gross energy intake by the means of a feeding model that takes into account animal performance and diet bio-chemical composition. A country-specific methane conversion rate (Y_m) was derived from a series of studies representing Swiss specific feeding conditions.

Emission estimation for all other cattle categories follows a Tier 2 approach. This means that detailed country-specific data on nutrient requirements and feed intake were used. CH_4 conversion rates were taken from the 2006 IPCC Guidelines (IPCC 2006).

Methods for all other animal categories are based on a Tier 2 approach, estimating country-specific energy intake rates. Methane conversion rates were taken from the 2006 IPCC Guidelines or from published peer reviewed literature.

The calculation of CH_4 emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2020).

5.2.2.2 Emission factors

All emission factors for 3A Enteric fermentation are country-specific, based on IPCC equation 10.21 (IPCC 2006):

$$EF = \frac{GE * (Y_m \div 100) * 365\,days/y}{55.65\,MJ/kg\,CH_4}$$

EF = annual CH_4 emission factor (kg/head/year)

GE = gross energy intake (MJ/head/day)

Y_m = methane conversion rate, which is the fraction of gross energy in feed converted to methane (%)

55.65 MJ/kg = energy content of methane.

5.2.2.2.1 Gross energy intake (GE)

For calculating the gross energy intake (GE), country-specific methods based on available data on requirements of net energy, digestible energy and metabolisable energy were used. The different energy levels used for energy conversion from energy required for maintenance and production to GE intake are illustrated in Figure 5-4. The respective conversion factors are given in Table 5-4.

For the **cattle categories** detailed estimations for energy requirements are necessary. As the Swiss Farmers Union (SBV) does not provide these estimates on a detailed cattle sub-category level, requirements for each cattle source category were calculated individually following the feeding recommendations for Switzerland provided in RAP (1999) and Morel et al. (2015). These RAP recommendations are also used by the Swiss farmers as the basis for their cattle feeding regimes and for filling in application forms for direct payments; they are therefore highly appropriate.

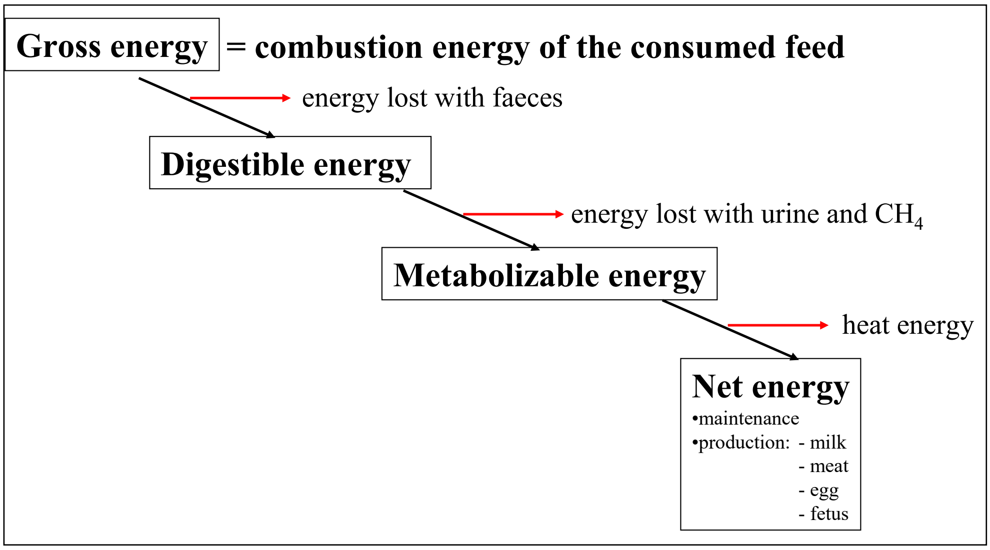


Figure 5-4 Levels of feed energy conversion (Soliva 2006).

Table 5-4 Conversion factors used for calculation of energy requirements of individual livestock categories (Soliva 2006). GE: Gross energy; DE: Digestible energy; ME: Metabolisable energy; NEL: Net energy for lactation; NEV: Net energy for growth. Blue: annually changing parameters, value for 2018.

Livestock Category		**Conversion Factors**	
Mature Dairy Cattle		NEL to GE	0.342
Other Mature Cattle		NEL to GE	0.265
Growing Cattle	*Fattening Calves*	*ME to GE*	*0.939*
	Pre-Weaned Calves	*NEL to GE*	*0.299*
	Breeding Calves	*NEL to GE*	*0.358*
	Breeding Cattle (4-12 months)	*NEL to GE*	*0.319*
	Breeding Cattle (> 1 year)	*NEL to GE*	*0.313*
	Fattening Calves (0-4 months)	*NEV to GE*	*0.355*
	Fattening Cattle (4-12 months)	*NEV to GE*	*0.397*
Sheep	*Fattening Sheep*	*NEV to GE*	*0.350*
	Milksheep	*NEL to GE*	*0.287*
Swine		DE to GE	0.682
Buffalo		NA	NA
Camels and Llamas		NA	NA
Deer		NA	NA
Goats		NEL to GE	0.283
Horses		DE to GE	0.700
Mules and Asses		DE to GE	0.700
Poultry		ME to GE	0.700
Rabbits		NA	NA
Livestock NCAC		NA	NA

For **mature dairy cattle** a detailed feeding model from the Agroscope department for Livestock Sciences was used to predict gross energy intake (Agroscope 2014c).

Energy and protein requirements were estimated based on animal performance (body weight, milk production, pregnancy) following the standard feeding recommendations for Switzerland (RAP 1999). An average body weight of 650 kg was assumed for the typical Swiss mature dairy cattle (Menzi et al. 2016). Statistics of annual milk production are provided by the Swiss Farmers Union (SBV 2019, Table 5-5). Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry (MISTA 2019). It should be noted that daily milk yield refers to milk production during lactation (305 days) and not during the whole year (365 days). Accordingly, milk production and energy requirement for lactation was zero during the two remaining months when the cows are dry. During the dry months additional energy requirements for pregnancy were accounted for.

To cover total animal energy and protein requirements, typical Swiss specific basic feed rations were defined as model inputs. The average basic feed ration in summer consisted of 92% fresh grass and 8% maize cubes. In winter the feed ration consisted of 10% maize silage, 13% grass silage, 72% hay and 5% fodder beet. Concentrates are automatically supplemented in the model according to additional energy and protein requirements not covered by the basic feed ration. Concentrates consisted of a varying mixture of barley grains, wheat grains, maize grains, maize gluten, soybean meal and rapeseed meal according to specific animal requirements. Subsequently, average bio-chemical composition and properties of the total feed ration (e.g. energy content, protein content, digestibility) were derived, weighing the respective values of the individual feed ingredients given in the Swiss Feed Database (Agroscope 2014b). Finally, gross energy intake was estimated based on the total feed intake and the gross energy content of the total ration that was 18.26 MJ/kg on average for the years 1990–2018.

In the year 2003 yearly milk yield surpassed 6000 kg per head. To achieve yearly milk yields higher than 6000 kg, cows have to be fed with an increasing share of feed concentrates that have a substantially higher net energy (NE) density than the basic feed ration. The model reproduces this behaviour. Due to the increasing ratio of net energy to gross energy the increase of gross energy intake is slower after the year 2003 although milk yield increases more or less at the same rate (Table 5-6).

A more exhaustive model description is contained in Agroscope (2019a).

Table 5-5 Average daily milk production during 305 days of lactation in Switzerland.

Milk Production Cattle		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Population Size Mature Dairy Cattle	head	783'100	780'500	763'500	744'450	749'700	739'641	736'043	711'613	701'343	683'545
Lactation Period	day	305	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	16.06	16.35	16.39	16.78	16.75	17.09	16.96	17.48	17.97	18.40
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20

Milk Production Cattle		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Population Size Mature Dairy Cattle	head	669'410	669'410	657'924	638'288	621'008	620'708	618'065	614'795	628'516	599'361
Lactation Period	day	305	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	18.75	18.97	19.34	19.77	20.43	20.45	20.57	21.21	21.66	22.27
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20

Milk Production Cattle		2010	2011	2012	2013	2014	2015	2016	2017	2018
Population Size Mature Dairy Cattle	head	589'024	589'239	591'212	586'609	587'385	583'277	575'766	569'185	564'190
Lactation Period	day	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	22.46	22.63	22.57	22.27	22.87	23.10	22.98	22.74	23.18
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20

For **other mature cattle** and **growing cattle,** data on energy intake were based on the feeding requirements according to RAP (1999) and Morel et al. (2015). In the calculation of the NE data, the animal’s weight, daily growth rate, daily feed intake (dry matter), daily feed energy intake, and energy required for milk production and pregnancy for the respective sub-categories were considered. The method is described in detail in Soliva (2006) but has been revised slightly. A distinction is made between NE for lactation (NEL) and NE for growth (NEV)(Table 5-4). For some of the growing cattle categories NEL is used instead of NEV, even if NEV would seem appropriate. However, cattle-raising is often coupled with dairy cattle activities and therefore the same energy unit (NEL) is used in these cases. Exceptions are the fattening calves (milk-fed calves), whose requirement for energy is expressed as metabolisable energy (ME).

Table 5-6 Gross energy intake per head of different livestock groups. Sub-categories not contained in the reporting tables (CRF) are displayed in italic. The entire time series at a livestock sub-category level is provided in Annex A3.3.

Gross Energy Intake		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		MJ/head/day									
Cattle											
Mature Dairy Cattle		259.3	267.4	280.1	291.6	292.2	295.2	297.2	299.8	300.7	301.4
Other Mature Cattle		250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)		103.3	103.9	103.6	101.0	101.1	100.9	101.0	100.3	99.8	99.9
	Fattening Calves	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*
	Pre-Weaned Calves	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*
	Breeding Calves	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*
	Breeding Cattle (4-12 months)	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*
	Breeding Cattle (> 1 year)	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
	Fattening Calves (0-4 months)	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*
	Fattening Cattle (4-12 months)	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*
Sheep		21.2	24.0	22.4	22.8	22.6	22.2	22.0	22.7	22.6	22.6
Swine		25.7	26.5	25.1	24.5	23.9	24.2	24.6	24.9	24.7	24.6
Buffalo (weighted average)		NA	136.6	146.9	140.6	138.9	130.4	129.1	134.8	136.9	139.8
Camels (weighted average)		NA	NA	34.8	31.7	31.7	31.7	31.6	31.5	31.0	31.4
Deer (weighted average) [1)]		50.5	55.3	56.4	55.4	55.8	55.9	56.5	56.8	56.5	56.7
Goats		25.0	27.9	25.7	25.4	25.3	25.0	25.0	25.3	25.1	25.6
Horses (weighted average)		107.3	106.9	107.4	107.7	107.7	107.7	107.7	107.8	107.9	107.9
Mules and Asses (weighted average)		39.2	39.7	39.5	39.4	39.5	39.3	39.2	40.0	40.2	39.9
Poultry [2)]		1.2	1.2	1.3	1.1	1.1	1.1	1.1	1.1	1.0	1.0
Rabbits		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)		95.6	83.4	37.7	33.3	33.2	32.9	31.7	34.3	36.9	37.2

Gross Energy Intake		2012-2018						
		2012	2013	2014	2015	2016	2017	2018
		MJ/head/day						
Cattle								
Mature Dairy Cattle		301.2	299.8	302.5	303.6	303.1	301.9	304.0
Other Mature Cattle		250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)		100.2	100.1	99.9	99.7	99.2	99.0	98.6
	Fattening Calves	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*
	Pre-Weaned Calves	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*
	Breeding Calves	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*
	Breeding Cattle (4-12 months)	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*
	Breeding Cattle (> 1 year)	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
	Fattening Calves (0-4 months)	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*
	Fattening Cattle (4-12 months)	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*
Sheep		22.5	22.4	22.6	22.5	22.9	22.9	22.9
Swine		24.4	25.1	25.1	25.4	25.8	25.8	26.5
Buffalo (weighted average)		135.9	136.0	134.6	134.5	134.4	133.1	162.8
Camels (weighted average)		31.6	31.9	31.8	31.6	31.2	31.2	31.0
Deer (weighted average) [1)]		57.0	58.1	58.0	58.0	58.5	58.8	59.3
Goats		25.6	25.6	25.0	25.5	25.1	24.9	24.9
Horses (weighted average)		107.9	108.0	108.1	108.3	108.4	108.4	108.5
Mules and Asses (weighted average)		39.9	39.6	39.6	39.6	39.6	39.5	38.6
Poultry [2)]		1.0	1.0	1.0	1.1	1.0	1.0	1.1
Rabbits		1.2	1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)		37.9	38.2	38.5	37.2	38.3	38.7	38.8

[1)] Deer: Gross energy intake per animal place (mother with offspring)

[2)] Poultry data is not gross energy intake (GE) but metabolizable energy intake (ME)

The gross energy intake for other mature cattle is significantly higher than IPCC default values, since the category “other mature cattle” in Switzerland only includes mature cows that produce offspring for meat (so-called “suckler cows” or “mother cows”). Milk production of other mature cattle is 2500 kg per head and year (305 days of lactation) and has not changed over the inventory time period (Morel et al. 2015).

The gross energy intake of growing cattle was calculated separately for all sub-categories displayed in Table 5-6 (in italics) and subsequently averaged (weighted average). No methane is generated from milk. Nevertheless, energy intake from milk or milk products is considered when estimating methane emission factors from enteric fermentation of calves. However, the methane conversion rate is adjusted accordingly as explained under chp. 5.2.2.2.2. The energy intake values for all 7 sub-categories are constant over time. Since the composition of the growing cattle category changed over time (e.g. more pre-weaned calves, fewer fattening calves, see Table 5-8), the average gross energy intake for growing cattle also changes slightly. To calculate an annual emission factor, the categories breeding calves and breeding cattle 4-12 months were combined in the category breeding cattle 1st year (not shown in Table 5-6 and Table 5-8). Accordingly, the respective animals have two separate gross energy intake values, i.e. 44.0 MJ/head/day for the first 4 months and 90.1 MJ/head/day for the last 8 months. The same procedure is applied for fattening calves 0–4 months (56.9 MJ/head/day) and fattening cattle 4–12 months (126.3 MJ/head/day) summing up to the category fattening cattle.

Energy requirements and gross energy intake of **sheep**, **swine**, **goats** and **poultry** were obtained from the respective estimates of the Swiss Farmers Union (SBV 2019, Giuliani 2019). These estimates are not officially published anymore in the statistical yearbooks (e.g. SBV 2017) but are still available from background data and are based on the same method as used for energy requirement statistics in earlier years (e.g. SBV 2007).

Gross energy intake for **horses**, **mules and asses** were estimated by Stricker (2012), mainly based on Meyer and Coenen (2002).

Table 5-7 Dry matter and gross energy requirements for buffalo, camels and deer according to Richner et al. (2017).

		DM Intake	GE Intake
		kg DM/head/day	MJ/head/day
Buffalo	Bisons < 3 years	4.93	90.99
	Bisons > 3 years	10.68	197.14
Camels	Llamas < 2 years	1.34	24.77
	Llamas > 2 years	2.33	42.97
	Alpacas < 2 years	0.82	15.16
	Alpacas > 2 years	1.51	27.80
Deer [1)]	Fallow Deer	2.74	50.55
	Red Deer	5.48	101.10

1) Requirements for deer are assessed per animal place i.e. mother with offspring.

For **buffalo**, **camels** and **deer**, energy intake was derived from data on dry matter intake provided in Richner et al. (2017) (Table 5-7). According to the 2006 IPCC Guidelines an energy density of 18.45 MJ*kg^{-1} was used to convert dry matter to gross energy.

Energy intake of **rabbits** was estimated by Menzi (2014) based on Schlegel and Menzi (2013).

Finally for **livestock NCAC** the same energy intakes as the respective animal categories in the official census were used.

Final compilation of livestock gross energy intake was conducted in Agroscope (2020). Resulting estimates are provided in Table 5-6 (main categories) and in Annex A3.3 (all years and all sub-categories).

5.2.2.2.2 Methane conversion rate (Y_m)

For the methane conversion rate (Y_m), few country-specific data exist. Accordingly, for most animal categories default or literature values were used. Due to its great importance a country-specific Y_m was used for **mature dairy cattle**. A value of 6.9% was derived from a series of measurements conducted under Swiss specific feeding and husbandry conditions at the Federal Institute of Technology in Zurich (based on data compiled in Zeitz et al. (2012) and additional measurements described in Estermann et al. (2001), Külling et al. (2002) and Staerfl et al. (2012)).

For all **other cattle categories**, **sheep** and **buffalo** default values recommended by the IPCC for developed countries in Western Europe were used (IPCC 2006: Table 10.12, 10.13, 10A.2, 10A.3). For all juvenile cattle consuming milk or milk products (i.e. calves) the methane conversion rate is weighted, assuming a Y_m of zero for milk energy and a Y_m of 6.5 for all other energy.

According to table 10.13 in IPCC (2006) two different Y_m were used for **sheep**, namely 4.5% for lambs <1 year and 6.5% for mature sheep. Overall Y_m was subsequently weighted according to the population structure. For **camels** and **deers** the same methane conversion rate as for sheep was applied, assuming the same relationship between adult and juvenile animals.

For **swine** a methane conversion rate of 0.6% was used. This value was suggested by Crutzen et al. (1986) and was confirmed by the compilation of references in Minonzio et al. (1998). Since the 2006 IPCC Guidelines do not provide a default value for **goats**, an Y_m of 6% was adopted based on the work of Martínez-Fernández et al. (2014) and Fernández et al. (2013). For **Horses**, **mules and asses** an Y_m of 2.45% was used, which corresponds to a methane energy loss of 3.5% of digestible energy (Vermorel et al. 1997, Minonzio et al. 1998) and a feed digestibility of 70% (Stricker 2012). For **poultry** a country-specific value (0.16% of metabolisable energy) was used. This value was evaluated in an in vivo trial with broilers (Hadorn and Wenk 1996). For **rabbits** an Y_m of 0.6% was applied as suggested in the national GHG inventory of Italy (ISPRA 2014). Finally, as for gross energy intake, the same methane conversion rates as for the respective animals in the official census were used for **livestock NCAC**.

5.2.2.3 Activity data

Livestock population data were obtained from statistics published by the Swiss Farmers Union (SBV 2019) and the Swiss Federal Statistical Office (SFSO 2019a) (Table 5-8). All activity data were revised and harmonised during a joint effort of the Agroscope Reckenholz-Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012).

The category other mature cattle only includes mature cows used to produce offspring for meat.

Emission estimation for growing cattle was conducted at a more disaggregated level than the one displayed in the reporting tables (CRF). The livestock category growing cattle in the reporting tables includes the sub-categories fattening calves, pre-weaned calves, breeding calves, breeding cattle 4–12 months, breeding cattle >1 year, fattening calves 0–4 months and fattening cattle 4–12 months. The two sub-categories of fattening calves are distinguished by their weight at slaughter and their feeding regime. The first sub-category ("fattening calves") refers to animals raised for veal with a milk based diet (slaughtered at approximately 100 days) whereas the second sub-category ("fattening calves 0-4 months") refers to animals fattened for beef meat (slaughtered at app. 400 days). Although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle (>1 year) and fattening cattle (4–12 months) according to their purposes. This disaggregation of the category growing cattle enhances the accuracy of the emission estimation procedure from livestock activities (also refer to chp. 5.3.2.1).

Emission estimation for buffalo, camels, horses, mules and asses and deers was also conducted on a more disaggregated level than displayed in the reporting tables (CRF). Additional data on a livestock sub-category level are contained in Annex A3.3. The livestock category "buffalo" in the Swiss GHG Inventory contains only bisons (*Bos bison* and/or *Bos bonasus*). Water buffalos (*bubalus bubalis*) are included under cattle. The category "camels" contains only llamas and alpacas.

For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in order to correctly consider animal turnover rates (SFSO 2019b). The values for these subcategories are thus higher than in the official statistics.

Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed. The respective category "Livestock NCAC" (livestock not covered by agricultural census) consists of sheep, goats, horses and mules and asses held for non-agricultural purposes (e.g. horses for sports and leisure) and/or livestock held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. Data for the respective horses, mules and asses were derived from Poncet et al. (2007, 2009) and Schmidlin et al. (2013). For sheep and goats, data from individual cantons having full livestock census were used to estimate the relative share for the whole of Switzerland. The respective estimates were conducted in the course of the elaboration of the gross nutrient balance of the Swiss Federal Statistical Office (SFSO 2019b).

Table 5-8 Activity data for calculating methane emissions from 3A Enteric fermentation (ART/SHL 2012, SBV 2019, SFSO 2019a, SFSO 2019b). The complete time series on a livestock sub-category level are provided in Annex A3.3.

Population Size		**1990-2011**									
		1990	**1995**	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
		1'000 head									
Cattle		1'855	1'748	1'588	1'555	1'567	1'572	1'604	1'597	1'591	1'577
Mature Dairy Cattle		783	740	669	621	618	615	629	599	589	589
Other Mature Cattle		12	23	45	78	87	94	98	108	111	111
Growing Cattle		1'060	986	874	856	862	863	877	890	891	877
	Fattening Calves	*112*	*102*	*103*	*106*	*101*	*100*	*95*	*107*	*114*	*111*
	Pre-Weaned Calves	*10*	*18*	*36*	*62*	*67*	*72*	*76*	*84*	*86*	*86*
	Breeding Cattle 1st Year	*346*	*295*	*236*	*222*	*223*	*223*	*232*	*224*	*222*	*216*
	Breeding Calves	*214*	*166*	*76*	*75*	*77*	*76*	*80*	*76*	*75*	*73*
	Breeding Cattle (4-12 months)	*132*	*129*	*161*	*147*	*147*	*147*	*152*	*148*	*146*	*142*
	Breeding Cattle (> 1 year)	*404*	*378*	*352*	*318*	*320*	*320*	*322*	*328*	*326*	*322*
	Breeding Cattle 2nd Year	*253*	*239*	*222*	*205*	*210*	*210*	*213*	*216*	*215*	*213*
	Breeding Cattle 3rd Year	*151*	*139*	*130*	*113*	*110*	*109*	*110*	*112*	*111*	*109*
	Fattening Cattle	*188*	*193*	*147*	*147*	*149*	*148*	*152*	*147*	*144*	*143*
	Fattening Calves (0-4 months)	*88*	*82*	*43*	*35*	*35*	*34*	*36*	*35*	*34*	*34*
	Fattening Cattle (4-12 months)	*100*	*110*	*105*	*112*	*114*	*114*	*116*	*112*	*110*	*109*
Sheep		395	387	421	446	448	444	446	432	434	424
Swine		1'965	1'739	1'670	1'744	1'797	1'748	1'671	1'691	1'750	1'726
Buffalo		0	0	0	0	0	0	0	1	1	1
Camels		0	0	1	3	3	4	4	5	6	6
Deer [1)]		0	1	3	4	4	4	5	5	6	6
Goats		68	53	62	74	76	79	81	81	83	83
Horses		28	41	50	55	56	58	59	60	62	57
Mules and Asses		6	8	12	16	16	17	18	19	20	19
Poultry		7'310	6'656	7'160	8'911	8'107	9'303	9'813	10'099	10'629	10'904
Rabbits		61	41	28	25	24	27	25	28	35	34
Livestock NCAC		28	30	94	86	82	80	86	90	91	99

Population Size		**2012-2018**						
		2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
		1'000 head						
Cattle		1'565	1'557	1'563	1'554	1'555	1'545	1'543
Mature Dairy Cattle		591	587	587	583	576	569	564
Other Mature Cattle		114	117	118	118	121	123	125
Growing Cattle		859	854	857	853	859	852	854
	Fattening Calves	*103*	*102*	*102*	*103*	*107*	*108*	*111*
	Pre-Weaned Calves	*88*	*90*	*91*	*91*	*93*	*96*	*97*
	Breeding Cattle 1st Year	*210*	*208*	*210*	*210*	*211*	*209*	*208*
	Breeding Calves	*72*	*71*	*71*	*71*	*72*	*71*	*71*
	Breeding Cattle (4-12 months)	*139*	*137*	*138*	*139*	*139*	*138*	*137*
	Breeding Cattle (> 1 year)	*317*	*313*	*312*	*308*	*306*	*305*	*302*
	Breeding Cattle 2nd Year	*211*	*210*	*210*	*209*	*209*	*208*	*207*
	Breeding Cattle 3rd Year	*106*	*103*	*101*	*99*	*97*	*98*	*94*
	Fattening Cattle	*140*	*141*	*143*	*142*	*141*	*134*	*136*
	Fattening Calves (0-4 months)	*33*	*34*	*34*	*34*	*33*	*32*	*32*
	Fattening Cattle (4-12 months)	*107*	*108*	*109*	*108*	*107*	*102*	*104*
Sheep		417	409	403	395	397	398	403
Swine		1'678	1'615	1'631	1'605	1'553	1'544	1'498
Buffalo		1	0	1	1	1	1	1
Camels		6	6	6	6	6	7	7
Deer [1)]		6	6	6	6	6	6	6
Goats		85	85	85	84	85	88	91
Horses		58	57	57	55	56	56	55
Mules and Asses		20	20	20	20	20	21	27
Poultry		11'409	11'844	12'446	12'541	13'180	13'399	13'944
Rabbits		28	28	27	25	25	22	22
Livestock NCAC		112	107	106	112	106	103	105

[1)] Deer: numbers correspond to animal places i.e. mother with offspring.

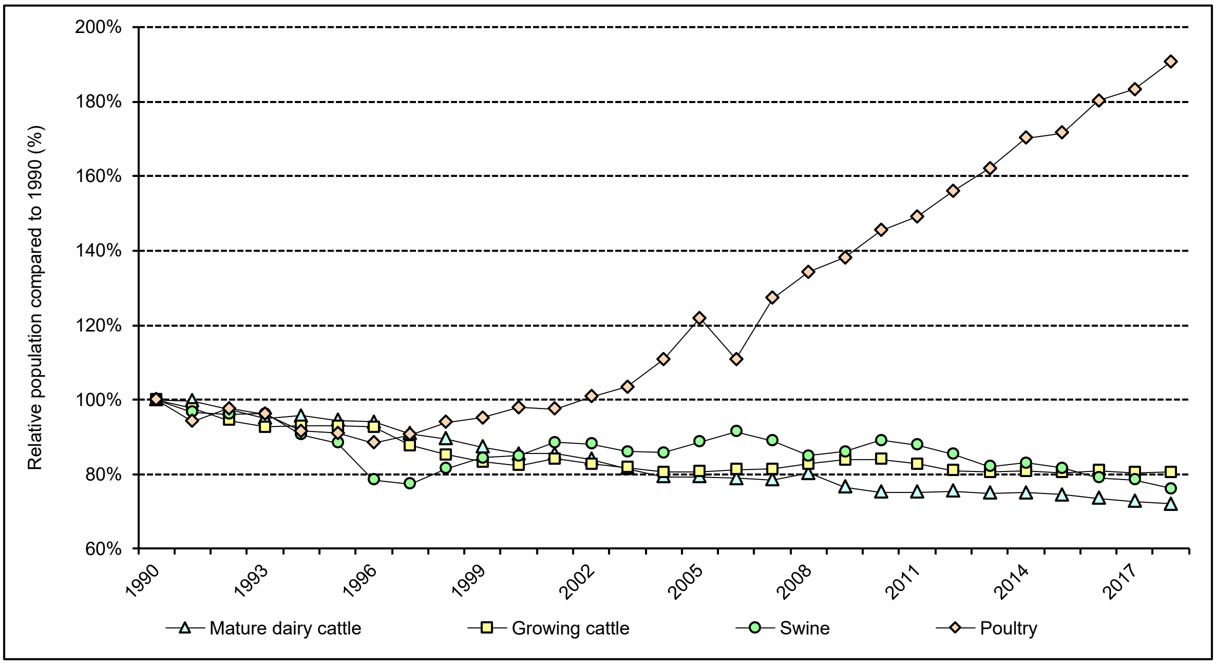


Figure 5-5 Relative development of the populations of main animal categories. The category with the strongest increase, i.e. other mature cattle, is not displayed, as it increases to over 1000% of the 1990 value by 2018.

Livestock populations in Switzerland are primarily influenced by the general agricultural policy, i.e. the subsidy system, the milk quotation system and the development of the economic framework conditions. The number of cattle declined slightly until the year 2004. However, cattle livestock numbers increased between 2004 and 2008, mainly due to an increase of the number of growing cattle. Since 2008 the cattle population was decreasing again, possibly due to the suspension of the milk quotation system in 2009.

After a decrease until 1996, the number of swine increased until 2006 – a process that has been observed in many other European countries (SBV 2004: p.69). Since then, the number of swine has fluctuated slightly below the level of 2006. During the most recent years a slight downward trend can be observed. The number of poultry shows a rapid increase between 1990 and 2018 with a distinct dip only between 2005 and 2006, a consequence of changed human consumption patterns as a result of the avian flu in 2006.

The number of sheep was more or less constant while the number of goats increased following a decline between 1990 and 1995.

5.2.3 Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties of the 2006 IPCC Guidelines. The higher value of the lower and upper bound uncertainty was used for activity data (6.5%) and for emission factors (19.4%), resulting in a combined uncertainty of 20.4% for Approach 1 analysis.

For further results and discussion of the uncertainties see chp. 1.6.1 and Annex 2.

The time series 1990–2018 are all considered consistent, although the following issues should be considered:

- Between 1998 and 1999 the questionnaire for the collection of livestock data was modified. In some animal categories this led to minor ruptures in the time series. Consequences for overall emissions are, however, of minor importance. An analysis conducted in 2012 revealed, that while the average annual change for the years 1990–2011 over all animal categories (excluding other mature cattle) was 3.3% points, the annual change for the years 1998–1999 was 3.8% points (ART/SHL 2012).
- Since 2009 the population statistics of growing cattle are derived from the animal traffic database. Aggregation was adapted to the format necessary for the AGRAMMON-model and the GHG inventory by the School of Agricultural, Forest and Food Science (HAFL, Kupper et al. 2018). Data in the animal traffic database are considered more complete than the data from the survey of the SFSO because the animal traffic database includes also animals held outside agricultural enterprises.
- Since 2015 the census date for sheep and goats is the 1st of January instead of May as before. This is especially relevant for juveniles as they are usually only born in spring. Accordingly, a rupture in the official time series can be observed. This has been corrected in the GHG Inventory by extrapolating the ratio between adults and juveniles.
- Since 2018 the population statistics of bisons is assessed in the animal traffic database. The age limit between young and adult bisons changed from 3 years (1095 days) to 900 days. This causes a rupture in the time series. However, as the contribution of bisons to overall emissions is negligible further actions are not envisaged at the moment.
- Since 2018 the population statistics of horses, mules and asses are assessed in the animal traffic database. The age limit between young and adult animals changed from 3 years (1095 days) to 900 days. Furthermore, allocation of different breeds to the categories horses, mules and asses changed. To assure time series consistency the animals were regrouped according to the allocation scheme used before 2018. Nevertheless, small ruptures occur. Influence on the overall emissions should, however, be negligible.
- Gross energy intake of some of the aggregated animal categories reveals some fluctuations during the inventory period due to varying shares of the sub-categories.
- Gross energy intake as well as the implied emission factor for mature dairy cattle increase, mainly as a result of higher milk production (Table 5-5).

5.2.4 Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC) standard values are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

Livestock data were compared with the livestock data provided by the FAO and checked for plausibility. In all cases the new recalculated data according to ART/SHL (2012) are considered more reliable than the FAO data. Small inconsistencies (usually in the order of ±2%) are due to updates of provisional data that are not considered by the FAO. For horses, mules and asses disagreements might be due to the different accounting of agricultural and non-agricultural horses. The Swiss inventory system accounts for all animals and differentiates between animals captured by the official agricultural census and livestock not covered by agricultural census. Moreover, the numbers of mules and asses is higher in the Swiss GHG inventory because unlike the FAO, Switzerland accounts also for ponies and lesser horses. The total numbers of poultry in the GHG inventory and the FAO data also show minor discrepancies due to different accounting of turkeys, geese, ducks and quails.

Seasonal fluctuation of the cattle population was analysed for the years 2005–2007 based on detailed information from the Swiss Farmers Union (SBV 2007a). Seasonal fluctuations are usually in the order of ±3% with census data (April) always slightly above the annual mean. Data from the animal traffic database (i.e. cattle populations for the years 2009–2018) refer to annual mean population.

IPCC tables with data for estimating emission factors for cattle (such as weight, weight gain, milk production) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A3.3).

Country-specific energy-intake rates for all cattle categories were compared to intake rates estimated with the IPCC (2006) Tier 2 default methodology (see Agroscope (2019a) for details). Both approaches are comparable in the assessment of net energy requirements. However, the IPCC approach resulted in higher estimates of GE-intake. Further analyses suggest that the IPCC conversion rates of net energy into gross energy are unrealistic for conditions in Switzerland. Given the experimentally verified high feed quality standards in Switzerland, the results of the country-specific inventory method are thus much more plausible than the estimates using the unaltered IPCC default method. Moreover, a discrepancy of approximatively 5.9% was found when comparing the overall GE-intake of the cattle population with the respective estimate of the Swiss Farmers Union (Giuliani 2019). As found for the comparison with the IPCC approach, different assumptions on net energy densities of the feed might explain the divergence.

For mature dairy cattle the implied methane emission factor was confirmed by a long term field study, where methane emissions from a herd of twenty dairy cows were measured over a full grazing season with the eddy covariance method (Felber et al. 2015).

During the past years a couple of studies were conducted to verify methane emissions at the regional scale, comparing bottom-up estimates with atmospheric measurements. While virtually all these measurements are subject to great uncertainties, the overall picture support the bottom-up approach in the Swiss GHG inventory or at least does not indicate the omission of a significant methane source. Hiller et al. (2014a) found that methane emissions might be underestimated by the inventory method when they measured atmospheric CH_4 concentrations over the Reuss-valley with an airplane. However, the methodological approach applied by Hiller et al. (2014a) still relies on a number of rather uncertain basic assumptions and is therefore not beyond doubts. Additionally, it should be noted, that methane emission estimates from the agriculture sector in the Swiss GHG inventory were revised since, and currently lie approximately 10% above the estimates used by Hiller et al. (2014a) in their study. Stieger (2013) and Stieger et al. (2015) reported a very good agreement of bottom-up estimates and flux measurements with a tethered balloon system. Bamberger et al. (2014) conducted regional CH_4 measurements with a measurement device mounted on a car. Measurement precision and duration was not sufficient to validate bottom-up inventory estimates. Nonetheless, they concluded that a locally relevant emission source considered negligible in the emission inventory would have been identified. Finally Henne et al. (2015, 2016, 2017) found a very good agreement between inventory estimates of CH_4 emissions and independent atmospheric measurements over Switzerland (see A5.2).

5.2.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalents are assessed quantitatively. All other recalculations are only described qualitatively.

- Emissions from "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) were revised for all years due to a new assessment of animal turnover rates in stables. Corrections for animal turnover rates in stables are now accounted for in the activity data (animal population according to SFSO (2019b) instead of the emission factor. AD and EF were adjusted accordingly. The impact on overall emissions in kt CO_2 equivalents per year is approximately: 1990: +56.9; 2017: +18.2; mean 1990–2017: +42.1 (including emissions from 3A, 3B and 3D).
- CH_4 emissions from enteric fermentation of dairy cattle were recalculated for the years 2016 and 2017 due to revised emission factors based on new model results. The impact on overall emissions is negligible (<0.5 kt CO_2 equivalent).
- CH_4 emissions from sheep, swine, goats and poultry and "other" (livestock NCAC) were recalculated for the years 2015–2017 due to revised EF. Provisional estimates for net energy intake from the Swiss Farmers Union were updated (Giuliani 2019). The impact on overall emissions in kt CO_2 equivalents is approximately +0.4, +0.9 and +4.1 for the years 2015, 2016 and 2017 (including 3A and 3B).

5.2.6 Category-specific planned improvements

No category-specific improvements are planned.

5.3 Source category 3B – Manure management

5.3.1 Source category description

Table 5-9 Key categories of 3B Manure management. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
3B1-3B4	Manure management	CH4	L1, L2
3B1-3B4	Manure management	N2O	L1, L2
3B5	Indirect N2O emissions from manure management	N2O	L1, L2, T2

The emission source is the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by agricultural census (Livestock NCAC) (Table 5-10). Six (CH_4) respectively five (N_2O) different manure management systems are considered as well as indirect N_2O emissions from 3B Manure management (Table 5-11). Additionally, NO_x emissions from manure management are estimated. In the reporting tables all NO_x emissions are reported under 3D Agricultural soils.

The total emissions from 3B Manure management closely follow the development of the cattle population. Emissions declined from 1990 until 2004, increased until 2008 and subsequently remained more or less constant. During the most recent years a slight downward trend can be observed.

Significant contributors to CH_4 emissions from 3B Manure management are cattle with approximatively 72% and swine with approximatively 24% on average over the period 1990–2018. Cattle and swine contribute significantly to N_2O emissions with 69% and 19%, respectively, on average over the period 1990–2018.

Leaching of NO_3^- from manure management systems is not occurring in Switzerland and is thus not included in the estimates. This assessment is principally based on expert judgement from Thomas Kupper from the “School for Agricultural, Forest and Food Sciences (HAFL)” (Kupper 2014) and based on his personal expertise and on the following literature: Sagoo et al. (2007); Petersen et al. (1998); Webb (2001); Monteny et al. (2006); Oenema et al. (2007) and Chadwick (2005).

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss animal protection law (Swiss Confederation 2003). See also chp. 5.2.1.

Table 5-10 Specification of source category 3B Manure management by livestock categories.

3B	Source	Specification
3B1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year (Breeding Cattle 2nd year + Breeding Cattle 3rd year), Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months))
3B2	Sheep	Lambs < 1 year Mature Sheep Fattening Sheep Milk Sheep
3B3	Swine	Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars
3B4a	Buffalo	Bisons < 3 years[3] Bisons > 3 years[3]
3B4b	Camels	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years
3B4c	Deer	Fallow Deer Red Deer
3B4d	Goats	Goat Places
3B4e	Horses	Horses < 3 years Horses > 3 years
3B4f	Mules and Asses	Mules Asses
3B4g	Poultry	Growers Layers Broilers Turkey Other Poultry
3B4h i	Rabbits	
3B4h ii	Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

Table 5-11 Specification of source category 3B Manure management by manure management systems.

3B	Source	Specification CH_4		Specification N_2O	
3B6a	Direct Emissions	Liquid systems		Liquid systems --> Pit storage below animal confinement	
3B6b		Solid storage and dry lot		Solid storage and dry lot	
3B6c / 3D		Pasture, range and paddock		NA[1]	
3B6d		Digesters (anaerobic digestion)		Digesters (anaerobic digestion)	
3B6e		Other	Deep litter	Other	Deep litter
			Poultry system		Poultry system
3B5a	Indirect Emissions	NA		Atmospherical deposition	
3B5b		NA		Leaching and run-off	

1) Reported under 3D Agricultural Soils

5.3.2 Methodological issues

5.3.2.1 Methodology

The calculation is based on methods described in the 2006 IPCC Guidelines (CH_4: IPCC 2006 equation 10.23; N_2O: IPCC 2006 equation 10.25).

CH_4 emissions from 3B Manure management were generally estimated using a Tier 2 methodology. For cattle a more detailed Tier 3 method was applied, estimating volatile solids (VS) excretion based on gross energy intake estimates as used for enteric fermentation. VS excretion from buffalo, camels, horses and deer was equally estimated based on gross energy intake. For the remaining livestock categories default parameters were used. Methane conversion factors (MCF) are from IPCC (2006; solid storage, pasture range and paddock, anaerobic digesters, poultry manure), country-specific (deep litter) or were modelled according to Mangino et al. (2001) (liquid systems, anaerobic digesters).

N_2O emissions from 3B Manure management were estimated using a country-specific Tier 3 methodology. Activity data were adjusted to the particular situation of Switzerland in coordination with the Swiss ammonia model AGRAMMON (Kupper et al. 2018). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied. Emission factors for direct N_2O emissions (EF_3) are based on IPCC (2006) whereas the emission factor for indirect emissions from atmospheric deposition is country-specific (Bühlmann et al. 2015 and Bühlmann 2014).

The N_2O emissions from pasture, range and paddock are reported under 3D Agricultural soils, source category 3Da3 Urine and dung deposited by grazing animals.

For calculation of CH_4 and N_2O emissions, slightly different livestock sub-categories were used (Table 5-12). The livestock categories reported in the reporting tables (CRF) are the same, but the respective sub-categories as a basis for the calculation are different. The categorisation for the estimation of CH_4 emissions had to be adapted to data availability for energy requirements, while the categorisation for the estimation of N_2O emissions is determined by the respective categorisation of the Swiss ammonia inventory (AGRAMMON, Kupper et al. 2018, Richner et al. 2017). Nevertheless, there is no inconsistency in the total number of animals as they are the same both for CH_4 and N_2O emissions. Note that although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle >1 year, breeding cattle 3rd year and/or fattening cattle according to their purposes.

The calculation of CH_4 and N_2O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2020).

Table 5-12 Livestock categories for estimating CH_4 and N_2O emissions from 3B Manure management.

3B	CH_4		N_2O	
Cattle	Mature Dairy Cattle		Mature Dairy Cattle	
	Other Mature Cattle		Other Mature Cattle	
	Growing Cattle	Fattening Calves[1] Pre-Weaned Calves Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months) Breeding Cattle > 1 year Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months)	Growing Cattle	Fattening Calves[1] Pre-Weaned Calves Breeding Cattle 1st year Breeding Cattle 2nd year Breeding Cattle 3rd year Fattening Cattle
Sheep	Lambs < 1 year Mature Sheep		Fattening Sheep Milk Sheep	
Swine	Swine		Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars	
Buffalo	Bisons < 3 years[3] Bisons > 3 years[3]		Bisons < 3 years[3] Bisons > 3 years[3]	
Camels	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years		Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years	
Deer	Fallow Deer Red Deer		Fallow Deer Red Deer	
Goats	Goats		Goat places	
Horses	Horses < 3 years Horses > 3 years		Horses < 3 years Horses > 3 years	
Mules and Asses	Mules Asses		Mules Asses	
Poultry	Poultry		Growers Layers Broilers Turkey Other Poultry	
Rabbits	Rabbits		Rabbits	
Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses		Sheep Goats Horses < 3 years Horses > 3 years Mules Asses	

[1)] Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.
[2)] Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.
[3)] Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

5.3.2.2 Emission factors CH_4

Calculation of CH_4 emissions from 3B Manure management is based on methods described in the 2006 IPCC Guidelines (IPCC 2006, equation 10.23):

$$EF_T = VS_T \bullet 365 days / year \bullet B_{0T} \bullet 0.67 kg / m^3 \bullet \sum_S MCF_S \bullet MS_{TS}$$

EF_T = annual CH_4 emission factor for livestock category *T* (kg/head/year)

VS_T = daily volatile solids (VS) excreted for livestock category *T* (kg/head/day)

B_{0T} = maximum CH_4 producing capacity for manure produced by livestock category *T* (m^3/kg)

0.67 kg/m^3 = conversion factor of m^3 CH_4 to kilograms CH_4

MCF_S = CH_4 conversion factors for each manure management system *S* (%)

MS_{TS} = fraction of livestock category *T*'s manure handled using manure management system *S* (dimensionless)

5.3.2.2.1 Volatile solids excretion (VS)

The daily excretions of volatile solids (VS) for **all cattle sub-categories** were estimated according to equation 10.24 in the 2006 IPCC Guidelines (IPCC 2006):

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100} \right) + (UE \bullet GE) \right] \bullet \left[\frac{1 - ASH}{EDF} \right]$$

VS = volatile solids excretion per day on a dry-organic matter basis (kg/day)

GE = gross energy intake (MJ/head/day)

DE = digestibility of the feed (%)

(UE • GE) = urinary energy expressed as fraction of GE

ASH = ash content of manure calculated as a fraction of the dry matter feed intake

EDF = energy density of feed, conversion factor for dietary GE per kg of dry matter (MJ/kg)

Gross energy intake was calculated according to the method described in chp. 5.2.2.2.1. In the case of **mature dairy cattle** the same model was used as for the estimation of CH_4 emissions from 3A Enteric fermentation. Content of net energy, gross energy and ash in feed dry matter as well as feed digestibility were also estimated using the Agroscope feeding model (Agroscope 2014c). The digestibility of feed is of crucial importance for the calculation of volatile solids. The modelled values for dairy cattle are somewhat higher than the IPCC default and were compared to measurements from feeding trials in Switzerland. The comparison revealed that modelled values are on average slightly higher than measurements. Accordingly, an adjustment was made in order to take account of the high feeding level that is usually above maintenance (Ramin and Huhtanen 2012). High feeding levels may lead to an increase in rumen passage rate and subsequently to lower feed digestibility (Nousiainen et al. 2009). The correction decreased the feed digestibility on average by 2.5 percent points. Resulting feed digestibility was 72.2% on average, gross energy content (EDF) was 18.26 MJ/kg and ash content was 9.0% each with very small fluctuations along the time series. Urinary energy expressed as fraction of gross energy was 0.04 (IPCC 2006).

For **calves and other growing cattle** IPCC default values of 65% respectively 60% were taken for the feed digestibility. For the urinary energy expressed as fraction of gross energy and for the energy density of the feed (EDF) the IPCC default values, i.e. 0.04 and 18.45 MJ/kg were adopted. Furthermore, an ash content of 8.0% was used for all these categories.

For VS excretion of the livestock categories **sheep**, **swine**, **goats**, **mules and asses**, **poultry**, **rabbits** and **livestock NCAC**, default values from IPCC were taken (IPCC 2006, Tables 10A-7, 10A-8, 10A-9).

For **buffalo**, **camels, horses** and **deer** VS excretion was again estimated using equation 10.24 in the 2006 IPCC Guidelines with default values for feed digestibility and ash content (IPCC 2006). Feed digestibility was 55% for buffalos, 60% for camels and deer (assuming similar feed composition as for sheep) and 70% for horses. The urinary energy as fraction of the gross energy was 0.04, the energy density of the feed (EDF) was 18.45 MJ/kg. The ash content of manure was 8.0% for buffalo, camels and deer and 4.0% for horses (IPCC 2006).

Finally for **livestock NCAC** the same VS excretion rates as for the respective animal categories in the official census were used.

5.3.2.2.2 Maximum CH_4 producing capacity (B_0)

For the methane producing capacity (B_o) default values were used (IPCC 2006). For deer the same value as for sheep was applied as no default value was available (i.e. 0.19 m^3/kg).

5.3.2.2.3 Methane conversion factor (MCF)

For estimating CH_4 emissions from manure management, six different manure management systems are distinguished. Switzerland has an average annual temperature below 15°C (MeteoSwiss 2014) and was therefore allocated to the cool climate region without differentiation.

In the case of **solid manure** and **pasture range and paddock** the default MCF values from table 10.17 of the 2006 IPCC Guidelines were used (Table 5-13).

Liquid/slurry systems are responsible for the major part of methane emissions from Manure management (89% on average). Accordingly a more detailed model was used to determine the respective MCF. For this purpose the model developed by Mangino et al. (2001), that is also used to derive the 2006 IPCC default values, was adapted to the specific conditions of Switzerland. On a monthly time step, loading of a virtual liquid/slurry manure system was simulated according to the VS excretion of the total livestock herd and the manure management system distribution (MS) in the respective inventory year. Thereby it was assumed that excretion on pasture, range and paddock takes only place during summer months, i.e. from April to September. Subsequently, monthly manure degradation was forecast using the temperature-dependent van't Hoff-Arrhenius equation with the parametrization as suggested by Mangino et al. (2001). Monthly mean air temperatures for the Swiss central plateau during the 1981–2010 time period were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2014). Minimum temperature in the liquid/slurry system was allowed to drop to 1°C instead of 5°C as proposed in the original model (see e.g. Vergé et al. 2007, Van der Zaag et al. 2013). Any carry-over effect of undergraded manure from one month to the next was neglected (see e.g. Park et al. 2006, Van der Zaag et al. 2013). Finally, an annual methane conversion factor was calculated by dividing the total VS degraded by the total load of VS.

Several authors have found that the simulated MCF-values according to the model described above are unrealistically high (Park et al. 2006, Van der Zaag et al. 2013). Consequently they propose to use a management and design practice factor (MDP factor) to bring the modelled factors into accordance with measurements. Accordingly, a MDP factor of 0.8 was applied here as suggested by Mangino et al. (2001). The resulting MCF-values for liquid/slurry systems range from 13.3% to 14.4%. The variation of the MCF along the time series is due to varying shares of manure dropped on pasture, range and paddock. The higher the share of manure dropped on pasture, range and paddock, the lower is the overall MCF for liquid/slurry systems (as livestock is only grazing during summer, the relative share of low methane conversion factors during the cold winter month increases when summer grazing time increases).

Anaerobic digestion of animal manure is increasing in Switzerland since the 1990s but is still not widespread (4.9% of all volatile solids in 2018). Emissions from the digestion plant itself are reported under source category 5B2 (Anaerobic digestion at biogas facilities) and described in chp. 7.3.2.2. However, emissions from manure storage before alimentation into the digester are reported in source category 3B Manure management. The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2019a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014). According to the data in the monitoring protocols the total amount of manure entering the plant originated mainly from cattle manure stored as liquid/slurry (57%) and solid storage (23%) and from swine manure stored as liquid/slurry (20%). It is assumed that 22.5% of the liquid/slurry manure is coming from the farm where the biogas plant is located and is hence directly fed into the digester on a daily basis without being stored (Koehli 2014). The respective MCF was thus set to zero. As solid manure usually has a low MCF and is stored for only a short period before being fed into the digester, the respective MCF was also set to zero. The MCF for the remaining liquid/slurry manure that is delivered from neighbouring farms to the biogas plant was estimated with the methodology described in the "Standard method for compensating projects of the type "agricultural biogas plants"" (FOEN 2014n). This method is based on the "Approved small scale baseline and monitoring methodology AMS-III.D./Version 19.0. Methane recovery in animal manure management systems" and relies thus on a generally accepted foundation (UNFCCC 2013c).

According to this methodology the MCF value for conventional liquid/slurry systems given in Table 5-13 is reduced according to the duration of pre-storage before the manure is delivered to the digester:

$$MCF_{PSAD} = MCF_{LS} * \left(\frac{14.49 * \left(e^{-k * AI_j} - 1 \right)}{AI_j} + 1 \right)$$

MCF_{PSAD} = CH_4 conversion factor for pre-storage of liquid manure before delivery to biogas plants (%)

MCF_{LS} = CH_4 conversion factor for liquid/slurry systems (%)

k = degradation rate constant (0.069)

AI_j = average pre-storage time period (day)

The average pre-storage time was estimated to be 12 days (Koehli 2014). The resulting weighted average MCF-value for anaerobic digestion varies between 2.5% and 2.7%. Variation is due to the variation of the underlying MCF of liquid/slurry systems.

Fattening calves, sheep, camels, deer and goats are kept in **deep litter systems**. A MCF of 10% was adopted, which is the mean value between the IPCC default values for cattle and swine deep bedding <1 month and >1 month at 10°C (IPCC 2006). The choice of a MCF of 10% for deep litter is supported by the specific feeding and manure management regime in Switzerland (especially cold winter temperatures) and confirmed by a number of studies representative for the country-specific management conditions (Amon et al. 2001, Külling et al. 2002, Külling et al. 2003, Moller et al. 2004, Hindrichsen et al. 2006, Park et al. 2006 and Sommer et al. 2007, Zeitz et al. 2012). For further details see FOEN 2011 (16.5 attachment E).

For all poultry categories a MCF value of 1.5% was used according to the default value for **poultry manure systems** in the 2006 IPCC Guidelines.

Table 5-13 Manure management systems and methane conversion factors (MCFs). Blue: annually changing parameters, value for 2018.

Manure management system		Description	MCF (%)
Pasture		Manure is allowed to lie as it is, and is not managed (distributed, etc.).	1.0
Solid storage		Dung and urine are excreted in a barn. The solids (with and without litter) are collected and stored in bulk for a long time (months) before disposal.	2.0
Liquid/slurry systems		Combined storage of dung and urine under animal confinements for longer than 1 month.	13.5
Digesters		Storage before alimentation into anaerobic digester. Storage system can be liquid/slurry or solid storage.	2.6
Other	Deep litter	Dung and urine is excreted in a barn with lots of litter and is not removed for a long time (months).	10.0
	Poultry system	Manure is excreted on the floor with or without bedding.	1.5

5.3.2.2.4 Manure management system distribution (MS)

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each livestock category (Table 5-14). The fractions are determined by the livestock husbandry system (e.g. tie stall or loose housing system) as defined in Richner et al. (2017). Estimation is conducted within the Swiss ammonium model AGRAMMON (Kupper et al. 2018) based on expert judgement and values from the literature

(1990, 1995) and on extensive farm surveys (2002, 2007, 2010 and 2015). The data clearly reproduce the shift towards an increased use of pasture, range and paddocks and a decrease in solid storage. The changes of the manure management system distribution reflect the shift to a more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 20th century. One of the most important voluntary programmes in this context is called “RAUS” and implies at least 156 days of pasture per year (Swiss Confederation, 2008). Accordingly, the share of mature dairy cattle (and other animals) going to pastures increased substantially and so did the length of stay on the pasture. In the year 2007 78% of the dairy cattle were held on farms participating in the RAUS programme. The average number of pasture days (including all farms) in that year was 181, and it was 173 in 2010. It can thus be assumed, that already in the early years of the new millennium most farms accomplished the transition to RAUS and that a new management standard was reached at this point of time, which did not change significantly afterwards.

Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables usually have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. For cattle categories the MS-distribution for nitrogen as provided by Kupper et al. (2018) was thus adjusted using data on stable systems and manure accumulation from Richner et al. (2017) as well as data on occurrence of stable system on farms from (Kupper et al. 2018). More or less the same result could be gained by correcting the distribution of nitrogen by the VS/N-ratio. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS.

The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2019a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014) as described under 5.3.2.2.3.

5.3.2.3 Activity data CH_4

Activity data of all livestock categories covered by the official census were obtained from SBV (2019) and the SFSO (2019a). The respective data were revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed (Poncet et al. 2007, Poncet et al. 2009, Schmidlin et al. 2013, SFSO 2019b). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Annex A3.3.

Table 5-14 Manure management system distribution for nitrogen (MS) according to the AGRAMMON model. Detailed data on livestock sub-category levels for the distribution of nitrogen and volatile solids are provided in Annex A3.3.

MS Distribution	1990					1995					2002				
	%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	63.6	27.6	8.3	0.5	0.0	65.6	24.5	9.5	0.4	0.0	65.2	16.3	18.0	0.5	0.0
Other Mature Cattle	41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	39.7	20.7	39.1	0.5	0.0
Growing Cattle (weighted average)	47.4	31.8	15.7	0.5	4.5	48.4	30.9	15.8	0.4	4.5	42.1	25.5	27.3	0.5	4.6
Fattening Calves	*14.5*	*0.0*	*0.0*	*0.5*	*85.1*	*14.9*	*0.0*	*0.0*	*0.4*	*84.7*	*21.5*	*0.0*	*0.3*	*0.5*	*77.6*
Pre-Weaned Calves	*41.1*	*32.2*	*26.3*	*0.5*	*0.0*	*39.2*	*34.2*	*26.2*	*0.4*	*0.0*	*41.2*	*21.0*	*37.3*	*0.5*	*0.0*
Breeding Cattle 1st Year	*36.8*	*48.6*	*14.1*	*0.5*	*0.0*	*37.9*	*47.5*	*14.2*	*0.4*	*0.0*	*33.6*	*38.8*	*27.0*	*0.5*	*0.0*
Breeding Cattle 2nd Year	*45.2*	*29.0*	*25.4*	*0.5*	*0.0*	*47.2*	*26.8*	*25.6*	*0.4*	*0.0*	*37.7*	*23.4*	*38.4*	*0.5*	*0.0*
Breeding Cattle 3rd Year	*50.4*	*29.1*	*20.0*	*0.5*	*0.0*	*51.3*	*28.0*	*20.3*	*0.4*	*0.0*	*42.1*	*22.5*	*34.8*	*0.5*	*0.0*
Fattening Cattle	*70.0*	*24.1*	*0.0*	*0.5*	*5.5*	*66.3*	*27.7*	*0.0*	*0.4*	*5.6*	*67.3*	*26.8*	*2.2*	*0.5*	*3.2*
Sheep (weighted average)	0.0	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	33.2	0.0	66.8
Swine (weighted average)	98.8	0.0	0.0	1.2	0.0	98.8	0.0	0.0	1.2	0.0	97.6	0.3	0.1	1.9	0.0
Buffalo (weighted average)	NA	NA	NA	NA	NA	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0
Camels (weighted average)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	33.5	0.0	66.5
Deer (weighted average)	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5
Goats	0.0	0.0	13.6	0.0	86.4	0.0	0.0	13.6	0.0	86.4	0.0	0.0	12.2	0.0	87.8
Horses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.1	23.9	0.0	0.0
Mules and Asses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0
Poultry (weighted average)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.5	0.0	99.5	0.0	0.0	2.6	0.0	97.4
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	89.5	7.1	0.0	3.4	0.0	37.3	27.7	0.0	35.0

MS Distribution	2007					2010					2015				
	%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	67.2	13.7	17.7	1.4	0.0	66.6	14.5	16.9	2.1	0.0	69.0	11.2	15.9	3.9	0.0
Other Mature Cattle	49.3	20.3	29.0	1.4	0.0	47.5	18.0	32.4	2.1	0.0	50.1	14.5	31.5	3.9	0.0
Growing Cattle (weighted average)	45.3	24.0	24.7	1.4	4.7	44.4	25.0	22.7	2.1	5.8	46.3	22.2	22.4	3.9	5.3
Fattening Calves	*21.6*	*0.0*	*0.2*	*1.4*	*76.8*	*16.4*	*0.0*	*0.2*	*2.1*	*81.3*	*22.8*	*0.0*	*1.7*	*3.9*	*71.7*
Pre-Weaned Calves	*49.8*	*18.7*	*30.1*	*1.4*	*0.0*	*44.2*	*32.9*	*20.9*	*2.1*	*0.0*	*34.5*	*29.7*	*32.0*	*3.9*	*0.0*
Breeding Cattle 1st Year	*40.7*	*34.6*	*23.3*	*1.4*	*0.0*	*42.9*	*33.5*	*21.5*	*2.1*	*0.0*	*43.7*	*31.5*	*20.9*	*3.9*	*0.0*
Breeding Cattle 2nd Year	*41.2*	*20.9*	*36.5*	*1.4*	*0.0*	*42.8*	*20.9*	*34.3*	*2.1*	*0.0*	*41.4*	*19.9*	*34.8*	*3.9*	*0.0*
Breeding Cattle 3rd Year	*45.4*	*21.4*	*31.8*	*1.4*	*0.0*	*45.8*	*21.6*	*30.6*	*2.1*	*0.0*	*53.0*	*17.6*	*25.6*	*3.9*	*0.0*
Fattening Cattle	*62.1*	*29.0*	*4.3*	*1.4*	*3.2*	*57.2*	*32.9*	*4.0*	*2.1*	*3.9*	*62.0*	*26.0*	*4.9*	*3.9*	*3.3*
Sheep (weighted average)	0.0	0.0	39.3	0.0	60.7	0.0	0.0	33.7	0.0	66.3	0.0	0.0	37.0	0.0	63.0
Swine (weighted average)	92.8	0.1	1.3	5.8	0.0	91.3	0.2	0.1	8.3	0.0	82.5	0.0	0.0	17.4	0.0
Buffalo (weighted average)	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	44.8	20.4	34.8	0.0	0.0
Camels (weighted average)	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Deer (weighted average)	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Goats	0.0	0.0	7.1	0.0	92.9	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4
Horses (weighted average)	0.0	78.7	21.3	0.0	0.0	0.0	74.4	25.6	0.0	0.0	0.0	78.7	21.3	0.0	0.0
Mules and Asses (weighted average)	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	77.6	22.4	0.0	0.0
Poultry (weighted average)	0.0	0.0	3.4	0.0	96.6	0.0	0.0	2.4	0.0	97.6	0.0	0.0	2.9	0.0	97.1
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	33.8	30.1	0.0	36.2	0.0	39.5	28.1	0.0	32.4	0.0	42.1	27.0	0.0	30.9

5.3.2.4 Emission factors N_2O

Estimation of direct N_2O emissions from manure management relies basically on the same animal waste management systems as the estimation of CH_4 emissions (compare chp. 5.3.2.2). All emission factors are based on default values given in table 10.21 of the 2006 IPCC Guidelines (Table 5-15). For liquid/slurry storage systems an emission factor of

0.002 kg N_2O-N/kg N as suggested for “Pit storage below animal confinements” was considered appropriate.

Table 5-15 Emission factors for calculating N_2O emissions from manure management. Blue: annually changing parameters, value for 2018.

Animal waste management system	**Emission factor**
	kg N_2O-N / kg N
Liquid/Slurry: Pit storage below animal confinement	0.002
Solid storage	0.005
Anaerobic digester	0.000
Cattle and swine deep bedding: no mixing	0.010
Poultry manure	0.001
Indirect emissions due to volatilisation	0.026

The emission factor for indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems was reassessed during a literature review by Bühlmann et al. 2015 and Bühlmann 2014. Due to the fragmented land use in Switzerland, where agricultural land use alternates with natural and semi-natural ecosystems over short distances, the share of volatilised nitrogen that is re-deposited in (semi-)natural habitats is on average higher than 55%. Thus, the assumption made in the 2006 IPCC Guidelines that “a substantial fraction of the indirect emissions will in fact originate from managed land”, cannot be applied to Switzerland. Accordingly, the overall emission factor for indirect emissions was estimated by calculating an area-weighted mean of the indirect emission factor for managed land (i.e. 0.01 based on IPCC 2006) and the indirect emission factor for (semi-)natural land (as provided in Bühlmann 2014). Due to slightly changing land use over the inventory time period, the resulting emission factor shows some small temporal variation around a mean value of 2.56%. Note that the emission factor in cell R37 of CRF Table3.B(b) refers to kg N_2O/kg N instead of kg N_2O-N/kg N.

5.3.2.5 Activity data N_2O

Activity data for N_2O emissions from 3B Manure management were estimated according to equation 10.25 of the 2006 IPCC Guidelines:

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

$N_2O_{D(mm)}$ = direct N_2O emissions from manure management (kg N_2O/year)

$N_{(T)}$ = number of head of livestock species/category *T* (head)

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* (kg N/head/year)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S* (kg N_2O-N/kg N)

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

5.3.2.5.1 Livestock population

Activity data of all livestock categories covered by the official census were obtained from SBV (2019) and the SFSO (2019a). The respective dataset was revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Swiss Federal Statistical Office were assessed (Poncet et al. 2007, Poncet et al. 2009, Schmidlin et al. 2013, SFSO 2019b). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Annex A3.3.

5.3.2.5.2 Nitrogen excretion (N_{ex})

Data on nitrogen excretion per animal category (kg N/head/year) are country-specific and were obtained from Kupper et al. (2018) (Table 5-16). These values are based on the "Principles of Fertilisation in Arable and Forage Crop Production" (Richner et al. 2017). Unlike to the method in the IPCC Guidelines, the age structure of the animals and the different use of the animals (e.g. fattening and breeding) are considered. Standard nitrogen excretion rates are modified within the AGRAMMON model in order to account for changing agricultural structures and production techniques over the years (e.g. milk yield, use of feed concentrates, protein reduced animal feed etc.; Kupper et al. (2018)). This more disaggregated approach leads to considerable lower calculated nitrogen excretion rates compared to IPCC (2006) mainly because lower N_{ex}-rates of young animals are considered explicitly.

The nitrogen excretion rates are given on an annual basis, considering replacement of animals (growing cattle, swine, poultry, rabbits) and including excretions from corresponding offspring and other associated animals (sheep, deer, goats, swine, rabbits) (ART/SHL 2012).

Nitrogen excretion of mature dairy cattle is dependent on milk production and feed properties. After the year 2006 the yearly increase of nitrogen excretion slowed down due to an increased use of energy dense feedstuff (concentrates) and a slower increase of the milk yield.

Sheep in Switzerland are fed mainly on roughage from extensive pasture and meadows (Richner et al. 2017) and are estimated to excrete approximately 8.0 kg N per head and year. This is considerably lower than IPCC default (IPCC 2006). However, nitrogen excretion is averaged over the whole population, of which roughly 40% are lambs and other immature animals. **Swine** show a significant decrease in nitrogen excretion rates until 2006, which can be explained by the increasing use of protein-reduced fodder (Kupper et al. 2018). The same is true for **poultry**.

Table 5-16 Nitrogen excretion rates of Swiss livestock. The complete time series on a livestock sub-category level are provided in Annex A3.3.

Nitrogen Excretion		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		kg N/head/year									
Mature Dairy Cattle		100.4	101.5	103.9	108.0	109.1	110.1	110.3	110.4	110.5	110.7
Other Mature Cattle		85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)		33.0	33.1	33.1	32.6	32.7	32.7	32.9	32.8	32.7	32.8
	Fattening Calves	*13.0*	*13.0*	*13.0*	*14.2*	*14.6*	*15.0*	*15.3*	*15.7*	*16.0*	*16.4*
	Pre-Weaned Calves	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*
	Breeding Cattle 1st Year	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*
	Breeding Cattle 2nd Year	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*
	Breeding Cattle 3rd Year	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*
	Fattening Cattle	*33.0*	*33.0*	*33.0*	*34.2*	*34.6*	*35.0*	*35.3*	*35.7*	*36.0*	*36.4*
Sheep (weighted average)		7.5	7.6	8.0	8.1	8.2	8.2	8.2	8.4	8.5	8.4
Swine (weighted average)		14.3	14.0	11.3	9.9	9.7	9.5	9.6	9.7	9.7	9.6
Buffalo (weighted average)		NA	37.2	41.1	38.7	38.0	34.9	34.4	36.5	37.3	38.4
Camels (weighted average)		NA	NA	14.1	12.8	12.8	12.8	12.8	12.8	12.6	12.7
Deer (weighted average) [1)]		20.0	21.9	22.3	21.9	22.1	22.1	22.4	22.5	22.4	22.4
Goats		11.2	11.1	11.3	11.1	11.3	11.2	11.2	11.4	11.2	11.4
Horses (weighted average)		43.6	43.5	43.6	43.7	43.7	43.7	43.7	43.7	43.7	43.7
Mules and Asses (weighted average)		16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rabbits		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)		38.8	34.0	14.5	12.6	12.5	12.6	12.3	13.2	14.3	14.9

Nitrogen Excretion		2012-2018						
		2012	2013	2014	2015	2016	2017	2018
		kg N/head/year						
Mature Dairy Cattle		111.0	111.2	111.4	111.6	111.6	111.6	111.6
Other Mature Cattle		85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)		33.0	33.1	33.1	33.1	33.0	32.9	32.8
	Fattening Calves	*16.8*	*17.2*	*17.6*	*18.0*	*18.0*	*18.0*	*18.0*
	Pre-Weaned Calves	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*
	Breeding Cattle 1st Year	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*
	Breeding Cattle 2nd Year	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*
	Breeding Cattle 3rd Year	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*
	Fattening Cattle	*36.8*	*37.2*	*37.6*	*38.0*	*38.0*	*38.0*	*38.0*
Sheep (weighted average)		8.5	8.6	8.5	8.4	8.4	8.5	8.5
Swine (weighted average)		9.5	9.4	9.4	9.4	9.4	9.4	9.3
Buffalo (weighted average)		36.9	36.9	36.4	36.4	36.4	35.9	47.1
Camels (weighted average)		12.8	12.9	12.8	12.7	12.6	12.6	12.5
Deer (weighted average) [1)]		22.5	23.0	23.0	23.0	23.1	23.3	23.4
Goats		11.5	11.6	11.6	11.4	11.4	11.4	11.4
Horses (weighted average)		43.7	43.8	43.8	43.8	43.8	43.9	43.9
Mules and Asses (weighted average)		16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)		0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rabbits		1.0	1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)		15.4	15.6	15.7	14.9	15.3	15.4	15.5

[1)] Deer: Excretion per animal place

5.3.2.5.3 Manure management system distribution (MS)

The split of nitrogen flows into the different animal waste management systems and its temporal dynamics are based on the respective analysis in the AGRAMMON model (Kupper et al. 2018) and on data provided in Richner et al. (2017). For cattle, the distribution of animal excreta to the various manure management systems is different with regard to estimating CH_4 emissions from 3B Manure management (for further information refer to chp. 5.3.2.2.4) compared to estimating N_2O emissions from 3B Manure management. This is because cattle stables usually have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS. A detailed table of the distribution of VS is contained in Annex A3.3.

5.3.2.5.4 Volatilisation of NH_3, NO_x and N_2 from manure management systems

For indirect N_2O emissions from manure management the deposition of volatilised NH_3 and NO_x is considered. Losses of ammonia from stables and manure storage systems to the atmosphere are calculated according to the Swiss ammonia model AGRAMMON (Kupper et al. 2018). Specific loss-rates for all major livestock categories are estimated based on agricultural structures and techniques (e.g. stable type, manure management system, measures to reduce NH_3 emissions). Accordingly, the overall fraction of nitrogen volatilised underlies certain temporal dynamics that can be explained by changes in agricultural management practices (e.g. the transition to more animal friendly housing systems). It ranges from 15.1 to 20.6%.

For the volatilisation of NO_x values from van Bruggen et al. (2014) were used. Accordingly, it is estimated that 0.2%, 0.5%, 1.0% and 0.1% of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively. In this context the management systems “anaerobic digestion” is treated as liquid/slurry system.

For the estimation of the amount of animal manure applied to soils, the volatilisation of dinitrogen (N_2) during manure management is also considered. It is estimated that 0.020%, 0.025%, 0.050% and 0.025% of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively (van Bruggen et al. 2014).

Note that volatilisation from pasture, range and paddock manure is included under 3Db (Indirect N_2O emissions from managed soils). A graphical overview of the nitrogen flow system is given in Figure 5-6 and respective numbers are provided in Table 5-20.

5.3.2.6 NMVOC emissions from manure management

The NMVOC emission factors for all livestock categories are based on default Tier 1 emission factors (EMEP/EEA 2019, chp. 3B Manure management, Table 3.4) taking into account the fractions of cattle getting silage feeding. A comprehensive literature study by Bühler and Kupper (2018) has shown that the data base of NMVOC emissions from animal husbandry is very scarce and that the derived emission factors differ widely. The studies on which the emission factors in the EMEP/EEA Guidebook 2019 (EMEP/EEA 2019) are based show several inconsistencies that could affect significantly the emission factors. It remains also unknown, how the emissions from the studies performed in the United States were adapted to European agricultural feeding conditions and how the corresponding emission factors were derived. Therefore, a study was launched in 2018 in order to measure NMVOC emissions from dairy cattle with and without silage feeding in an experimental housing system during summer, winter and the transitional season. In the meantime, NMVOC emissions are reported in the inventory based on a Tier 1 approach using default Tier 1 emission factors (EMEP/EEA 2019). Preliminary measurements indicate that emissions based on default Tier 1 emission factors rather tend to overestimate the actual NMVOC emissions.

5.3.3 Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties from the 2006 IPCC Guidelines. The higher value of the lower and upper bound uncertainty was used for activity data and for emission factors in the Approach 1 analysis (Table 5-17).

For further results also consult chp. 1.6.1.

Table 5-17 Uncertainties for 3B Manure management. (AD: Activity data; EF: Emission factor; CO: Combined).

Uncertainty 3B	Approach 1		
	AD	EF	CO
	%		
CH_4	6.5	54.9	55.3
N_2O direct	23.5	70.7	74.5
N_2O indirect	54.9	400.0	403.7

The time series 1990–2018 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data and gross energy intake see chp. 5.2.3.
- The MCF for liquid/slurry systems varies according to the development of the grazing management over the years as described under chp. 5.3.2.2.3.
- Input data from the AGRAMMON-model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010 and 2015 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2016, 2017 and 2018 the same values as in 2015 were applied.
- The emission factor for indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems varies according to varying land use as described in chp. 5.3.2.4.

5.3.4 Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006) standard values are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

For quality assurance of livestock population data and livestock energy intake consult chp. 5.2.4.

5.3.4.1 QA/QC and verification – CH_4

IPCC tables with data for estimating emission factors of all livestock categories (such as weight, feed digestibility, maximum CH_4 producing capacity (B_0) or daily excretion of volatile solids) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A3.3).

VS excretion of various animal categories is based on IPCC default values (IPCC 2006). A cross check of these estimates was conducted during the 2016 submission. VS excretion of the total livestock population was estimated by using exclusively equation 10.24 of the 2006 IPCC Guidelines and GEI data for all animal categories. Using this approach, total VS excretion for the year 2014 was 4.1% higher than reported in the Swiss GHG inventory. Most of the discrepancy can be attributed to swine, for which the default value for VS excretion (also used in the inventory) is rather low (i.e. 0.31 kg/head/day as weighted mean for 2014 compared to 0.43 kg/head/day from the approach based on equation 10.24). However, Minonzio et al. 1998 also suggest a low VS-excretion of 0.30 kg/head/day on average, based on the Swiss typical feeding recommendations. They assume a digestibility of the organic matter of 83%. Using this value in IPCC equation 10.24 would also yield a VS-excretion of 0.31 kg/head/day. This finding supports the adoption of the IPCC default VS-excretion for swine. As for swine, equation 10.24 yields higher VS-excretion values for sheep and goats. Also in these cases the default values for feed digestibility (i.e. 60%) might be too low for Swiss specific conditions. In summary there is no clear indication that the approach using exclusively equation 10.24 would result in a better estimate of overall VS excretion. As for some of the parameters used in equation 10.24 (such as e.g. feed digestibility for swine) no reliable country-specific data were available, it was thus decided to still use the IPCC (2006) default values for VS excretion of the animal categories concerned.

Factors for methane conversion (MCF) and manure management system distribution (MS) were analysed considering the national agricultural context. The estimated MCF-values for liquid/slurry systems in Switzerland are lower than the IPCC (2006) default value for liquid/slurry system, without natural crust cover or pit storage below animal confinements > 1 month, at a temperature ≤10°C. However, a relatively low MCF is supported by the fact that more than 80% of all liquid/slurry storage tanks are covered and approximately one third of the remaining tanks have a surface crust (Kupper et al. 2018). Furthermore, a series of laboratory measurements of MCF-values by the group of animal nutrition from the Swiss

Federal Institute of Technology in Zurich yielded consistently low MCF-values (Zeitz et al. 2012).

During the past years studies were conducted to verify methane emissions at the regional scale comparing bottom-up estimates with atmospheric measurements (Bamberger et al. 2014, Henne et al. 2015, Henne et al. 2016, Henne et al. 2017, Hiller et al. 2014, Hiller et al. 2014a, Stieger 2013, Stieger et al. 2015). For further information on these studies see chp. 5.2.4. and Annex A5.2.

5.3.4.2 QA/QC and verification – N_2O

Estimation of N_2O emissions is mainly based on the Swiss ammonium emission model AGRAMMON that is documented in Kupper et al. (2018).

All relevant data needed for the calculation of N_2O emissions such as nitrogen excretion rates, manure management system distribution and N_2O emission factors were checked for consistency and were compared to the corresponding values of other countries and to the IPCC default value if available (Agroscope 2019a).

As one of the most important parameters, nitrogen excretion rates were analysed in more detail. In order to validate the total nitrogen excretion of the whole livestock population a cross check was conducted comparing the bottom up inventory estimates with an independent top down approach. Thereby, the total amount of nitrogen contained in animal livestock products such as meat, milk or eggs (output) was subtracted from the total amount of nitrogen in animal feedstuff produced in or imported to the country (input). Under the condition that the nitrogen pool in the animal population remains constant, the result should be equal to the amount of nitrogen excreted in the manure (see e.g. Spiess 2011). There was good agreement (average discrepancy of ±2%) for the years 1990–2005. However, for later years the top down estimates were on average 10% higher than the bottom up estimates. Reasons for this observation are not yet clear and this finding will be subject to further analysis.

N_{ex}-values for the most important animal categories (mature dairy cattle and swine, being responsible for 65% of total nitrogen excretion) were compared to the values of the alternative gross energy approach suggested in equation 10.32 in the 2006 IPCC Guidelines. For swine, the IPCC approach estimated on average 18% lower N_{ex} values for the years 1990–2004. This is probably due to an underestimation of the feed protein content in this model calculation and the inventory estimates are considered more realistic. Differences were smaller than 3% for years after 2005. All QA/QC checks of the N_{ex} values are further elaborated in Agroscope (2019a).

Henne et al. (2019) conducted a top-down assessment of Swiss N_2O emissions using atmospheric measurements and an inverse modelling framework. The best estimate of annual N_2O emissions for the investigated period in 2017/2018 was 10.9±1.7 Gg yr^{-1}, which compares to 8.2±1.7 Gg yr^{-1} given in this NIR for the year 2017 (2-σ confidence level). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see also Annex A5.2).

5.3.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalents are assessed quantitatively. All other recalculations are only described qualitatively.

- Emissions from "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) were revised for all years due to a new assessment of animal turnover rates in stables. Corrections for animal turnover rates in stables are now accounted for in the activity data (animal population according to SFSO (2019b) instead of the emission factor. AD and EF were adjusted accordingly. The impact on overall emissions in kt CO_2 equivalents per year is approximately: 1990: +56.9; 2017: +18.2; mean 1990–2017: +42.1 (including emissions from 3A, 3B and 3D).
- CH_4 emissions from manure management of dairy cattle were recalculated for the years 2016 and 2017 due to revised estimates of VS excretion based on new model results. The impact on overall emissions is negligible (<0.5 kt CO_2 equivalent).
- CH_4 emissions from sheep, swine, goats and poultry and "other" (livestock NCAC) were recalculated for the years 2015–2017 due to revised estimates of VS excretion. Provisional estimates for net energy intake from the Swiss Farmers Union were updated (Giuliani 2019). The impact on overall emissions in kt CO_2 equivalents is approximately +0.4, +0.9 and +4.1 for the years 2015, 2016 and 2017 (including 3A and 3B).
- Emissions of CH_4 (EF) and N_2O (AD) for 3B Manure management were recalculated for the years 2008–2017 due to revised estimates of manure handled in anaerobic digesters. The impact on overall emissions (including revised estimates in 3B and 3D) in kt CO_2 equivalents is approximately: 2017: -1.5; mean 2008–2017: -1.0.
- CH_4 emissions from liquid manure systems were slightly revised for all years due to revised estimates of the MCF values from new model runs. New model runs were conducted based on revised VS distributions to the different manure management systems. The impact on overall emissions in kt CO_2 equivalents is approximately: 1990: +0.6; 2017: +0.4; mean 1990–2017: +0.8.

5.3.6 Category-specific planned improvements

An external peer review of the source category 3B Manure management is planned in 2020. Eventual revisions will be conducted as soon as the results from the review are available.

5.4 Source category 3C – Rice cultivation

Rice cultivation is of minor importance in Switzerland. The agricultural land used for rice cultivation and the annual yield of rice are not estimated by the Swiss Farmers Union (SBV 2019). Only one farm in the south of Switzerland is cultivating upland rice since 1997. CH_4 emissions are assumed to be zero. The area of upland rice was revised and is reported from 1997 onward in CRF Table3.C (EMIS 2020/4C “Reisanbau”).

5.5 Source category 3D – Agricultural soils

5.5.1 Source category description

Table 5-18 Key categories of 3D Agricultural soils. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
3Da	Direct emissions from managed soils	N2O	L1, L2
3Db	Indirect emissions from managed soils	N2O	L1, L2, T1, T2

The source category 3D includes direct and indirect N_2O emissions from managed soils (Table 5-19). Direct emissions are further subdivided in emissions from 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter, 6. Cultivation of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of synthetic fertilisers). Indirect N_2O emissions are further subdivided in 1. Atmospheric deposition and 2. Nitrogen leaching and run-off. All indirect N_2O emissions after deposition of NO_x and NH_3 or after leaching of NO_3^- are reported under source category 3Db Indirect N_2O Emissions from managed soils. This includes indirect N_2O emissions after NO_3^- leaching from N mineralisation in cropland remaining cropland and grassland remaining grassland. To avoid double counting the respective emissions are not reported under source category 4(IV) Indirect N_2O emissions from managed soils or in CRF Table6 “Indirect emissions of N_2O and CO_2” (see also chp. 9).

Table 5-19 Specification of source category 3D Agricultural soils.

3D	Source	Specification
3Da	Direct N_2O emissions from managed soils	1. Inorganic N fertilisers 2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils) 3. Urine and dung deposited by grazing animals 4. Crop residues (incl. residues from meadows and pasture) 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Cultivation of organic soils (i.e. histosols) 7. Other (domestic use of synthetic fertilisers)
3Db	Indirect N_2O emissions from managed soils	1. Atmospheric deposition 2. Nitrogen leaching and run-off

Furthermore, NO_x emissions from managed soils as well as NMVOC emissions are estimated.

Direct and indirect N_2O emissions from managed soils have decreased since 1990 in almost all major sub-categories. Only N_2O emissions from 3Da3 (Urine and dung deposited by grazing animals) increased due to a higher share of manure excreted on pasture, range and paddock. NO_x emissions have declined by 22% since 1990. The general trends can be explained by a reduction in the number of cattle and a reduced input of mineral fertilisers due to the introduction of the “Proof of Ecological Performance (PEP)” requiring a balanced fertiliser management (Agroscope 2019a, Leifeld and Fuhrer 2005). Major changes occurred mainly in the 1990s while most emissions were more or less stable after the year 2000.

The most significant N_2O emission sources are animal manure applied to soils (26%, mean 1990–2018), nitrogen input from atmospheric deposition (19%, mean 1990–2018), inorganic nitrogen fertilisers (15%, mean 1990–2018) and urine and dung deposited by grazing animals (11%, mean 1990–2018).

5.5.2 Methodological issues

5.5.2.1 Methodology

For the calculation of most N_2O emissions from 3D Agricultural soils a Tier 1 method was applied that is based on the IULIA model from Schmid et al. (2000). IULIA is an IPCC-derived method for the calculation of N_2O emissions from agriculture that basically uses the default emission factors (IPCC 2006), but adjusts the activity data to the particular situation of Switzerland. For the estimation of N_2O emissions from animal manure applied to soils as well as for the estimation of indirect N_2O emissions a more detailed Tier 3 approach was used. IULIA is continuously updated. New values for nitrogen excretion rates, manure management system distribution and ammonium emission factors from the Swiss ammonium model AGRAMMON were adopted (Kupper et al. 2018). Furthermore, the updated version of the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner et al. 2017) was used instead of obsolete data from Flisch et al. (2009), FAL/RAC (2001) and Walther et al. (1994). Most recently, the N-flow modell was extended to include all gaseous N-species (including N_2) and new NO_x emission factors were implemented (Kupper 2017). Emission factors for N_2O are all IPCC (2006) default with the exception of the emission factor for indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (EF_4) which is country-specific.

The modelling of the N_2O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2020) and is consistent with source category 3B N_2O emissions from manure management. The model structure is displayed in Figure 5-6 and the corresponding amounts of nitrogen are given in Table 5-20.

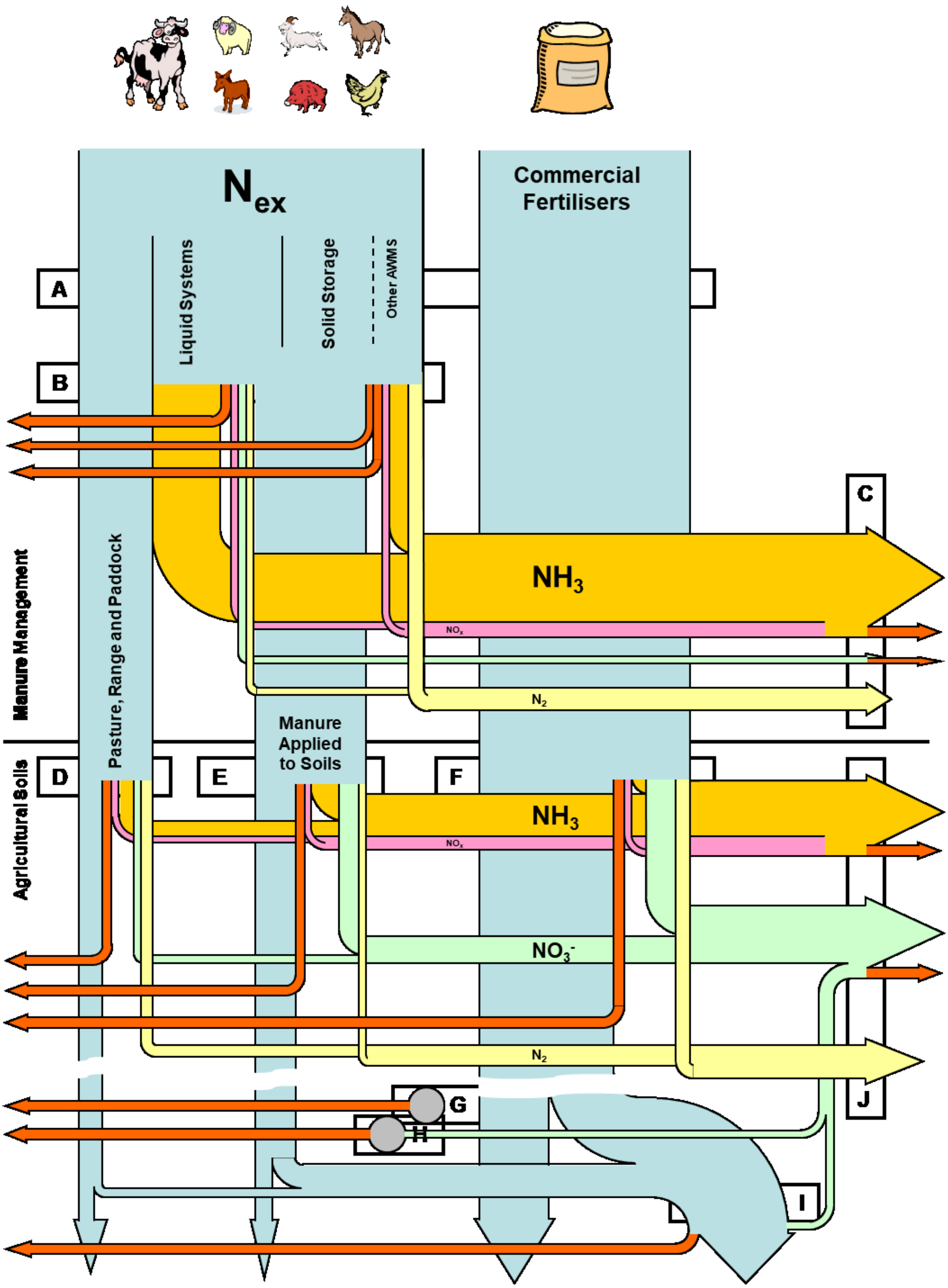


Figure 5-6 Diagram depicting the methodology of the approach to calculate the N_2O emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-20. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical nitrogen flows. Commercial fertilisers refer to the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers. Blue: nitrogen; orange: ammonia (NH_3); pink: nitrogen oxides (NO_x); green: nitrate (NO_3^-); yellow: dinitrogen (N_2).

Table 5-20 Nitrogen flows of the N-flow-model for Swiss agriculture. Letters refer to the letters in Figure 5-6. Processes refer to the nitrogen flows in the black frames in Figure 5-6 from left to right or from top to bottom.

	Process	Amount of N			CRF table
		1990	2018		
		tN			
A	1 Pasture, range and paddock	13'424	22'368	= B	3.Da3
	2 Liquid/slurry systems	94'919	70'870		3.B(b)
	3 Solid storage	35'486	17'571		3.B(b)
	4 Other AWMS	9'096	20'549		3.B(b)
	5 Commercial fertiliser	75'085	53'850	= F	3.Da1,2bc,7
B	1 Pasture, range and paddock	13'424	22'368	= A1 + A2 + A3 + A4	3.Da3
	2 NH_3 volatilisation housing	11'698	14'773		3.B(b)5
	3 N_2O emission liquid/slurry	190	142		3.B(b)
	4 NO_x volatilisation liquid/slurry and digester	192	160		3.B(b)5
	5 Leaching manure management	0	0		3.B(b)5
	6 N_2 volatilisation liquid/slurry and digester	1'916	1'596		
	7 Manure applied to soils	114'921	84'257		3.Da2a
	8 N_2O emission solid storage	177	88		3.B(b)
	9 N_2O emission other AWMS	47	59		3.B(b)
	10 NO_x volatilisation solid storage and deep litter	224	147		3.B(b)5
	11 NH_3 volatilisation storage	8'936	6'906		3.B(b)5
	12 N_2 volatilisation solid storage and deep litter	1'200	863		
C	1 NH_3 deposition manure management	20'634	21'679	= B2+B11	3.B(b)5
	2 NO_x deposition manure management	416	307	= B4+B10	
	3 Leaching manure management	0	0	= B5	
D	1 Plant available N PR&P and N2 volatilisation	9'703	16'723	= B1	
	2 N_2O emission PR&P	257	422		3.Da3
	3 NO_x volatilisation PR&P	74	123		
	4 NH_3 volatilisation PR&P	625	1'109		
	5 Leaching and run-off PR&P	2'767	3'990		
E	1 Plant available N animal manure and N_2 vol.	61'671	51'143	= B7	
	2 N_2O emission application animal manure	1'149	843		3.Da2a
	3 NO_x volatilisation application animal manure	632	463		
	4 NH_3 volatilisation application animal manure	27'785	16'777		
	5 Leaching and run-off application animal manure	23'683	15'031		
F	1 Plant available N com. fertiliser and N_2 vol.	53'804	40'451	= A5	
	2 N_2O emission application com. fertiliser	751	528		3.Da1,2bc,7
	3 NO_x volatilisation application com. fertiliser	413	296		
	4 NH_3 volatilisation application com. fertiliser	4'644	3'080		
	5 Leaching and run-off application com. fertiliser	15'474	9'494		
G	1 Cultivation of organic soils (ha)	*18'039*	*17'313*		3.Da6
H	1 Mineralisation/immobilisation soil organic matter	5'525	4'447		3.Da5
I	1 N in crop residues pasture, range and paddock	27'117	26'313		3.Da4
	2 N in crop residues arable crops	11'953	11'163		
J	1 NH_3 deposition fertiliser appl. and PR&P	33'054	20'966	= D4+E4+F4	3.Db1
	2 NO_x deposition fertiliser appl. and PR&P	1'119	883	= D3+E3+F3	
	4 Leaching and run-off fertiliser appl. and PR&P	41'923	28'515	= D5+E5+F5	3.Db2
	5 Leaching and run-off mineralisation SOM	1'139	793		
	6 Leaching and run-off crop residues	8'052	6'686		

5.5.2.2 Direct N_2O emissions from managed soils (3Da)

Calculation of Direct N_2O emissions from managed soils is based on IPCC 2006 equation 11.1 including six terms for activity data and three different emission factors:

$$N_2O_{Direct} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1 + F_{OS} \bullet EF_2 + F_{PRP} \bullet EF_3$$

N_2O_{Direct}-N = annual direct N_2O–N emissions produced from managed soils (kg N_2O–N/year)

F_{SN} = annual amount of synthetic fertiliser N applied to soils (kg N/year)

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N/year)

F_{CR} = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

F_{OS} = annual area of managed/drained organic soils (ha)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (kg N/year)

EF_1 = emission factor for N_2O emissions from N inputs (kg N_2O–N/kg N input)

EF_2 = emission factor for N_2O emissions from drained/managed organic soils (kg N_2O–N/ha)

EF_3 = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (kg N_2O–N/kg N input)

5.5.2.2.1 Emission factors

Emission factors for calculating 3Da Direct N_2O emissions from managed soils are based on default values as provided in the 2006 IPCC Guidelines (Table 5-21). Since the year 2007 mineral fertilisers with nitrification inhibitors are used in Switzerland. The use of nitrification inhibitors reduces direct N_2O emissions from these fertilisers by 65% (Pfab et al. 2012). The applied amounts are still small and the weighted EF_1 reported is thus only slightly below 1.0%. The amount of fertilisers with nitrification inhibitors is classified as confidential (C). An additional table is available to reviewers on request, including all confidential data and information (Table 5-22). Due to the lack of data no other source specific emission factors were applied for EF_1. The emission factor for urine and dung deposited by grazing animals was calculated as the weighted mean between the emission factor for cattle, poultry and pigs ($EF_{3PRP,CPP}$ = 0.02 kg N_2O–N/kg N) and the emission factor for sheep and “other animals” ($EF_{3PRP,SO}$ = 0.01 kg N_2O–N/kg N) according to the shares of nitrogen excreted by the respective animals.

Table 5-21 Emission factors for calculating direct N_2O emissions from managed soils (IPCC 2006). Blue: annually changing parameters, value for 2018.

Emission source	Emission factor
EF_1 Inorganic N fertilisers (kg N_2O-N/kg)	0.0098
EF_1 Organic N fertilisers (kg N_2O-N/kg)	0.0100
EF_1 Crop residue (kg N_2O-N/kg)	0.0100
EF_1 Mineralisation/immobilisation soil organic matter (kg N_2O-N/kg)	0.0100
EF_1 Other (domestic synthetic fertilisers) (kg N_2O-N/kg)	0.0100
EF_2 Cultivation of organic soils (kg N_2O-N/ha)	8.0000
EF_3 Urine and dung deposited by grazing animals (kg N_2O-N/kg)	0.0189

Table 5-22 In the confidential NIR, the amount of mineral fertilisers with and without nitrification inhibitors and corresponding emission factors are separately reported and available to reviewers.

5.5.2.2.2 Activity data

Activity data for calculation of 3Da Direct soil emissions include 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Nitrogen from mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Area of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of inorganic fertilisers).

Emissions from **inorganic nitrogen fertilisers** include urea and other mineral fertilisers (mainly ammonium-nitrate). The amount of nitrogen input due to these fertilisers is obtained from Agricura (2018). Fertiliser statistics are based on sales statistics of the compulsory stockpiling of fertilisers (Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import-data received by the Directorate General of Customs (Oberzolldirektion). The estimates contain fertilisers used in Liechtenstein which are subtracted for the Swiss GHG inventory. Furthermore, it is estimated that 4% of the mineral fertilisers are used for non-agricultural purposes (i.e. domestic use of inorganic fertilisers; Kupper et al. 2018). These fertilisers are used in public green areas, sports grounds and home gardens. In the reporting tables (CRF) they are reported under 3Da7 **Other (Domestic inorganic fertilisers)** while emission calculation is conducted together with 3Da1. In some occasions, as for instance for the estimation of indirect N_2O emissions from managed soils, the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers is referred to as “commercial fertilisers” (see also Figure 5-6 and Table 5-20).

Organic nitrogen fertilisers include animal manure, sewage sludge and other organic fertilisers. The amount of nitrogen in **animal manure applied to soils** is calculated according to the methods described in chp. 5.3.2.5. As suggested in chp. 10.5.4. and equation 10.34 of the 2006 IPCC Guidelines, all nitrogen excreted on pasture, range and paddock as well as all nitrogen volatilised prior to final application to managed soils is subtracted from the total excreted manure (for the estimation of the respective N–volatilisation during manure management see chp. 5.3.2.5, compare also Figure 5-6). $Frac_{GASM}$ in CRF Table3.D represents the amount of nitrogen volatilised as NH_3, NO_x, N_2O and N_2 from housing and manure storage divided by the manure excreted in the stable (liquid/slurry, solid storage, digesters, deep litter and poultry manure). The nitrogen input from manure applied to soils under 3Da2a in CRF Table3.D can thus be calculated with the numbers given in CRF Table3.B(b) and 3.D. Nitrogen from bedding material was not accounted for under animal manure applied to soils. The respective nitrogen is included in the nitrogen returned to soils as crop residues.

The amount of **sewage sludge** applied to agricultural soils was estimated according to Kupper et al. (2018). Since 2003 the use of sewage sludge as fertiliser is prohibited in Switzerland. However, a transition period applied for some areas. Cantons could therefore prolong this period until 2008 in individual cases (UVEK 2003). **Other organic fertilisers** include compost as well as liquid and solid digestates from biogas plants and are also estimated according to Kupper et al. (2018). Additionally nitrogen input through co-substrates in agricultural biogas plants is accounted for under this sub-category.

Calculation of emissions from **urine and dung deposited by grazing animals** is based on equation 11.5 of the 2006 IPCC Guidelines. Estimation of total livestock nitrogen excretion was described under chp. 5.3.2.5. The share of manure nitrogen excreted on pasture, range and paddock was estimated according to the AGRAMMON-model (Kupper et al. 2018; Table 5-14). For each livestock category the share of animals that have access to grazing, the number of days per year they are actually grazing as well as the number of hours per day grazing takes place was assessed. Estimates are based on values from the literature and expert judgement (1990, 1995) and on surveys on approximatively 3000 Swiss farms (2000, 2007, 2010, 2015).

N_2O emissions from **crop residues** are based on the amount of nitrogen in crop residues returned to soil. For **arable crops**, data on total annual crop yields were adopted from the statistical yearbooks of the Swiss Farmers Union (SBV 2019). Subsequently, the relationship between nitrogen returned in crop residues and fresh matter crop yield was determined for each crop and hereafter the overall amount of nitrogen returned to soils was calculated as follows:

$$F_{CR,AC} = \sum_T \left(Y_T \bullet \frac{NR_T}{SY_T} \right)$$

$F_{CR,AC}$ = amount of nitrogen in crop residues from arable crops returned to soils (t N)

Y_T = amount of fresh matter crop yield for crop *T* (t)

NR_T = standard amount of nitrogen in crop residues for crop *T* (dt/ha)

SY_T = standard amount of fresh matter crop yield for crop *T* (dt/ha)

Standard values for fresh matter crop yields and nitrogen contained in crop residues are given in the “Principles of Fertilisation in Arable and Forage Crop Production” (FAL/RAC 2001 and Richner et al. 2017). For sugar beet and fodder beet it is assumed that 10% of the crop residues are removed from the fields for animal fodder. The use of crop residues for fuel or the (open) burning of crop residues are not common practice in Switzerland and are subject to strong regulations. These activities are therefore not considered to reduce the amount of N returned to soils.

Crop residues from **meadows and pastures** were also assessed. Two thirds of the agricultural land consists of grassland which underscores the importance of this source for Switzerland. According to the 2006 IPCC Guidelines (chp. 11.2.1.3) crop residues on pastures should be included in the estimation of N_2O emission from agricultural soils only for years when renewal of pastures happened. However, the area of meadows and pastures applied here refers to permanent grassland (in contrast to leys and intensive meadows). Renewal of these grasslands is not common practice in Switzerland. Crop residues from meadows and pasture therefore refer here only to field losses during harvest, from feed not eaten by the animals and feed losses due to trampling effects.

$$F_{CR,MP} = \sum_{P} \left(A_P \bullet \frac{SY_{DM,P}}{10} \bullet N_{DM,P} \div 1000 \bullet R_P \right)$$

$F_{CR,MP}$ = amount of nitrogen in crop residues from meadows and pastures returned to soils (t N)

A_P = area of meadow and pasture of type *P* (ha)

$SY_{DM,P}$ = standard dry matter yield per area of meadow and pasture of type *P* (dt/ha)

$N_{DM,P}$ = dry matter nitrogen content of meadow and pasture of type *P* (kg/t)

R_P = ratio of residues to harvested yield for meadows and pasture of type *P* (kg/kg)

Areas of intensive meadows, natural meadows, pasture and alpine and Jurassic pasture were obtained from SBV (2019) and from the SFSO (2019a). Standard dry matter yields per area, nitrogen content of dry matter as well as % yield losses were based on the original IULIA model (Schmid et al. 2000), FAL/RAC 2001 and on Richner et al. (2017).

Estimated values of total crop production, nitrogen incorporated with crop residues $F_{(CR)}$, residue/crop ratio, dry matter fraction of residues and nitrogen content of residues are provided in Annex A3.3.

Assessment of nitrogen **mineralisation/immobilisation associated with loss/gain of soil organic matter** was conducted based on data from the LULUCF sector. For reasons of consistency, losses and gains of soil organic matter on cropland and grasslands were accounted for. The same methodology as described under chp. 6.10.2 was applied. Nitrogen mineralisation was estimated by dividing the carbon loss on cropland remaining cropland and grassland remaining grassland with a C/N-ratio of 9.8 according to Leifeld et al. (2007). It should be noted that the carbon losses were assessed based on land use changes on a sub-category level. Only land use changes that led to a net carbon stock loss were considered, excluding land use changes that led to a net carbon stock increase. Consequently, the carbon losses used for calculating N_2O emissions from nitrogen mineralisation are not identical with the net carbon stock changes reported in the reporting tables (CRF Table4.B and Table4.C). N_2O emissions from nitrogen mineralisation of land converted to cropland or land converted to grassland are reported under source category 4(III) “Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralisation/immobilisation associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils”.

Estimates of N_2O emissions from **cultivated organic soils** are based on the area of cultivated organic soils and the IPCC default emission factor for N_2O emissions from cultivated organic soils (IPCC 2006). The area of cultivated organic soils corresponds to the total area of organic soils under cropland and grassland as reported in CRF Table4.B and 4.C (see also chp. 6.2.2).

The relevant activity data for calculating N_2O emissions from soils are displayed in Table 5-23. Additional information is given in Annex A3.3.

Table 5-23 Activity data for calculating 3Da Direct N_2O emissions from managed soils.

Activity Data		1990-1999									
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		t N/yr									
1. Inorganic N fertilisers	Urea	16'284	11'966	11'650	11'335	11'021	10'707	10'391	7'555	6'405	6'690
	Other mineral fertilisers	50'391	54'913	55'035	50'646	47'326	47'652	45'899	41'086	42'511	44'461
2. Organic N fertilisers	a. Animal manure	114'921	113'137	110'800	108'587	107'596	106'384	102'239	97'187	94'586	91'182
	b. Sewage sludge	4'815	4'840	4'866	4'891	4'916	4'942	4'624	4'307	3'990	3'673
	c. Other organic fertilisers	817	884	988	1'033	1'151	1'286	1'369	1'427	1'489	1'686
3. Urine and dung deposited by grazing animals		13'424	13'664	13'744	13'649	13'905	14'035	15'978	17'208	18'451	19'217
4. Crop residues	Arable crops	11'953	11'620	11'805	11'741	11'134	11'350	12'670	12'053	12'454	10'933
	Residues M&P	27'117	26'952	26'813	26'643	26'435	26'263	26'438	26'632	26'886	26'995
5. Min./imm. associated with loss/gain of SOM		5'525	607	610	17'997	15'411	17'578	677	5'547	8'587	1'778
6. Cultivation of organic soils (ha)		18'039	18'014	17'989	17'964	17'941	17'912	17'883	17'850	17'817	17'784
7. Other (domestic inorganic fertilisers)		2'778	2'787	2'779	2'583	2'431	2'432	2'345	2'027	2'038	2'131

Activity Data		2000-2009									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		t N/yr									
1. Inorganic N fertilisers	Urea	7'631	7'815	8'020	6'754	7'875	6'605	5'977	8'305	6'603	5'307
	Other mineral fertilisers	43'042	46'788	45'281	44'098	43'392	43'478	43'227	43'282	41'982	40'451
2. Organic N fertilisers	a. Animal manure	87'900	86'604	83'621	82'665	81'975	83'526	84'382	85'122	86'661	85'739
	b. Sewage sludge	3'356	2'596	1'836	1'542	1'248	1'054	859	573	286	0
	c. Other organic fertilisers	1'829	1'948	1'994	1'998	2'089	2'201	2'406	2'638	2'784	3'037
3. Urine and dung deposited by grazing animals		21'315	23'015	24'480	24'187	23'761	23'905	24'088	24'116	24'293	23'767
4. Crop residues	Arable crops	12'345	10'752	11'722	10'011	12'152	11'750	10'876	11'786	11'690	12'103
	Residues M&P	27'166	27'162	27'126	27'180	27'123	26'912	26'673	26'462	26'238	26'248
5. Min./imm. associated with loss/gain of SOM		27'708	18'527	11'911	2'464	1'829	17'576	1'262	11'712	2'284	4'818
6. Cultivation of organic soils (ha)		17'751	17'718	17'685	17'653	17'620	17'586	17'558	17'531	17'505	17'484
7. Other (domestic inorganic fertilisers)		2'111	2'275	2'221	2'119	2'136	2'087	2'050	2'149	2'024	1'907

Activity Data		2010-2018								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
		t N/yr								
1. Inorganic N fertilisers	Urea	7'101	6'502	5'358	5'770	7'916	7'069	8'845	9'126	8'274
	Other mineral fertilisers	45'986	40'228	39'790	37'946	41'420	36'676	37'558	40'238	37'498
2. Organic N fertilisers	a. Animal manure	86'088	85'811	85'894	85'411	85'937	85'516	85'093	84'543	84'257
	b. Sewage sludge	0	0	0	0	0	0	0	0	0
	c. Other organic fertilisers	3'399	3'802	4'492	4'841	5'093	5'476	5'830	6'010	6'171
3. Urine and dung deposited by grazing animals		23'343	23'076	23'094	22'863	22'768	22'493	22'441	22'391	22'368
4. Crop residues	Arable crops	10'740	12'460	11'429	10'330	12'504	10'925	10'144	11'849	11'163
	Residues M&P	26'365	25'659	26'114	25'754	27'102	26'232	26'606	26'122	26'313
5. Min./imm. associated with loss/gain of SOM		6'844	8'556	24'999	9'946	14'254	13'927	15'053	18'618	4'447
6. Cultivation of organic soils (ha)		17'464	17'443	17'422	17'403	17'384	17'365	17'346	17'331	17'313
7. Other (domestic inorganic fertilisers)		2'212	1'947	1'881	1'822	2'056	1'823	1'933	2'057	1'907

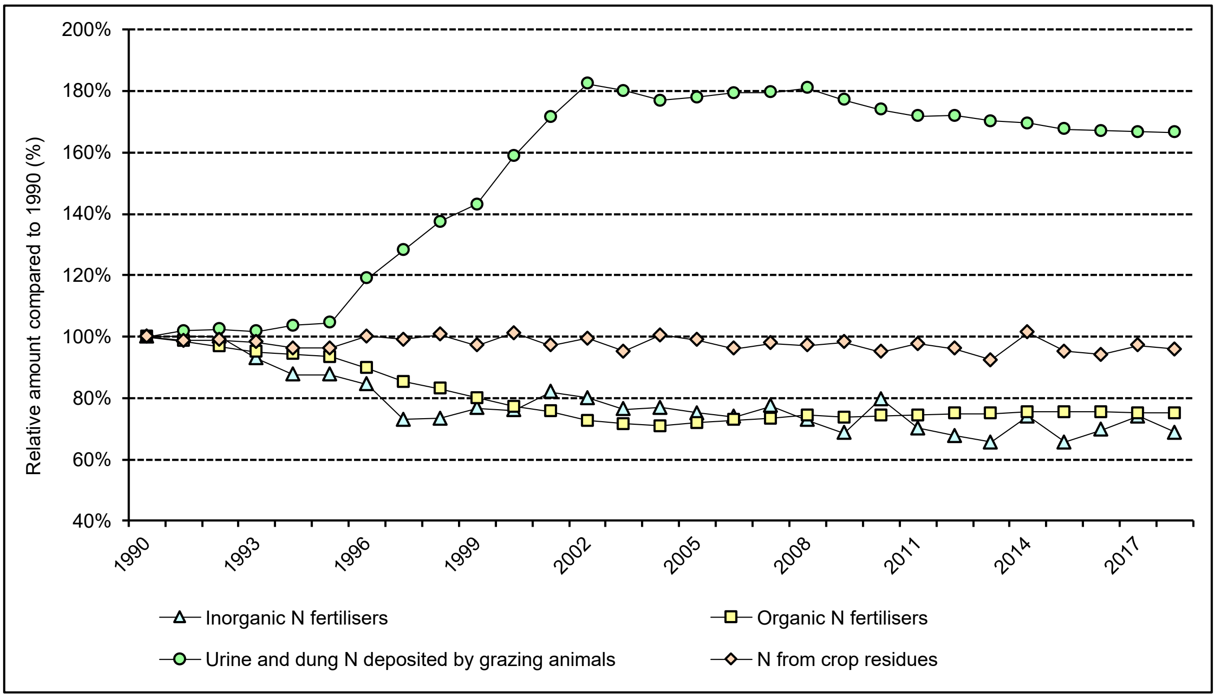


Figure 5-7 Relative development of the most important activity data for 3Da Direct N_2O emissions from managed soils.

Figure 5-7 represents the development of the most important activity data for 3Da Direct N_2O emissions from managed soils. The use of inorganic N-fertiliser declined mainly during the 1990s due to the agricultural policy reforms and the introduction of the “Proof of Ecological Performance (PEP)” that requires a balanced fertiliser management. Simultaneously, nitrogen input from animal manure declined due to declining livestock populations (mainly cattle). Urine and dung deposited by grazing animals increased substantially due to the shift to more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 21st century (see also chp. 5.3.2.2.4). N inputs from crop residues remained more or less constant during the inventory time period due to more or less stable crop production.

5.5.2.3 Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (3Db1)

N_2O emissions from atmospheric deposition of N volatilised from managed soils were estimated based on equations 11.9 and 11.11 of the 2006 IPCC Guidelines. However, the method was adapted to the far more detailed approach of Switzerland:

$$N_2O_{(ATD)} - N = \left\{ \left[\sum_i \left(F_{CN_i} * Frac_{GASF_i}\right) + \sum_T \left(F_{AM_T} * Frac_{GASM_T}\right) + \sum_T \left(F_{PRP_T} * Frac_{GASP_T}\right) \right] + \left[(F_{CN} + F_{AM}) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP} \right] \right\} * EF_4$$

$N_2O_{(ATD)}$-N = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils (kg N_2O–N/year)

F_{CNi} = annual amount of commercial fertiliser N of type *i* applied to soils (kg N/year)

$Frac_{GASFi}$ = fraction of commercial fertiliser N of type *i* that volatilises as NH_3 (kg N/kg N)

F_{AMT} = annual amount of managed animal manure N of livestock category *T* applied to soils (kg N/year)

$Frac_{GASMT}$ = fraction of applied animal manure N of livestock category *T* that volatilises as NH_3 (kg N/kg N)

F_{PRPT} = annual amount of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* (kg N/year)

$Frac_{GASPT}$ = fraction of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* that volatilises as NH_3 (kg N/kg of N)

F_{CN} = total amount of commercial fertiliser N applied to soils (kg N/year)

F_{AM} = total amount of managed animal manure N applied to soils (kg N/year)

$Frac_{NOXA}$ = fraction of applied N (commercial fertilisers and animal manure) that volatilises as NO_x (kg N/kg N)

F_{PRP} = total amount of urine and dung N deposited on pasture, range and paddock by grazing animals (kg N/year)

$Frac_{NOXP}$ = fraction of urine and dung N deposited on pasture, range and paddock that volatilises as NO_x (kg N/kg of N)

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N_2O-N/ kg N volatilised).

5.5.2.3.1 Emission factor

The emission factor for indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils is the same as used for the assessment of indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems. The emission factor was reassessed by a literature review by Bühlmann et al. (2015) and Bühlmann (2014). Due to slightly changing land use, the resulting emission factor shows some small variations around a mean value of 2.56%. For further information see chp. 5.3.2.4.

5.5.2.3.2 Activity data

The estimation of volatilisation of ammonia and NO_x was harmonised with the Swiss ammonia model AGRAMMON using the same emission factors and basic parameters (Table 5-24). Losses of commercial fertiliser nitrogen, animal manure N applied to soils, as well as urine and dung N deposited on pasture, range and paddock by grazing animals were considered. For the calculation of NH_3 emissions, changes of agricultural structures (changes to more animal friendly housing systems) and techniques (manure management, measures to reduce NH_3 emissions) are considered and explain temporal dynamics.

Ammonia volatilisation from **commercial fertiliser N** was estimated separately for synthetic fertilisers (based on EMEP/EEA 2016), sewage sludge, and other organic fertilisers (compost, liquid and solid digestates from biogas plants). Ammonia volatilisation of nitrogen in synthetic fertilisers was assessed separately for individual fertiliser types based on (EMEP/EEA 2016). The weighted mean value for synthetic fertilisers excluding urea is 2.8% (mean 1990–2018). Furthermore 13.1% of urea-nitrogen is lost as ammonia. Ammonia emission factors for sewage sludge range from 20% to 26% depending on the composition of the sludge (Kupper et al. 2018). Other organic fertilisers include compost as well as liquid and solid digestates. Ammonia emission factors are 3.4% for compost, 21%–30% for liquid digestate and 4.0% for solid digestate. The ammonia loss rate for liquid digestates decreased from 2001 until 2010 due to the increasing use of trailing hoses during field application.

Total $Frac_{GASF}$ (including NO_x emissions) as reported in CRF Table3.D declined considerably from 6.7% in 1990 to 5.0% in 2006 and then increased again to 6.3% in 2018 due to a change in the shares of the different commercial fertilisers.

Different ammonia loss factors were used for **animal manure N applied to soils** from different livestock categories according to the detailed approach of the AGRAMMON model (Kupper et al. 2018). Overall weighted $Frac_{GASMT}$ for animal manure applied to soils slightly declined from 24.7% in the early 1990s to 20.5% in 2018 (Table 5-24).

Ammonia volatilisation from **urine and dung N deposited on pasture, range and paddock by grazing animals** was also assessed individually for each livestock category. Weighted mean loss rates ($Frac_{GASPT}$) range from 4.7% to 5.0%.

NO_x emissions were estimated separately for applied fertiliser N (commercial fertilisers, animal manure) and for urine and dung N deposited on pasture, range and paddock by grazing animals. NO_x emission factors ($Frac_{NOXA}$ and $Frac_{NOXP}$) for applied fertilisers and for urine and dung N deposited on pasture, range and paddock are 0.55% each, based on Stehfest and Bouwman (2006).

Nitrogen pools and flows for calculating 3Db Indirect N_2O emissions from managed soils are displayed in Table 5-25. Additional information is given in Annex A3.3.

Table 5-24 Overview of NH_3 and NO_x emission factors used for the assessment of 3Db Indirect N_2O emissions from atmospheric deposition. Complete time series on a livestock sub-category level are provided in Annex A3.3.

Emission factors volatilisation	1990-2011									
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
	%									
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	6.19	6.05	5.42	4.67	4.46	4.84	4.70	4.59	4.72	4.82
Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	2.72	2.72	2.51	2.76	2.65	2.74	2.94	3.12	3.07	2.99
Recycling Fertilisers (weighted average)	17.60	19.97	18.81	13.52	12.96	12.06	10.85	9.46	9.78	10.18
Sewage Sludge	20.00	23.94	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	30.00	30.00	30.00	26.06	25.05	24.04	23.03	22.01	21.00	21.00
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NH_3 from application of animal manure N ($Frac_{GASMT}$)	24.18	24.18	22.52	22.36	22.63	22.81	22.30	21.68	21.08	20.88
Mature Dairy Cattle	26.69	26.78	25.40	25.30	25.47	25.63	25.00	24.38	23.76	23.44
Other Mature Cattle	24.16	23.68	21.76	22.65	23.20	23.72	23.31	22.88	22.45	22.28
Growing Cattle (weighted average)	24.47	24.54	22.60	22.80	23.19	23.57	23.02	22.47	21.92	21.73
Sheep (weighted average)	3.73	4.39	4.11	5.19	5.61	6.04	5.86	5.69	5.54	5.40
Swine (weighted average)	21.52	21.02	19.82	19.89	20.16	20.48	19.85	19.25	18.66	18.53
Other Livestock (weighted average)	8.83	9.85	8.73	8.93	8.88	9.05	9.38	9.72	10.12	10.13
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.65	4.69	4.78	4.91	4.93	4.97	4.92	4.88	4.84	4.85
Mature Dairy Cattle	4.67	4.65	4.64	4.61	4.61	4.60	4.60	4.59	4.59	4.59
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	NA	NA	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Other Livestock (weighted average)	5.00	7.00	7.82	9.48	9.72	10.26	9.61	8.97	8.44	8.58
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Emission factors volatilisation	2012-2018						
	2012	2013	2014	2015	2016	2017	2018
	%						
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	4.86	5.08	5.26	5.65	5.54	5.65	5.72
Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	3.11	3.12	3.04	3.37	2.82	3.05	3.08
Recycling Fertilisers (weighted average)	10.76	11.10	11.34	11.59	11.85	11.98	12.12
Sewage Sludge	26.07	26.07	26.07	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	21.00	21.00	21.00	21.00	21.00	21.00	21.00
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NH_3 from application of animal manure N ($Frac_{GASMT}$)	20.64	20.43	20.21	20.00	19.97	19.95	19.91
Mature Dairy Cattle	23.12	22.80	22.49	22.18	22.18	22.18	22.18
Other Mature Cattle	22.11	21.94	21.77	21.60	21.60	21.60	21.60
Growing Cattle (weighted average)	21.57	21.38	21.19	21.01	21.01	21.01	21.00
Sheep (weighted average)	5.26	5.12	4.96	4.81	4.81	4.81	4.80
Swine (weighted average)	18.40	18.27	18.14	18.00	17.99	18.00	18.00
Other Livestock (weighted average)	10.04	10.09	10.12	10.12	10.25	10.29	10.32
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.86	4.87	4.88	4.90	4.92	4.94	4.96
Mature Dairy Cattle	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Other Livestock (weighted average)	8.58	8.84	9.08	9.43	9.81	9.98	10.14
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Table 5-25 Overview of N pools and flows for calculating 3Db Indirect N_2O emission from managed soils. Complete time series are provided in Annex A3.3.

Nitrogen pools and flows		1990-2011									
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011
		t N/yr									
	Animals manure N applied to soils	114'921	106'384	87'900	83'526	84'382	85'122	86'661	85'739	86'088	85'811
	Commercial fertiliser	75'085	67'018	57'969	55'425	54'519	56'947	53'680	50'701	58'698	52'479
Deposition	Sum volatised N (NH_3 and NO_x)	34'173	31'469	24'875	23'336	23'609	24'287	23'946	22'953	22'979	22'451
	NH_3 emissions from commercial fertilisers	4'644	4'058	3'142	2'591	2'432	2'755	2'522	2'325	2'772	2'527
	NH_3 emissions from applied animal manure	27'785	25'722	19'795	18'677	19'093	19'419	19'323	18'586	18'151	17'917
	NH_3 emissions from pasture, range and paddock	625	659	1'019	1'173	1'187	1'199	1'195	1'160	1'131	1'119
	NO_x emissions from commercial fertilisers	413	369	319	305	300	313	295	279	323	289
	NO_x emissions from applied animal manure	632	585	483	459	464	468	477	472	473	472
	NO_x emissions from PR&P	74	77	117	131	132	133	134	131	128	127
Leaching and run-off	Sum leaching and run-off	51'114	50'001	46'143	41'107	37'490	39'727	37'262	36'640	37'812	37'087
	Leaching and run-off from commercial fertilisers	15'474	13'811	11'411	10'399	10'128	10'446	9'737	9'122	10'450	9'335
	Leaching and run-off from applied animal manure	23'683	21'924	17'303	15'671	15'676	15'656	15'780	15'453	15'357	15'308
	Leaching and run-off from pasture, range and paddock	2'767	2'892	4'196	4'485	4'475	4'436	4'423	4'284	4'164	4'117
	Leaching and run-off from crop residues	8'052	7'751	7'778	7'254	6'976	7'035	6'906	6'912	6'619	6'800
	Leaching and run-off from mineralisation of SOM	1'139	3'623	5'454	3'298	234	2'154	416	868	1'221	1'526

Nitrogen pools and flows		2012-2018						
		2012	2013	2014	2015	2016	2017	2018
		t N/yr						
	Animals manure N applied to soils	85'894	85'411	85'937	85'516	85'093	84'543	84'257
	Commercial fertiliser	51'521	50'380	56'484	51'043	54'166	57'430	53'850
Deposition	Sum volatised N (NH_3 and NO_x)	22'238	21'992	22'357	21'967	21'992	22'122	21'849
	NH_3 emissions from commercial fertilisers	2'504	2'560	2'970	2'886	3'001	3'244	3'080
	NH_3 emissions from applied animal manure	17'729	17'446	17'367	17'104	16'997	16'869	16'777
	NH_3 emissions from pasture, range and paddock	1'122	1'114	1'111	1'102	1'105	1'105	1'109
	NO_x emissions from commercial fertilisers	283	277	311	281	298	316	296
	NO_x emissions from applied animal manure	472	470	473	470	468	465	463
	NO_x emissions from PR&P	127	126	125	124	123	123	123
Leaching and run-off	Sum leaching and run-off	39'763	36'486	39'052	37'459	38'053	39'332	35'994
	Leaching and run-off from commercial fertilisers	9'164	8'960	10'051	9'078	9'628	10'161	9'494
	Leaching and run-off from applied animal manure	15'323	15'237	15'330	15'255	15'180	15'082	15'031
	Leaching and run-off from pasture, range and paddock	4'120	4'079	4'062	4'013	4'003	3'994	3'990
	Leaching and run-off from crop residues	6'697	6'437	7'065	6'629	6'556	6'774	6'686
	Leaching and run-off from mineralisation of SOM	4'460	1'774	2'543	2'484	2'685	3'321	793

Figure 5-8 shows the development of the most important activity data for 3Db Indirect N_2O emissions from managed soils. Ammonia emissions from application of commercial fertilisers declined mainly due to reduced fertiliser use and partly also due to the decreasing share of fertilisers with high ammonia emission rates (i.e. urea and sewage sludge). Ammonia emissions from applied animal manure declined mainly due to declining livestock populations and hence due to the reductions of available manure N. The fraction of applied animal manure N that volatilises as NH_3 ($Frac_{GASMT}$) declined slightly and also contributed to the decreasing trend.

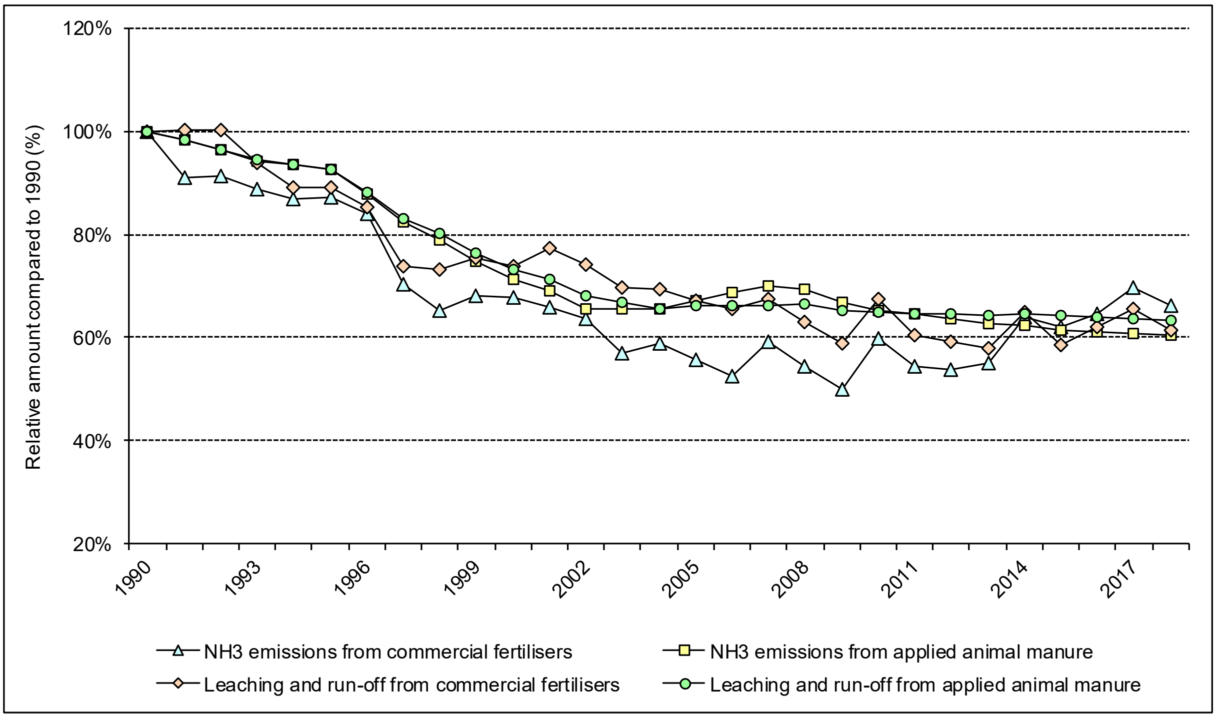


Figure 5-8 Relative development of the most important activity data for 3Db Indirect N_2O emissions from managed soils.

5.5.2.4 Indirect N_2O emissions from leaching and run-off from managed soils (3Db2)

N_2O emissions from leaching and run-off from managed soils are estimated based on equation 11.10 of the 2006 IPCC Guidelines:

$$N_2O_{(L)} - N = \left(F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}\right) \bullet Frac_{LEACH-(H)} \bullet EF_5$$

$N_2O_{(L)}$–N = annual amount of N_2O–N produced from leaching and run-off of N additions to managed soils (kg N_2O–N/year)

F_{CN} = annual amount of commercial fertiliser N applied to soils (kg N/year)

F_{AM} = annual amount of managed animal manure N applied to soils (kg N/year)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals (kg N/year)

F_{CR} = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff (kg N/kg of N additions)

EF_5 = emission factor for N_2O emissions from N leaching and run-off (kg N_2O–N/kg N leached and run-off)

5.5.2.4.1 *Emission factor*

The emission factor for indirect N_2O emissions from leaching and run-off from managed soils is 0.0075 kg N_2O–N/kg N according to the 2006 IPCC Guidelines (IPCC 2006).

5.5.2.4.2 *Activity data*

For the calculation of N_2O emissions from leaching and run-off from managed soils, N-leaching from commercial fertilisers (including synthetic fertilisers, sewage sludge, compost, and liquid and solid digestates from biogas plants)(F_{CN}), managed animal manure N applied to soils (F_{AM}), urine and dung N deposited by grazing animals (F_{PRP}), N in crop residues returned to soils (F_{CR}) and N mineralised in mineral soils (F_{SOM}) were accounted for. The method for the assessment of the respective amounts of nitrogen is described in chp. 5.5.2.2 and activity data are contained in Table 5-23.

$Frac_{LEACH-H}$ was estimated for the years 1990 and 2010 by dividing the available amount of nitrogen by the amount of nitrogen that is lost due to leaching and run-off in Switzerland according to model estimates of Prasuhn 2016. The respective loss rates are 20.6% for 1990 and 17.8% for 2010. Spiess and Prasuhn (2006), confirm that the loss rates were somewhat higher in the early 1990s and then declined due to the agricultural policy reforms. Accordingly, the reduction in the nitrate loss rate was implemented between 1995 and 2010 with constant loss rates after 2010. The same loss rates were applied to all nitrogen pools independent of their origin and composition. An additional reduction of the nitrate loss rate originates from the application of fertilisers with nitrification inhibitors. The nitrogen loss rate is reduced by 23% for fertilisers with nitrification inhibitors (Weiske et al. 2001). Due to the limited application of nitrification inhibitors the respective effect is still small (see also chp. 5.5.2.2.1). The overall amount of nitrogen that is lost through leaching and run-off is given in Table 5-25.

Figure 5-8 illustrates the development of the most important activity data for 3Bb Indirect N_2O emissions from managed soils. Both leaching and run-off from commercial fertiliser and animal manure N declined during the inventory time period due to the reduced nitrogen inputs and the decreasing nitrate loss rates ($Frac_{LEACH-H}$).

5.5.2.5 NMVOC emissions from agricultural soils

The NMVOC emissions from crop production and agricultural soils were revised completely for the entire times series using a Tier 2 approach according to the EMEP/EEA Guidebook 2019 (EMEP/EEA 2019). Three types of agricultural areas are differentiated, i.e. cropland, grassland and summer pastures. The NMVOC emission factors for cropland and grassland are based on the values for wheat and grass (15°C), respectively, of Table 3.3 of the EMEP/EEA Guidebook 2019 taking into account country-specific values for the mean dry matter yield (Richner et al. 2017). For summer pastures, the same NMVOC emission value as for grass (15°C) and a fraction of the growing period of 0.3 (Bühler and Kupper 2018) are assumed using a country-specific value for the mean dry matter yield (Richner et al. 2017). The resulting NMVOC emission factors are constant for the entire time series.

5.5.3 Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties of the 2006 IPCC Guidelines. The higher value of the lower and upper bound uncertainty is used for activity data and for emission factors, resulting in combined Approach 1 uncertainties as shown in Table 5-26. For 3Da (Direct N_2O emissions – Fertilisers) the sub-positions 3Da 1, 2, 4, 5 and 7 were combined according to Approach 1 error propagation.

For further results also consult chp. 1.6.1.

Table 5-26 Uncertainties for 3D Agricultural soils. (AD: Activity data; EF: Emission factor; CO: Combined).

Uncertainty 3D		Approach 1		
		AD	EF	CO
		%		
Direct soil emissions	Fertilisers	15.1	200.0	200.6
	Organic soils	46.3	200.0	205.3
	Urine and dung deposited on PR&P	82.8	200.0	216.5
Indirect soil emissions	Atmospheric deposition	48.4	400.0	402.9
	Leaching and run-off	22.3	233.3	234.4

The time series 1990–2018 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data see chp. 5.2.3.
- Input data from the AGRAMMON model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010 and 2015 (extensive surveys on approximatively 3000 farms). Values in-between the assessment years were interpolated linearly.
- $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{GASP}$ are fluctuating along the time series due to fluctuating shares of different fertiliser types and animal populations with different ammonia emission factors.
- The emission factor for indirect N_2O emissions following volatilisation of NH_3 and NO_x from applied fertilisers and urine and dung excreted on pasture, range and paddock varies according to varying land use as described in chp. 5.3.2.4.

For more details on time-series consistency see also chp. 5.2.3 and 5.3.3.

5.5.4 Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC) standard values are being analysed and discussed.

The Swiss ammonium emission model AGRAMMON is documented in Kupper et al. (2018) and Agrammon (2010). Generally the reporting of N_2O emissions in the Swiss national GHG inventory is consistent with the reporting of other nitrogen compounds (NH_3, NO_x) under the CLRTAP.

All relevant parameters needed for the calculation of direct and indirect nitrogen inputs to agricultural soils (e.g. F_{CN}, MS-distribution, $Frac_{GASF}$, N_{ex}, $Frac_{GASMT}$, F_{ON}, F_{CR}, $Frac_{LEACH-H}$) were checked for consistency and confidence and were compared (where possible) to IPCC default values (IPCC 2006), values of other countries as well as values in the literature. Nitrogen excretion, being one of the most important parameters, was analysed in more detail as described in chp. 5.3.4.2.

For quality assurance of livestock population data consult chp. 5.2.4.

N_2O emission factors were compared to values in the literature to ensure plausibility. Implied emission factors are similar to measured values from the literature representative for Swiss conditions (Agroscope 2019a). The N_2O emission factor for cultivated organic soils was validated by a study from Leifeld (2018) that used a large dataset of C/N ratios in Swiss organic soils to predict N_2O emissions. The study concluded that the current national GHG inventory neither systematically over- nor underestimates total emissions. Furthermore, in 2018 a focus study in the context of the national research programme 68 (Nationales Forschungsprogramm 68: Ressource Boden) made an independent assessment of the N_2O emission factors under Swiss conditions based on a literature review (Krause et al. 2018). The authors found that the N_2O emission factors of mineral soils were 2.06±2.66% for arable soils and 1.45±1.07% for grassland soils. Based on the limited data availability and on the great variability between the different measurements they concluded, that these emission factors are not significantly different to the IPCC (2006) values. Still, the numerical difference indicates that further efforts should be made to development country-specific emission factors (see chp. 5.5.6).

The estimate for the area of cultivated histosols in the agricultural sector is consistent with the estimates reported under cropland and grassland in the LULUCF sector. A literature study conducted by Leifeld et al. (2003) estimates 17’000±5’000 ha which is close to the numbers reported in the LULUCF sector (17’700 ha on average).

The country-specific value of $Frac_{LEACH-H}$ is based on a very detailed model for the assessment of leaching and run-off in Switzerland (Hürdler et al. 2015, Prasuhn 2016) that takes into account regional parameters such as topography, different crop species as well as fertiliser application levels.

Henne et al. (2019) conducted a top-down assessment of Swiss N_2O emissions using atmospheric measurements and an inverse modelling framework. The effort is ongoing and updated numbers are presented in Annex A5.2. The best estimate of annual N_2O emissions for the years 2017 and 2018 was 11.4±1.8 Gg yr^{-1} and 10.8±1.1 Gg yr^{-1}, respectively. This compares to 10.5±2.1 Gg yr^{-1} and 9.8±1.9 Gg yr^{-1} given in this NIR (incl. emissions from LULUCF; 1- σ confidence level).

5.5.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalents are assessed quantitatively. All other recalculations are only described qualitatively.

- For recalculations of livestock population data and emissions from manure management (affecting the amount of animal manure applied to soils) refer to chp. 5.2.5 and chp.5.3.5.
- Emissions of N_2O from 3Da1 “N input from application of inorganic fertilizers to cropland and grassland” were recalculated for the years 2008–2017 due to the inclusion of urea from urea-ammonia-nitrate fertilisers (AD). The impact on overall emissions (including revised estimates in 3D and 3H) in kt CO_2 equivalents were negligible (<0.5).
- Emissions of N_2O from 3Da2 “N input from organic N fertilizers to cropland and grassland” were recalculated for the years 2008–2017 due to a new assessment of nitrogen inputs from co-substrates of agricultural biogas plants (AD). The impact on overall emissions in kt CO_2 equivalents is approximately: 2017: +0.3; mean 2008–2017: +0.2.
- N_2O emissions from 3Da4 “N in crop residues returned to soils” were recalculated for the year 2017 due to revised AD. Provisional data on crop harvests from the Swiss Farmers Union (SFU/SBV) were updated. The impact on overall emissions in kt CO_2 equivalents is negligible (<0.2).
- Emissions of N_2O from 3Da4 “N in crop residues returned to soils” were recalculated for the years 1990–2017 due to revised estimates of yields from meadows and pastures (AD)(see chp. 6.3.5). The impact on overall emissions in kt CO_2 equivalents is approximately: 1990: -2.6; 2017: -3.7; mean 1990–2017: -1.6.
- Emissions of N_2O from 3Da5 “N in mineral soils that is mineralized/immobilized in association with loss of soil C“ were recalculated for the years 1990–2017 due to revised estimates of mineralised nitrogen (AD)(see chp. 6.5.5 and 6.6.5). The impact on overall emissions in kt CO_2 equivalents is approximately: 1990: +6.0; 2017: +9.8; mean 1990–2017: +3.9.
- Emissions of N_2O from 3Da6 “cultivation of organic soils” were recalculated for the years 1990–2017 due to revised estimates of the area of organic soils (AD) (see chp. 6.3.5). The impact on overall emissions in kt CO_2 equivalents is negligible (<0.1).
- Indirect N_2O emissions from agricultural soils were revised according to the revised estimates of nitrogen volatilized or leached as consequence of the recalculations mentioned above.
- Emissions of N_2O from 3Db1 “Atmospheric deposition” (indirect emissions) were recalculated for the years 1990–2017 due to revised estimates of NH_3 volatilisation from urea and other mineral fertilisers (AD). The impact on overall emissions in kt CO_2 equivalents is negligible (<0.02).

5.5.6 Category-specific planned improvements

Starting in 2020, FOEN funds the development and evaluation of a process-oriented model for N_2O emissions in agricultural soils subject to common Swiss management practices.

5.6 Source category 3E – Prescribed burning of savannahs

Burning of savannahs does not occur (NO) in Switzerland.

5.7 Source category 3F – Field burning of agricultural residues

Field burning of agricultural residues does not occur (NO) in Switzerland.

Open burning of natural forest, field and garden waste is regulated in the Ordinance on Air Pollution Control OAPC, (Swiss Confederation 1985: Art. 26b). In Switzerland, cantonal authorities are responsible for the enforcement of the OAPC regulations. The 26 cantons have thus probably slightly different interpretations and implementations of the federal ordinance. An inquiry of some cantonal authorities was performed in order to assess the activity data for these processes (INFRAS 2014).

Emissions from open burning of branches in agriculture and forestry were reported here in the past. However, the respective emissions were moved to the sectors 4 LULUCF and 5 Waste based on recommendations from the UNFCCC expert review teams (e.g. FCCC/ARR/2016/CHE W12 and W13). Respective information can be found under source category 4V “Biomass Burning” (see chp. 6.4.2.13) and source category 5C “Incineration and open burning of waste” (see chp. 7.4).

5.8 Source category 3G – Liming

5.8.1 Source category description

CO_2 emission from 3G Liming is not a key category.

Emissions from the application of lime ($Ca(CO_3)$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils are reported.

The emissions due to liming of agricultural soils range from 22.2 to 32.9 kt CO_2 per year.

5.8.2 Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of lime and dolomite applied and IPCC (2006) default emission factors.

5.8.2.1 Emission factor

The availability of country-specific emission factors for agricultural lime and dolomite application was investigated, but no domestic measurement data could be found. Consequently, the IPCC default carbon conversion factors for carbonate containing lime (0.12 t C per t $Ca(CO_3)$) and for dolomite (0.13 t C per t $CaMg(CO_3)_2$) were used (IPCC 2006).

5.8.2.2 Activity data

The total annual amount of lime and dolomite applied to agricultural soils is between 50'300 Mg (1990) and 74'050 Mg (2008–2018). It was estimated by Agroscope in 2009 for the period 1990–2008. Major retailers / providers of lime in Switzerland were directly contacted and interviewed. For 2009–2018 the same value as for 2008 was used: An inquiry in 2013 including the most important production and trading companies of lime products suggests that the consumption of limestone remained constant in this period (Agroscope 2014a). This assumption is further supported by the fact that agricultural structures and management did not change fundamentally in recent years. Furthermore, the import of calciumcarbonate mixed with ammoniumnitrate (contributing 20% to lime use in Switzerland) is assessed yearly via the import statistics. These statistics do not show a significant trend along the past 20 years (FCA 2019a).

The split of lime into calcium carbonate and dolomite is based on the following assumptions and data:

- $Ca(CO_3)$ contained in mixed compound fertilisers as reported by Agricura (2018)
- All material originating from nuclear power plants and from the sugar beet industry is $Ca(CO_3)$
- The remaining lime not covered under the points above was divided equally into $Ca(CO_3)$ and $CaMg(CO_3)_2$.

5.8.3 Uncertainties and time-series consistency

The amount of total lime applied in agriculture is mainly based on expert judgement; the resulting number is uncertain. A relative uncertainty of ±40% was used as an approximation (Agroscope 2014a). For the emission factor of lime a lower uncertainty of ±5% was chosen, because it is a simple chemical process. The combined Approach 1 uncertainty is thus ±40.3%.

For further results also consult chp. 1.6.1.

Consistency: Time series for 3G Liming are all considered consistent.

5.8.4 Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

No further category-specific quality assurance activities were conducted.

5.8.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

No category-specific recalculations were carried out.

5.8.6 Category-specific planned improvements

No category-specific improvements are planned.

5.9 Source category 3H – Urea application

5.9.1 Source category description

CO_2 emission from 3H Urea application is not a key category.

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed during the industrial production process of the fertiliser. Emissions in Switzerland range from 8.7 to 26.7 kt CO_2 per year with a general decreasing trend from 1990 to 2018.

5.9.2 Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC (2006) default emission factors.

5.9.2.1 Emission factor

No country-specific emission factors are available. Consequently, the IPCC (2006) default emission factor of 0.20 t of C per t of urea was applied.

5.9.2.2 Activity data

The amount of urea applied to agricultural soils was obtained from Agricura (2018). Two positions of the customs tariff list were considered, namely “urea” (tariff number 3102.1000.011) and “urea-ammonia-nitrate” (tariff number 3102.8000.011). For urea-ammonia-nitrate it was assumed that half of the nitrogen is from urea. Fertiliser statistics are based on sales statistics by the compulsory stockpiler of fertilisers (Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import-data received by the Directorate General of Customs (Oberzolldirektion).

5.9.3 Uncertainties and time-series consistency

An uncertainty of ±5% for the activity data was estimated according to ART (2008a). An uncertainty of ±5% was assumed for the emission factor since it is a simple chemical process. The combined Approach 1 uncertainty is hence ±7.1%.

For further results also consult chp. 1.6.1.

Consistency: Time series for 3H Urea application are all considered consistent.

5.9.4 Category-specific QA/QC and verification

General QA/QC measures are described in NIR chp. 1.2.3.

No further category-specific quality assurance activities were conducted.

5.9.5 Category-specific recalculations

General information on recalculations is provided in chp. 10.

Emissions of CO_2 from 3H Urea application were recalculated for the years 2008–2017 due to the inclusion of urea from urea-ammonia-nitrate fertilisers (AD). The impact on overall emissions (including revised estimates in 3D and 3H) in kt CO_2 equivalents is negligible (<0.5).

5.9.6 Category-specific planned improvements

No category-specific improvements are planned.

6 Land use, land-use change and forestry (LULUCF)

Responsibilities for sector Land use, land-use change and forestry (LULUCF)	
Overall responsibility	Andreas Schellenberger (FOEN)
Lead author	Beat Rihm (Meteotest)
Authors and sector experts	Daniel Bretscher (Agroscope; Cropland, Grassland), Markus Didion (WSL; Forest Land, Yasso07 Modelling), Andreas Gubler (Agroscope; NABO Data), Sonja Keel (Agroscope; Cropland Soils, Grassland Soils), Nele Rogiers (FOEN; Forest Land), Andreas Schellenberger (FOEN; QA/QC, Cross-cutting Issues), Esther Thürig (WSL; Forest Land, National Forest Inventory), Chloé Wüst (Agroscope; Cropland Soils, Grassland Soils, Organic Soils)
Sector experts	Michael Bühler (SFSO; Land Use Statistics), Oliver Gardi (BFH-HAFL; Tree Biomass in non-Forest Land), Lena Gubler (WSL; Organic Soils), Armin Keller (Kompetenzzentrum Boden; Digital Soil Mapping, NABO Data), Christoph Könitzer (Sigmaplan; Activity Data), Jens Leifeld (Agroscope; non-Forest Land Soils), Martin Lindenmann (Sigmaplan; Activity Data), Lukas Mathys (Nategra; Activity Data, Tree Biomass in non-Forest Land), Stefan Müller (Meteotest; QA/QC LULUCF Database), Sonja Paul (Agroscope; Organic Soils), Felix Stumpf (Kompetenzzentrum Boden; Digital Soil Mapping)
EMIS database operation	Anouk-Aimée Bass (FOEN)
Technical contributor	Dominik Eggli (Meteotest)
Internal review	Daniel Bretscher (Agroscope), Markus Didion (WSL), Christoph Könitzer (Sigmaplan), Andreas Schellenberger (FOEN)

6.1 Overview of LULUCF

6.1.1 Methodology

Chapter 6 presents estimates of GHG emissions by sources and removals by sinks from land use, land-use change and forestry (LULUCF). The sector LULUCF includes emissions and removals from the carbon pool in Harvested wood products (HWP). Data acquisition and calculations are based on the Guidelines for National Greenhouse Gas Inventories (IPCC 2006), Volume 4 "Agriculture, Forestry and Other Land Use" (AFOLU). In many subcategories country-specific emission factors were used.

The land areas in the period 1990–2018 are represented by geographically explicit land use data with a resolution of one hectare (following approach 3 for representing land areas; IPCC 2006). Direct and repeated assessment of land use with full spatial coverage also enables to calculate spatially explicit land-use change matrices. In 2004, the Swiss Land Use Statistics AREA was launched. Simultaneously, aerial photos from two earlier Swiss Land Use Statistics (1979/85 and 1992/97) were re-evaluated, applying the same approach. The AREA surveys 1, 2 and 3 were completed in 2013 and the interpretation of the entire Swiss territory is available for three time slices. In this submission, results of the ongoing AREA4 survey for the southwestern and central mountain parts of Switzerland were included.

The six main land-use categories required by IPCC (2006) are: A. Forest land, B. Cropland, C. Grassland, D. Wetlands, E. Settlements and F. Other land. These categories were divided in 18 sub-divisions of land use. A further spatial stratification reflects ”elevation” (3 zones), ”geomorphologic and climatic conditions” (adopting the five production regions of the National Forest Inventory; NFI) and ”soil type” (mineral, organic).

Country-specific emission factors and carbon stocks for Forest land were derived from three National Forest Inventories (NFI1, NFI2, NFI3, finalized in 1985, 1995, and 2006, respectively) and five annual tranches of the continuous NFI4 (2013–2017). The inventories comprised ca. 3'350 (5-years interval from NFI4), 6'500 (NFI2 and NFI3) and 11'000 (NFI1) terrestrial plots (see Table 6-12), where biomass stock, growth, cut and mortality were measured.

For the remaining land-use categories, carbon stocks and GHG emissions and removals were derived from domestic surveys, particular research activities, measurements, and modelling approaches. Partially, IPCC default values and expert estimates were used.

6.1.2 Emissions and removals

Table 6-1 and Figure 6-1 summarize the CO_2 emissions and removals as a result of carbon losses and gains for the years 1990–2018. The total net emissions and removals of CO_2 varied between -6'252 kt (1996) and 5'798 kt (2000).

Table 6-1 and Figure 6-1 show a breakdown of Switzerland's CO_2 balance in the LULUCF sector. Five components were differentiated:

- Gains in carbon stock of living biomass on all land uses and due to land-use changes; this component represents the largest sink of carbon.
- Losses in carbon stock of living biomass on all land uses and due to land-use changes; this component represents the largest source of carbon. The highest losses were observed in the year 2000 after a heavy storm with windfall in December 1999.
- Net carbon stock changes in dead organic matter (DOM; consisting of dead wood and litter) on Forest land remaining forest land as well as land converted to or from Forest land. This component represents a sink of carbon in most years.
- Net carbon stock changes (1) in soils due to the use of mineral and organic soils and (2) in mineral and organic soils due to land-use changes. In the majority of years soils are net emitters of CO_2.
- Net carbon stock changes in Harvested wood products (HWP). With the exception of 2013 this component represents a sink of carbon, i.e. the overall carbon stock stored in wood products was increasing.

The largest part of gains and losses in carbon stocks of living biomass occurred in forests, where growth of biomass (gains) exceeded cut and mortality (losses), except for the years 2000, 2006, and 2007 (see also chp. 2.3.3). Overall, the LULUCF sector was a sink of on average -2'292 kt CO_2 yr^{-1} between 1990 and 2018 (see Table 6-1 .

Table 6-1 CO_2 emissions and removals in the LULUCF sector broken down for (1) CO_2 removals due to the gain (growth) of living biomass, (2) CO_2 emissions due to the loss (cut and mortality) of living biomass, (3) net CO_2 emissions and removals from dead organic matter, (4) net CO_2 emissions and removals from organic and mineral soils, and (5) net CO_2 emissions and removals from Harvested wood products. Positive values refer to emissions; negative values refer to removals. In this table, both CH_4 and N_2O emissions are not included.

LULUCF	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt CO_2									
Gains of living biomass	-12'808	-12'855	-12'744	-12'759	-12'821	-12'809	-12'700	-12'697	-12'809	-12'673
Losses of living biomass	12'000	9'223	8'961	8'754	9'236	9'313	9'135	9'920	10'993	10'704
Net change in dead organic matter	-330	-1'015	-298	-483	239	-555	-2'187	-1'222	-1'201	-820
Net change in organic and mineral soils	288	-531	-43	942	797	971	-199	241	425	-16
LULUCF (excluding HWP)	-850	-5178	-4123	-3545	-2550	-3080	-5950	-3758	-2592	-2806
Net change in Harvested wood products (HWP)	-1'169	-764	-556	-477	-359	-487	-302	-257	-309	-386
Total LULUCF	-2019	-5942	-4680	-4022	-2908	-3567	-6252	-4015	-2901	-3192

LULUCF	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt CO_2									
Gains of living biomass	-12'684	-12'678	-12'890	-12'691	-12'737	-12'778	-13'303	-13'257	-13'328	-13'539
Losses of living biomass	18'385	12'267	10'146	11'181	11'147	11'501	13'404	13'385	12'472	11'727
Net change in dead organic matter	-543	-748	-214	-1'195	-742	-1'140	-1'047	-452	-816	-958
Net change in organic and mineral soils	1'363	982	720	-346	-169	941	95	621	-20	240
LULUCF (excluding HWP)	6521	-178	-2238	-3052	-2500	-1476	-851	297	-1691	-2529
Net change in Harvested wood products (HWP)	-723	-427	-301	-359	-582	-728	-543	-366	-433	-423
Total LULUCF	5798	-605	-2539	-3411	-3082	-2204	-1394	-69	-2124	-2952

LULUCF	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
	kt CO_2									
Gains of living biomass	-13'380	-13'365	-13'528	-13'400	-13'478	-13'532	-13'598	-13'449	-13'522	-13'062
Losses of living biomass	12'339	12'332	11'291	11'670	12'095	11'071	10'865	11'599	12'575	11'369
Net change in dead organic matter	-1'485	-74	-535	-824	337	-420	-221	-529	-131	-676
Net change in organic and mineral soils	495	356	1'275	691	825	849	867	1'020	-218	464
LULUCF (excluding HWP)	-2031	-751	-1497	-1863	-221	-2032	-2087	-1359	-1296	-1'906
Net change in Harvested wood products (HWP)	-457	-356	-134	57	-116	-100	-57	-24	-78	-387
Total LULUCF	-2489	-1106	-1632	-1806	-337	-2132	-2144	-1383	-1375	-2'292

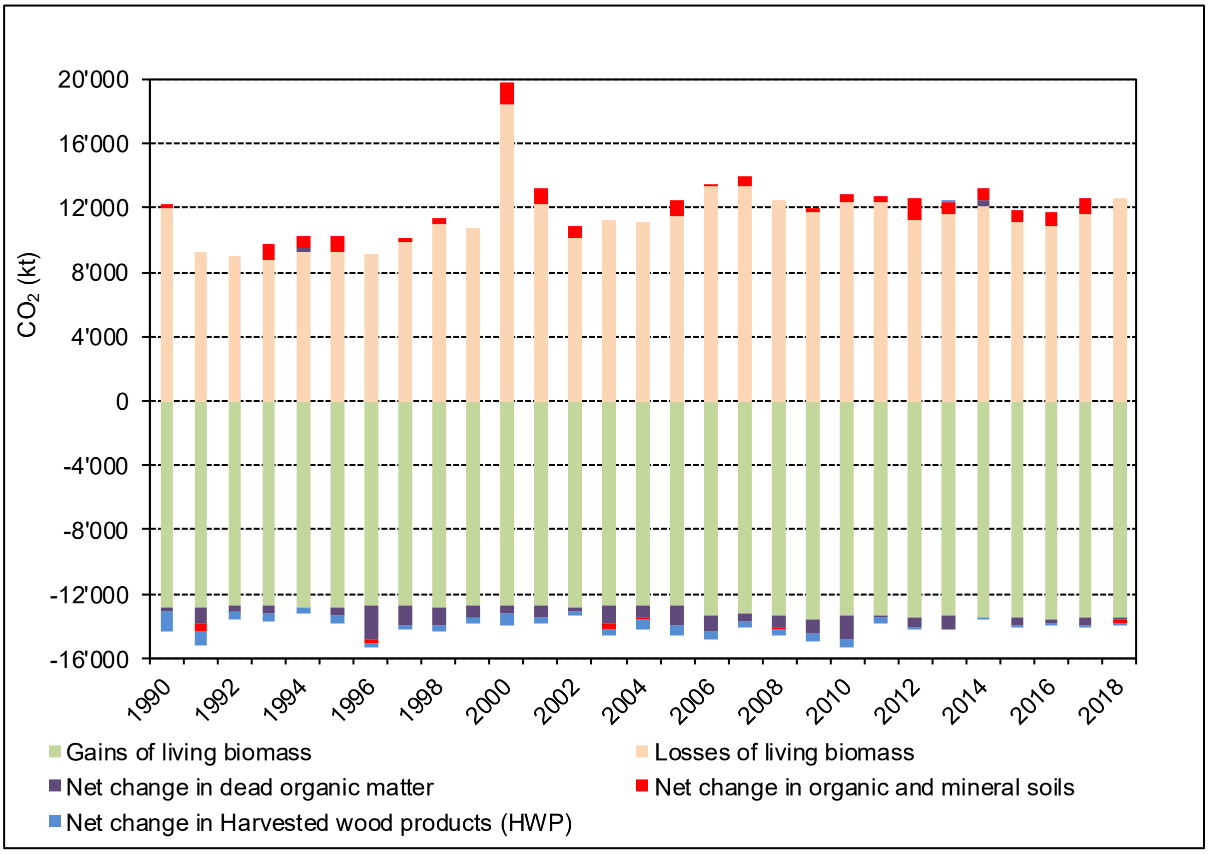


Figure 6-1 CO_2 emissions and removals in the LULUCF sector (in kt CO_2) broken down for (1) CO_2 removals due to the gain (growth) of living biomass, (2) CO_2 emissions due to the loss (cut and mortality) of living biomass, (3) net CO_2 emissions and removals from dead organic matter, (4) net CO_2 emissions and removals from organic and mineral soils, and (5) net CO_2 emissions and removals from Harvested wood products. Positive values refer to net emissions, negative values refer to net removals.

The non-CO_2 emissions associated with land use, land-use change and forestry were relatively small. Maximum annual CH_4 emissions were 1.53 kt yr^{-1} (38 kt CO_2 eq; 2018), and maximum annual N_2O emissions were 0.19 kt yr^{-1} (57 kt CO_2 eq; 1997) (Figure 6-2). The emissions arose from (1) drained organic soils (N_2O; CRF Table4(II)), (2) flooded lands/reservoirs (CH_4; CRF Table4(II)), (3) nitrogen mineralisation associated with loss of soil organic matter resulting from land use on non-agricultural soils and land-use change (direct N_2O emissions; CRF Table4(III)), (4) nitrogen leaching and run-off on non-agricultural soils and land-use change (indirect N_2O emissions; CRF Table4(IV)), (5) wildfires on Forest land and Grassland (CH_4 and N_2O; CRF Table4(V)), and (6) controlled burning of residues from forestry (CH_4 and N_2O; CRF Table4(V)).

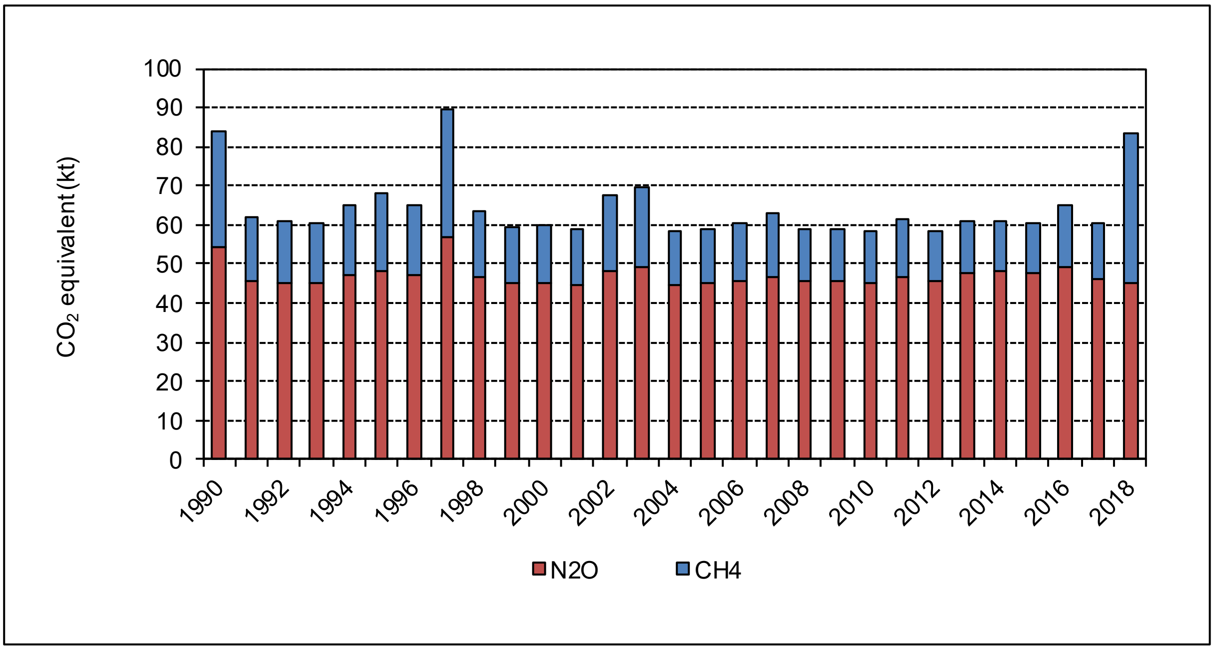


Figure 6-2 N_2O and CH_4 emissions in the LULUCF sector (in kt CO_2 eq).

Figure 6-3 shows the resulting net GHG (CO_2, CH_4, N_2O) emissions and removals in the LULUCF sector 1990–2018 broken down for subcategories 4A-4G. GHG fluxes were dominated by biomass dynamics in forests (4A). Further explanatory notes on LULUCF data can be found in chp. 2.3.3 “Emission trends in sector 4 LULUCF”.

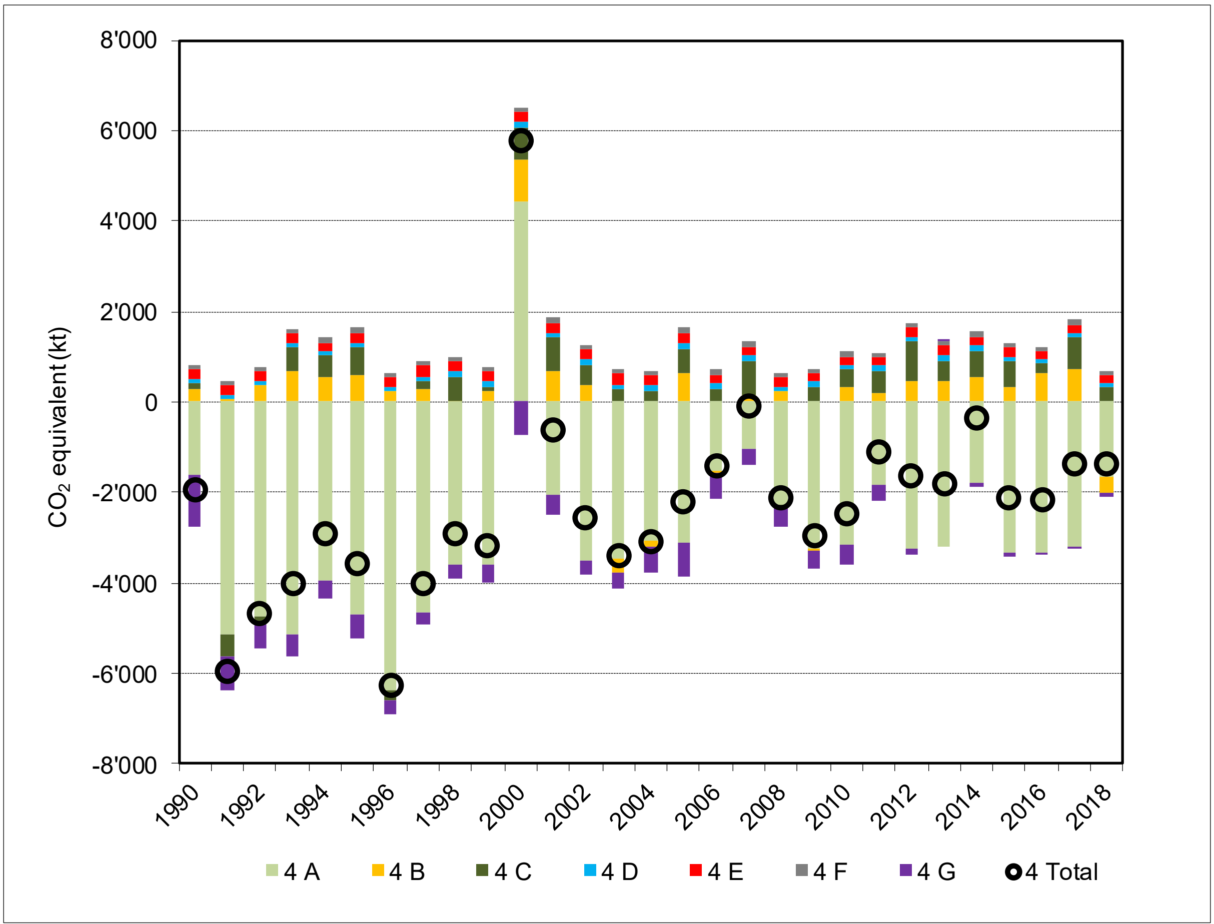


Figure 6-3 Net GHG (CO_2, CH_4, N_2O) emissions and removals in the LULUCF sector (in kt CO_2 eq) broken down for subcategories 4A-4G. "Total" indicates the resulting annual net emissions (positive values) or net removals (negative values), respectively. Figure 2-8 shows a simplified representation of the dataset.

6.1.3 Approach for calculating carbon emissions and removals

6.1.3.1 Work steps

The selected procedure for calculating carbon emissions and removals in the LULUCF sector corresponds to a Tier 2 approach as described in IPCC 2006 (Volume 4, chp. 3). It can be summarised as follows:

- Define managed and unmanaged land: In Switzerland, all land besides Other land is considered to be managed. Other land (CC61, see Table 6-2) is unmanaged. It is defined as the residual country's land area without relevant human activity.
- Define land-use categories and sub-divisions with respect to available land use data (see Table 6-2). Combination categories (CC) were defined on the basis of the AREA land-use and land-cover categories (Table 6-6; SFSO 2006a).
- Define criteria and collect data for the spatial stratification of the land-use categories.
- For Forest land: Measure, model or estimate the carbon stocks in living biomass (stockC$_l$), in dead wood (stockC$_d$), in litter (stockC$_h$), and in soil (stockC$_s$) for each spatial stratum of the combination categories (CC).
  For non-Forest land: Measure, model or estimate the carbon stocks in living biomass

(stockC_l), in dead organic matter (stockC_{dom}), and in soil (stockC_s) for each spatial stratum of the combination categories (CC).

- For Forest land: Measure, model or estimate the gain of carbon in living biomass (gainC_l), the loss of carbon in living biomass (lossC_l), the net carbon stock change in dead wood (changeC_d), in litter (changeC_h), and in soil (changeC_s) for each spatial stratum of the combination categories (CC).
  For non-Forest land: Measure, model or estimate the gain of carbon in living biomass (gainC_l), the loss of carbon in living biomass (lossC_l), the net carbon stock change in dead organic matter (changeC_{dom}), and in soil (changeC_s) for each spatial stratum of the combination categories (CC).
- Calculate the land use and the land-use change matrix for each spatial stratum.
- For Forest land: Calculate the net carbon stock changes in living biomass (deltaC_l), in dead wood (deltaC_d), in litter (deltaC_h), and in soil (deltaC_s) for all cells of the land-use change matrix for each year under consideration.
  For non-Forest land: Calculate the net carbon stock changes in living biomass (deltaC_l), in dead organic matter (deltaC_{dom}), and in soil (deltaC_s) for all cells of the land-use change matrix for each year under consideration.
- Finally, aggregate the results by summarising the carbon stock changes over combination categories and spatial strata according to the level of disaggregation displayed in the reporting tables.
- Calculate emissions and removals of the carbon pool in Harvested wood products (HWP).

The combination category CC11 (see Table 6-2) refers to a conversion from land to forest land that corresponds to the Swiss definition for afforestation activities under Article 3, paragraph 3, of the Kyoto Protocol as defined in the Initial Report for the first commitment period (FOEN 2006h). For the reporting under the UNFCCC, afforested areas were allocated to category 4A2 (Land converted to forest land), where they were reported in an individual subdivision afforestation (no capitalisation, first letter in lowercase; see chp. 6.4.1). The identical afforested areas were reported as Afforestations (with capitalisation, first letter in uppercase) under the Kyoto-Protocol (see chp. 11.1.3). In a nutshell, the diction Afforestation was consistently used to indicate the Kyoto Protocol Article 3, paragraph 3 activity.

Table 6-2 Land-use categories used in this report (combination categories CC): 6 main land-use categories (identical to the UNFCCC land-use categories) and 18 sub-divisions. Additionally, descriptive remarks, abbreviations used in the reporting tables, and CC codes are given. For a detailed definition of the combination categories see Table 6-6 and SFSO (2006a).

CC Main category	**CC Sub-division**	**Remarks**	**Terminology in CRF tables**	**CC code**
A. Forest Land	afforestation	areas converted to forest by active measures, e.g. planting	afforestation	11
	productive forest	dense and open forest meeting the criteria of forest land	4A1: CC12 4A2: productive	12
	unproductive forest	brush forest and forest on unproductive areas meeting the criteria of forest land	4A1: CC13 4A2: unproductive	13
B. Cropland		arable and tillage land (annual crops and leys in arable rotations)	CC21	21
C. Grassland	permanent grassland	meadows, pastures (low-land and alpine)	4C1: CC31 4C2: permanent	31
	shrub vegetation	agricultural and unproductive areas predominantly covered by shrubs	4C1: CC32 4C2: woody	32
	vineyard, low-stem orchard, tree nursery	perennial agricultural plants with woody biomass	4C1: CC33 4C2: woody	33
	copse	agricultural and unproductive areas covered by perennial woody biomass including trees	4C1: CC34 4C2: woody	34
	orchard	permanent grassland with fruit trees	4C1: CC35 4C2: woody	35
	stony grassland	grass, herbs and shrubs on stony surfaces	4C1: CC36 4C2: unproductive	36
	unproductive grassland	unproductive grass vegetation	4C1: CC37 4C2: unproductive	37
D. Wetlands	surface water	lakes and rivers	surface water	41
	unproductive wetland	reed, extensively managed wetland	unprod wetland	42
E. Settlements	buildings and constructions	areas without vegetation such as houses, roads, construction sites, dumps	building	51
	herbaceous biomass in settlements	areas with low vegetation, e.g. lawns	herb	52
	shrubs in settlements	areas with perennial woody biomass (no trees)	shrub	53
	trees in settlements	areas with perennial woody biomass including trees	tree	54
F. Other Land		unmanaged areas without soil and vegetation: rocks, sand, scree, glaciers		61

6.1.3.2 Calculating carbon stock changes

For calculating carbon stock changes, the following input parameters (mean values per hectare) were quantified for all combination categories (CC) and spatial strata (i):

$stockC_{l,i,CC}$ carbon stock in living biomass (t C ha^{-1})

$stockC_{d,i,CC}$ carbon stock in dead wood (t C ha^{-1})

$stockC_{h,i,CC}$ carbon stock litter (organic soil horizons) (t C ha^{-1})

$stockC_{s,i,CC}$ carbon stock in soil (t C ha^{-1})

$gainC_{l,i,CC}$ annual gain (gross growth) of carbon in living biomass (t C ha^{-1} yr^{-1})

$lossC_{l,i,CC}$ annual loss (cut and mortality) of carbon in living biomass (t C ha^{-1} yr^{-1})

$changeC_{d,i,CC}$ annual net carbon stock change in dead wood (t C ha^{-1} yr^{-1})

$changeC_{h,,i,CC}$ annual net carbon stock change in litter (t C ha^{-1} yr^{-1})

$changeC_{s,i,CC}$ annual net carbon stock change in soil (t C ha^{-1} yr^{-1})

In the reporting tables on non-forest land under the UNFCCC (Table4.B to Table4.F), the carbon stocks and carbon stock changes of litter and dead wood are merged into "dead organic matter" (DOM):

$stockC_{dom,i,CC} = stockC_{d,i,CC} + stockC_{h,i,CC}$

$changeC_{dom,i,CC} = changeC_{d,i,CC} + changeC_{h,i,CC}$

On this basis, the total changes in carbon stocks (t C yr^{-1}) in living biomass ($deltaC_l$), in dead wood ($deltaC_d$), in litter ($deltaC_h$), and in soils ($deltaC_s$) were calculated for all cells of the land-use change matrix for each year under consideration. Each cell is characterized by a land-use category before the conversion (b), a land-use category after the conversion (a), and the area of converted land within the spatial stratum (i). This approach includes cases without any land-use change (a = b).

Equations 6.1–6.8 show, according to the AFOLU guidelines (IPCC 2006, Volume 4), two approaches and their application for calculating carbon gains and losses: (1) the gain-loss approach (Equation 2.4; IPCC 2006, Volume 4) and (2) the stock-difference approach (Equation 2.5; IPCC 2006, Volume 4).

The gain-loss approach for calculating (net) carbon stock changes is defined as:

$$deltaC_{l,i,ba} = (gainC_{l,i,a} - lossC_{l,i,a}) * A_{i,ba} \quad (6.1)$$

$$deltaC_{d,i,ba} = changeC_{d,i,a} * A_{i,ba} \quad (6.2)$$

$$deltaC_{h,i,ba} = changeC_{h,i,a} * A_{i,ba} \quad (6.3)$$

$$deltaC_{s,i,ba} = changeC_{s,i,a} * A_{i,ba} \quad (6.4)$$

The stock-difference approach for calculating carbon stock changes is defined as:

$$deltaC_{l,i,ba} = [(stockC_{l,i,a} – stockC_{l,i,b}) / CT] * A_{i,ba} \quad (6.5)$$

$$deltaC_{d,i,ba} = [(stockC_{d,i,a} – stockC_{d,i,b}) / CT] * A_{i,ba} \quad (6.6)$$

$$deltaC_{h,i,ba} = [(stockC_{h,i,a} – stockC_{h,i,b}) / CT] * A_{i,ba} \quad (6.7)$$

$$deltaC_{s,i,ba} = [(stockC_{s,i,a} – stockC_{s,i,b}) / CT] * A_{i,ba} \quad (6.8)$$

where:

a	land-use category after conversion (CC = a)
b	land-use category before conversion (CC = b)
ba	land-use conversion from b to a
i	spatial stratum
$A_{i,ba}$	area of land (ha) converted from b to a in the spatial stratum i (area converted in the inventory year if CT=1 year, or the sum of the areas converted within the last 20 years if CT=20 years)
CT	conversion time (yr), see chp. 6.1.3.3.

Table 6-3 pinpoints which approach was used for calculating the carbon stock changes for the various types of land-use conversion and carbon pools (living biomass, dead wood / litter, mineral soil and organic soil).

The gain-loss approach was used in cases of no land-use change and generally for continuous transitions, e.g. the growth of living biomass on land converted to forest land. The stock-difference approach was used for abrupt changes following discrete events (e.g. loss of biomass by deforestation, CT = 1 year) as well as for slow processes such as the change in soil carbon content (CT = 20 years, see chp. 6.1.3.3).

For the conversions between different forest combination categories the approach was chosen in such a way that potential carbon losses of living biomass cannot be underestimated: e.g. for CC12 to CC13 stock-difference is used, and for CC13 to CC12 gain-loss is used, respectively (see Table 6-3).

In case of land-use changes to "Buildings and constructions" (CC51) a loss of 20% of the initial soil carbon stock was reported (for a detailed documentation see chp. 6.8.2.3). In case of land-use changes from CC51 to other categories the regular stock-difference approach according to equation 6.8 and Table 6-3, respectively, were applied.

Table 6-3 Calculation approach (gain-loss or stock-difference with conversion time in years) applied for different land-use changes and carbon pools. KP = corresponding activity under the Kyoto Protocol; NF = non-forest combination categories. Combination categories CC11 to CC61 were introduced in Table 6-2 .

Change in main land-use category or sub-division	**Living biomass**	**Dead wood, litter**	**Mineral soil**	**Organic soil**	**Remarks**
no change in category KP and UNFCCC	gain-loss	gain-loss	gain-loss	gain-loss	
CC13 to CC12 UNFCCC: 4A1 KP: Forest management	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	
CC12 to CC13 UNFCCC: 4A1 KP: Forest management	stock-diff., 20	stock-diff., 20	stock-diff., 20	gain-loss	
CC11 to CC12 UNFCCC: 4A1 KP: Afforestation >20 yr	gain-loss	gain-loss	gain-loss	gain-loss	
change to CC11 UNFCCC: 4A2 KP: Afforestation ≤20 yr	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	Dead organic matter is 0 in CC11 and in NF; direct human-induced
NF to CC12/CC13 UNFCCC: 4A2 KP: Forest management	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	
change to CC51 UNFCCC: 4E2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20 (20%)	stock-diff., 20 (20%)	Soil carbon stock reduced by 20% (buildings and constructions; sealed areas)
change to CC52-54 UNFCCC: 4E2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Unsealed settlement areas
change to CC21 UNFCCC: 4B2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Cropland
change to CC31-37 UNFCCC: 4C2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Grassland
change to CC41 UNFCCC: 4D2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	Surface water
change to CC42 UNFCCC: 4D2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	Unproductive wetland
change to CC61 UNFCCC: 4F2 KP: Deforestation	stock-diff., 1	stock-diff., 1	stock-diff., 20	stock-diff., 20	Other land

6.1.3.3 Conversion time (CT) in the stock-difference approach

Table 6-3 shows the conversion times applied in the stock-difference approach to carbon stock changes in living biomass, in dead organic matter (dead wood, litter), and in soils for different land-use changes.

Changes in the soil carbon stock, and this is also true for the increase of woody biomass, as a result of land-use changes are slow processes that might take decades. Therefore, IPCC (2006, Volume 4, chp. 2) suggests implementing a conversion time (CT). Following the IPCC default value (CT = 20 years), carbon emissions or removals due to a soil carbon stock difference ($stockC_{s,i,a}$ – $stockC_{s,i,b}$) do not occur in one year but are distributed evenly over the 20 years following the land-use conversion.

A conversion time of 20 years was applied to all mineral soil carbon stock changes (except for land converted to surface water). Accordingly, the area of mineral soil of each category 2 in reporting tables Table4.A to Table4.F contains the cumulative area remaining in the respective category in the reporting year.

The combination category afforestations (CC11) is a transitional category by definition in the land-use survey. Areas converted to afforestations are reported in category 2 in CRF Table4.A with the same conversion time as for other forest subcategories (20 years). However, after 20 years afforestations remaining afforestations (according to the land-use survey) are reported in category 1 of CRF Table4.A and are merged with productive forests (CC12). Under the Kyoto Protocol Afforestations are processed differently (see chp. 11.2.3).

There are no consistent data sources on land-use changes before 1990, but it is well known, that the main trends of the Swiss land-use dynamics, e.g. increase of forest area (chapter 1 in FOEN 2020f) and settlements (ARE/FOEN 2007) did arise before 1972. Therefore, it was assumed that between 1971 and 1989 the annual rate of all land-use changes was the same as in 1990. Based on this assumption it was possible to produce the land-use data required for the consideration of the conversion time in that period and to consider it in the years 1990 to 2009 in accordance with the 20 years conversion period.

6.1.3.4 Displaying results in the Common Reporting Format (CRF)

In the reporting tables Table4.A to Table4.F, a part of the combination categories (CC) and associated spatial strata are shown at an aggregated level for optimal documentation and overview. The values of deltaC are accordingly summarised. Positive values of $deltaC_{l,i,ba}$ were inserted in the column “Gains” and negative values in the column “Losses”, respectively. The values of $deltaC_{d,i,ba}$, $deltaC_{h,i,ba}$ were inserted into columns “Net carbon stock change in dead wood” and “Net carbon stock change in litter” in CRF Table4.A, and the values of $deltaC_{dom,i,ba}$ were inserted into columns “Net carbon stock change in dead organic matter” in the reporting tables Table4.B to Table4.F. The values of $deltaC_{s,i,ba}$ were inserted into columns "Net carbon stock change in soils" in the reporting tables Table4.A to Table4.F.

The reporting tables Table4.B to Table4.F are subdivided in two parts: (1) X land remaining X land and (2) Land converted to X land. Changes of areas from one combination category to another within the same main land-use category are reported in part (1) of the reporting tables. For example, the area of ”shrub vegetation” (CC32) converted to ”permanent grassland” (CC31) would be reported in CRF Table4.C under 4C1 in the sub-division “permanent”. As CC31 and CC32 do have different carbon stocks in biomass and soils, carbon stock changes would be calculated according to the equations presented in chp. 6.1.3.2.

The CRF reporter generated errors or inconsistent content in several reporting tables related to the LULUCF sector (see Annex 6).

6.1.4 Carbon stocks and stock changes at a glance

Table 6-4 lists carbon stocks, gains, losses and net changes of carbon for the pools living biomass, dead wood, litter and soil stratified by combination category (CC) and spatial strata for the year 1990. The values remain constant during the inventory period 1990–2018 with the following exceptions (highlighted cells):

- Productive forest (CC12): (1) Carbon stock in living biomass, gain and loss of living biomass, (2) carbon stock and net change in dead wood, (3) carbon stock and net change in litter, and (4) net change in mineral soil. Derivation of data and annual values are described in chp. 6.4.2.5, chp. 6.4.2.6 and chp. 6.4.2.7.
- Cropland (CC21): (1) Carbon stock in living biomass, gain and loss of living biomass, (2) carbon stock and net change in mineral soil. Derivation of data and annual values are described in chp. 6.5.2.
- Permanent grassland (CC31): (1) Carbon stock in living biomass, gain and loss of living biomass, (2) carbon stock and net change in mineral soil. Derivation of data and annual values are described in chp. 6.6.2.

The derivation of the individual carbon stocks, gains, losses, and net changes is explained in detail in chapters 6.4 to 6.9. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stocks.

Table 6-4 Carbon stocks and carbon stock changes in living biomass, in dead wood, in litter and in mineral and organic soils for the combination categories (CC), stratified by elevation zone, NFI production region, and soil type. The values are valid for the whole inventory period since 1990 with the exception of the values in the highlighted cells, which change annually (numbers given here are for the year 1990); cf. main text.

Combination category (CC)	NFI region	Elevation zone z	Carbon stock in living biomass (stockCl,i)	Carbon stock in dead wood (stockCd,i)	Carbon stock in litter (stockCh,i)	Carbon stock in mineral soil (stockCs,i)	Carbon stock in organic soil (stockCs,i)	Gain of living biomass (gainCl,i)	Loss of living biomass (lossCl,i)	Net change in dead wood (changeCd,i)	Net change in litter (changeCh,i)	Net change in mineral soil (changeCs,i)	Net change in (drained) organic soil (changeCs,i)
	Strata		[t C ha^{-1}]					[t C ha^{-1} yr^{-1}]					
11 Afforestations	1	1	10.00	0	0	82.65	145.6	2.39	-0.21	0	0	0	-2.6
	1	2	10.00	0	0	102.03	145.6	2.39	-0.21	0	0	0	-2.6
	1	3	7.50	0	0	121.34	145.6	1.35	-0.1	0	0	0	-2.6
	2	1	10.00	0	0	55.40	145.6	2.39	-0.21	0	0	0	-2.6
	2	2	10.00	0	0	62.12	145.6	2.39	-0.21	0	0	0	-2.6
	2	3	7.50	0	0	122.00	145.6	1.35	-0.1	0	0	0	-2.6
	3	1	10.00	0	0	66.10	145.6	2.39	-0.21	0	0	0	-2.6
	3	2	10.00	0	0	75.91	145.6	2.39	-0.21	0	0	0	-2.6
	3	3	7.50	0	0	95.78	145.6	1.35	-0.1	0	0	0	-2.6
	4	1	10.00	0	0	66.47	145.6	2.39	-0.21	0	0	0	-2.6
	4	2	10.00	0	0	74.39	145.6	2.39	-0.21	0	0	0	-2.6
	4	3	7.50	0	0	69.48	145.6	1.35	-0.1	0	0	0	-2.6
	5	1	10.00	0	0	102.37	145.6	2.39	-0.21	0	0	0	-2.6
	5	2	10.00	0	0	108.99	145.6	2.39	-0.21	0	0	0	-2.6
	5	3	7.50	0	0	107.08	145.6	1.35	-0.1	0	0	0	-2.6
12 Productive forest	1	1	128.65	4.86	12.02	82.65	145.6	3.60	-2.38	0.02	-0.11	0.00	-2.6
	1	2	125.27	5.24	12.13	102.03	145.6	3.21	-2.28	0.03	-0.06	0.00	-2.6
	1	3	84.74	4.54	10.12	121.34	145.6	1.95	-1.36	-0.03	-0.16	0.00	-2.6
	2	1	134.51	8.10	12.38	55.40	145.6	4.63	-4.77	0.03	-0.13	0.00	-2.6
	2	2	147.20	7.79	13.25	62.12	145.6	4.63	-4.61	0.03	-0.09	0.00	-2.6
	2	3	102.11	7.79	13.25	122.00	145.6	1.60	-1.05	0.03	-0.09	0.00	-2.6
	3	1	135.07	7.61	14.30	66.10	145.6	4.56	-3.35	0.09	-0.01	0.00	-2.6
	3	2	147.49	7.61	14.30	75.91	145.6	4.15	-3.78	0.09	-0.01	0.00	-2.6
	3	3	118.79	6.00	13.71	95.78	145.6	2.48	-2.75	0.02	-0.03	0.00	-2.6
	4	1	92.97	5.67	11.94	66.47	145.6	3.24	-3.19	0.09	0.01	0.00	-2.6
	4	2	103.37	5.67	11.94	74.39	145.6	2.49	-2.59	0.09	0.01	0.00	-2.6
	4	3	94.98	5.14	14.75	69.48	145.6	1.81	-2.47	0.11	0.11	0.00	-2.6
	5	1	72.68	2.22	8.36	102.37	145.6	2.74	-0.92	0.07	0.02	0.00	-2.6
	5	2	76.85	2.08	9.88	108.99	145.6	2.20	-0.61	0.07	0.14	0.00	-2.6
	5	3	76.43	1.76	11.07	107.08	145.6	1.61	-0.30	0.02	0.15	0.00	-2.6
13 Unproductive forest	1	1	38.53	0	12.28	82.65	145.6	0	0	0	0	0	-2.6
	1	2	51.10	0	12.69	102.03	145.6	0	0	0	0	0	-2.6
	1	3	51.34	0	10.29	121.34	145.6	0	0	0	0	0	-2.6
	2	1	20.45	0	12.18	55.40	145.6	0	0	0	0	0	-2.6
	2	2	35.83	0	13.16	62.12	145.6	0	0	0	0	0	-2.6
	2	3	51.33	0	13.16	122.00	145.6	0	0	0	0	0	-2.6
	3	1	20.45	0	14.92	66.10	145.6	0	0	0	0	0	-2.6
	3	2	47.53	0	14.92	75.91	145.6	0	0	0	0	0	-2.6
	3	3	42.36	0	12.89	95.78	145.6	0	0	0	0	0	-2.6
	4	1	21.60	0	12.57	66.47	145.6	0	0	0	0	0	-2.6
	4	2	31.48	0	12.57	74.39	145.6	0	0	0	0	0	-2.6
	4	3	29.88	0	15.64	69.48	145.6	0	0	0	0	0	-2.6
	5	1	20.83	0	9.15	102.37	145.6	0	0	0	0	0	-2.6
	5	2	23.82	0	11.72	108.99	145.6	0	0	0	0	0	-2.6
	5	3	24.35	0	12.39	107.08	145.6	0	0	0	0	0	-2.6

(Table 6-4 continued)

Combination category (CC)	NFI region	Elevation zone z	Carbon stock in living biomass (stockCl,i)	Carbon stock in dead wood (stockCd,i)	Carbon stock in litter (stockCh,i)	Carbon stock in mineral soil (stockCs,i)	Carbon stock in organic soil (stockCs,i)	Gain of living biomass (gainCl,i)	Loss of living biomass (lossCl,i)	Net change in dead wood (changeCd,i)	Net change in litter (changeCh,i)	Net change in mineral soil (changeCs,i)	Net change in (drained) organic soil (changeCs,i)
	Strata		[t C ha^{-1}]					[t C ha^{-1} yr^{-1}]					
21 Cropland	n.s.	1	6.44	0	0	50.21	240	0.07	0.00	0	0	0.07	-9.52
	n.s.	2	6.46	0	0	50.14	240	0.06	0.00	0	0	-0.01	-9.52
	n.s.	3	6.07	0	0	42.35	240	0.09	0.00	0	0	0.16	-9.52
31 Permanent Grassland	n.s.	1	5.88	0	0	60.44	240	0.00	-0.02	0	0	-0.02	-9.52
	n.s.	2	5.38	0	0	65.26	240	0.00	-0.01	0	0	-0.13	-9.52
	n.s.	3	3.31	0	0	62.60	240	0.00	0.00	0	0	0.15	-9.52
32 Shrub Vegetation	n.s.	1	20.45	0	0	58.74	240	0	0	0	0	0	-5.3
	n.s.	2	20.45	0	0	63.99	240	0	0	0	0	0	-5.3
	n.s.	3	20.45	0	0	63.91	240	0	0	0	0	0	-5.3
33 Vineyards et al.	n.s.	n.s.	5.57	0	0	50.58	240	0	0	0	0	0	-9.52
34 Copse	n.s.	1	20.45	0	0	58.74	240	0	0	0	0	0	-5.3
	n.s.	2	20.45	0	0	63.99	240	0	0	0	0	0	-5.3
	n.s.	3	20.45	0	0	63.91	240	0	0	0	0	0	-5.3
35 Orchards	n.s.	n.s.	23.34	0	0	59.79	240	0	0	0	0	0	-9.52
36 Stony Grassland	n.s.	n.s.	7.16	0	0	22.36	240	0	0	0	0	0	-5.3
37 Unproductive Grassland	n.s.	n.s.	3.45	0	0	63.69	240	0	0	0	0	0	-5.3
41 Surface Waters	n.s.	n.s.	0	0	0	0	240	0	0	0	0	0	0
42 Unproductive Wetland	n.s.	n.s.	6.50	0	0	62.86	240	0	0	0	0	0	-5.3
51 Buildings, Constructions	n.s.	n.s.	0	0	0	0	0	0	0	0	0	0	0
52 Herbaceous Biomass in S.	n.s.	n.s.	9.54	0	0	50.58	240	0	0	0	0	0	-9.52
53 Shrubs in Settlements	n.s.	n.s.	15.43	0	0	50.58	240	0	0	0	0	0	-5.3
54 Trees in Settlements	n.s.	n.s.	20.72	0	0	50.58	240	0	0	0	0	0	-5.3
61 Other Land	n.s.	n.s.	0	0	0	0	0	0	0	0	0	0	0

Legend

Elevation zones:
1 < 601 m
2 601 - 1200 m
3 > 1200 m

NFI regions:
1 Jura
2 Central Plateau
3 Pre-Alps
4 Alps
5 Southern Alps

n.s. = no stratification
Annual data

6.1.5 Uncertainty estimates

Table 6-5 gives an overview of uncertainty estimates of activity data (AD) and of emission factors (EF). The term emission factor is not quite appropriate for categories 4A-4G as the basic processes are carbon stock changes (CSC) causing either net emissions or net removals of CO_2.

For categories 4A-4F, the uncertainties of AD mainly depend on the uncertainty of the AREA survey data (highlighted in yellow; see chp. 6.3.3, Table 6-10). For categories 4D1, 4(II)–4(V), and 4G other data sources are relevant, e.g. for 4D1 the uncertainty of the area of organic soils. They are presented in detail in the respective chapters (6.X.3), along with the uncertainty estimates for EF.

In general, AD uncertainty is lower than EF uncertainty, because AD are mostly based on a systematic survey with high spatial resolution (such as AREA), while EFs include parameters that are difficult to measure or to model such as carbon stocks in biomass, growth rates and biogeochemical processes.

Table 6-5 Uncertainty estimates in the LULUCF sector, expressed as half of the 95% confidence intervals. Highlighted activity data (AD) uncertainties depend mainly on the uncertainty of the AREA survey. EF = emission factor, CSC = carbon stock change.

IPCC category		Gas	AD uncertainty	EF/CSC uncertainty 1990	EF/CSC uncertainty 2018
			%	%	
4A1	Forest land remaining forest land	CO_2	1.1	46.7	46.7
4A2	Land converted to forest land	CO_2	1.5	46.7	46.7
4B1	Cropland remaining cropland	CO_2	4.9	231.7	133.1
4B2	Land converted to cropland	CO_2	5.1	89.0	144.0
4C1	Grassland remaining grassland	CO_2	5.2	2879.7	1224.7
4C2	Land converted to grassland	CO_2	5.3	55.4	43.5
4D1	Wetlands remaining wetlands	CO_2	90.8	72.2	72.2
4D2	Land converted to wetlands	CO_2	3.9	23.8	20.6
4E1	Settlements remaining settlements	CO_2	4.4	50.0	50.0
4E2	Land converted to settlements	CO_2	4.6	50.0	50.0
4F1	Other land remaining other land	CO_2	NA	NA	NA
4F2	Land converted to other land	CO_2	3.3	50.0	50.0
4(II)	Drained organic soils	N_2O	48.8	66.9	66.9
4(II)D2	Flooded land	CH_4	10.0	70.0	70.0
4(III)	N mineralization	N_2O	83.5	135.0	135.0
4(IV)2	N leaching and runoff	N_2O	85.8	161.5	161.5
4(V)	Biomass burning	CH_4	30.0	70.0	70.0
4(V)	Biomass burning	CO_2	NA	NA	NA
4(V)	Biomass burning	N_2O	30.0	70.0	70.0
4G	Harvested wood products	CO_2	11.2	54.8	54.8

6.2 Land-use definitions and classification systems

6.2.1 Combination Categories (CC) as derived from AREA Land Use Statistics

The nomenclature of the Swiss Land Use Statistics (AREA) processed by the Swiss Federal Statistical Office (SFSO 2006a) is the basis for the land-use categories used for land area representation in the LULUCF sector. In the course of the AREA surveys (see chp. 6.3.1), every sample point on a hectare-mesh in Switzerland was assigned to a land-use category (NOLU04) and to a land-cover category (NOLC04) (SFSO nomenclature version 2004). The interpretation is backed by a large set of geodata (e.g. forest boundary layer from the NFI; for just a public subset of geodata available to the SFSO interpreters see https://map.geo.admin.ch; English version available) that can be superimposed if required. These geodata also include data sets indicating the legal status of land use (e.g. residential zones, crop rotation areas, nature reserves). Ambiguous sample points are visited by the AREA staff to verify the on-screen classification of land use (ground control).

The AREA survey is a highly sophisticated and well-established land use statistic (see the links to visualization examples in chp 6.3.1). It allows for the identification of country-specific categories that are more detailed than those defined in IPCC (2006) (see Table 6-2). Thus, the 46 NOLU04 categories and 27 NOLC04 categories of AREA were aggregated to 18 combination categories (CC) following the assignment shown in Table 6-6 (The first digit of the CC code represents the IPCC main land-use category, whereas the second digit stands for the respective sub-division). This approach enables more precise estimates of carbon stocks and carbon stock changes in the LULUCF sector than on the basis of the IPCC main categories alone because each CC can be fed with individual carbon data and distinctive carbon dynamics can be assumed (see below).

The CCs were defined in 2006 in an evaluation process involving experts from the FOEN, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Swiss Federal Statistical Office and Agroscope as well as private consultants. The evaluation process resulted in the elaboration of Table 6-6.

With regard to carbon content in living biomass, there is a strong relation to the vegetation type (i.e. to land cover in most cases). This is exemplarily reflected by the mainly horizontal arrangement of the individual CCs in Table 6-6. With regard to carbon changes in living biomass, dead organic matter, and in soils the CC definition was driven by the consideration that frequently individual vegetation units – like e.g. orchards – are subject to a similar management all over Switzerland leading to comparable carbon fluxes in biomass, dead organic matter, and in soils.

For individual CCs (especially for Forest land, i.e. CC11, CC12, CC13) further spatial stratifications were introduced (cf. chp. 6.2.2) with the intent to approximate the real/natural differences in carbon stock, carbon stock changes and soil conditions as good as possible.

The underlying criteria to include land use sub-divisions such as shrub vegetation, vineyards, low-stem orchards, tree nurseries, copse and orchards under Grassland with woody biomass are: (1) They do not fulfil the criteria for forests; (2) There is an agricultural management in general; (3) They all have woody biomass (i.e. perennial vegetation) with grass understory. Under Cropland, in contrast, there are no perennial crops, but annual crops and leys in arable rotations. All perennial crops are included in the Grassland sub-divisions.

All sub-divisions of Forest land, Grassland and Wetlands are defined as managed and reported under managed land in CRF Table4.1. Cropland and Settlements are regarded to be managed by default. Other land is regarded to be unmanaged by default. In a nutshell, the entire land area of Switzerland – except for 4F Other land – is reported to be managed.

Table 6-6 Derivation of 18 combination categories (CC) from AREA NOLU04 and NOLC04 categories.

Land Use (NOLU04) acc. to AREA

Settlement and urban areas

18 Combination Categories (CC)	Building areas								Transport surfaces					Special urban areas							Recreational areas and cemeteries					
Land Cover (NOLC04) acc. to AREA	101 Industrial and commercial areas > 1 ha	102 Industrial and commercial areas < 1 ha	103 Residential areas (one and two-family house	104 Residential areas (terraced houses)	105 Residential areas (blocks of flats)	106 Public buildings and surroundings	107 Agricultural buildings and surroundings	108 Unspecified buildings and surroundings	121 Motorways	122 Roads	123 Parking areas	124 Railway surface	125 Airports and airfields	141 Energy supply plants	142 Waste treatment plants	143 Other supply or waste treatment plants	144 Dumps	145 Quarries, mines	146 Construction sites	147 Unexploited urban areas	161 Public parks	162 Sport facilities	163 Golf courses	164 Camping areas	165 Garden allotments	166 Cemeteries
10 Artificial areas																										
11 Sealed surfaces	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
12 Buildings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
13 Greenhouses	52	52	52	52	52	52	52	52			52	52	52						52	52	52	52	52	52	52	52
14 Gardens with border and patch structures	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
15 Lawns	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
16 Trees in artificial areas	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54			54	54	54	54	54	54	54	54
17 Mix of small structures	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
20 Grass and herb vegetation																										
21 Grass and herb vegetation	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
30 Brush vegetation																										
31 Shrub	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
32 Brush meadows	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
33 Short-stem fruit trees	53	53	53	53	53	53	53	53	53	53	53	53								53	53				53	53
34 Vines	53	53	53	53	53	53	53	53	53	53	53	53								53	53				53	53
35 Permanent garden plants and brush crops	52	52	52	52	52	52	52	52	52	52	52	52								52	52				52	52
40 Tree vegetation																										
41 Closed forest	54	54	54	54	54	54	54	54	54		54									54	54	54		54	54	54
42 Forest edges	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54	54	54	54	54
43 Forest strips	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54		54	54	54
44 Open forest	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54		54	54	54
45 Brush forest																					53			53		
46 Linear woods	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
47 Clusters of trees	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
50 Bare land																										
51 Solid rock	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
52 Granular soil	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
53 Rocky areas	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
60 Watery areas																										
61 Water	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
62 Glacier, perpetual snow																										
63 Wetlands	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
64 Reedy marshes	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42

18 Combination Categories (CC)	Agricultural areas: Orchards, vineyards, horticulture			Arable and grassland			Alpine grazing areas			Forest areas: Forest (not used for agriculture)				Unproductive areas: Lakes and rivers			Unproductive land			
Land Cover (NOLC04) acc. to AREA	201 Orchards	202 Vineyards	203 Horticulture	221 Arable land, in general	222 Semi-natural grassland, in general	223 Farm pastures, in general	241 Alpine meadows, in general	242 Alpine pastures, in general	243 Alpine sheep grazing pastures, in general	301 Forest	302 Afforestation	303 Lumbering areas	304 Damaged forest	401 Lakes	402 Streams, rivers	403 Flood protection structures	421 Unused	422 Avalanche and rockfall protection structures	423 Alpine sports facilities	424 Landscape intervention
10 Artificial areas																				
11 Sealed surfaces		51	51											51	51	51		51	51	51
12 Buildings																				
13 Greenhouses			21																	
14 Gardens with border and patch structures		21	21	21	21		21			12										
15 Lawns		31	31																	
16 Trees in artificial areas																				
17 Mix of small structures		21	21																	
20 Grass and herb vegetation																				
21 Grass and herb vegetation	31	31	31	21	31	31	31	31	31		11	12	12	37	37	37	37	37	37	31
30 Brush vegetation																				
31 Shrub		32	32								11	12	12	32	32	32	32	32	32	32
32 Brush meadows		32	32		32	32	32	32			11	12	12	32	32	32	32	32	32	32
33 Short-stem fruit trees	33		33																	
34 Vines		33	33																	
35 Permanent garden plants and brush crops			33							12										
40 Tree vegetation																				
41 Closed forest	35									12	11					12		12		
42 Forest edges	35									12	11	12	12			12		12		
43 Forest strips	35									12	11					12		12		
44 Open forest	35				12	12	12	12	13	12	11	12	12			12		12	12	12
45 Brush forest										13						13		13		
46 Linear woods	34	34	34	34	34	34	34	34	34		11	12	12	34	34	34	34	34	34	34
47 Clusters of trees	34	34	34	34	13	13	34	13	34		11	12	12	34	34	34	34	34	34	34
50 Bare land																				
51 Solid rock												13	13	61	61	61	61	61	61	61
52 Granular soil		61	61									12	12	61	61	61	61	61	61	61
53 Rocky areas		36	36			36	36	36			11	13	13	36	36	36	36	36	36	36
60 Watery areas																				
61 Water														41	41	41				41
62 Glacier, perpetual snow																	61		61	
63 Wetlands					42	42	42	42	42			12	13	42	42	42	42	42	42	42
64 Reedy marshes				21	42	42	42	42	42					42	42	42	42			

Combination Categories (CC):

- 11 Afforestations
- 12 Productive forest
- 13 Unproductive forest
- 21 Cropland
- 31 Permanent grassland
- 32 Shrub vegetation
- 33 Vineyards, Low-stem Orchads, Tree nurseries
- 34 Copse
- 35 Orchards
- 36 Stony grassland
- 37 Unproductive grassland
- 41 Surface waters
- 42 Unproductive wetland
- 51 Buildings and constructions
- 52 Herbaceous biomass in settlements
- 53 Shrubs in settlements
- 54 Trees in settlements
- 61 Other land

6.2.2 Spatial stratification

In order to quantify carbon stocks and GHG emissions and removals in the LULUCF sector as accurately as possible, Switzerland's territory was stratified by means of three site criteria: soil type (mineral or organic), elevation and forest production region.

Soil Type

Most soils in Switzerland are mineral soil types. A digital map showing estimates of the surface of organic soils in Switzerland was elaborated by Wüst-Galley et al. (2015). As there is no single data set from which the location of organic soils across the country could be adequately deduced, the authors evaluated numerous spatial and non-spatial data sets providing information on geology, soils, forest habitats and vegetation. According to Wüst-Galley et al. (2015) the total area of organic soils is 28 kha (0.8% of the total area covered by soils).

The definition of organic soils in the GHG inventory is as follows:

Intact or degraded peaty soils are considered organic soils. Where information on soil organic carbon (SOC) is known, the definition of organic soils from the IPCC (IPCC 2006, Volume 4, chp. 3, Annex 3A.5) was used to classify soils as mineral / organic (see Wüst-Galley et al. 2015: 11). Thus, this definition was used for the ground-truthing of forest habitat maps and fen inventories. This definition also formed the basis of the classification of soil types from the soils maps, as organic or mineral. Here however, two soils types ("anmoorig" and "antorfig" soils) could not be classified; these have a ranges of SOC and peat depth that are wider than those given in the IPCC definition, meaning they cannot be classified as either mineral or organic soils. Due to lack of information regarding their distribution, they were not explicitly considered in the estimate of organic soils (see Wüst-Galley et al. 2015: 14–15 and 61); including these additional soil types would lead to inconsistency of the definition of organic soils across the country, because their distribution is only known for a small area in Switzerland.

For the other data sets used in the construction of the organic soils map (geology maps, hydrogeology maps and other habitat maps), no information on SOC is available, and the presence of peat was used as evidence of organic soils. The carbon content of peat meets the IPCC definition of organic soils.

Consistency: A single map of organic soils is applied to all years (1990 to present), meaning the classifications used are consistent through time. The same definition of organic soils was used across the whole country.

Elevation

For Forest land (CC11-CC13), Cropland (CC21), and permanent grassland (CC31) three elevation zones were differentiated: <601 m a.s.l. (meters above sea level), 601–1200 m a.s.l., and >1200 m a.s.l. (Figure 6-4). Elevation data from the Federal Office of Topography (swisstopo.ch) on a 25x25 m raster (product DHM25) were used to map the three zones.

Forest production region

Forest land was furthermore differentiated into the five production regions of the National Forest Inventory (EAFV/BFL 1988; Brassel and Brändli 1999; Brändli 2010). The NFI production regions were adopted from EAFV/BFL (1988) as shown in Figure 6-4:

1. Jura, 2. Central Plateau, 3. Pre-Alps, 4. Alps, 5. Southern Alps.

Applying all spatial stratifications, 30 different strata (referred to as subscript i in chp. 6.1.3.2) would be theoretically possible. Not all of them, but altogether 29 have been actually realised and applied for the calculation of LULUCF-associated carbon emissions and removals.

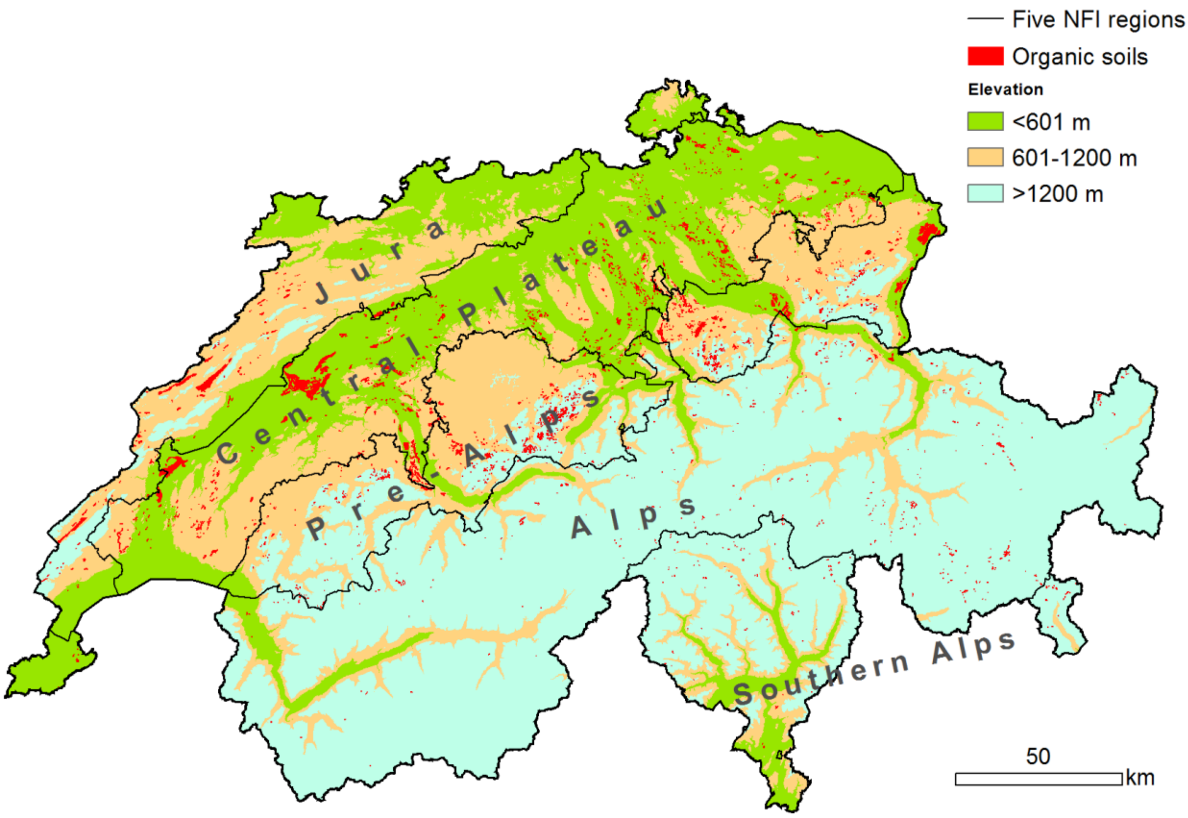


Figure 6-4 Map showing the spatial stratification according to NFI production region, elevation zone, and soil type.

6.2.3 The land-use tables and change matrices

In Table 6-7 the land-use statistics resulting from spatial stratification (chp. 6.2.2) and interpolation in time (chp. 6.3.2) are exemplarily shown for the year 1990. The table gives also the size of the individual spatial strata.

Table 6-7 Land use projection by the end of 1990 (in terms of combination categories CC), stratified separately for elevation (3 zones), soil type (mineral or organic) and NFI production region (1-5), in kha. The country's total area is 4'129'052 ha (SFSO 2019).

CC:	11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
Altitude																			
<601 m	1.1	224.8	6.2	299.8	153.8	2.6	22.5	32.4	1.2	0.5	2.9	138.6	5.2	116.7	47.5	2.8	18.6	2.0	1079.1
601-1200 m	1.4	504.2	18.1	131.7	358.2	8.7	3.9	29.9	0.3	2.5	1.5	9.7	5.7	46.4	17.0	0.9	5.3	8.1	1153.9
>1200 m	1.4	377.8	79.9	0.4	425.4	144.4	0.0	27.1	0.0	148.7	61.9	13.3	14.3	11.4	3.7	0.2	1.0	585.2	1896.1
	3.9	1106.9	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
Soil																			
mineral	3.9	1103.3	104.1	420.3	931.8	155.6	26.4	89.0	1.6	151.6	66.1	161.2	21.4	173.3	67.7	3.9	24.8	595.3	4101.3
organic	0.0	3.6	0.2	11.7	5.6	0.1	0.0	0.4	0.0	0.0	0.2	0.3	3.7	1.2	0.5	0.0	0.1	0.025	27.7
	3.9	1106.9	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
NFI region																			
1	0.7	197.2	8.3	78.0	122.6	0.9	4.7	11.9	0.3	0.2	0.6	23.6	1.2	26.8	10.9	0.5	4.7	0.5	493.5
2	0.8	227.2	4.1	307.0	152.4	0.9	9.9	27.4	1.0	0.2	1.6	70.4	4.1	84.9	34.7	1.6	12.6	0.7	941.5
3	1.0	214.3	13.0	30.2	261.3	10.4	0.8	17.8	0.1	8.5	6.8	30.6	12.0	26.8	9.2	0.5	2.9	15.0	661.2
4	1.1	331.6	56.1	13.8	365.4	110.2	9.5	24.5	0.2	118.1	49.2	26.2	7.2	26.9	9.8	0.8	3.0	524.8	1678.2
5	0.3	136.6	22.6	3.0	35.7	33.3	1.5	7.8	0.0	24.6	8.1	10.7	0.7	9.2	3.7	0.6	1.9	54.3	354.6
	3.9	1106.9	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1

Table 6-8 shows the overall trends of land-use changes between 1990 and 2018. For example, the area of afforestations (CC11) decreased by 84% during this period, while the area of productive forests (CC12) increased by 4%. Afforestation area is decreasing because afforestation activities slowed down over the inventory period (see Table 6-9) and because most of the afforestations turn into productive forests after a certain time.

Table 6-8 Statistics of land use (in terms of combination categories CC) and relative change (%) between 1990 and 2018, in kha. The country's total area is 4'129'052 ha (SFSO 2019).

CC:	11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
Year:																			
1990	3.9	1106.9	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
1991	3.8	1109.1	104.5	431.2	935.6	155.2	26.5	88.3	1.5	151.4	66.2	161.6	25.1	176.2	68.7	4.0	25.3	595.0	4129.1
1992	3.7	1111.3	104.7	430.4	933.8	154.7	26.6	87.3	1.4	151.1	66.0	161.6	25.1	177.9	69.3	4.0	25.6	594.6	4129.1
1993	3.5	1113.4	104.9	429.4	932.3	154.2	26.5	86.2	1.4	150.9	65.8	161.6	25.1	179.5	69.9	4.1	25.9	594.2	4129.1
1994	3.4	1115.4	105.1	428.0	931.7	153.7	26.5	85.2	1.3	150.8	65.7	161.6	25.1	181.1	70.4	4.2	26.2	593.8	4129.1
1995	3.2	1117.2	105.3	426.1	931.6	153.2	26.5	84.3	1.3	150.6	65.5	161.6	25.2	182.7	71.2	4.2	26.2	593.4	4129.1
1996	3.0	1118.7	105.4	424.2	931.8	152.7	26.4	83.4	1.3	150.5	65.3	161.6	25.2	184.2	71.9	4.2	26.2	593.0	4129.1
1997	2.8	1120.2	105.6	422.1	932.2	152.3	26.3	82.4	1.2	150.4	65.2	161.7	25.2	185.8	72.7	4.2	26.1	592.6	4129.1
1998	2.6	1121.5	105.7	420.0	932.6	152.1	26.2	81.5	1.2	150.4	65.0	161.7	25.2	187.3	73.6	4.2	26.0	592.2	4129.1
1999	2.4	1122.8	105.7	418.0	933.0	151.9	26.2	80.6	1.2	150.5	64.8	161.8	25.3	188.8	74.4	4.2	25.9	591.8	4129.1
2000	2.2	1124.1	105.8	415.9	933.3	151.7	26.1	79.6	1.2	150.5	64.6	161.8	25.3	190.3	75.2	4.2	25.8	591.4	4129.1
2001	2.0	1125.4	105.9	413.8	933.7	151.5	26.0	78.7	1.1	150.5	64.5	161.9	25.3	191.9	76.0	4.2	25.7	591.0	4129.1
2002	1.7	1126.7	106.0	411.8	934.1	151.4	25.9	77.7	1.1	150.6	64.3	161.9	25.3	193.4	76.9	4.2	25.6	590.6	4129.1
2003	1.5	1128.0	106.0	409.7	934.4	151.2	25.8	76.8	1.1	150.6	64.1	162.0	25.4	194.9	77.7	4.2	25.5	590.2	4129.1
2004	1.3	1129.3	106.1	407.6	934.8	151.0	25.7	75.8	1.1	150.6	63.9	162.0	25.4	196.4	78.5	4.2	25.4	589.8	4129.1
2005	1.2	1130.6	106.1	406.0	934.5	150.9	25.6	75.0	1.1	150.7	63.7	162.0	25.4	198.0	79.3	4.2	25.3	589.4	4129.1
2006	1.0	1132.1	106.2	404.1	934.3	150.7	25.5	74.0	1.0	150.8	63.6	162.1	25.5	199.7	79.9	4.2	25.3	589.1	4129.1
2007	0.9	1133.7	106.2	402.4	933.8	150.7	25.4	73.2	1.0	150.9	63.4	162.1	25.5	201.4	80.4	4.2	25.4	588.6	4129.1
2008	0.8	1135.9	106.4	400.6	933.0	150.7	25.4	72.5	1.0	151.1	63.0	162.2	25.5	202.9	80.6	4.2	25.6	587.6	4129.1
2009	0.8	1137.8	106.5	399.0	931.8	150.7	25.3	72.0	1.1	151.4	62.8	162.3	25.5	204.5	80.7	4.1	26.0	586.7	4129.1
2010	0.8	1139.4	106.6	397.3	930.6	150.8	25.3	71.8	1.1	151.6	62.5	162.3	25.5	206.1	80.8	4.1	26.4	586.0	4129.1
2011	0.7	1141.0	106.7	395.6	929.5	150.9	25.3	71.5	1.1	151.8	62.3	162.3	25.5	207.7	80.9	4.1	26.7	585.2	4129.1
2012	0.7	1142.5	106.8	393.9	928.3	151.1	25.2	71.3	1.2	152.1	62.1	162.4	25.5	209.3	81.0	4.1	27.1	584.5	4129.1
2013	0.7	1144.3	107.1	392.9	926.7	151.2	25.0	70.9	1.2	152.3	61.9	162.4	25.5	211.1	80.9	4.0	27.2	583.7	4129.1
2014	0.7	1146.7	107.6	392.5	924.8	151.2	24.9	70.3	1.2	152.7	61.5	162.5	25.5	212.7	80.6	3.9	27.2	582.5	4129.1
2015	0.7	1149.1	108.0	393.0	922.0	151.3	24.8	69.7	1.2	153.0	61.1	162.5	25.5	214.3	80.6	3.9	27.1	581.3	4129.1
2016	0.7	1151.2	108.4	393.4	919.4	151.4	24.7	69.1	1.3	153.3	60.8	162.6	25.5	215.9	80.6	3.8	27.0	580.1	4129.1
2017	0.6	1152.9	108.7	393.4	917.0	151.4	24.6	68.7	1.3	153.5	60.6	162.6	25.5	217.3	80.9	3.7	27.0	579.4	4129.1
2018	0.6	1154.4	108.8	391.9	915.7	151.5	24.5	68.5	1.3	153.7	60.4	162.7	25.5	218.8	81.0	3.7	27.3	578.7	4129.1
Change:	-84	4	4	-9	-2	-3	-7	-23	-15	1	-9	1	2	25	19	-5	9	-3	0

The annual land-use changes across the entire territory of Switzerland (change-matrices, see examples for 1990 and 2018 in Table 6-9) were obtained by adding up the annual changes on a hectare basis per combination category (CC). For calculating the carbon stock changes, fully stratified (cf. chp. 6.2.2) land-use change tables were used for each year (Meteotest 2020). More aggregated change-matrices are reported in CRF Table4.1 for each year of the inventory period.

It is worth noting that in general the numbers given in the change-matrices (Table 6-9) cannot be directly compared with the figures of category 2 in CRF Table4.A, Table4.B, Table4.C, Table4.D, Table4.E, and Table4.F (Land converted to X), where the cumulative area remaining in the respective category in the reporting year is recorded (cf. the description of conversion time of 20 years in chp. 6.1.3.3). In contrast, the change matrices present the land-use changes occurring in the specified year only.

Table 6-9 Annual land-use changes in 1990 and in 2018 (change matrices). Units: ha/year, rounded values. Empty cells indicate that no change occurred.

1990		change to CC																	
		11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	11		369	1	0	0	1		0						0	0	0		0	372
	12			158	5	125	86	6	59		12	19	11	7	117	27	11	17	49	709
	13		678		8	354	48	5	89	0	3	3	1	3	41	20	3	15	10	1280
	21	8	1	5		663	6	181	35	1	4	4	4	4	632	317	21	18	22	1926
	31	136	166	480	717		1007	123	311	4	46	43	9	11	870	490	27	44	67	4554
	32	24	1022	715	2	126		9	309		14	15	6	0	24	8	5	3	30	2313
	33	1	2	4	126	65	4		28	2	0	1	0		50	26	4	3	5	323
	34	20	536	63	143	866	49	35		11	9	23	4	3	171	94	6	41	14	2087
	35		0	0	8	13	0	4	46						4	2	0	1	0	80
	36	3	27	26	2	162	243	1	41			89	4	0	8	1	0		45	652
	37	7	26	6	1	8	234	1	68		10		3	0	6	2		0	13	384
	41	0	4	1	2	2	6	0	4		4	1		17	11	2	1	0	99	156
	42	5	27	6	1	3	2	0	2		0	0	6		4	1	0	0	1	59
	51	38	18	4	86	158	11	5	7		3	5	6	4		271	58	46	5	726
	52	7	4	1	16	32	3	1	1		0	1	1	2	349		68	387	0	874
	53	5	9	0	6	7	2	0	2				0	2	45	28		46	0	150
	54	2	6	0	1	2	0	0	3			0	0	1	78	152	8		0	253
	61	4	41	17	16	67	93	8	31		287	33	96	2	13	1	0	1		709
	increase	261	2936	1489	1140	2653	1794	381	1036	18	394	236	152	55	2425	1443	211	621	361	17607

2018		change to CC																	
		11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	11		51	0			0								0		0			52
	12			340	1	256	107	4	80	0	32	19	21	20	96	28	10	14	63	1092
	13		874		2	404	98	2	94	0	8	2	1	3	25	16	2	12	14	1557
	21	1	1	3		2515	6	167	45	8	5	7	4	7	460	197	8	4	14	3452
	31	11	156	554	1710		1189	89	435	13	94	48	10	18	798	435	17	17	70	5665
	32	2	778	627	2	164		3	416		29	15	6	1	11	4	2	1	37	2097
	33		5	2	107	93	6		35	4	0	1	0	0	36	26	3	2	2	323
	34	1	592	74	33	521	48	8		27	10	22	8	1	77	50	2	27	15	1515
	35		0		1	7		1	17						1					26
	36	0	24	31	1	146	298	0	55			80	5	1	6	1			60	708
	37	2	20	3		11	277		72		32		5	1	4	1			14	440
	41	0	5	1	0	2	7		4		6	5		16	6	1	0	0	116	169
	42	0	38	7	1	2	1		3		0	0	7		2	1	0	1	1	64
	51	14	19	2	59	149	9	1	5		7	8	6	3		371	53	45	9	761
	52	8	7	1	15	55	4	0	3		1	3	1	2	557		75	621	1	1353
	53	2	20	1	3	7	4		1		0	1	0	0	53	47		61		200
	54	1	10	2	0	3	1		4			0	0	0	144	310	26			502
	61	0	35	17	10	70	97	6	43		689	19	123	2	5	0	0			1116
	increase	42	2635	1664	1946	4404	2149	282	1311	52	914	230	199	74	2279	1488	197	806	417	21090

6.3 Approaches used for representing land areas, land-use databases

6.3.1 Swiss Land Use Statistics (AREA)

Data of the Swiss Land Use Statistics (AREA) processed by the Swiss Federal Statistical Office (SFSO 2019) form the basis of activity data. In the course of the AREA surveys, every hectare of Switzerland's territory (4'129'052 ha) is assigned to one of 46 land-use categories and to one of 27 land-cover categories by means of stereographic interpretation of aerial photos (SFSO 2006a).

For the reconstruction of the land use conditions in Switzerland during the inventory period four datasets were used:

- Land Use Statistics "1979/85" (AREA1), status: completed
- Land Use Statistics "1992/97" (AREA2), status: completed
- Land Use Statistics "2004/09" (AREA3), status: completed
- Land Use Statistics "2013/18" (AREA4), status: 71% of territory processed.

The aerial photos for AREA1, AREA2 and AREA3 were taken 1977–1986, 1990–1998 and 2004–2009, respectively. In the course of AREA3 all photos (including those from AREA1 and AREA2) were simultaneously (re-) interpreted according to the newly designed AREA set of land-use and land-cover categories based on the nomenclature 'NOAS04' (SFSO 2006a). The AREA4 survey was started in 2014. In this submission data based on aerial photos taken 2012–2017 were included.

The website https://map.geo.admin.ch allows a visualization of the completed AREA surveys. See the example https://s.geo.admin.ch/8054e4be63 for the change in direct neighbourhood of a FOEN building in Bern-Ittigen (Legend: yellow cross represents sample point; circles represent land cover, squares represent land use, from left to right for AREA1, AREA2 and AREA3, respectively). Click circles and squares for object information. To get a clue on the situation prior to the construction of the FOEN building check the box "Journey through time – Maps" (preset 1986, but year is freely selectable) and look out for the former course of the stream nowadays bound to the south of the rail tracks. (Please note: The background aerial photograph is of recent age).

The inter-survey period is not identical throughout the Swiss territory, but varies regionally. It averages approximately 12 years for AREA1, AREA2 and AREA3; for AREA4 the period will be shorter, approximately 9 years. This methodic characteristic needs to be considered when reconstructing the annual country-wide status of land use or when calculating annual rates of land-use change.

6.3.2 Interpolation of the status for each year

The exact dates of aerial photo shootings are known for each hectare. However, the exact occurrence date (year) of a land-use change on a specific hectare is unknown. The actual change can have taken place in any year between two AREA surveys. In this study, it was assumed that the probability of a land-use change from AREA1 to AREA2, from AREA2 to AREA3 and from AREA3 to AREA4 is uniformly distributed over the respective interim period between two surveys. Therefore, the land-use change of each hectare has to be equally distributed over its specific interim period.

Thus, the land-use status for the years between two data collection dates can be calculated by linear interpolation. Dates of aerial photo shootings (i.e. starting and ending year of the inter-survey period) and the land-use categories of AREA1, AREA2, AREA3 and AREA4 for every hectare were used for these calculations. An example is shown in Figure 6-5: A hectare had been assigned to the land-use category Cropland in AREA1 (aerial photo in 1980). A land-use change to 'Surrounding of Buildings' was discovered 10 years later (1990) in AREA2.

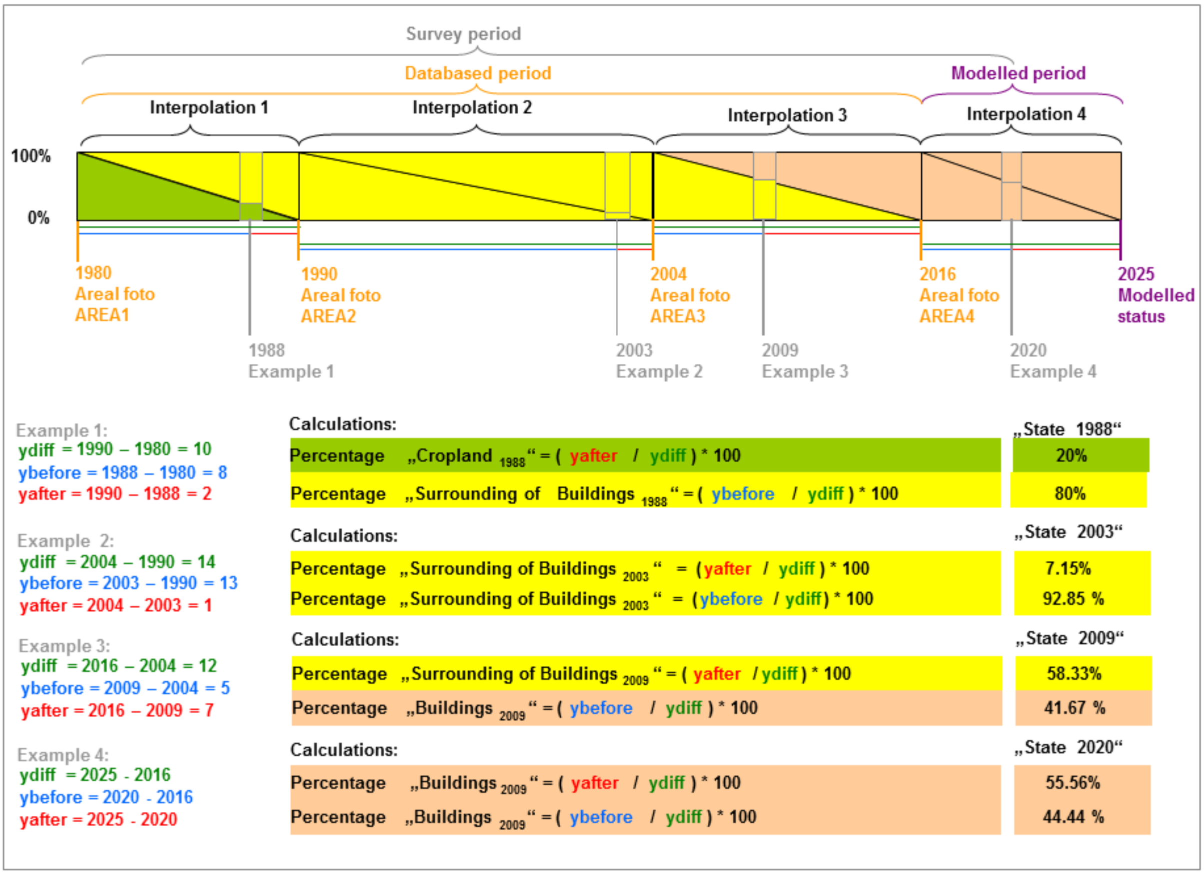


Figure 6-5 Hypothetical development of land use for a supposed survey period 1980–2020. The linear land-use changes between AREA1, AREA2, AREA3 and AREA4 considering as example a hectare changing from “Cropland” to “Surrounding of Buildings” and later from "Surrounding of Buildings" to "Buildings". For 2020, a linear interpolation has been carried out between AREA4 and a virtual fifth survey (AREA5v) that was modelled for the year 2025 (here resulting in no change of land use).

The “state 1988” of that hectare is determined by calculating the fractions of the two land-use categories for the year 1988. A linear development from “Cropland” to “Surrounding of Buildings” during the whole interim period was assumed. Thus, in 1988 the hectare was split up in two fractions: 80% is “Surrounding of Buildings” and 20% is “Cropland”. The same procedure can be applied for two survey dates between AREA2 and AREA3 (here exemplarily shown for the period 1990–2004, highlighting “state 2003”) or between AREA3 and AREA4 (here exemplarily shown for the period 2004–2016, highlighting “state 2009”).

After completion, AREA4 will comprehend aerial photos from 2012–2018.

To obtain consistent and complete nationwide data for each year during the ongoing AREA4 survey two analyses are required:

1) For those hectares that currently have no data in AREA4, the land-use states after AREA3 were interpolated between AREA3 and a "virtual" 4th survey (AREA4v). AREA4v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA3 and AREA4v were assessed based on the transition distribution between AREA2 and AREA3 within each spatial stratum (Sigmaplan 2020).

2) For those hectares that were already covered by AREA4, the land-use states after the flight year of AREA4 were interpolated between AREA4 and a "virtual" 5th survey (AREA5v). AREA5v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA4 and AREA5v were assessed based on the transition distribution between AREA3 and AREA4 within each spatial stratum (Sigmaplan 2020). Therefore, the land-use changes occurring after the flight year of AREA4 (i.e. when it was covered) were calculated from the linear development detected between AREA4 and the virtual 5th survey AREA5v for this type of hectare (regarding CC and spatial strata) (see Figure 6-5: example “state 2020”).

The wall-to-wall land-use status within Switzerland for each individual year in the inventory period results from the summation of the fractions of all hectares per combination category CC, additionally considering the spatial strata where appropriate.

6.3.3 Uncertainties and time-series consistency of activity data

An overview of uncertainty estimates for activity data (AD) and emission factors (or biomass parameters) is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while uncertainties of other AD (such as consumption of Harvested wood products) and uncertainties of emission factors are presented in the respective LULUCF chapters (6.X.3).

In most cases, the uncertainty of AD for categories 4A–4F depends on the quality of the AREA survey data. For categories with relevant emissions from drained organic soils, also the uncertainty of the spatial allocation of organic soils (see chp. 6.2.2 and below) was considered.

The uncertainty of AREA-based activity data has two main sources (Table 6-10). They were quantified on the basis of the AREA data (SFSO 2019) as follows:

1) Interpretation error: In the AREA survey, the first classification of the aerial photos is checked by a second independent interpreter. The portion of sampling points with a mismatch of the first and the second interpretation was used as the uncertainty of the interpretation. This uncertainty of interpretation integrates all errors related to the manual interpretation of land-use and land-cover classes on aerial photographs. While it is clear that this is rather an estimate of the maximum potential interpretation error than of the actual interpretation error, it is reported hereafter unless better information is available.

2) Statistical sampling error: In the AREA survey, the land-use types are interpreted on points situated on a regular 100x100 m grid. Thus, the uncertainty of the measured surface

area covered by a certain land-use type or land-use change decreases with increasing numbers of sampling points that are used for the measurement. Assuming a binomial distribution of the errors, this uncertainty was calculated as

$U_{sampling} = 100 * 1.96 * (\text{number of points})^{-0.5}$

The number of sampling points lies between 2’651 (for 4D2) and 1'345’711 (for 4C1) leading to values of $U_{sampling}$ between 3.8% and 0.2%.

The overall uncertainty was calculated as:

$U_{overall} = (U_{interpret}^2 + U_{sampling}^2)^{0.5}$

Table 6-10 Sources of AD uncertainty and overall uncertainties in the allocation of land-use categories, expressed as half of the 95% confidence intervals. Calculations are based only on AREA data from SFSO (2019); uncertainties with respect to other data sources (organic soils, wildfires) are not included, see main text.

Category	Description	Interpretation uncertainty	Sampling uncertainty	Overall uncertainty
4A1	Forest land remaining forest land	1.1	0.2	1.1
4A2	Land converted to forest land	1.1	1.1	1.5
4B1	Cropland remaining cropland	4.9	0.3	4.9
4B2	Land converted to cropland	4.9	1.5	5.1
4C1	Grassland remaining grassland	5.2	0.2	5.2
4C2	Land converted to grassland	5.2	0.9	5.3
4D1	Wetlands remaining wetlands	0.9	0.5	1.0
4D2	Land converted to wetlands	0.9	3.8	3.9
4E1	Settlements remaining settlements	4.4	0.4	4.4
4E2	Land converted to settlements	4.4	1.3	4.6
4F1	Other land remaining other land	1.4	0.3	1.4
4F2	Land converted to other land	1.4	3.0	3.3

An update of the uncertainty analysis of the spatial allocation of organic soils published by Wüst-Galley et al. (2015) (Wüst-Galley 2019) resulted in 35.3% for Forest land, 37.3% for Cropland, 68.6% for Grassland and 90.8% for Wetlands. For Forest land (chp. 6.4.3) and Settlements (chp. 6.8.3) CO_2 emissions from organic soils were not considered in the calculation of the overall uncertainty (Meteotest 2020).

Activity data for wildfires were taken from the Swissfire database (see chp. 6.4.2.12 and chp. 6.6.2.6). The uncertainty for areas affected by wildfires was estimated between 10% (NFI production region 5) and 30% (other NFI production regions) for forest land by expert judgment (Pezzatti 2017). For grassland the mean uncertainty is probably higher than for forest land. As a consequence, a value of 30% was agreed on for both land uses.

Consistency: Time series for activity data are all considered consistent; they were calculated based on consistent methods for interpolation and extrapolation and homogenous databases.

6.3.4 QA/QC and verification of activity data

The general QA/QC measures are described in chp. 1.2.3.

The AREA survey is a well-defined and controlled, long-term process in the responsibility of the Swiss Federal Statistical Office (SFSO 2006a). The data supplied by SFSO (2019) were checked for consistency (Sigmaplan 2020).

The temporal interpolation and extrapolation of the AREA sample is quite a complex procedure, whose internal consistency was checked systematically as described in Sigmaplan (2020). Further checks (interannual comparisons, plausibility) were carried out after producing the land-use change tables presented in chp. 6.2.3.

A systematic cross-check between the activity data reported under LULUCF category 4A Forest land and under the Kyoto Protocol activity Forest management was carried out (see chp. 11.3.2.2).

The total country area remains constant over the inventory period.

6.3.5 Recalculations of activity data

The AD time series 1991–2017 was updated as a result of the following activities:

- The most recent land-use data from the fourth area survey (AREA4) were included (SFSO 2019). They are based on aerial photographs from 2012 to 2017. The interpolation and projection procedures were adapted accordingly (see chp. 6.3.2 and Sigmaplan 2020).
- Along with the AREA4 survey the SFSO continuously performs consistency checks and, where appropriate, corrections in the data of AREA3 (2004–2009). Due to temporal interpolation (cf. chp. 6.3.2) the years 1991–2003 were affected.

6.3.6 Planned improvements for activity data

The uncertainty of Switzerland’s activity data for land areas will decrease gradually with the increase in the sample size of the current survey AREA4. Interpretation and further processing of AREA4 is expected to be completed in 2020.

The FOEN is currently evaluating the suitability of newly available satellite data (e.g. Sentinel 2) in the field of environmental reporting. Several feasibility studies were commissioned. Depending on the results (and on the future availability of EU satellite data in Switzerland) it is intended to refine the spatio-temporal pattern of land use dynamics in Switzerland provided by the Land Use Statistics AREA by the use of satellite data in the medium term. In the course of this evaluation the design of the land-use categories used in the GHG inventory (i.e. the combination categories CC) will be scrutinised.

6.4 Category 4A – Forest land

6.4.1 Description

Table 6-11 Key categories in category 4A. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T2

Only temperate forests occur in Switzerland. Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20% and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ (FOEN 2006h). The following forest areas are not subject to the criteria of minimum stand height and minimum crown cover, but must have the potential to achieve it: afforested, regenerated, as well as burnt, cut or damaged areas. Although orchards, parks, camping grounds, open tree formations in settlements, gardens, cemeteries, sports and parking fields may fulfil the (quantitative) forest definition, they were not considered as forests (FOEN 2006h).

According to the Federal Act on Forest, it is one objective to “conserve the forest in its area and spatial distribution” (Swiss Confederation 1991: Art. 1a). Any change of the forest area has to be authorized. Therefore, all forests in Switzerland are considered to be under management.

For reporting purposes, the different forest types were allocated to afforestations (CC11), productive forest (CC12) and unproductive forest (CC13) based on AREA categories (see Table 6-2 and Table 6-6; SFSO 2006a; Didion and Thürig 2013).

Note for afforested areas: The diction *afforestation* is consistently used for reporting under the UNFCCC, and the diction *Afforestation* (with uppercase letter) for reporting the activity under the Kyoto Protocol (see chp. 6.1.3.1 and chp. 11.1.3).

A detailed description of the category unproductive forest CC13 can be found in chp. 6.4.2.8.

6.4.2 Methodological issues

6.4.2.1 Choice of method and National Forest Inventories

The Swiss National Forest Inventory (NFI) is the primary source for estimating emission factors for forest land. Growing stock, cut and mortality are estimated based on tally trees with a diameter at breast height (DBH) ≥12 cm. For tally trees allometric relationships were developed to obtain accurate data on whole tree volume and biomass (Lanz et al. 2019). These data are further used to estimate the annual production of dead wood and litter that drive carbon stocks and carbon stock changes in the dead organic matter and soil carbon pools calculated with Yasso07.

For all carbon pools, the calculation approach and the applied conversion time periods for different land-use changes within, from and to forest land are shown in Table 6-3. FOEN (2020c) and Didion et al. 2019 (Fig. 14.1) contain a schematic overview and a detailed description of all tree biomass elements which are included in the estimation of reported carbon stocks and carbon stock changes and comprise stemwood including tree top and stump, large and small branches, seeds, foliage, coarse and fine roots. In response to UNFCCC (2020, ID#L.4) the description of tree elements included in the quantification of the dead organic matter pool, particularly of stumps was made more precise here and also in chapter 6.4.2.6.

The four available Swiss National Forest Inventories are NFI1, NFI2, NFI3, and NFI4 (see Table 6-12). A description of NFI1 and NFI2 methodologies can be found in EAFV/BFL (1988) and in Brassel and Brändli (1999). Data and methodology of NFI3 are described in Brändli (2010). The inventories NFI1, NFI2 and NFI3 were based on full surveys that were repeated in intervals of approximately 10 years. The fourth inventory (NFI4, 2009–2017) is carried out as a continuous survey where annually a nationally representative subsample of approximately 12% of the Swiss forests is surveyed and evaluated. Otherwise, the methodology remained identical to Brändli (2010). A detailed description of the current methods to estimate volume, biomass, and carbon for the GHG inventory can be found in (Herold et al. 2019 and Didion et al. 2019).

Table 6-12 Characteristics of the National Forest Inventories NFI1, NFI2, NFI3 and NFI4 (2013–2017), accessible forest plots without brush forest.

	NFI1	NFI2	NFI3	NFI4 (2013-2017)
Inventory cycle	1983-1985	1993-1995	2004-2006	2013-2017
Grid size	1 x 1 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km
Terrestrial sample plots	10'981	6'412	6'608	3'347
Tally trees	128'441	76'394	77'959	39'496

Data for growing stock (in carbon mass of total living biomass) were estimated for a particular inventory. Gross growth (gain in carbon stock of total living biomass), cut and mortality (loss in carbon stock of total living biomass), and dead wood and litter production were based on the observed changes between two consecutive inventories (chp. 6.4.2.3, 6.4.2.5, and 6.4.2.6; see Table 4 and 5 in Thürig et al. 2019a and chp. 2.3.3 in Didion 2019). Carbon stock changes between two inventories are obtained based on data from the common plots (Table 6-13). The total number of common plots can differ for inter-survey periods as a result of land use changes from or to forest land.

For assembling the results for the GHG inventory 1990–2018, NFI4 data for the years 2013–2017 were used in addition to the data from NFI1, NFI2, and NFI3, and the respective inventory periods NFI1-2, NFI2-3, and NFI3-4 (2013–2017). Results on growing stock based on the 5-year subset of the NFI4 and for growth and cut and mortality based on the inventory period NFI34 (2013–2017) were summarised in the data release NFI4 (2013–2017; Thürig et al. 2019a).

Table 6-13 Number of NFI sample plots in each NFI inter-survey period: number of plots which were forest also in the previous NFI inter-survey period and the number of plots newly converted to forest (Didion 2019). Data from the total number of plots is used to calculated carbon stock changes between two inventories. Footnote 1: not applicable in this first NFI period; footnote 2: for the period NFI3-4 only sample plots common to NFI3 and the sample plots in NFI4 visited in the years 2013 to 2017 were considered.

NFI period	Forest in previous period	Converted to forest since previous period	Total for period
	Number of sample plots		
NFI1-2	NA[1]	NA[1]	5456
NFI2-3	5'370	211	5581
NFI3-4 (2013-2017)[2]	3'046	165	3'211

Data available in the NFI

In the field surveys standing and lying stems are measured on two nested circular sample plots with 200 m^2 and 500 m^2 in area, respectively. On the smaller plot, trees and shrubs with DBH ≥12 cm are measured, whereas all trees with DBH ≥36 cm are measured on the larger plot. In order to asses the regeneration of the forest, young trees and the main shrub species with a minimum height of 10 cm and DBH <12 cm are assessed on a separate set of four circular sample plots with radii between 0.9 and 4 m (Brändli and Hägeli 2019).

For estimating C stocks and C stock changes in the Greenhouse Gas Inventory, currently, (1) trees with DBH <12 cm with branches, foliage, and roots, and (2) non-tree understory vegetation including shrubs, ferns, grasses, segdes, and herbs are not considered because Switzerland's country-specific allometric functions only apply to trees ≥12 cm DBH, and because for non-tree understory vegetation currently only cover estimates are available.

The omission of trees <12 cm DBH and of non-tree vegetation is justified because of their negligible effect on the C stock and C stock change estimates of productive forests in Switzerland:

- Trees with DBH <12 cm contribute only little to total forest biomass and C stock (Peichl and Arain 2006). Dunger et al. (2012) estimated this contribution to 1-2% for forests with similar forest structure as Switzerland.
- Gains of trees <12 cm are implicitly accounted for in the trees above this threshold as the cumulative C uptake. This is a statistically valid and accurate approach, particularly for the gains/loss approach applied by Switzerland ensuring that EF are neither over- nor underestimated.
- Regarding non-tree vegetation, work is ongoing to estimate biomass and carbon stocks and their changes in the context of planned improvements to obtain estimates of litter turnover produced by such vegetation (see second item in chp. 6.4.6). Preliminary results indicate that the contribution of non-tree vegetation to total C stock changes, i.e. from living biomass, dead wood, litter, and mineral soil on forest land is negligible (Didion et al. 2018).

Consequences of using new NFI data

No new NFI data compared to the previous submission were available for this submission.

In general, new NFI data have an influence on the time series of carbon stock changes, (gains and losses in living biomass, dead wood, litter and soil) because they are calculated based on observed changes between two forest inventories.

The change from periodic sampling (NFIs 1 to 3) to a continuous sampling NFI4, required a modification of the estimation of carbon stock changes for the inventory period NFI3 to 4 affecting estimates from 2005 onwards only. The adapted method requires NFI data from a shifting 5-year window to ensure accuracy and consistency (Thürig et al. 2017, 2019a) of the estimates of carbon stock changes. The method based on a shifting 5-year window of NFI data will also be used in future submissions and thus, recalculations will be performed when new NFI data become available. A shift to new NFI data (e.g. from NFI3-4 (2011–2015) used for the GHG inventory submissions in 2017 and 2018 to NFI3-4 (2013–2017) used for the GHG inventory submissions in 2019 and this submission) reflects the uncertainty in the data as the sample plots used for the estimation changes but does not affect time series consistency as carbon stock change estimates are based on representative subsamples of all NFI sample plots.

6.4.2.2 Stratification

Spatial strata

Forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions, tree species composition, and interannual growth variability. To account for the heterogeneity, the Swiss NFI uses a spatial stratification based on five production regions and three elevation belts (Brändli 2010). To find explanatory variables that significantly reduce the variance of gross growth, an analysis of variance was done (Table 6-14).

Table 6-14 Analysis of variance of gross growth of data from NFI2 and NFI3. Explanatory variables: Tree species, NFI production region, and elevation (Tab. 2b in Thürig et al. 2005).

	Gross growth	
	F-value	p-value
Coniferous / broadleaved	421	<0.0001
Production region	45	<0.0001
Elevation	34	<0.0001

The analysis of variance indicated that production region, elevation, and tree species all significantly explain differences in gross growth. Therefore, the explanatory variables considered here were:

- tree species: coniferous and broadleaved species
- the five NFI production regions (L):
  L1 Jura, L2 Central Plateau, L3 Pre-Alps, L4 Alps, L5 Southern Alps
- Elevation zones (Z):
  Z1 <601 m, Z2 601–1200 m, Z3 >1200 m.

Values for growing stock, gross growth, harvesting and mortality were calculated for each of the resulting 30 strata.

Additional stratification: eastern and western Alps

In the Swiss Alps (NFI production region 4) below an elevation of 1200 m, climate between the eastern and the western part differs substantially. An additional stratification for the eastern and the western part of the Alps below 1200 m (Alps <601 m east, Alps <601 m west, Alps 601-1200 m east, Alps 601-1200 m west was included; see Thürig et al. 2005a for details). This additional stratification resulted in very small datasets for these four strata in the NFI3-4.

Gains and losses in carbon stock of living biomass were estimated for the eastern and western Alps separately. The emission factors for the Alps below 1200 m were then calculated as a weighted mean of the percentage of forest biomass situated in the western and in the eastern Alps. The ratios for the pooled emission factors correspond to the biomass ratios for the two regions, which were calculated for the three periods between NFI1 and NFI2, NFI2 and NFI3, and NFI3 and NFI4 (2013–2017) (Table 6-15).

Table 6-15 Ratio of biomass in the eastern and western Alps (NFI production region 4) for 1985–1994 (derived from NFI1 and NFI2; source: Brassel and Brändli 1999), for 1995–2005 (derived from NFI2 and NFI3 data; source: Brändli 2010) and for 2006–2017 (derived from NFI3 and NFI4 (2013–2017) data; source: Thürig et al. 2019a). For NFI4 (2013–2017), NFI production region 4 <601 m and 601–1200 m were aggregated.

	1985 - 1994		1995 – 2005		2006-2017	
Elevation [m]	NFI1-2 Eastern	NFI1-2 Western	NFI2-3 Eastern	NFI2-3 Western	NFI3-4 Eastern	NFI3-4 Western
<601	0.56	0.44	0.53	0.47	0.58	0.42
601-1200	0.62	0.38	0.61	0.39	0.58	0.42

Aggregation of strata

The use of a 5-year shifting window (see chp. 6.4.2.1) results in a reduced number of sample plots that are available for estimating the forest carbon balance (Table 6-13), and several spatial strata are represented by a low number of plots. Due to the large variability between sample plots a minimum number of sample plots is needed to obtain reliable estimates of means and sampling errors. Smaller strata are thus merged with neighbouring strata and treated as single strata:

- NFI production region 2 Central Plateau 601-1200 m and >1200 m:
  new stratum NFI production region 2 Central Plateau >600 m (263 plots)
- NFI production region 3 Pre-Alps ≤600 m and 601-1200 m:
  new stratum NFI production region 3 Pre-Alps ≤1200 m (368 plots)
- NFI production region 4 Alps West ≤600 m and 601-1200 m:
  new stratum NFI production region 4 Alps West ≤1200 m (150 plots)
- NFI production region 4 Alps East ≤600 m and 601-1200 m:
  new stratum NFI production region 4 Alps East ≤1200 m (152 plots)

6.4.2.3 Estimation of growing stock in biomass

Growing stock of trees with DBH ≥ 12 cm in the Swiss GHG inventory is defined as the biomass of all tree elements (stemwood over bark including stump, large (coarse) and small branches, needles/leaves, and roots). It was estimated based on established allometries to tree dimensions and wood densities (Table 6-16). Biomass estimates for stemwood over bark including stump and for all branches are derived based on volume models (chp. 12.2 and 12.3 in Herold et al. 2019) and conversion to biomass (chp. 14.2 in Didion et al. 2019). Foliage and coarse root biomass are derived directly from tree DBH (chp. 14.3 in Didion et al. 2019). Fine roots are reported under litter (see chp. 6.4.2.6). Except for coarse roots, the biomass functions were empirically derived from a large number of single-tree data from Swiss forest sites (see references in Table 6-16). Data and methodology has not changed compared to previous inventory submission but information was made more accessible in new publications (UNFCCC 2020, ID#L.7).

Table 6-16 Applied allometric biomass functions, dependencies and references. DBH: tree diameter at breast height; D7: diameter at tree height 7 m.

Tree element	Input parameter	Dataset (N trees)	References
Stemwood over bark incl. stump	DBH, D7, Height, Wood density	ca. 38’000	chp. 12.2 in Herold et al. 2019 chp. 14.2 in Didion et al. 2019
Branches: small (< 7 cm) and large (≥ 7 cm diameter)	DBH, Wood density	14'712	chp. 12.4 in Herold et al. 2019 chp. 14.2 in Didion et al. 2019
Foliage: needles, leaves	DBH	631	Perruchoud et al. 1999 chp. 14.3 in Didion et al. 2019
Coarse roots (≥ 5mm) - broadleaved trees - coniferous trees	DBH	 443 114	 Wutzler et al. 2008 Zell and Thürig 2013 chp. 14.3 in Didion et al. 2019

The total biomass of all individual trees was calculated and, in a second step, single-tree estimates of gains and losses were obtained as the difference in tree biomass of alive trees between subsequent NFIs (chp. 6.4.2.5; Thürig and Herold 2013).

6.4.2.4 Carbon content

A mean carbon content of 50% was used to convert the biomass of alive trees to carbon stocks. The carbon content estimate represents an approximation which was based on carbon fractions for coniferous and broadleaved trees in temperate forests provided in Tab. 4.3 in Volume 4 of IPCC (2006), and on the fact that in Switzerland coniferous trees are more abundant than broadleaved trees (see Table 051 in Brändli 2010).

6.4.2.5 Productive forests (CC12): growing stock, gains and losses in living biomass

Estimates for growing stock, gains (gross growth) and losses (cut and mortality) of living biomass for productive forests (CC12, without afforestations) in 2005 (based on NFI3) were derived from measurements on 5’456 sample plots common to NFI1 and NFI2, 5’581 sample plots common to NFI2 and NFI3 and 3’211 sample plots common to NFI3 and NFI4 (2013–

2017) (see Table 6-13). All values derived from the national forest inventories refer to above- and below-ground biomass in mass units (t C ha^{-1}) per spatial stratum.

Gains in living biomass – gross growth

Values of gross growth were derived from the NFI1 and NFI2 datasets for the period 1985–1994, from the NFI2 and NFI3 datasets for the period 1995–2005 and from the NFI3 and NFI4 (2013–2017) datasets for the period 2006–2017. Values of gross growth were assumed to remain constant in the intersurvey periods of NFI1 to NFI2, NFI2 to NFI3 and of NFI3 to NFI4 (2013–2017), respectively (Table 6-18). The estimate for 2018 is assumed to be equal to gross growth calculated for the intersurvey period NFI3 to NFI4 (2013–2017).

Losses in living biomass – cut and mortality

An average value for cut and mortality (CM) was derived from the NFI1 and NFI2 dataset for the period 1985–1994, from the NFI2 and NFI3 datasets for the period 1995–2005 and from the NFI3 and NFI4 (2013–2017) datasets for the period 2006–2017. To obtain annual values of cut and mortality (CMy) for each individual NFI-intersurvey-period, i.e. the years 1985 to 1994, 1995 to 2005 and 2006 to 2017, respectively, the average amount of cut and mortality from NFI was weighted by the percentage of the relative harvesting amounts derived from the forest statistics (Table 6-17; FOEN 2020f and former editions; Swiss Federal Statistical Office: Wood production in Switzerland 1975–2018, https://www.pxweb.bfs.admin.ch). These relative harvesting amounts, used as weighting factors, were calculated for each year per NFI intersurvey period. The estimate for 2018 is assumed to be equal to cut and mortality from the intersurvey period NFI3 to NFI4 (2013–2017), which is then multiplied with the specific weighting factor from the forest statistics for the year 2018.

Data from the forest statistics (Table 6-17) show that harvesting rates were exceptionally high in 1990 after storm Vivian (February 1990) and in 2000 after the storm Lothar (December 1999). Harvesting rates in Swiss forests tended to increase since 1991. In 2008 harvesting rates started to decline due to the international and domestic economic framework conditions. Since 2013, harvesting rates are relatively constant. Besides the observed trends, there is still a remarkable year-to-year variability, like high harvesting volumes in 2006, 2007, 2008, 2011, 2014 and 2018. The higher harvest volumes in these years cause higher losses of living biomass.

Table 6-17 Annual harvesting amount in m^3 merchantable wood specified for five NFI production region as well as for coniferous and broadleaved tree species (FOEN 2020f and former editions; https://www.pxweb.bfs.admin.ch).

Year	1. Jura		2. Central plateau		3. Pre-Alps		4. Alps		5. Southern Alps		Total
	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	
	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]
1990	687'327	358'647	1'769'813	606'718	1'285'639	138'126	1'301'313	70'064	21'575	22'456	6'261'678
1991	476'956	354'002	1'017'232	489'742	877'851	133'155	1'064'650	72'229	24'356	26'736	4'536'909
1992	555'523	372'249	1'199'596	571'610	735'680	128'934	736'230	70'706	47'388	28'637	4'446'553
1993	550'536	373'298	1'206'294	562'232	723'565	132'676	649'938	63'940	42'511	32'785	4'337'775
1994	621'726	392'967	1'270'296	530'906	798'449	136'103	717'840	66'896	40'986	33'746	4'609'915
1995	650'572	407'119	1'388'932	570'552	774'040	154'108	590'859	56'714	51'643	33'869	4'678'408
1996	520'335	381'365	1'066'770	567'769	654'554	151'164	506'107	59'674	48'288	38'889	3'994'915
1997	599'981	394'846	1'176'333	576'415	742'830	153'719	574'152	63'650	61'043	40'189	4'383'158
1998	604'703	422'216	1'330'973	627'633	836'806	164'348	657'409	108'848	50'626	41'485	4'845'047
1999	602'652	398'648	1'342'905	639'150	824'142	173'845	593'844	68'786	44'556	39'181	4'727'709
2000	994'262	387'183	3'916'680	934'372	2'241'486	213'858	436'743	57'105	21'236	35'049	9'237'974
2001	443'612	338'751	2'020'561	594'616	1'477'489	157'710	510'730	60'152	22'237	35'722	5'661'580
2002	442'519	329'480	1'406'758	493'905	1'090'875	134'603	528'144	63'303	31'236	35'794	4'556'617
2003	557'454	315'096	1'669'605	518'273	1'195'090	142'055	588'062	62'739	37'111	35'486	5'120'971
2004	655'757	305'681	1'774'841	515'877	1'119'243	164'745	488'722	70'090	29'995	35'571	5'160'522
2005	653049	359808	1810839	614845	1010979	180546	514905	70603	35462	33614	5'284'650
2006	735'256	405'850	1'779'973	687'428	1'116'868	229'781	569'673	84'656	43'443	48'599	5'701'527
2007	793'459	425'790	1'587'494	699'076	1'144'370	230'284	621'234	82'414	62'799	43'638	5'690'558
2008	705'815	459'994	1'281'782	727'581	1'018'497	224'634	664'086	82'623	53'064	44'123	5'262'199
2009	598'292	461'055	1'149'202	701'188	878'565	224'490	678'212	90'001	56'375	42'316	4'879'696
2010	647'176	494'739	1'090'994	722'644	992'435	248'151	720'659	99'773	60'391	52'037	5'128'999
2011	617'887	513'720	1'061'986	741'587	983'040	253'300	686'797	101'644	61'822	53'305	5'075'088
2012	566'782	488'626	970'748	719'003	825'019	225'988	665'506	94'480	51'475	50'757	4'658'384
2013	576'744	521'122	948'706	739'180	834'166	254'726	670'170	117'841	64'745	50'928	4'778'328
2014	619'002	539'721	945'695	777'852	863'150	259'888	654'300	110'816	95'192	47'603	4'913'219
2015	528'202	505'431	916'020	766'645	753'783	244'149	625'555	96'230	62'233	53'649	4'551'897
2016	549'561	509'699	859'677	737'207	766'647	236'279	570'415	103'416	65'254	60'836	4'458'991
2017	545'998	514'176	993'430	765'711	806'033	242'423	596'105	96'622	72'298	54'746	4'687'542
2018	564'468	492'343	1'421'416	719'879	910'871	216'813	649'759	94'766	61'417	66'470	5'198'202

Growing stock: calculation of time series

In order to develop a consistent time series, annual growing stocks of living biomass ($stockC_l$) were calculated per spatial strata (i) for productive forests (CC12) backward or forward starting from the growing stock 2005, determined from common plots from NFI2-3 (Brändli 2010; abbreviations are explained in chp. 6.1.3.2):

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} - \sum_{n=2005}^{iy} [gainC_{l,i,CC12,n}] + \sum_{n=2005}^{iy} [lossC_{l,i,CC12,n}] \quad \text{for } iy < 2005$$

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} \quad \text{for } iy = 2005$$

$$stockC_{l,i,CC12,iy} = stockC_{l,i,CC12,2005} + \sum_{n=2006}^{iy} [gainC_{l,i,CC12,n}] - \sum_{n=2006}^{iy} [lossC_{l,i,CC12,n}] \quad \text{for } iy > 2005$$

where “iy” indicates the inventory year (here: 1985–2018), “n” the years between 2005 and the inventory year iy.

The backward calculation was used for the time period 1985–2004 (iy <2005), where the annual growing stock equals the growing stock 2005 minus the net change based on the gains due to the annual gross growth ($gainC_{l,i,CC12,iy}$) and the losses due to the annual amounts of cut and mortality ($lossC_{l,i,CC12,iy}$).

The forward calculation was used for the time period after 2005 (iy >2005), where the annual growing stock equals the growing stock 2005 plus the net change based on the gains due to the annual gross growth ($gainC_{l,i,CC12,iy}$) and the losses due the annual amounts of cut and mortality ($lossC_{l,i,CC12,iy}$).

Annual values of gross growth (gains in carbon stock of living biomass), cut and mortality (losses in carbon stock of living biomass) and calculated growing stocks (carbon stocks in living biomass) for the period 1990 to 2018 specified for all spatial strata are displayed in Table 6-18.

All working steps and data required to reproduce the calculation of emission factors for productive forests (CC12) in the period 1990–2018 are summarized in FOEN (2020c).

Table 6-18 Annual carbon data of living biomass for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.) for stocks (stockCl), gains (gross growth, gainCl) and losses (cut and mortality, lossCl). Highlighted data for 1990 are displayed in Table 6-4.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
1	1	128.65	130.14	131.45	132.77	133.91	134.96	134.44	133.64	132.63	131.80
1	2	125.27	126.64	127.81	128.99	129.98	130.87	131.58	132.08	132.48	132.96
1	3	84.74	85.71	86.53	87.36	88.06	88.69	89.46	90.11	90.73	91.37
2	1	134.51	135.97	136.89	137.82	138.74	139.34	140.14	140.70	140.83	140.90
2	2	147.20	148.86	149.99	151.13	152.23	153.02	154.09	154.91	155.30	155.63
2	3	102.11	103.09	103.95	104.81	105.64	106.40	106.82	107.17	107.41	107.64
3	1	135.07	136.81	138.76	140.67	142.46	144.02	146.17	148.18	149.97	151.71
3	2	147.49	148.86	150.59	152.32	153.87	155.38	156.92	158.20	159.16	160.12
3	3	118.79	119.37	120.26	121.17	121.92	122.71	123.80	124.70	125.41	126.14
4	1	92.97	93.11	93.52	94.22	94.77	95.74	97.85	99.66	100.68	102.39
4	2	103.37	103.65	104.48	105.50	106.38	107.54	108.53	109.44	109.85	110.69
4	3	94.98	94.76	95.15	95.71	96.14	96.81	97.56	98.15	98.54	99.09
5	1	72.68	74.33	75.88	77.27	78.63	79.97	80.57	81.13	81.63	82.23
5	2	76.85	78.33	79.69	80.96	82.22	83.44	84.94	86.40	87.86	89.37
5	3	76.43	77.69	78.73	79.79	80.87	81.85	83.06	84.13	85.31	86.56

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
1	1	130.14	130.09	130.12	129.97	129.67	128.99	129.11	129.01	128.93	129.08
1	2	132.57	133.59	134.64	135.47	136.09	136.57	136.80	136.81	137.01	137.52
1	3	91.47	92.38	93.30	94.06	94.70	95.30	95.38	95.30	95.40	95.76
2	1	135.39	134.39	134.81	134.68	134.37	133.68	132.11	130.96	130.46	130.34
2	2	150.00	149.04	149.58	149.52	149.25	148.67	145.84	144.61	144.11	144.02
2	3	106.15	105.96	106.20	106.26	106.25	106.19	145.84	144.61	144.11	144.02
3	1	151.23	152.21	153.91	155.40	156.81	158.25	156.33	155.52	155.17	155.29
3	2	156.83	156.00	156.38	156.43	156.59	156.97	156.33	155.52	155.17	155.29
3	3	123.92	123.30	123.49	123.46	123.58	123.92	124.41	124.85	125.50	126.39
4	1	104.45	106.39	108.26	110.07	111.88	113.65	116.32	116.70	116.98	117.16
4	2	111.91	112.98	113.98	114.88	115.91	116.88	116.32	116.70	116.98	117.16
4	3	99.99	100.73	101.42	101.99	102.77	103.49	104.55	105.52	106.42	107.28
5	1	82.98	83.71	84.43	85.17	85.90	86.70	87.45	88.34	89.23	90.19
5	2	90.98	92.58	94.16	95.74	97.33	98.93	100.27	101.62	102.99	104.37
5	3	88.06	89.54	90.93	92.26	93.67	95.02	96.45	97.74	99.10	100.45

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
1	1	128.97	128.83	128.92	128.83	128.57	128.66	128.69	128.70	128.78	
1	2	137.82	138.16	138.71	139.16	139.44	140.06	140.61	141.17	141.71	
1	3	95.97	96.24	96.65	97.01	97.26	97.74	98.18	98.62	99.03	
2	1	130.30	130.27	130.52	130.77	130.92	131.16	131.63	131.70	130.88	
2	2	144.04	144.08	144.42	144.76	145.01	145.37	145.95	146.11	145.26	
2	3	144.04	144.08	144.42	144.76	145.01	145.37	145.95	146.11	145.26	
3	1	154.92	154.55	154.86	155.00	155.01	155.47	155.93	156.22	156.27	
3	2	154.92	154.55	154.86	155.00	155.01	155.47	155.93	156.22	156.27	
3	3	127.08	127.79	128.76	129.71	130.62	131.71	132.78	133.78	134.61	
4	1	117.16	117.21	117.38	117.33	117.38	117.63	117.93	118.24	118.45	
4	2	117.16	117.21	117.38	117.33	117.38	117.63	117.93	118.24	118.45	
4	3	108.07	108.91	109.80	110.67	111.56	112.52	113.57	114.58	115.50	
5	1	90.77	91.29	91.94	92.55	93.21	93.72	93.95	94.39	94.42	
5	2	105.62	106.85	108.14	109.39	110.61	111.84	112.96	114.15	115.21	
5	3	101.73	103.00	104.36	105.61	106.63	107.90	109.11	110.29	111.52	

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: gain of living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
1	1	3.60	3.60	3.60	3.60	3.60	3.60	3.37	3.37	3.37	3.37
1	2	3.21	3.21	3.21	3.21	3.21	3.21	3.04	3.04	3.04	3.04
1	3	1.95	1.95	1.95	1.95	1.95	1.95	1.80	1.80	1.80	1.80
2	1	4.63	4.63	4.63	4.63	4.63	4.63	4.54	4.54	4.54	4.54
2	2	4.63	4.63	4.63	4.63	4.63	4.63	4.56	4.56	4.56	4.56
2	3	1.60	1.60	1.60	1.60	1.60	1.60	1.28	1.28	1.28	1.28
3	1	4.56	4.56	4.56	4.56	4.56	4.56	4.23	4.23	4.23	4.23
3	2	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15
3	3	2.48	2.48	2.48	2.48	2.48	2.48	2.50	2.50	2.50	2.50
4	1	3.24	3.24	3.24	3.24	3.24	3.24	3.44	3.44	3.44	3.44
4	2	2.49	2.49	2.49	2.49	2.49	2.49	2.50	2.50	2.50	2.50
4	3	1.81	1.81	1.81	1.81	1.81	1.81	1.90	1.90	1.90	1.90
5	1	2.74	2.74	2.74	2.74	2.74	2.74	2.04	2.04	2.04	2.04
5	2	2.20	2.20	2.20	2.20	2.20	2.20	2.18	2.18	2.18	2.18
5	3	1.61	1.61	1.61	1.61	1.61	1.61	1.79	1.79	1.79	1.79

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: gain of living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
1	1	3.37	3.37	3.37	3.37	3.37	3.37	3.57	3.57	3.57	3.57
1	2	3.04	3.04	3.04	3.04	3.04	3.04	3.25	3.25	3.25	3.25
1	3	1.80	1.80	1.80	1.80	1.80	1.80	2.13	2.13	2.13	2.13
2	1	4.54	4.54	4.54	4.54	4.54	4.54	4.51	4.51	4.51	4.51
2	2	4.56	4.56	4.56	4.56	4.56	4.56	4.82	4.82	4.82	4.82
2	3	1.28	1.28	1.28	1.28	1.28	1.28	4.82	4.82	4.82	4.82
3	1	4.23	4.23	4.23	4.23	4.23	4.23	4.20	4.20	4.20	4.20
3	2	4.15	4.15	4.15	4.15	4.15	4.15	4.20	4.20	4.20	4.20
3	3	2.50	2.50	2.50	2.50	2.50	2.50	2.37	2.37	2.37	2.37
4	1	3.44	3.44	3.44	3.44	3.44	3.44	2.35	2.55	2.55	2.55
4	2	2.50	2.50	2.50	2.50	2.50	2.50	2.35	2.55	2.55	2.55
4	3	1.90	1.90	1.90	1.90	1.90	1.90	2.12	2.12	2.12	2.12
5	1	2.04	2.04	2.04	2.04	2.04	2.04	2.70	2.70	2.70	2.70
5	2	2.18	2.18	2.18	2.18	2.18	2.18	2.07	2.07	2.07	2.07
5	3	1.79	1.79	1.79	1.79	1.79	1.79	1.93	1.93	1.93	1.93

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: gain of living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
1	1	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	
1	2	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	
1	3	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	
2	1	4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.51	
2	2	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	
2	3	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	
3	1	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	
3	2	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	
3	3	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	
4	1	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	
4	2	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55	
4	3	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	
5	1	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	
5	2	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	
5	3	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: loss of living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
1	1	-2.38	-2.12	-2.29	-2.29	-2.46	-2.55	-3.89	-4.17	-4.37	-4.20
1	2	-2.28	-1.83	-2.04	-2.03	-2.23	-2.32	-2.32	-2.54	-2.63	-2.56
1	3	-1.36	-0.99	-1.13	-1.12	-1.26	-1.32	-1.03	-1.15	-1.18	-1.16
2	1	-4.77	-3.17	-3.72	-3.70	-3.71	-4.03	-3.75	-3.97	-4.41	-4.47
2	2	-4.61	-2.98	-3.50	-3.49	-3.53	-3.84	-3.50	-3.74	-4.18	-4.23
2	3	-1.05	-0.62	-0.74	-0.74	-0.77	-0.84	-0.86	-0.93	-1.04	-1.05
3	1	-3.35	-2.82	-2.60	-2.64	-2.77	-2.99	-2.09	-2.22	-2.44	-2.49
3	2	-3.78	-2.78	-2.42	-2.41	-2.60	-2.63	-2.61	-2.87	-3.19	-3.20
3	3	-2.75	-1.90	-1.60	-1.57	-1.73	-1.69	-1.41	-1.59	-1.79	-1.77
4	1	-3.19	-3.10	-2.83	-2.55	-2.69	-2.27	-1.49	-1.62	-2.42	-1.72
4	2	-2.59	-2.21	-1.66	-1.48	-1.61	-1.33	-1.43	-1.59	-2.10	-1.67
4	3	-2.47	-2.03	-1.41	-1.25	-1.38	-1.14	-1.15	-1.30	-1.51	-1.35
5	1	-0.92	-1.09	-1.18	-1.35	-1.38	-1.40	-1.44	-1.49	-1.54	-1.45
5	2	-0.61	-0.72	-0.84	-0.92	-0.94	-0.98	-0.67	-0.72	-0.72	-0.67
5	3	-0.30	-0.35	-0.57	-0.54	-0.53	-0.63	-0.58	-0.71	-0.61	-0.54

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: loss of living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
1	1	-5.03	-3.41	-3.35	-3.51	-3.67	-4.05	-3.46	-3.67	-3.65	-3.42
1	2	-3.43	-2.02	-1.99	-2.21	-2.41	-2.56	-3.02	-3.24	-3.05	-2.74
1	3	-1.70	-0.89	-0.88	-1.03	-1.16	-1.20	-2.06	-2.21	-2.03	-1.78
2	1	-10.04	-5.54	-4.12	-4.67	-4.85	-5.23	-6.08	-5.66	-5.02	-4.63
2	2	-10.20	-5.52	-4.03	-4.62	-4.83	-5.14	-6.52	-6.05	-5.32	-4.90
2	3	-2.77	-1.47	-1.05	-1.22	-1.29	-1.34	-6.52	-6.05	-5.32	-4.90
3	1	-4.72	-3.24	-2.54	-2.74	-2.82	-2.80	-4.91	-5.01	-4.55	-4.07
3	2	-7.44	-4.99	-3.77	-4.10	-4.00	-3.77	-4.91	-5.01	-4.55	-4.07
3	3	-4.72	-3.12	-2.31	-2.53	-2.38	-2.16	-1.88	-1.93	-1.72	-1.49
4	1	-1.37	-1.50	-1.57	-1.62	-1.63	-1.67	-2.07	-2.17	-2.27	-2.37
4	2	-1.28	-1.44	-1.50	-1.61	-1.48	-1.53	-2.07	-2.17	-2.27	-2.37
4	3	-1.00	-1.16	-1.20	-1.33	-1.12	-1.18	-1.05	-1.14	-1.22	-1.25
5	1	-1.29	-1.32	-1.32	-1.31	-1.31	-1.24	-1.95	-1.81	-1.81	-1.75
5	2	-0.56	-0.58	-0.59	-0.60	-0.59	-0.57	-0.73	-0.71	-0.70	-0.68
5	3	-0.29	-0.31	-0.40	-0.46	-0.38	-0.44	-0.50	-0.64	-0.56	-0.58

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: loss of living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
1	1	-3.68	-3.71	-3.49	-3.66	-3.83	-3.48	-3.55	-3.56	-3.50	
1	2	-2.96	-2.91	-2.71	-2.81	-2.97	-2.63	-2.70	-2.70	-2.71	
1	3	-1.92	-1.86	-1.72	-1.77	-1.89	-1.65	-1.70	-1.70	-1.72	
2	1	-4.56	-4.54	-4.26	-4.27	-4.37	-4.26	-4.05	-4.44	-5.33	
2	2	-4.80	-4.78	-4.48	-4.47	-4.57	-4.46	-4.23	-4.66	-5.67	
2	3	-4.80	-4.78	-4.48	-4.47	-4.57	-4.46	-4.23	-4.66	-5.67	
3	1	-4.57	-4.56	-3.89	-4.06	-4.18	-3.73	-3.74	-3.90	-4.14	
3	2	-4.57	-4.56	-3.89	-4.06	-4.18	-3.73	-3.74	-3.90	-4.14	
3	3	-1.68	-1.66	-1.40	-1.42	-1.46	-1.28	-1.30	-1.37	-1.54	
4	1	-2.56	-2.50	-2.38	-2.60	-2.50	-2.31	-2.25	-2.24	-2.35	
4	2	-2.56	-2.50	-2.38	-2.60	-2.50	-2.31	-2.25	-2.24	-2.35	
4	3	-1.33	-1.27	-1.23	-1.25	-1.22	-1.16	-1.06	-1.11	-1.20	
5	1	-2.13	-2.18	-2.06	-2.10	-2.04	-2.19	-2.47	-2.26	-2.68	
5	2	-0.82	-0.84	-0.78	-0.81	-0.84	-0.84	-0.94	-0.88	-1.01	
5	3	-0.65	-0.66	-0.57	-0.68	-0.91	-0.67	-0.71	-0.75	-0.70	

6.4.2.6 Productive forests (CC12): carbon stocks in dead wood, in litter and in mineral soil

Method

Switzerland uses the soil carbon model Yasso07 to estimate temporal changes in carbon stocks in dead wood, organic soil horizons (LFH; litter) and mineral forest soil (0–100 cm depth) for productive forests (CC12). The implementation of Yasso07 (Tuomi et al. 2009, 2011) in the Swiss GHG inventory is described in detail in Didion et al. (2012) and, for the current submission, in Didion (2019). Didion et al. (2014a) demonstrated the validity of the model for application in Swiss forests. Consistently with the estimation procedure for living biomass, the model is applied on the common plots between two inventories (chp. 6.4.2.5; Table 6-13).

Yasso07 is a model of carbon cycling in mineral soil, litter and dead wood. For estimating stocks of organic carbon in mineral soil up to a depth of ca. 100 cm and the temporal dynamics of the carbon stocks, Yasso07 requires information on carbon inputs (see below) and climate (annual monthly temperature and precipitation).

The Swiss NFI is the source of carbon inputs and of the state change of each sample tree between two consecutive inventories (i.e. survivor, cut, mortality, ingrowth and nongrowth trees; Didion et al. 2019). The tree state in two consecutive inventories determines the type and quantity of carbon inputs. Turnover rates reflecting the longevity of leaves and needles, seeds and fruits, fine roots, and small branches are used to estimate carbon inputs that are produced annually. Stemwood, incl. tree top and stump, large branches, and coarse roots are assumed to accrue only as the result of mortality. Depending on the cause of mortality, i.e. natural or timber harvesting, either the total mass of these tree elements or only the non-merchantable fraction (coarse root, stump, top, and small branches) is considered for carbon inputs.

By default, Yasso07 does not provide separate estimates of carbon pool sizes for dead wood, litter and soil. In order to report estimates for each pool, the model structure of Yasso07 was examined for deriving separate estimates. Dead wood, litter and soil pools could be correlated with modelled data based on the category of carbon input, i.e., non-woody and woody material, and the five carbon compartments in Yasso07, i.e. four chemical partitions (insoluble, soluble in ethanol, soluble in water or in acid) and humus. The approach was validated using independent, measured data (see Didion et al. 2012).

Carbon stocks in dead wood, litter and mineral soil

Carbon stocks in dead wood are simulated and estimated based on source of carbon inputs, including (1) stemwood of trees ≥12 cm (diameter at breast height; DBH), (2) large branches ≥ ca. 7 cm in diameter, and (3) dead coarse roots > ca. 5 mm in diameter. These tree elements were estimated according to Table 6-16.

Litter carbon stocks are derived from simulations of carbon inputs of the tree elements small branches and twigs < ca. 7 cm in diameter, bark of the tree bole, foliage (see Table 6-19 for estimation of these elements), seeds and fruits (based on published allometries, cf. Didion and Zell 2019), and fine roots < ca. 5 mm (estimated as fraction of coarse roots; Perruchoud et al. 1999). Following improvements to the simulation of litter with Yasso07 (chp. 2.4.1 in

Didion and Thuerig 2018), simulated litter carbon stocks replace the former estimates derived from Nussbaum et al. (2012), resulting in consistency and comparability of dead wood and litter estimates.

Stratified estimated stocks of dead wood and litter for 1990 are shown in Table 6-19. Annual values for stocks of dead wood and litter since 1990 are displayed in Table 6-20.

Due to the incomplete knowledge of the origin of the high carbon stocks in mineral soils, particularly pyrogenic carbon in the mountainous soils of Southern Switzerland (Eckmeier et al. 2010; Nussbaum et al. 2012; Nussbaum et al. 2014; Zanelli et al. 2006), they cannot be reproduced by models yet. Hence, soil carbon stocks were estimated by Nussbaum et al. (2012, 2014) based on soil profiles and robust geostatistical methods. The soil profiles are part of a pedothek maintained at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The data used by Nussbaum et al. (2012, 2014) were collected over the past 30 years (n=1033 sites) distributed among different forest types throughout Switzerland.

The data for soil carbon stocks were stratified by the five NFI production regions and three elevation levels (Table 6-19). The national average carbon stocks in mineral forest soils calculated by Nussbaum et al. (2012) were 79.9 t C ha^{-1} (0–30 cm topsoil) and 125.8 t C ha^{-1} (0–100 cm). The sites in the WSL soil database which were used by Nussbaum et al. (2012, 2014) were visited mostly between 1990 and 2005. Hence, it is not possible to attribute the national estimates of carbon stocks in mineral forest soils to one single year. Consequently, a combination of these carbon stocks and the carbon stock changes derived from the Yasso07 model (Didion 2019; see chp. 6.4.2.7) would not result in a consistent time series for soil carbon stocks. Thus, it was assumed that the values from Nussbaum et al. (2012, 2014) are representative for current conditions of Swiss forests soils and are therefore used for the period 1990 until the latest inventory year.

Table 6-19 Carbon stocks in dead wood ($stockC_d$) and litter ($stockC_h$) in Swiss productive forests (CC12) by spatial stratum in t C ha^{-1} for 1990 (Source: Tables A-23, A-24 (means) and A-25, A-26 (SE) in Didion 2019). Carbon stocks in mineral soil (0–30 cm; $stockC_s$) (Sources: Table 5 in Nussbaum et al. 2012, Nussbaum et al. 2014; used for CC11, CC12, CC13) were assumed to be representative for 1990–2018. The data were stratified for NFI production regions and elevation zones. Dead wood and litter stocks in some strata were aggregated due to the low number of samples. Average values ± single standard errors are given.

NFI region	Elevation [m]	Carbon stock in dead wood 1990 ($stockC_{d,i,CC12}$) [t C ha^{-1}]	Carbon stock in litter ($stockC_{h,i,CC12}$) [t C ha^{-1}]	Carbon stock in mineral topsoil 0-30 cm ($stockC_{s,i,CC11}$, $stockC_{s,i,CC12}$, $stockC_{s,i,CC13}$) [t C ha^{-1}]
1	<601	4.86 ± 0.05	12.02 ± 0.11	82.65 ± 3.34
1	601-1200	5.24 ± 0.03	12.13 ± 0.07	102.03 ± 3.56
1	>1200	4.54 ± 0.08	10.12 ± 0.13	121.34 ± 5.39
2	<601	8.10 ± 0.05	12.38 ± 0.07	55.40 ± 1.55
2	601-1200	7.79 ± 0.06	13.25 ± 0.08	62.12 ± 1.68
2	>1200	7.79 ± 0.06	13.25 ± 0.08	122.00 ± 7.07
3	<601	7.61 ± 0.05	14.3 ± 0.08	66.10 ± 2.06
3	601-1200	7.61 ± 0.05	14.3 ± 0.08	57.91 ± 2.00
3	>1200	6.00 ± 0.07	13.71 ± 0.11	95.78 ± 3.27
4	<601	5.67 ± 0.06	11.94 ± 0.08	66.47 ± 2.44
4	601-1200	5.67 ± 0.06	11.94 ± 0.08	74.39 ± 2.42
4	>1200	5.14 ± 0.04	14.75 ± 0.07	69.48 ± 1.85
5	<601	2.22 ± 0.09	8.36 ± 0.16	102.37 ± 4.07
5	601-1200	2.08 ± 0.05	9.88 ± 0.18	108.99 ± 4.09
5	>1200	1.76 ± 0.03	11.07 ± 0.11	107.08 ± 4.11
Switzerland		5.76 ± 0.02	12.89 ± 0.03	79.93 ± 1.52

Table 6-20 Carbon stock in dead wood and in litter for CC12 stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4 and in Table 6-19.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
1	1	4.86	4.92	4.95	4.97	4.97	4.99	5.30	5.64	5.92	6.16
1	2	5.24	5.30	5.33	5.36	5.37	5.40	5.42	5.49	5.56	5.61
1	3	4.54	4.54	4.51	4.50	4.47	4.46	4.23	4.13	4.05	3.98
2	1	8.10	8.18	8.23	8.27	8.26	8.29	8.59	8.92	9.19	9.41
2	2	7.79	7.86	7.90	7.93	7.93	7.95	8.28	8.64	8.95	9.22
2	3	7.79	7.86	7.90	7.93	7.93	7.95	8.28	8.64	8.95	9.22
3	1	7.61	7.73	7.81	7.90	7.94	8.02	8.44	8.82	9.17	9.49
3	2	7.61	7.73	7.81	7.90	7.94	8.02	8.44	8.82	9.17	9.49
3	3	6.00	6.04	6.06	6.09	6.09	6.12	5.94	6.00	6.07	6.14
4	1	5.67	5.77	5.85	5.93	5.99	6.07	5.94	5.93	5.93	5.92
4	2	5.67	5.77	5.85	5.93	5.99	6.07	5.94	5.93	5.93	5.92
4	3	5.14	5.26	5.36	5.46	5.53	5.63	5.39	5.38	5.38	5.37
5	1	2.22	2.29	2.34	2.39	2.44	2.49	2.47	2.51	2.55	2.58
5	2	2.08	2.15	2.20	2.25	2.30	2.35	2.14	2.04	1.95	1.87
5	3	1.76	1.78	1.80	1.82	1.84	1.86	1.74	1.72	1.71	1.70

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
1	1	6.39	6.59	6.76	6.99	7.16	7.33	7.32	7.37	7.45	7.54
1	2	5.65	5.69	5.72	5.78	5.82	5.88	6.34	6.51	6.68	6.84
1	3	3.90	3.84	3.77	3.72	3.67	3.63	3.11	3.29	3.46	3.62
2	1	9.61	9.78	9.94	10.18	10.34	10.51	10.63	10.64	10.68	10.74
2	2	9.45	9.67	9.85	10.10	10.29	10.49	9.85	9.96	10.09	10.23
2	3	9.45	9.67	9.85	10.10	10.29	10.49	9.85	9.96	10.09	10.23
3	1	9.77	10.04	10.26	10.51	10.73	10.96	10.72	10.97	11.22	11.46
3	2	9.77	10.04	10.26	10.51	10.73	10.96	10.72	10.97	11.22	11.46
3	3	6.19	6.24	6.28	6.32	6.37	6.43	6.60	6.50	6.42	6.36
4	1	5.91	5.91	5.89	5.90	5.91	5.94	5.42	5.73	6.01	6.28
4	2	5.91	5.91	5.89	5.90	5.91	5.94	5.42	5.73	6.01	6.28
4	3	5.36	5.35	5.34	5.34	5.36	5.38	5.06	5.07	5.09	5.12
5	1	2.61	2.64	2.66	2.70	2.72	2.76	3.00	3.21	3.40	3.58
5	2	1.79	1.73	1.67	1.62	1.58	1.54	1.54	1.56	1.58	1.60
5	3	1.69	1.68	1.67	1.67	1.67	1.67	1.20	1.27	1.34	1.41

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
1	1	7.65	7.71	7.77	7.84	7.86	7.94	7.97	8.03	8.07	
1	2	7.02	7.14	7.26	7.39	7.45	7.55	7.62	7.71	7.78	
1	3	3.78	3.89	4.01	4.13	4.21	4.30	4.37	4.45	4.51	
2	1	10.83	10.87	10.91	10.96	10.94	11.00	11.00	11.05	11.08	
2	2	10.39	10.49	10.59	10.70	10.72	10.81	10.86	10.94	10.99	
2	3	10.39	10.49	10.59	10.70	10.72	10.81	10.86	10.94	10.99	
3	1	11.72	11.88	12.07	12.27	12.36	12.49	12.59	12.72	12.82	
3	2	11.72	11.88	12.07	12.27	12.36	12.49	12.59	12.72	12.82	
3	3	6.33	6.24	6.19	6.16	6.09	6.03	5.98	5.94	5.89	
4	1	6.55	6.75	6.96	7.16	7.30	7.45	7.60	7.73	7.85	
4	2	6.55	6.75	6.96	7.16	7.30	7.45	7.60	7.73	7.85	
4	3	5.17	5.17	5.18	5.21	5.21	5.21	5.23	5.24	5.24	
5	1	3.75	3.89	4.02	4.15	4.25	4.35	4.44	4.54	4.62	
5	2	1.62	1.63	1.65	1.67	1.67	1.68	1.70	1.71	1.72	
5	3	1.47	1.53	1.58	1.63	1.67	1.71	1.75	1.78	1.82	

(Table 6-20 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
1	1	12.02	12.15	12.09	12.08	11.90	11.86	12.04	12.20	12.23	12.19
1	2	12.13	12.25	12.22	12.22	12.08	12.08	12.29	12.44	12.55	12.61
1	3	10.12	10.09	9.98	9.92	9.77	9.75	9.54	9.61	9.73	9.80
2	1	12.38	12.50	12.46	12.41	12.23	12.20	12.36	12.50	12.53	12.48
2	2	13.25	13.37	13.34	13.32	13.14	13.15	13.29	13.39	13.45	13.44
2	3	13.25	13.37	13.34	13.32	13.14	13.15	13.29	13.39	13.45	13.44
3	1	14.30	14.46	14.45	14.47	14.32	14.38	14.60	14.68	14.80	14.89
3	2	14.30	14.46	14.45	14.47	14.32	14.38	14.60	14.68	14.80	14.89
3	3	13.71	13.81	13.76	13.80	13.67	13.74	13.41	13.45	13.61	13.72
4	1	11.94	12.06	12.04	12.07	11.98	12.05	12.05	12.20	12.40	12.49
4	2	11.94	12.06	12.04	12.07	11.98	12.05	12.05	12.20	12.40	12.49
4	3	14.75	14.96	14.98	15.10	15.03	15.18	14.89	15.06	15.31	15.41
5	1	8.36	8.41	8.40	8.40	8.35	8.41	8.67	8.84	9.01	9.13
5	2	9.88	10.04	10.10	10.17	10.16	10.28	10.48	10.73	10.98	11.19
5	3	11.07	11.27	11.32	11.44	11.42	11.58	11.38	11.70	12.02	12.29

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
1	1	12.18	12.16	12.09	12.38	12.38	12.47	12.35	12.26	12.30	12.39
1	2	12.63	12.68	12.63	12.83	12.86	12.99	12.83	12.78	12.84	12.93
1	3	9.81	9.87	9.85	9.91	9.96	10.07	10.27	10.38	10.54	10.69
2	1	12.44	12.39	12.33	12.58	12.58	12.68	12.19	11.96	11.89	11.89
2	2	13.40	13.40	13.33	13.53	13.55	13.66	12.96	12.82	12.82	12.87
2	3	13.40	13.40	13.33	13.53	13.55	13.66	12.96	12.82	12.82	12.87
3	1	14.89	14.97	14.91	15.01	15.08	15.21	15.12	15.06	15.11	15.17
3	2	14.89	14.97	14.91	15.01	15.08	15.21	15.12	15.06	15.11	15.17
3	3	13.75	13.85	13.81	13.83	13.94	14.08	12.19	12.05	12.01	11.97
4	1	12.54	12.64	12.60	12.75	12.86	13.05	12.37	12.44	12.55	12.71
4	2	12.54	12.64	12.60	12.75	12.86	13.05	12.37	12.44	12.55	12.71
4	3	15.44	15.58	15.54	15.72	15.90	16.15	15.36	15.50	15.66	15.87
5	1	9.19	9.30	9.33	9.47	9.50	9.68	9.37	9.36	9.37	9.40
5	2	11.29	11.46	11.50	11.67	11.74	11.98	12.47	12.53	12.62	12.70
5	3	12.44	12.65	12.71	12.91	13.04	13.36	11.81	12.08	12.34	12.57

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
1	1	12.54	12.52	12.51	12.56	12.39	12.52	12.45	12.52	12.52	
1	2	13.13	13.04	13.06	13.14	12.97	13.00	12.94	13.00	12.96	
1	3	10.93	10.88	10.96	11.08	10.98	10.97	10.95	10.99	10.94	
2	1	11.99	11.92	11.89	11.90	11.71	11.79	11.69	11.74	11.73	
2	2	13.02	12.95	12.96	13.01	12.81	12.86	12.78	12.83	12.82	
2	3	13.02	12.95	12.96	13.01	12.81	12.86	12.78	12.83	12.82	
3	1	15.37	15.22	15.28	15.38	15.16	15.12	15.06	15.09	15.07	
3	2	15.37	15.22	15.28	15.38	15.16	15.12	15.06	15.09	15.07	
3	3	12.08	11.87	11.86	11.91	11.73	11.64	11.59	11.57	11.50	
4	1	12.96	12.90	12.95	13.07	12.95	12.95	12.94	12.98	12.92	
4	2	12.96	12.90	12.95	13.07	12.95	12.95	12.94	12.98	12.92	
4	3	16.21	16.15	16.19	16.33	16.25	16.22	16.28	16.32	16.22	
5	1	9.52	9.49	9.51	9.53	9.43	9.45	9.45	9.47	9.47	
5	2	12.92	12.87	12.90	12.97	12.88	12.87	12.86	12.89	12.89	
5	3	12.91	12.92	13.00	13.15	13.13	13.14	13.19	13.23	13.26	

6.4.2.7 Productive forests (CC12): changes in carbon stocks of dead wood, of litter and of mineral soils

Annual stratified values of carbon stock changes for dead wood, litter and mineral soils are calculated from the simulated annual stocks (chp. 6.4.2.6) and results are given in Table 6-21. Despite limitations to reproduce the comparably high carbon stocks in mineral soils in Swiss forests (chp. 6.4.2.6), the stock changes derived from simulated stocks are accurate because (1) the pyrogenic carbon which is found particularly in the soils of the Southern Alps is very stable (Eckmeier et al. 2010), and (2) the simulated carbon stock changes including standard error are less than the minimum detection limit of repeated soil carbon stock measurements (chp. 6.4.4). Furthermore, carbon stock changes were validated as described in Didion (2019).

Carbon stock changes in the soil pool are small (Table 6-21). The Yasso07 estimates are supported by measurements of the Swiss Soil Monitoring Network (see chp. 6.4.4). Carbon stock changes in litter are higher and more erratic than changes in the dead wood and soil pools (Figure 6-6). This is expected since non-woody material decomposes faster than dead wood (Tuomi et al. 2011) and there is a higher interannual variability in the production of foliage (Etzold et al. 2011). The carbon stock change in the dead wood pool is to a large extend driven by the increase in dead wood volume in Swiss forests since the mid-1990s (Brändli 2010). Dead wood accumulation as a consequence of the winterstorm Lothar which occurred in 1999, i.e. between the NFI2 (1993–1995) and NFI3 (2004–2006), strongly affects the results of the change analysis for dead wood volume in the period NFI2 to NFI3. Although the majority of the windthrown trees were removed from the forest, the dead wood stock increased significantly. As particularly the larger-sized felled trees decay slowly (Didion et al. 2014a), the storm resulted in a sustained carbon sink. The trend of decreasing harvesting rates for several years after NFI3 (see Table 6-17) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest and potentially contribute to the dead wood pool. Large-scale disturbance events like Lothar occurring between two consecutive NFIs can strongly affect the estimates of annually accumulating mass of dead wood that drives the Yasso07 simulation. Results of the NFI4 indicate that dead wood volume is still increasing (Brändli et al. 2020).

Table 6-21 Net carbon stock change in dead wood, in litter and in mineral soil for productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stock.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
1	1	0.02	0.06	0.03	0.03	0.00	0.02	0.39	0.34	0.28	0.24
1	2	0.03	0.06	0.03	0.03	0.01	0.03	0.10	0.07	0.07	0.05
1	3	-0.03	-0.01	-0.02	-0.01	-0.03	-0.01	-0.08	-0.10	-0.08	-0.08
2	1	0.03	0.09	0.04	0.04	-0.01	0.03	0.37	0.33	0.27	0.22
2	2	0.03	0.07	0.04	0.03	-0.01	0.03	0.41	0.35	0.31	0.27
2	3	0.03	0.07	0.04	0.03	-0.01	0.03	0.41	0.35	0.31	0.27
3	1	0.09	0.12	0.09	0.08	0.04	0.08	0.45	0.38	0.35	0.32
3	2	0.09	0.12	0.09	0.08	0.04	0.08	0.45	0.38	0.35	0.32
3	3	0.02	0.04	0.02	0.03	0.00	0.03	0.10	0.06	0.07	0.07
4	1	0.09	0.11	0.08	0.08	0.05	0.08	0.01	-0.01	0.00	-0.01
4	2	0.09	0.11	0.08	0.08	0.05	0.08	0.01	-0.01	0.00	-0.01
4	3	0.11	0.12	0.10	0.10	0.07	0.10	0.01	-0.02	0.00	-0.01
5	1	0.07	0.06	0.05	0.05	0.04	0.05	0.05	0.03	0.04	0.03
5	2	0.07	0.07	0.05	0.05	0.04	0.05	-0.11	-0.11	-0.09	-0.08
5	3	0.02	0.03	0.02	0.02	0.01	0.02	-0.01	-0.02	-0.01	-0.01

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
1	1	0.22	0.20	0.17	0.24	0.17	0.17	0.09	0.05	0.08	0.09
1	2	0.04	0.04	0.03	0.07	0.04	0.06	0.20	0.16	0.17	0.17
1	3	-0.08	-0.06	-0.07	-0.05	-0.05	-0.04	0.21	0.18	0.17	0.16
2	1	0.20	0.18	0.15	0.24	0.16	0.18	0.06	0.00	0.04	0.06
2	2	0.23	0.22	0.18	0.25	0.18	0.20	0.17	0.11	0.13	0.14
2	3	0.23	0.22	0.18	0.25	0.18	0.20	0.17	0.11	0.13	0.14
3	1	0.28	0.27	0.22	0.25	0.22	0.23	0.30	0.24	0.25	0.24
3	2	0.28	0.27	0.22	0.25	0.22	0.23	0.30	0.24	0.25	0.24
3	3	0.05	0.06	0.03	0.04	0.05	0.06	-0.10	-0.10	-0.07	-0.07
4	1	-0.01	0.00	-0.02	0.01	0.01	0.03	0.35	0.31	0.28	0.27
4	2	-0.01	0.00	-0.02	0.01	0.01	0.03	0.35	0.31	0.28	0.27
4	3	-0.01	0.00	-0.02	0.01	0.01	0.03	0.02	0.02	0.02	0.03
5	1	0.03	0.03	0.02	0.04	0.02	0.04	0.25	0.21	0.19	0.17
5	2	-0.07	-0.06	-0.06	-0.05	-0.05	-0.04	0.03	0.02	0.02	0.02
5	3	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.09	0.08	0.07	0.07

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
1	1	0.11	0.06	0.06	0.07	0.01	0.08	0.03	0.06	0.04	
1	2	0.18	0.11	0.12	0.13	0.06	0.10	0.07	0.09	0.06	
1	3	0.16	0.11	0.12	0.12	0.08	0.08	0.08	0.08	0.06	
2	1	0.09	0.04	0.04	0.05	-0.03	0.06	0.00	0.05	0.03	
2	2	0.17	0.09	0.10	0.11	0.02	0.09	0.04	0.08	0.06	
2	3	0.17	0.09	0.10	0.11	0.02	0.09	0.04	0.08	0.06	
3	1	0.27	0.16	0.19	0.20	0.09	0.13	0.11	0.13	0.10	
3	2	0.27	0.16	0.19	0.20	0.09	0.13	0.11	0.13	0.10	
3	3	-0.03	-0.08	-0.05	-0.03	-0.07	-0.06	-0.05	-0.04	-0.05	
4	1	0.27	0.20	0.20	0.20	0.14	0.15	0.14	0.14	0.11	
4	2	0.27	0.20	0.20	0.20	0.14	0.15	0.14	0.14	0.11	
4	3	0.04	0.00	0.01	0.03	0.00	0.01	0.01	0.01	0.00	
5	1	0.17	0.14	0.13	0.13	0.10	0.11	0.09	0.09	0.08	
5	2	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	
5	3	0.07	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.03	

(Table 6-21 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
1	1	-0.11	0.13	-0.06	-0.02	-0.17	-0.04	0.31	0.16	0.03	-0.04
1	2	-0.06	0.12	-0.03	0.00	-0.14	0.01	0.35	0.14	0.12	0.05
1	3	-0.16	-0.03	-0.11	-0.06	-0.16	-0.01	0.26	0.07	0.11	0.07
2	1	-0.13	0.13	-0.05	-0.04	-0.19	-0.03	0.25	0.14	0.03	-0.05
2	2	-0.09	0.12	-0.03	-0.02	-0.18	0.01	0.25	0.10	0.06	-0.01
2	3	-0.09	0.12	-0.03	-0.02	-0.18	0.01	0.25	0.10	0.06	-0.01
3	1	-0.01	0.15	-0.01	0.02	-0.15	0.06	0.33	0.08	0.12	0.08
3	2	-0.01	0.15	-0.01	0.02	-0.15	0.06	0.33	0.08	0.12	0.08
3	3	-0.03	0.10	-0.05	0.04	-0.13	0.08	0.31	0.04	0.16	0.11
4	1	0.01	0.12	-0.02	0.03	-0.09	0.07	0.36	0.15	0.19	0.10
4	2	0.01	0.12	-0.02	0.03	-0.09	0.07	0.36	0.15	0.19	0.10
4	3	0.11	0.21	0.02	0.12	-0.07	0.15	0.41	0.17	0.24	0.11
5	1	0.02	0.05	-0.01	-0.01	-0.04	0.06	0.31	0.16	0.17	0.13
5	2	0.14	0.16	0.06	0.07	-0.01	0.12	0.50	0.25	0.25	0.21
5	3	0.15	0.20	0.05	0.11	-0.02	0.16	0.63	0.32	0.32	0.27

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
1	1	-0.01	-0.02	-0.07	0.29	0.00	0.09	0.06	-0.09	0.03	0.09
1	2	0.03	0.05	-0.05	0.19	0.04	0.13	0.05	-0.06	0.06	0.09
1	3	0.01	0.06	-0.03	0.06	0.05	0.11	0.20	0.11	0.16	0.14
2	1	-0.05	-0.04	-0.07	0.25	0.00	0.10	-0.10	-0.22	-0.07	0.00
2	2	-0.04	0.00	-0.07	0.20	0.02	0.12	-0.01	-0.13	0.00	0.05
2	3	-0.04	0.00	-0.07	0.20	0.02	0.12	-0.01	-0.13	0.00	0.05
3	1	0.00	0.07	-0.06	0.11	0.07	0.13	0.04	-0.06	0.05	0.06
3	2	0.00	0.07	-0.06	0.11	0.07	0.13	0.04	-0.06	0.05	0.06
3	3	0.03	0.10	-0.04	0.03	0.10	0.15	-0.17	-0.14	-0.04	-0.04
4	1	0.04	0.10	-0.04	0.15	0.12	0.19	0.20	0.07	0.11	0.15
4	2	0.04	0.10	-0.04	0.15	0.12	0.19	0.20	0.07	0.11	0.15
4	3	0.03	0.13	-0.04	0.18	0.19	0.25	0.26	0.14	0.16	0.21
5	1	0.05	0.11	0.03	0.14	0.03	0.18	0.13	0.00	0.01	0.03
5	2	0.11	0.16	0.04	0.17	0.07	0.24	0.22	0.06	0.09	0.09
5	3	0.16	0.21	0.07	0.19	0.13	0.32	0.44	0.27	0.27	0.23

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
1	1	0.16	-0.03	-0.01	0.05	-0.17	0.13	-0.07	0.08	0.00	
1	2	0.20	-0.09	0.02	0.08	-0.17	0.03	-0.06	0.06	-0.05	
1	3	0.24	-0.05	0.08	0.12	-0.10	-0.01	-0.02	0.04	-0.05	
2	1	0.09	-0.06	-0.04	0.01	-0.19	0.08	-0.10	0.05	-0.01	
2	2	0.15	-0.07	0.01	0.05	-0.20	0.06	-0.08	0.05	-0.01	
2	3	0.15	-0.07	0.01	0.05	-0.20	0.06	-0.08	0.05	-0.01	
3	1	0.20	-0.14	0.05	0.10	-0.22	-0.03	-0.06	0.03	-0.02	
3	2	0.20	-0.14	0.05	0.10	-0.22	-0.03	-0.06	0.03	-0.02	
3	3	0.11	-0.21	-0.01	0.04	-0.17	-0.10	-0.05	-0.01	-0.07	
4	1	0.25	-0.06	0.06	0.12	-0.12	0.00	-0.01	0.03	-0.05	
4	2	0.25	-0.06	0.06	0.12	-0.12	0.00	-0.01	0.03	-0.05	
4	3	0.34	-0.06	0.04	0.15	-0.08	-0.03	0.06	0.04	-0.10	
5	1	0.12	-0.02	0.02	0.02	-0.10	0.02	-0.01	0.03	-0.01	
5	2	0.22	-0.05	0.03	0.06	-0.09	-0.01	0.00	0.02	0.00	
5	3	0.34	0.01	0.09	0.14	-0.01	0.00	0.05	0.05	0.02	

(Table 6-21 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
1	2	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001
1	3	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
2	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
2	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
2	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
3	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
3	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
3	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
4	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
4	3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
5	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
5	2	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004
5	3	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.004

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
1	1	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1	2	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
1	3	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001
2	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
2	2	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001
2	3	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001
3	1	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
3	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
3	3	0.000	0.001	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.001	-0.001
4	1	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
4	2	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003
5	1	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003
5	2	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.006	0.006	0.006
5	3	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.004	0.004

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
1	1	0.002	0.002	0.002	0.002	0.003	0.002	0.003	0.002	0.003	
1	2	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
1	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
2	1	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	
2	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
2	3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
3	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
3	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
3	3	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	
4	1	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
4	2	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
5	1	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.004	0.004	
5	2	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
5	3	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	

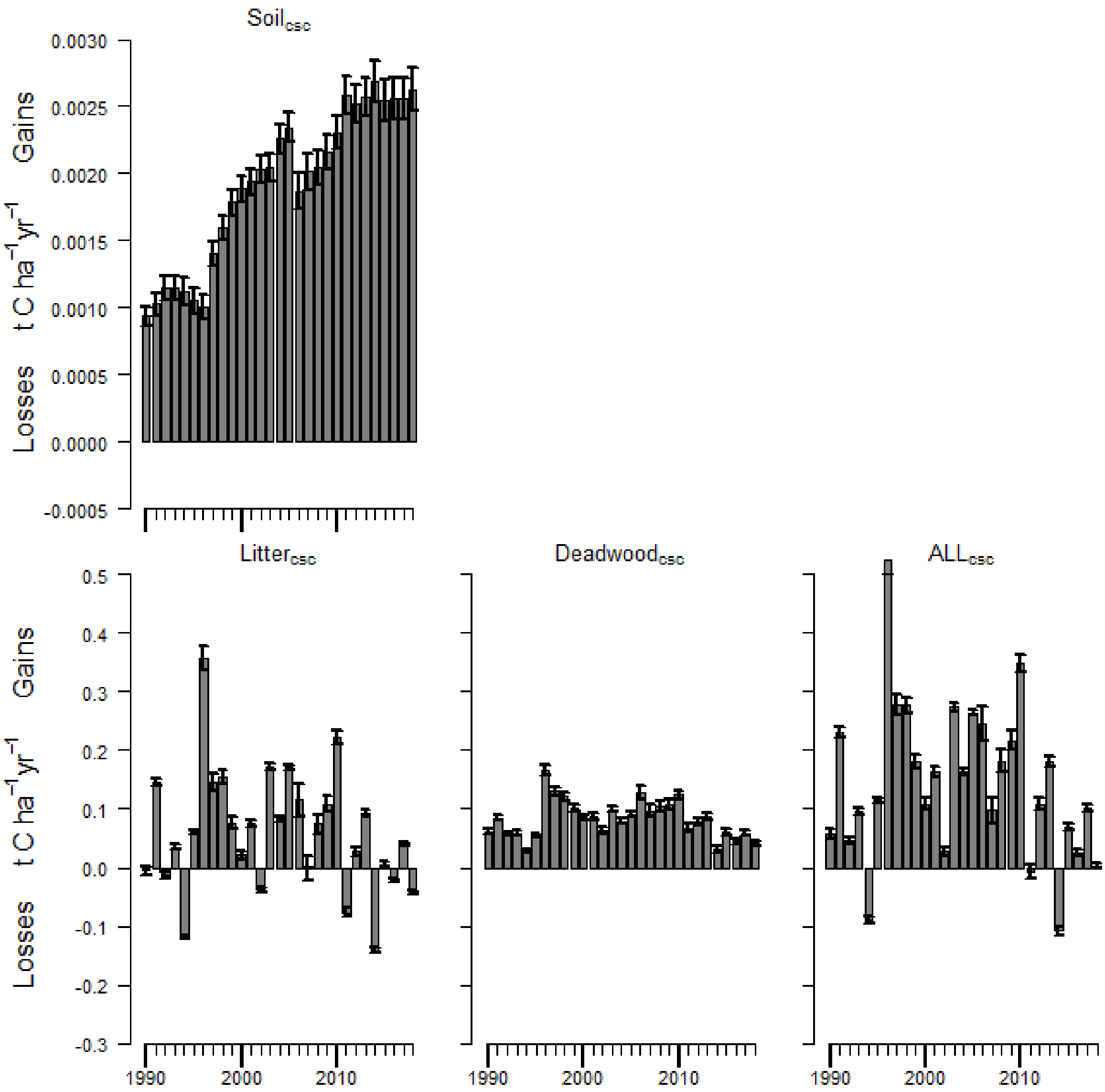


Figure 6-6 Mean carbon stock change (CSC) for three pools soil (0–100 cm), litter, dead wood and their sum (ALL) in t C ha^{-1} yr^{-1}. Note the difference of the y-axis scale between Soil$_{csc}$ and Litter$_{csc}$, Dead wood$_{csc}$ and ALL$_{csc}$, respectively. Negative values indicate losses in carbon stock, positive values gains in carbon stock. The error bars indicate the double standard error.

6.4.2.8 Unproductive forests (CC13)

Unproductive forests consist of brush forests, inaccessible stands and unproductive forest not covered by the NFI. Unproductive forests exhibit a high variability (see examples of unproductive forests in Switzerland in FOEN 2014f).

For transparency reasons, productive and unproductive forest areas are reported separately. However, there is only scarce information available on unproductive forests. In unproductive forests, wood is not harvested for economic reasons. Only in exceptional cases (e.g. wood log blocks a hiking trail) there can be an intervention where the log is moved, but not removed from the stand. Moreover, since yearly harvesting amounts from forest statistics (Table 6-17) are distributed over the productive forests, total harvesting in Swiss forests was accounted for under productive forests (CC12), and thus all harvesting amounts were accounted for.

The NFI does not include unproductive stands CC13 in its regular inventory scheme because (1) the plots are not relevant for timber production or it is not possible to carry out precise measurements (brush forests), (2) the plots are inaccessible or (3) the NFI forest definition is not fulfilled (forest not covered by the NFI).

- Brush forests: Since brush forests have no direct economic value in terms of wood harvest, an inventory of these stands has not been attributed high priority. During NFI3, some plots in brush forests were visited for the first time, but only a limited number of attributes such as tree species, stem diameter and crown cover were collected.
- Inaccessible stands: Inaccessible stands are forests which cannot be visited because of safety reasons (see description in Brändli 2010: p. 89). They are mainly located in the Alps and often grow on sites of low productivity, including rocky sites and sites at high elevation near the tree line with a short vegetation period and low biological activity.
- Unproductive forests not covered by NFI: After the review of its first Initial Report (FOEN 2006h), Switzerland had to apply a forest definition for reporting activities under the Kyoto Protocol Art. 3.3 and Art. 3.4, which is different from the definition applied by the Swiss NFI and the Land Use Statistics AREA. The same definition is used for reporting under the UNFCCC and under the Kyoto Protocol. Because the definition of NFI and AREA was not in line with the specific requirements of the Kyoto Protocol forest definition, Switzerland had to develop an approach to classify certain AREA categories as forest. Those areas are not covered by the regular NFI and are situated in the threshold range between forests and alpine pastures with woody biomass of very low productivity. More specifically, it concerns combination categories of “pastures or grasslands with clusters of trees” (NOLC04 47/NOLU04 222, NOLC04 47/NOLU04 223, NOLC04 47/NOLU04 242) and “alpine sheep grazing pastures, in general with open forest” with “clusters of trees”) NOLC04 44/NOLU04 243; cf. Table 6-6).

Carbon stocks in living biomass

- Brush forest: Brush forests in Switzerland mainly consist of *Alnus viridis*, horizontal *Pinus mugo var. prostrata* with a percentage cover of 65% and 16%, respectively (Table 1 in Düggelin and Abegg 2011). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. For brush forests, no NFI data are available to derive their growing stock. In a case study, Düggelin and Abegg (2011) analysed the carbon stock of total living biomass in Swiss brush forests and found an average value of 20.45 t C ha^{-1}.
- Inaccessible stands: Inaccessible stands are considered the same as brush forest regarding biomass and carbon stock. Their area is determined based on land cover ”tree vegetation” in typically remote and high-elevation land uses such as avalanche chutes (NOLU04 403 and 422; Table 6-6).
- Unproductive forests not covered by NFI: These forests are mainly associated with extensively pastured land where sparse tree vegetation (NOLC04 44 and 47; Table 6-6) is found. As those forests are assumed to grow preferably on bad site conditions, an average growing stock (>7 cm diameter) of 150 m^3 ha^{-1} was assumed. Multiplied by the mean BCEF of 0.69 (i.e. weighted mean based on the quotient of stemwood

volume and total tree biomass of coniferous and broadleaved trees as described in Thürig and Herold 2013), an average biomass for these forests of 102.75 t ha^{-1} was estimated, which corresponds to 51.38 t C ha^{-1} (using a carbon content of 50%; see chp. 6.4.2.4).

The carbon stock of living biomass (C_l) in unproductive forest (CC13) was calculated as a weighted average of brush forest, inaccessible stands and unproductive forest not covered by NFI per spatial stratum:

$stockC_{l,i,CC13} = F_i * stockC_{l,i,CC13bi} + (1 - F_i) * stockC_{l,i,CC13u}$

where F_i is the fraction of the brush and inaccessible forest per spatial stratum i,

$stockC_{l,i,CC13bi}$ is the carbon stock of brush and inaccessible forest (20.45 t C ha^{-1}),

$stockC_{l,i,CC13u}$ is the carbon stock of forest on unproductive areas (51.38 t C ha^{-1}).

Table 6-22 shows the resulting carbon stocks in living biomass of unproductive forest per spatial stratum in t C ha^{-1}.

Table 6-22 Area of brush forest, inacessesibble forest and unproductive forest not covered by NFI, their areal fractions (F_i: fraction of brush and inaccessible forest per stratum i) and the resulting weighted carbon stocks in living biomass in t C ha^{-1} of unproductive forests (CC13) specified for all spatial strata ($stockC_{l,i,CC13}$).

NFI region	Elevation [m]	Brush forest [ha]	Inacessessible forest [ha]	Forest not covered by NFI [ha]	Fraction of brush and inaccessible forest (F_i)	Fraction of forest not covered by NFI ($1-F_i$)	Carbon stock in living biomass ($stockC_{l,i,CC13}$) [t C ha^{-1}]
1	<601	49	0	69	0.42	0.58	38.53
	601-1200	44	0	4'841	0.01	0.99	51.10
	>1200	6	0	4'648	0.00	1.00	51.34
2	<601	188	0	0	1.00	0.00	20.45
	601-1200	94	0	93	0.50	0.50	35.83
	>1200	1	0	633	0.00	1.00	51.33
3	<601	11	0	0	1.00	0.00	20.45
	601-1200	172	0	1'210	0.12	0.88	47.53
	>1200	3'486	5	8'482	0.29	0.71	42.36
4	<601	26	0	1	0.96	0.04	21.60
	601-1200	1'058	5	589	0.64	0.36	31.48
	>1200	42'795	50	18'808	0.69	0.31	29.88
5	<601	243	1	3	0.99	0.01	20.83
	601-1200	2'249	0	275	0.89	0.11	23.82
	>1200	17'776	7	2'568	0.87	0.13	24.35

Carbon stocks in dead wood, in litter, and in mineral soil

As stated above, CC13 consists of different types of forests. Carbon stocks in dead wood, litter and in mineral soil under unproductive forests reveal a high spatial heterogeneity, and specific data are not available.

So far, there are no data available for carbon stocks in dead wood in unproductive forests (CC13). Dead wood on CC13 forest stands was assumed to be zero.

Carbon stocks of litter on CC13 are assigned to the mean value of the modelled CC12 litter stocks with Yasso07 for the period 1990 until the latest inventory year (see Table 6-20).

Soil carbon stocks were assumed to be the same as for productive forests, which were derived from Nussbaum et al. (2012, 2014) (see Table 6-19).

Values for carbon stocks in dead wood, litter, and in mineral soil for CC13 are listed in Table 6-4.

Changes in carbon stocks of living biomass

There are only few case studies on carbon stocks in unproductive forests, but similarly to neighbouring countries with forests in mountainous regions, there are no repeated forest inventory data available for these forests (also known as “mountain forest without harvest”). As no harvesting is conducted in unproductive forests, gross growth and cut and mortality of unproductive forest were assumed to be in equilibrium. This approach is confirmed by three studies in which basal area and crown cover were used as a proxy for the stock of living biomass (Huber and Thürig 2014; Ginzler 2014; Huber and Frehner 2013). An increase in basal area or crown cover, respectively, was positively correlated with an increase in living biomass (e.g. Nowak and Crane 2002). Living biomass in brush forests was increasing during the stage of establishment: the stand developed from a stand with grasses, herbs and some shrubs towards a stand dominated by shrubs and with a denser crown cover. A decrease in crown cover in unproductive forests was observed when natural disturbances like avalanches or rock fall partially damaged the stand. The following studies provide evidence that living biomass in unproductive forests is not a source of carbon:

- Huber and Thürig (2014) analysed the available data on diameters of the terrestrial inventories NFI3 and NFI4 (2009–2012). The authors found that the number of trees had increased over the approximately 6 year period between the two inventories. Since no allometric functions were available for these stands, it was not possible to calculate stocks from these data. The authors estimated an increase in the mean basal area from 4.59 m^2 ha^{-1} in 2006 to 5.47 m^2 ha^{-1} in 2012.
- Ginzler (2014) analysed the crown cover density of 135 aerial photographs between 2006 (NFI3) and 2011 (NFI4) and found no statistical change in crown cover density of well-established, existing brush forests. The terrestrial NFI data, however, showed a slight increase in the basal area of trees in brush forests.
- Huber and Frehner (2013) showed that the expansion of Green Alder (*Alnus viridis*) in eastern Switzerland has doubled in the past 75 years. Especially in the Alps or at unproductive sites, brush forests were expanding as summer pastures were abandoned. At these sites, an increase in crown cover was observed which correlates with an increment in carbon stocks. A literature review by Huber and Frehner (2012; for an overview see FOEN 2014f) showed that Green Alder has in general a strong annual gross growth, not only in very young stands, and that stands of Green Alder can be very vital at an age of over 100 years.

Considering the observed dynamics in Swiss brush forests, it was concluded that living biomass in unproductive forests was not a net source of carbon over the last decades. Applying a Tier 1 approach, living biomass is reported to be in equilibrium. In Table 6-4 and in CRF Table4.A, this approach is transcribed into “gains ($gainC_{l,i,13}$) = losses ($lossC_{l,i,13}$) = 0”.

Changes in carbon stocks of dead wood, of litter, and of mineral soil
There are no repeated measurements of carbon stocks in dead wood, in litter, and in mineral soil.

Above, transparent and verifiable information is given that in Switzerland living biomass in brush forest is increasing. An increase in biomass leads to an increase in dead wood and litter production, which in turn can lead to an accumulation in soil carbon. Based on these conceptional considerations, it was concluded that dead wood, litter, and mineral soil in unproductive forests were not a net source of carbon over the last decades. Applying a Tier 1 approach, thus, dead wood, litter, and mineral soil are reported to be in equilibrium. In Table 6-4 and in CRF Table4.A, this approach is transcribed into "$changeC_{d,i,11}$= $changeC_{h,i,11}$ = $changeC_{s,l,13}$ = 0". The Tier 1 approach is supported by the following evidences:

- Unproductive forest stands occur on higher elevation where microbiological processes in soils are slow (Hagedorn et al. 2010; Davidson and Janssens 2006).
- Unproductive forests grow on poor or rocky sites with thin or no organic layer. Brush forest protect the soils; in particular Alder brush is not even destroyed by avalanches or small-to-medium rock fall (Huber and Frehner 2012). By stabilizing soils, brush forests act as a good protection against soil erosion (Richard 1995; Stangl 2004).
- Green Alder has an ameliorative effect on the soil with its nitrogen-fixing root nodules (Huber and Frehner 2012). Amelioration of soils enables an increase in biomass production which on the other hand increases the amount of litter and dead wood and finally leads to accumulation of soil carbon.
- No active logging occurs on unproductive stands and consequently, there is no human impact on the soils, litter and dead wood.

By providing this transparent and verifiable information (survey of peer-reviewed literature and reasoning based on sound knowledge of likely system responses), the requirements for an application of the Tier 1 approach are considered to be fulfilled.

For conversions within Forest land (CC13 to CC12 and CC12 to CC13) no changes in carbon stocks of soil carbon of mineral soils were calculated because carbon stocks of mineral soil are the same for CC12 and CC13. With the exception of brush forests, it is very likely that carbon stocks in mineral soil are smaller under unproductive forests than under productive forests. As the area changing from CC13 to CC12 is larger than from CC12 to CC13 (see Table 6-9), by applying the stock-difference method (see Table 6-3) with the same carbon stocks for mineral soil under productive and unproductive forest, the resulting emissions are not underestimated.

6.4.2.9 Afforestations (CC11)

Carbon stock and changes in carbon stocks of living biomass
Thürig and Traub (2015: Table 6) estimated the average carbon stock and gains and losses in living biomass of afforestations and young stands in Switzerland. Data are shown in Table 6-4.

In Switzerland, land-use change from non-forest to forest is usually not caused by plantation but by abandonment of agricultural land-use (Rutherford et al. 2008, Rigling and Schaffer

2015). Such newly forested areas typically exhibit a large diversity in diameter at breast height (DBH) and tree age. Afforested stands established by plantation or even-aged young forest stands, however, are generally characterized by a large number of trees in small DBH classes and few trees in large DBH classes. Thürig and Traub (2015) selected NFI plots to represent both types of afforestation. Young stands were defined as stands that changed from non-forest to forest between two consecutive NFIs with at least 85% of the trees with a DBH smaller or equal to 20 cm. As there is almost no land-use change from non-forest to forest below 600 m above sea level, results were stratified for below 1200 m above sea level and above 1200 m. As a consequence of the plot selection, small losses caused by natural mortality or cut of single trees occur.

Carbon stock and changes in carbon stocks of dead wood and of litter
On afforestations, carbon stocks in litter and dead wood were assumed to be zero (IPCC 2006, Volume 4, chp. 4.3.2). Applying the stock-difference calculation approach (Table 6-3), calculated changes in the litter and dead wood pool after an afforestation are zero since the major part of afforestations (CC11) in Switzerland occur on grasslands and in settlements (see Table 6-9) where there is no litter and no dead wood (Table 6-4).

Carbon stock and changes in carbon stocks of mineral soil
The estimates for soil carbon stocks from Nussbaum et al. (2012, 2014) were used for afforestations (see Table 6-4 and Table 6-19), i.e. the same as for productive and unproductive forests. Carbon stock changes of afforestations (≤20 years) were calculated with the stock-difference method (see Table 6-3).

6.4.2.10 Organic soils

Carbon stock in organic soils
The mean soil organic carbon stock (0–30 cm) for organic soils under forest land is 145.6 ± 24.1 t C ha^{-1} (Wüst-Galley et al. 2016). This value was used for CC11, CC12, and CC13 (cf. Table 6-4).

Changes in carbon stocks of organic soils
Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or were established on drained areas. Abegg (2017) estimated the amount of drained organic soils by comparing information on drainage from NFI plots with spatial data of organic soils in Switzerland produced by Wüst-Galley et al. (2015): 3% of organic soils in forest land appeared to be subject to drainage.

For the calculation of changes in carbon stocks of organic soil, the default emission factor of 2.6 t C ha^{-1} yr^{-1} was applied for all forest stands (CC11, CC12, and CC13; cf. Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

6.4.2.11 N_2O emissions from Forest land

Fertilisation of forests is prohibited by the Federal Act on Forest and the adherent ordinance (Swiss Confederation 1991, 1992). The Federal Act on Forest (Art. 18) states: “The use of environmentally hazardous substances in the forest is prohibited” with a direct reference to the Federal Act on the Protection of the Environment (Swiss Confederation 1983). Details of the Federal Act on Forest Art. 18 had initially been regulated in the Ordinance on Forest (Art. 27). Since 2005, the Ordinance on Chemical Risk Reduction (Swiss Confederation 2005: Art. 4) prohibits the application of fertilisers, including liming, in forests. Hence, the application of fertilisers, including liming in forests was prohibited since 1991 in Switzerland. Furthermore, these management practices have never been common practice in Swiss forestry. There is thus considerable evidence to justify the assumption that this situation is valid since 1990. Additionally, the reporting of N_2O emissions from fertiliser application in the agriculture sector encompasses all fertilisers applied in Switzerland. Therefore, no emissions were reported in category A in CRF Table4(I) (notation key “NO”).

N_2O emissions from drainage of organic soils was calculated for Forest land with an emission factor of 2.8 kg N_2O-N ha^{-1} for 3% of the area of organic soils (see chp. 6.4.2.10) and reported in category A in CRF Table4(II). The emission factor used is the default value given in the Wetlands Supplement (IPCC 2014a, Table 2.5) for temperate forest land.

The calculation of emissions reported in CRF Table4(III) and CRF Table4(IV), i.e. direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils, is described in chp. 6.10.

6.4.2.12 Emissions from wildfires

Data on wildfires affecting Swiss forest land were obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database). These data are updated regularly based on analysing data from cantonal archives (Pezzatti et al. 2019). Table 6-23 shows the time series 1990 to 2018 of the area affected and associated emissions.

As controlled burning of forest stands is not allowed in Switzerland all fires in forests were considered wildfires. All fires were assigned to productive forests. In this way, emissions are not underestimated, since the available fuel of productive forests is higher than the carbon stocks of afforestations and unproductive forests. Moreover, this approach reflects reality quite well, since fires on afforestations or in unproductive forests are rather unlikely to occur for the following reasons:

- Non-Forest land to Forest land (or Afforestations under the Kyoto Protocol Art. 3.3) and unproductive forest: the available fuel is small, there is very little dead woody material on the surface which can catch fire (Zumbrunnen et al. 2012).
- Unproductive forests: the available fuel is small since tree cover is not very dense (Zumbrunnen et al. 2012). Moreover, in remote areas the cause of fire is restricted to lightning strikes.

CO_2 emissions from wildfires were noted “IE” in CRF Table4(V) and are encompassed in the data in CRF Table4.A. Losses in living biomass are reflected in the NFI dataset. Carbon changes in dead wood, litter and soil carbon calculated with Yasso07 also cover the influence of forest fires and other disturbances by using NFI data as an input (see chp. 2.3.3 in Didion 2019).

- CH_4 and N_2O emissions from wildfires (Table 6-23) were calculated using equation 2.27 in Volume 4 of IPCC (2006) with the following parameters:
- For CH_4 the default emission factor of 4.7 g kg^{-1} dry matter burnt and for N_2O, the default emission factor of 0.26 g kg^{-1} dry matter burnt were applied (IPCC 2006 Volume 4, Table 2.5).
- The mass of available fuel encompasses carbon stocks of living biomass, dead wood, and litter. On average, the amount of living biomass amounts to 95.19 t C ha^{-1} or 190.39 t biomass ha^{-1}. This value was derived from the mean growing stock in NFI1, NFI2, NFI3 and NFI4 2013–2017 (Brassel and Brändli 1999; Brändli 2010; Thürig et al. 2019a) as a weighted value of the regions affected by forest fires (82% of the fires occur in the Southern Alps, 15% in the Central Alps). The average amount of litter in Swiss forests was 16.73 t C ha^{-1} or 33.46 t biomass ha^{-1}(Nussbaum et al. 2012). Average carbon stocks of dead wood were calculated per NFI period based on data from Didion 2019 (see Table 6-20).
- The fraction of the biomass combusted was 0.45 (IPCC 2006, Volume 4, Table 2.6).

CH_4 and and N_2O emissions caused by wildfires are reported in CRF Table4(V). CH_4 and N_2O emissions from wildfires of all types of forests were reported under 4(V)A1, because it is not known which fires occur on Forest land remaining forest land and which on Land converted to forest land. Consequently, category 4(V)A2 has the notation key "IE".

Table 6-23 Forest land affected by wildfires (WSL, Swissfire database) and resulting CH_4 and N_2O emissions.

Forest land	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Area burnt	ha	1'067.1	70.5	27.9	17.7	233.2	362.8	232.6	1'389.5	197.7	11.2
CH_4	t	538.7	35.6	14.1	8.9	117.7	183.1	117.4	701.5	99.8	5.7
N_2O	t	29.8	2.0	0.8	0.5	6.5	10.1	6.5	38.8	5.5	0.3

Forest land	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Area burnt	ha	47.4	12.9	418.0	527.1	24.5	41.2	112.2	238.2	38.5	50.3
CH_4	t	23.9	6.5	211.0	266.1	12.4	20.8	56.6	120.3	19.4	25.4
N_2O	t	1.3	0.4	11.7	14.7	0.7	1.1	3.1	6.7	1.1	1.4

Forest land	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018
Area burnt	ha	26.1	170.7	25.9	24.2	43.2	42.6	255.8	103.4	54.2
CH_4	t	13.2	86.2	13.1	12.2	21.8	21.5	129.1	52.2	27.3
N_2O	t	0.7	4.8	0.7	0.7	1.2	1.2	7.1	2.9	1.5

6.4.2.13 Emissions from controlled burning

Emissions from controlled burning on Forest land covers the burning of harvest residues only since controlled burning of whole forest stands is not allowed in Switzerland.

The amount of natural residues burnt openly was estimated by INFRAS (2014). Open burning of such residues is regulated in the Ordinance on Air Pollution Control OAPC, (Swiss Confederation 1985: Art. 26b). In Switzerland cantonal authorities are responsible for the enforcement of the OAPC regulations. For INFRAS (2014) an inquiry of some cantonal authorities was performed in order to assess the activity data for these processes.

CH_4 and N_2O emissions were calculated by a Tier 2b approach based on chp. 5.2. in Volume 5 of IPCC (2006). The emissions of burning of residues in forestry are calculated by multiplying the annual estimate of residues burnt (in kt, see FOEN 2020b, chp. 7.3) by emission factors as documented in EMIS 2020/5C2: 6.8 kg t^{-1} for CH_4 and 0.180 kg t^{-1} for N_2O.

CO_2 emissions from controlled burning were noted “IE” in the CRF Table4(V) and are encompassed in the data in CRF Table4.A since carbon losses in living biomass are reflected in the NFI dataset.

The emission factors of CH_4, N_2O and NMVOC of burning of residues in forestry were calculated based on EMEP/CORINAIR (EMEP/EEA 2019), see also documentation in EMIS 2020/5C2 & 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.

6.4.2.14 NMVOC emissions

Estimates for annual biogenic emissions of NMVOC in Switzerland for forests include emissions from the forest stands, wildfires and emissions from burning of residues in forestry.

The biogenic NMVOC emissions from forest stands were calculated for the years 1990–2018 on the basis of monthly maps for the parameters temperature, vegetation period and for 12 different tree species (Meteotest 2019a and updates in EMIS 2020/11C Wald). This corresponds to the simplified method according to chapter 11C in EMEP/EEA (2016). The values after 2018 are interpolated between the modelled years 2018 and 2050. In 1990, the NMVOC emission from forest stands was 60.83 kt.

The methods for calculating the NMVOC emissions from wildfires and from burning of residues in forestry are presented in FOEN 2020b (chp. 7). In 1990, these emissions amounted to 0.98 kt.

6.4.3 Uncertainties and time-series consistency

6.4.3.1 Uncertainties

Activity data

Uncertainties of activity data of category 4A Forest land are described in chp. 6.3.3. Table 6-5 lists the relative uncertainties in the LULUCF sector. The relative uncertainty of the total carbon stock change for Forest land was calculated as follows.

Emission Factors

Uncertainties were estimated for the pools living biomass, dead wood, litter and soil. One source of uncertainty common to all pools is the error resulting from the estimates of changes in the pools between two NFIs based on shifting samples of sample plots common to NFI3 and 5-year NFI4 subsets (cf. chp. 6.4.2.1 ”Consequences of using new NFI data”), i.e. 2009–2011 (GHG inventory submission 2013), 2009–2012 (GHG inventory submission 2014), 2009–2013 (GHG inventory submissions 2015 and 2016), 2011–2015 (GHG inventory submissions 2017 and 2018), and 2013–2017 (GHG inventory submission 2019 and this submission). This was taken into account to obtain an multi-annual uncertainty estimate valid for the time of the second commitment period of the Kyoto Protocol.

Living biomass – sources of uncertainty (relative uncertainty, 2 SE) considered:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets: 30.2%
- Carbon content in solid wood: 2% based on 2% relative standard deviation (RSD) in Monni et al. (2007), and 4-8% RSD in Lamlom and Savidge (2003)
- Biomass expansion function (for Forest land in the Swiss GHG inventory, allometric functions for individual trees were applied) and conversion into mass with wood density: 21.2% sampling uncertainty and 22.2% model uncertainty; based on Lehtonen and Heikkinen (2016).

Thus, the total uncertainty of net carbon stock change in living biomass ($U_{liv.biom}$) in terms of carbon per unit area can be calculated following equation 3.1 in chp. "'Quantifying Uncertainties" (Volume 1 of IPCC 2006):

$$U_{liv.biom} = \sqrt{30.2^2 + 2^2 + 21.2^2 + 22.2^2} = 43.1\%$$

Dead wood, litter, soil – sources of uncertainty considered in the Monte-Carlo simulation approach as described in Didion 2019 (chp. 2.3):

- NFI sampling between NFIs 3 and 5-year NFI4 subsets
- carbon input estimates obtained from the NFI (measurement errors, allometries, etc.) (chp. 2.3.3 in Didion 2019)
- decomposition parameters used in the Yasso07 model (chp. 2.3.1 in Didion 2019).

The resulting relative uncertainties are:

- U_{Soil} = 37.0%
- U_{Litter} = 96.7%
- $U_{Dead\ wood}$ = 16.6%.

Overall uncertainty 4A

The total uncertainty associated with carbon stock change in all four pools was estimated using equation 3.2 in chp. "Quantifying Uncertainties" (Volume 1 of IPCC 2006):

$$U_{tot} = \frac{\sqrt{(U_{\text{liv.biom}} * X_{\text{liv.biom}})^2 + (U_{soil} * X_{soil})^2 + (U_{Litter} * X_{Litter})^2 + (U_{Deadwood} * X_{Deadwd})^2}}{|X_{\text{liv.biom}} + X_{soil} + X_{Litter} + X_{Deadwood}|}$$

with mean carbon stock changes in

living biomass ($X_{liv.biom}$): 1.060 t C ha^{-1} yr^{-1},

soil (X_{Soil}): -0.002 t C ha^{-1} yr^{-1},

litter (X_{Litter}): -0.009 t C ha^{-1} yr^{-1}, and

dead wood ($X_{Dead\ wood}$): -0.071 t C ha^{-1} yr^{-1},

where positive values refer to gains in carbon stock; negative values refer to losses in carbon stock. Thus, the resulting relative uncertainty of the total carbon stock change for Forest land is 46.7%. This value is used for the whole inventory period (see also Table 6-5).

Drainage of organic soils (CO_2; pool organic soil in CRF Table4.A)

The CO_2 emissions from drained organic forest soils are very small (<0.1% of category 4A total) and were neglected in the uncertainty calculation.

Drainage of organic soils (N_2O; category 4(II))

The contribution of forest land to N_2O emissions from drained organic soils (category 4(II)A) is small (around 5%). Its uncertainty was included in the uncertainty calculation for wetlands (see chp. 6.7.3).

Biomass burning (CH_4, N_2O; category 4(V))

The emission factor uncertainty for category 4(V) (biomass burning, wildfires) is 70%. It is derived from the uncertainty of the combustion factor from IPCC (2006; Volume 4, Table 2.6, mean = 0.45, 2SE = 0.32). The activity data uncertainty for wildfires is 30% (see chp. 6.3.3).

6.4.3.2 Time-series consistency

Consistent time series of annual carbon stocks of living biomass were calculated backward or forward starting from the growing stock 2005, as derived from NFI3 (see chp. 6.4.2.5).

Consistent time series of dead wood, litter and soil organic carbon were calculated with the model Yasso07 (see Didion 2019 and chp. 6.4.2.7).

6.4.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

Suitability of the soil carbon model Yasso07 for application for forests in Switzerland

The validity of the Yasso07 model in Swiss forests was examined by Didion et al. (2014a). The study analysed, among other, the accuracy of Yasso07 for reproducing observed carbon decomposition in litter and dead wood in Swiss forests. The authors found that no significant differences existed between simulated and observed remaining carbon in foliage and fine root litter after 10 years and in lying dead trees after 14 to 21 years.

Afforestation – Growing stock and changes in growing stock

A comparison of Swiss carbon data for living biomass in afforestations with IPCC default values and NFI data from neighbouring countries is included in Thürig and Traub (2015). The study supports the plausibility of the Swiss estimates: they are well within the range of the IPCC default values as well as the Austrian and German estimates.

Swiss estimates were also compared with literature values. Based on data of the German forest inventory (*Bundeswaldinventur II*), Paul et al. (2009) reported a carbon sequestration rate of 2.8 t C ha^{-1} yr^{-1} in the first 20 years following an afforestation.

Afforestation – Litter

In an experiment by Zimmermann and Hiltbrunner (2012; COST E639-project “Turnover and stabilization of soil organic matter: effect of land-use change in alpine regions”), litter accumulation in a 40 year old afforestation with Norway Spruce was determined. The authors found accumalation rates of 0.17-0.20 t C ha^{-1} yr^{-1}. Further relevant studies are discussed in chp. 11.3.1.2.

**Carbon balance of two mountain forest ecosystems in Switzerland –
Net ecosystem exchange and soil respiration**

Measurements of the net ecosystem exchange (NEE) and of soil respiration were conducted at a montane mixed forest over 5 years (Lägeren; 2005–2009; NFI production region 2), and at a subalpine coniferous forest over 12 years (Davos; 1997–2009; Swiss Plateau, NFI production region 4).

(1) Etzold et al. (2011) determined the net ecosystem exchange (NEE) by eddy covariance (EC) measurements. EC measurements as well as biometric estimates indicate that both sites with two different mountain forest types were significant carbon sinks in the respective periods. During 2005 to 2009 NEE of the Lägeren forest ranged from -366 to -662 g C m^{-2} yr^{-1} (mean: -415 g C m^{-2} yr^{-1}), and of the Davos forest from -47 to -274 g C m^{-2} yr^{-1} (mean: -154 g C m^{-2} yr^{-1}). For comparison, net removals for 4A1 amounted to -312 g C m^{-2} yr^{-1} in 2018 (CRF Table4.A).

(2) Rühr and Eugster (2009) measured soil respiration rates at these two Swiss forest sites. Modelled changes in soil carbon storage with the dynamic soil carbon model Yasso07 gave comparable results with measured soil respiration. Rühr and Eugster (2009) found that soils at the alpine site Davos acted as a significant carbon sink. Soils at the Lägeren site were neither a significant carbon sink nor a significant carbon source. This domestic study confirms the broadly spread knowledge that it is very difficult to detect short term changes in soil carbon stocks, since the uncertainty of the measurement is often higher than the actual change of the annual estimates (e.g. Falloon and Smith 2003).

Changes in soil carbon stocks –
Soil organic carbon (SOC) dataset of the Swiss Soil Monitoring Network

The objective of the Swiss Soil Monitoring Network (http://www.nabo.ch; NABO) is to assess soil quality in the long term and to validate appropriate soil protection measures. NABO operates about 110 long-term monitoring sites throughout Switzerland covering all relevant land uses, such as cropland, grassland, and forest. Most of them were sampled for the first time between 1985 and 1989 and resampled every five years ever since (SAEFL 1993).

At each site, four replicate bulked soil samples from the upper soil layer 0–20 cm are taken within an area of 10m*10m. Each bulked sample consists of 25 single cores taken according to a stratified random sampling scheme. Further details are provided by SAEFL (2000a) and FOEN (2015p). Currently, results of sampling campaigns 1 to 6 are available for Forest Land, Grassland, and Cropland.

The spatial variation of bulk density was included in calculating the carbon pools. Bulk density and soil skeleton (>2 mm) were measured repeatedly for all monitoring sites at the occasion of sampling campaigns 4 to 6 (2000–2014), but not in the previous campaigns. The mass of fine earth (<2 mm; M_{FE}) per total soil volume (V_{tot}, including skeleton and pores) was determined for four volumetric samples 0–20 cm per site and campaign to derive the so-called apparent density of fine earth ($D = M_{FE} / V_{tot}$). Subsequently, SOC pools 0–20 cm [t/ha] were calculated by D [g/cm^3] * SOC [% w./w.] * 20 [cm]. For each site, the site-specific apparent density was used; repeated apparent density measurements per site were used to account for the variability of the bulk density.

The data presented here are based on samples collected from 1985 to 2014 at 27 forest sites. SOC pools for the top 20 cm of forest soils ranged from 38 to 165 t C ha^{-1} with a mean of 72 t C ha^{-1}, although only few sites have pools higher than 90 t C ha^{-1} (Figure 6-7). There where no significant changes in SOC pools over time except for the periods between the second and third, and the third and fourth sampling campaigns due to the extraordinarily high SOC pools in the third campaign. Previous NABO studies showed that the elevated SOC pools for the third sampling campaign must be considered as artefact induced by sub-optimal conditions during field work. These samples were collected earlier in the year and, thus, soils were moister. It is known that soil carbon has a high natural variation which may be pronounced if soil moisture differences are high. For instance, six resamplings within three years at two forest sites revealed short-term variation of SOC contents between ± 1.8% and ± 0.6% (single standard errors; Keller et al. 2006). In conclusion, the results by NABO indicate that Swiss forest mineral soils did not act as a net source or sink of carbon over the last 30 years.

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5% per 10 years for forest soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC pools (mean ≈ 72 t ha^{-1}), this corresponds to a minimum detectable change of roughly 0.18 t C ha^{-1} yr^{-1} for SOC pools. In comparison, the mean change in SOC obtained with Yasso07 for the period 1991–2010 was -0.00075 ±0.00053 t C ha^{-1} yr^{-1} (2SE; based on data in Didion and Thürig 2017). This value is several orders of magnitude smaller than the minimum detectable change that can be identified in the NABO monitoring scheme.

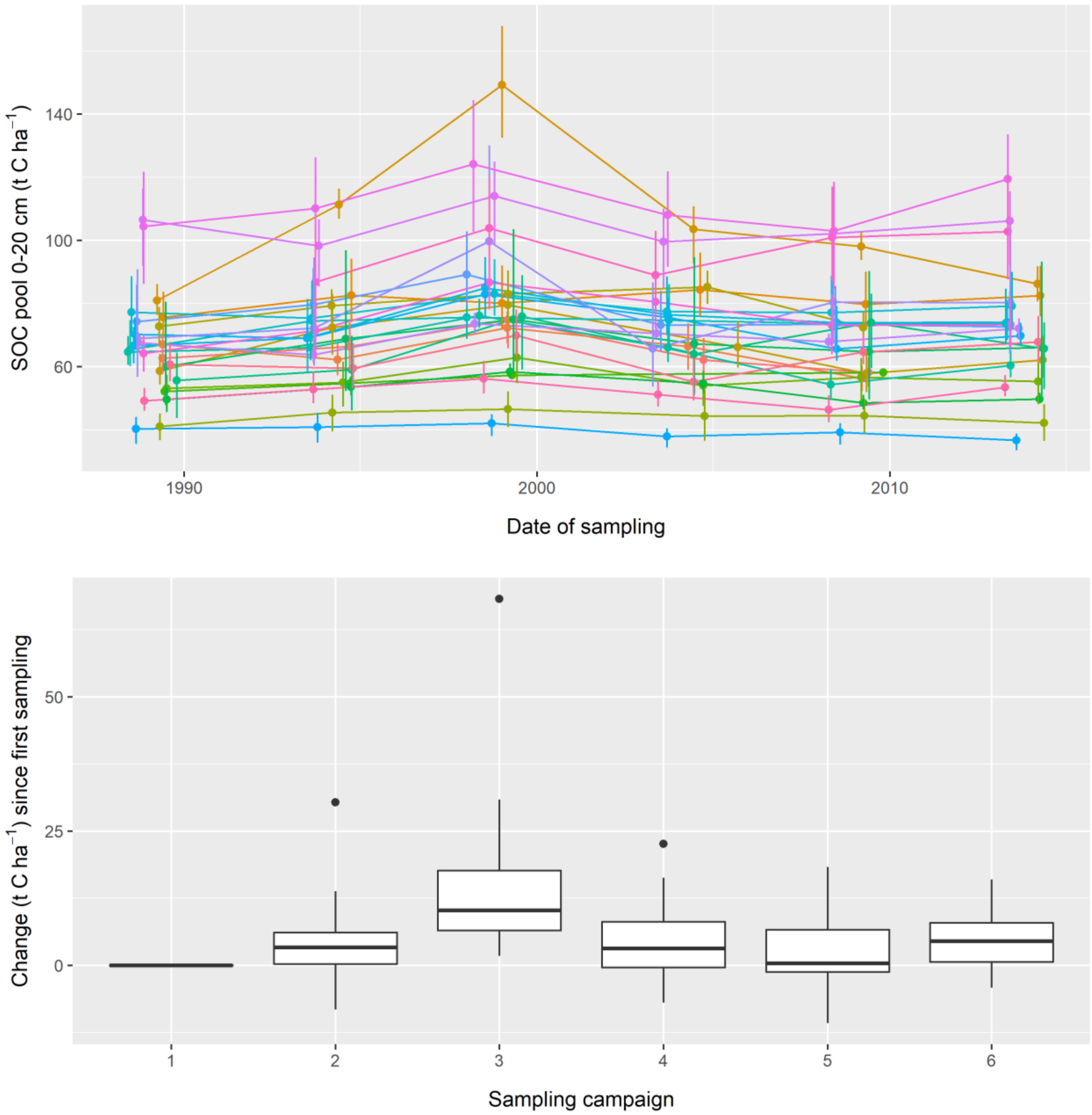


Figure 6-7 Measured SOC pools for topsoils (0–20 cm) and their changes for 27 NABO long-term monitoring sites in forest during the time period 1985–2014. The elevation of the sites ranges from 383 to 1690 m a.s.l. Top panel: SOC pools 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC pools since first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

Uncertainty Estimates

The uncertainty for carbon stock changes in dead wood, litter and soil organic matter reported by Finland, where the Yasso07 model is also applied, was 31.5% for the year 2015 (Statistics Finland 2017: chp. 6.4.3.2). For the total uncertainty in the change of living biomass, Finland reported 20% (Statistics Finland 2017: chp. 6.4.3.1).

6.4.5 Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4A between the latest and the previous submission are additionally presented in chp. 10.1.2.4.

- 4A: Activity data 1991–2017 were updated (see chp. 6.3.5).
- 4A: The time series of gains, losses and stocks in living biomass for aggregated strata (see chp. 6.4.2.2) was recalculated from 2006 onwards (Z2+Z3 L2, Z1+Z2 L3, Z1+Z2 L4) since an error occurred in the last submission while merging these strata.
- 4A: Estimates of annual litter stocks from Yasso07 were used for CC12 and CC13 instead of litter stocks from Nussbaum et al. (2012). For CC12 annual values were used (see chp. 6.4.2.6). For CC13 the mean value of Yasso litter stocks from the period 1990 until the latest inventory year was applied (see chp. 6.4.2.8). The model based estimates provide a precise separation of the dead wood and litter pools, which is not ensured for the reported litter estimates based on observations. The litter carbon stocks from Yasso07 are less variable than estimates derived with geostatistical methods (Nussbaum et al. 2012), with particular differences in production regions Pre-Alps, Alps, and Southern Alps. In these regions there is a larger elevation gradient in the values by Nussbaum et al. (2012) than what may be expected (i.e. ca. 2.5 t C per 100m; Hagedorn et al. 2010b). Compared to estimates obtained with Yasso07, previous carbon stocks are generally lower in elevations <600 m and significantly higher in elevations >1200 m (see chp. 10.1.2.4 for impacts on net CO_2 eq removals).
- 4A1: The biogenic NMVOC emissions from forests were updated. Extrapolated values for the year 2017 were replaced with modelled values (EMIS 2020/11C Wald).
- 4(V)A1: The time series 1990–2017 of activity data in the Swissfire database was updated by the database administrators (Pezzatti et al. 2019).

6.4.6 Category-specific planned improvements

As a result of the continuous monitoring of the Swiss Forests, new NFI data will be available regularly. The adoption of new NFI data can affect the estimates of all reported pools as well as the calculation of the available fuel for wildfires in forests (see section “Consequences of using new NFI data” in chp. 6.4.2.1).

The implementation of the soil model Yasso07 to improve the accuracy in the estimates of temporal changes in soil carbon, litter and dead wood is continuously developed. Depending on the availability of relevant data and studies, planned improvements include:

- Investigating the validity of the further development of Yasso07 for application in Switzerland. The new model version Yasso15 includes, among other, a new parameter set that improves the sensitivity of the simulated decomposition to temperature and precipitation. Preliminary results from Switzerland using a beta-version of Yasso15 indicate improvements over Yasso07, particularly with regards to soil carbon stocks. In 2020, a closer collaboration between Parties that apply the Yasso model for GHG reporting (Finland, Norway, Austria, and Switzerland) or are evaluating the model (Germany, Slovakia, Spain) and the model developers was initiated, which is expected to result in further improvements to accuracy and comparability of modelled estimates. Status of the project: ongoing.
- Review of the litter production estimates, including turnover rates, and improving the uncertainty estimates (for GHG inventory submission 2021).

For the calculation of available fuel for wildfires (chp. 6.4.2.12) the average amount of litter in Swiss forests taken from Nussbaum et al. (2012) will be replaced with the new Yasso07 estimates (see chp. 6.4.5 and Table 6-19).

6.5 Category 4B – Cropland

6.5.1 Description

Table 6-24 Key categories in category 4B. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2

Swiss croplands belong to the cold temperate wet climatic zone. Croplands (CC21) include annual crops and leys in arable rotations (see Table 6-2 and Table 6-6).

Carbon stocks in above-ground living biomass and carbon stocks in mineral and organic soils were considered.

In 2018, category 4B1 Cropland remaining cropland was a net sink of -356.04 kt CO_2 due to pronounced net removals in mineral soil. Over all inventory years the net emissions and removals in category 4B1 were dominated by carbon stock changes in mineral soils and by carbon mineralisation in organic soils in the lowest elevation zone (although organic soils accounted only for 2.7% of cropland area in Switzerland; Table 6-7). Average living biomass in 4B1 increased slightly over the inventory period. The annual CO_2 fluxes of both the living biomass and the mineral soil pools display a high variability.

Category 4B2 Land converted to cropland was a small net source of 31.32 kt CO_2 in 2018 mainly due to carbon losses in mineral soils under 4B2.2 Grassland converted to cropland.

6.5.2 Methodological issues

Carbon in living biomass, carbon stocks and carbon stock changes in mineral soils were estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2019). The results were integrated in the GHG inventory by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The difference in carbon stock between a specific year and the preceding year was reported as net change for living biomass and for mineral soil.

6.5.2.1 Carbon in living biomass

Annual biomass carbon stocks per elevation zone (cf. chp. 6.2.2) are shown in Table 6-25. They were calculated as area-weighted means of harvested biomass for the 19 most important annual crops (barley, broad beans ["Ackerbohnen"], fallow, fodder beet, maize [grain], oat, peas ["Eiweisserbsen"], potatoes, rape [cooking oil], rye, sugar beet, silage and green corn, sun flowers [cooking oil], soybean, spelt, triticale, vegetables, wheat) and as cumulated annual harvested biomass for clover-grass (leys).

Annual values 1990–2018 for harvested biomass were published by the Swiss Farmers Union (SBV 2019 and former editions). For the year 2018 provisional values were calculated (mean of time span 2012–2017). Root biomass was considered as in the soil organic carbon modelling (Wüst-Galley et al. 2019). A carbon fraction of 0.45 was assumed based on Bolinder et al. (2007).

The resulting area-weighted (across the three elevation zones) mean biomass stock for Swiss cropland over the inventory time period was 6.81 ± 0.32 (1 SD) t C ha^{-1}.

Carbon stock and carbon stocks changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990). The rationale for this approach is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years (see Figure 6-8).

Table 6-25 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha^{-1}) and net carbon stock changes (gain/loss) (t C ha^{-1} yr^{-1}) in arable crop yields (living biomass of CC21) reported as moving average over five years, stratified for elevation zone (Elev.: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; cf. chp. 6.2.2). A carbon fraction of 0.45 was assumed. Highlighted data for 1990 are displayed in Table 6-4.

Living biomass	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC21: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	6.44	6.53	6.50	6.49	6.53	6.56	6.60	6.64	6.74	6.68
Stock	2	6.46	6.54	6.52	6.51	6.54	6.57	6.62	6.66	6.76	6.73
Stock	3	6.07	6.16	6.16	6.14	6.15	6.14	6.22	6.30	6.43	6.48
Gain/loss	1	0.07	0.09	-0.03	-0.01	0.04	0.03	0.04	0.03	0.10	-0.06
Gain/loss	2	0.06	0.08	-0.02	-0.01	0.03	0.03	0.05	0.04	0.10	-0.03
Gain/loss	3	0.09	0.10	0.00	-0.02	0.02	-0.01	0.08	0.08	0.13	0.05

Living biomass	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC21: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	6.68	6.57	6.72	6.71	6.74	6.79	6.92	6.92	6.93	7.08
Stock	2	6.74	6.65	6.78	6.78	6.81	6.85	6.94	6.94	6.94	7.04
Stock	3	6.53	6.49	6.63	6.67	6.72	6.80	6.87	6.86	6.85	6.88
Gain/loss	1	0.00	-0.11	0.15	-0.01	0.03	0.05	0.13	0.01	0.00	0.16
Gain/loss	2	0.01	-0.09	0.13	0.00	0.03	0.04	0.10	-0.01	0.00	0.10
Gain/loss	3	0.05	-0.04	0.13	0.04	0.06	0.08	0.07	-0.01	-0.01	0.03

Living biomass	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		CC21: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	7.11	7.04	7.13	7.13	6.95	7.01	7.10	6.97	7.00	
Stock	2	7.05	6.99	7.07	7.07	6.95	7.01	7.08	6.99	7.01	
Stock	3	6.86	6.82	6.87	6.87	6.82	6.86	6.92	6.86	6.90	
Gain/loss	1	0.02	-0.07	0.09	0.00	-0.18	0.05	0.09	-0.13	0.03	
Gain/loss	2	0.01	-0.06	0.08	0.01	-0.12	0.05	0.08	-0.10	0.02	
Gain/loss	3	-0.01	-0.04	0.05	0.00	-0.05	0.04	0.06	-0.05	0.03	

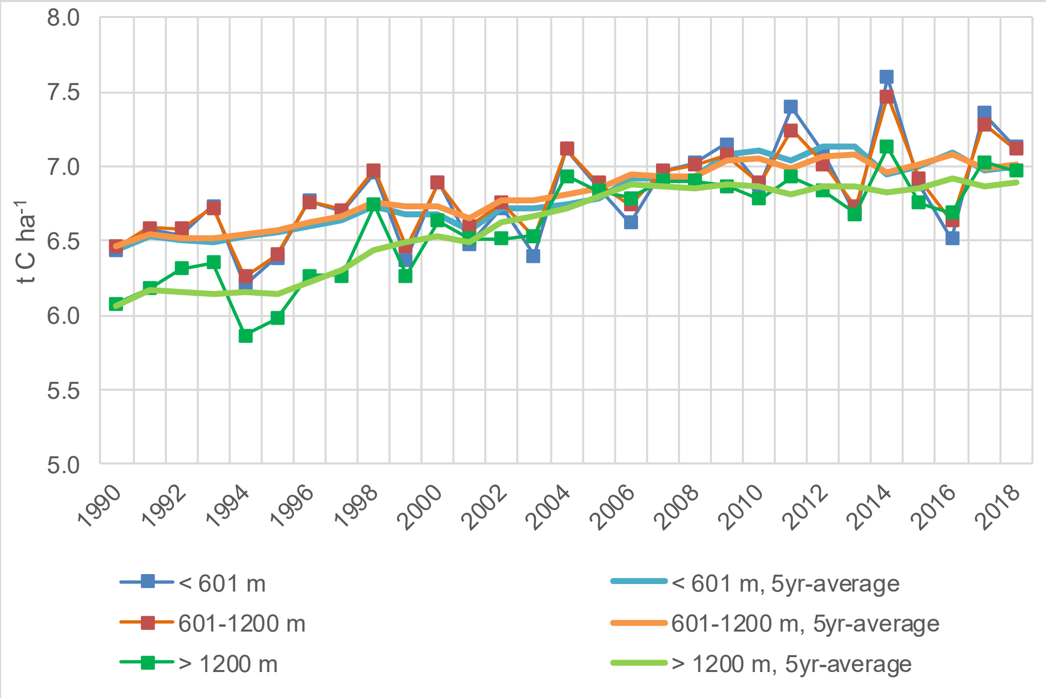


Figure 6-8 Carbon stocks in living biomass of cropland stratified for elevation zone and corresponding moving averages over five years. Elevation zone >1200 m is less important as it covers only 0.1% of the total cropland area (cf. Table 6-7).

6.5.2.2 Carbon in dead organic matter

Applying a Tier 1 approach carbon stocks in dead organic matter were not assessed.

6.5.2.3 Carbon in soils

6.5.2.3.1 Mineral soils

Initial carbon stocks

Soil carbon stocks in mineral soils under cropland were calculated based on Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). The approach correlated measured soil organic carbon stocks (t ha^{-1}) with measured clay content. The relationship was applied to the national level using soil texture information from the Swiss digital soil map (SFSO 2000a), correcting for soil depth and stone content. Average stocks were calculated as weighted means using the location of arable land and leys, according to the Swiss Land Use Statistics AREA (see chp. 6.2.1). The median soil organic carbon stock (0–30 cm, in 1975) for cropland is 49.1 t C ha^{-1}. The variability of carbon stocks across the country is 8.6 t C ha^{-1} (1 SD). These stocks were applied to 1975 and were used for the initialisation of RothC modelling (see below).

Simulation of carbon stocks through time

Switzerland used the soil carbon model RothC (Coleman et al. 1997; Coleman & Jenkinson 1999) to estimate carbon stocks in mineral soil (0–30 cm) under cropland for the period 1990 to 2018. The implementation of RothC in the Swiss GHG inventory is described in detail in Wüst-Galley et al. (2019).

RothC is a model for the turnover of organic carbon in mineral soil, implementing four active carbon pools each associated with their own decomposition rates. In addition, there is a small carbon pool that is considered to be stable (inert). The model runs and calculates soil carbon stocks on a monthly basis. The decomposition rates are altered by temperature, moisture, soil cover and the soil's clay content. RothC requires information on climate (monthly precipitation, temperature and evapotranspiration), monthly carbon inputs (from organic manures and from plants, including above- and below-ground harvest residues and root exudates) and soil (clay content, monthly soil cover). Plant inputs were derived using an allometric function, adapted from Bolinder et al. (2007) as described in Wüst-Galley et al. (2019), using annual harvest information as input data. Calibration and validation of RothC are described in Wüst-Galley et al. (2019).

Input data

Gridded climate data were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss), including monthly average temperature and monthly (total) precipitation. Monthly evapotranspiration was calculated using these two data sets as well as monthly surface incoming shortwave radiation (SIS), also obtained from MeteoSwiss. The most important 19 crops (as introduced in chp. 6.5.2.1, covering over 99% of Swiss cropland area) were considered. Annual crop yields were obtained from the Swiss Farmers Union (SBV 2019 and former editions); yields for 2018 are based on extrapolation from the previous five years. Based on yield data from crops, plant carbon inputs to the soil from crop residues, roots and rhizodeposition were estimated according to a modified version of Bolinder et al. (2007) as described in Wüst-Galley et al. (2019). Annual carbon inputs from organic manures to different crops or grassland management types were calculated based on: (1) organic manure production, calculated as a function of excretion rate of volatile solids (VS), using the method described in chp. 5.3.2.2.1; (2) animal herd size, described in chp. 5.3.2.5.1; (3) manure management systems, described in chp. 5.3.2.2.4 (using the data for VS); (4) the tendency of farmers to apply different types of manure onto different (broad) crop / grass types, using information obtained from the Swiss ammonium model AGRAMMON (Kupper et al. 2018); (5) the different fertilisation needs of individual crops or grasslands of differing management intensities (obtained from the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner et al. 2017); (6) straw production, using annual values published by the Swiss Farmers Union; (7) the amount of manure digested anaerobically in biogas plants, as described in chp 5.3.2.2.3; (8) the amount of liquid and solid digestates, as described in chp 5.5.2.2.2; (9) the number of livestock units moving annually to the summer pasture regions, using annual data (1999 to present, years prior using extrapolation) from the Swiss Federal Office for Agriculture. Clay content was derived from the Swiss Soil Suitability Map (Bodeneignungskarte) (SFSO 2000a) as described in Wüst-Galley et al. (2019). Soil cover and the distribution of plant inputs throughout the year were determined using sowing and harvest dates from various agricultural guidelines, as described in Wüst-Galley et al. (2019).

Up-scaling

The RothC modelling was carried out for 4560 different combinations (19 crops x 240 regions) representing similar climate, crop type, management systems and clay content, as described in Wüst-Galley et al. (2019).

Area-weighted average values, accounting for the extent of cropland (according to the AREA Land Use Statistics) and different crops were used to up-scale the RothC results to Switzerland. These results were integrated in the GHG inventory by calculating area-weighted (using the relative surface of crops) average values per elevation zone (see Table 6-26).

Table 6-26 Area-weighted (using the relative surface of crops per elevation zone) carbon stock means (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in mineral soils (0-30cm) for cropland (CC21), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; cf. chp. 6.2.2). Highlighted data for 1990 are displayed in Table 6-4. The resulting area-weighted (across the three elevation zones) mean carbon stock for cropland over the inventory period is 50.58 ± 0.46 (1 SD) t C ha^{-1}.

Mineral soil	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	1	50.21	50.37	50.40	50.19	50.03	49.86	49.92	49.95	50.16	50.33
Stock	2	50.14	50.34	50.46	50.36	50.28	50.16	50.31	50.40	50.50	50.66
Stock	3	42.35	42.73	42.96	42.99	43.03	43.04	43.33	43.80	43.95	44.36
Net change	1	0.07	0.16	0.03	-0.20	-0.16	-0.17	0.06	0.03	0.21	0.18
Net change	2	-0.01	0.20	0.12	-0.10	-0.08	-0.12	0.15	0.10	0.10	0.16
Net change	3	0.16	0.38	0.23	0.03	0.04	0.01	0.30	0.47	0.15	0.41

Mineral soil	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	1	49.89	49.77	49.62	50.19	50.57	50.34	50.52	50.67	50.76	50.94
Stock	2	50.40	50.34	50.31	50.73	51.06	50.84	51.06	51.25	51.36	51.51
Stock	3	44.76	45.18	45.35	46.15	47.04	47.25	47.69	47.76	47.76	47.88
Net change	1	-0.44	-0.13	-0.15	0.58	0.38	-0.23	0.18	0.14	0.10	0.18
Net change	2	-0.26	-0.05	-0.03	0.41	0.33	-0.22	0.22	0.19	0.11	0.15
Net change	3	0.40	0.42	0.17	0.81	0.89	0.21	0.44	0.07	0.01	0.11

Mineral soil	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018
		CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]								
Stock	1	50.94	51.18	51.05	50.96	50.97	50.95	50.62	50.47	51.07
Stock	2	51.57	51.72	51.56	51.51	51.57	51.51	51.31	51.15	51.48
Stock	3	48.09	48.16	47.95	47.78	47.68	47.54	47.59	47.29	47.91
Net change	1	0.00	0.24	-0.13	-0.09	0.02	-0.03	-0.32	-0.16	0.61
Net change	2	0.06	0.15	-0.17	-0.04	0.06	-0.07	-0.20	-0.16	0.33
Net change	3	0.21	0.08	-0.22	-0.17	-0.10	-0.14	0.05	-0.30	0.62

6.5.2.3.2 Organic soils

Soil carbon stocks in organic soils under cropland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils. The mean soil organic carbon stock (0–30 cm) of cultivated organic soils was 240 ± 48 t C ha^{-1} (uncertainty 20%).

6.5.2.4 Changes in carbon stocks

6.5.2.4.1 Living biomass

Carbon stocks in living biomass intermittently increased from 1990 to 2018 (Figure 6-8; SBV 2019). The difference in biomass stock (five-year moving average) between a specific year and the preceding year was reported as net change (gain or loss) of carbon (see Table 6-25). The resulting values are in the range between -0.67 and 0.87 t C ha^{-1} yr^{-1} with an average of 0.03 t C ha^{-1} yr^{-1} for the inventory time period (weighted average across all elevation zones).

6.5.2.4.2 Dead organic matter

Applying a Tier 1 approach, carbon stocks in dead organic matter were assumed to be in equilibrium for Cropland remaining cropland.

6.5.2.4.3 Mineral soils

The difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils (Table 6-26 and Figure 6-9). In Figure 6-9, carbon stock changes are additionally presented as moving averages over five years (from year -2 to year +2, e.g. 1988–1992 for the year 1990). Interannual changes in carbon stocks mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. However, the 5-year averages are not used in the reporting. The mean annual carbon stock change in the inventory period for elevation zone 1 is +0.032 t C ha^{-1} and for elevation zone 2 is +0.046 t C ha^{-1} (elevation zone 3 is less important as it covers 0.1% of cropland; cf. Table 6-7). The average annual stock change area-weighted across all elevation zones is +0.037 t C ha^{-1}. Annual carbon stocks in croplands on a per hectare basis deviate very little from the stocks predicted by linear regression across the inventory time period (i.e. accounting for the long-term trend); annual stocks vary by -1.52 to +0.91%, or -0.75 to +0.47 t C ha^{-1} (data not shown).

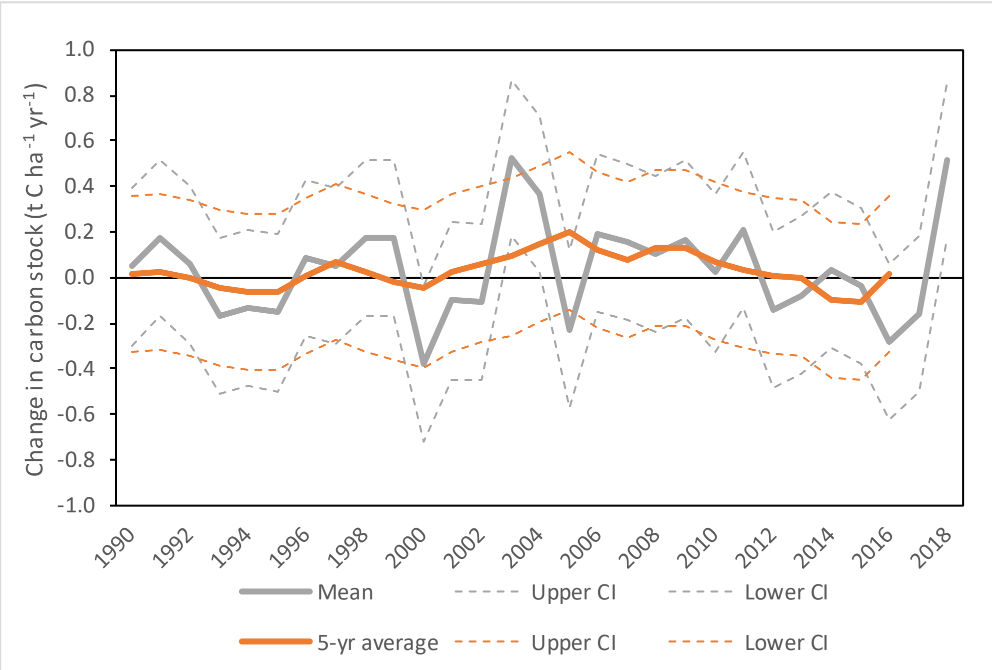


Figure 6-9 Annual carbon stock changes (t C ha^{-1} yr^{-1}) and corresponding 5-year moving averages in mineral soil (0-30 cm) for cropland, area-weighted across three elevation zones, plus upper and lower confidence intervals (see chp. 6.5.3). The 5-year averages are displayed to highlight the trends; they are not used for reporting.

6.5.2.4.4 Organic soils

The annual net carbon stock change in organic soils was estimated to -9.52 t C ha^{-1} according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018).

6.5.2.4.5 Land-use change

In the case of land-use change, the net carbon changes in biomass and soil were calculated as described in chp. 6.1.3.

6.5.2.5 N_2O emissions from cropland

N_2O emissions from drainage of organic soils (category 4(II)) on cropland are reported in the agriculture sector (CRF Table3.D).

The calculation of emissions for categories 4(III) and 4(IV) (direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils) is described in chp. 6.10.

6.5.3 Uncertainties and time-series consistency

6.5.3.1 Uncertainties

Activity data

Uncertainties of activity data of category 4B Cropland are described in chp. 6.3.3. For calculating the overall uncertainty of category 4B, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2020).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from agricultural land (Leifeld and Fuhrer 2005). The absolute uncertainties per hectare, calculated with the implied emission factors of 2018, are 0.004 t C ha^{-1} yr^{-1} for 4B1 and 0.010 t C ha^{-1} yr^{-1} for 4B2.

Mineral soils

The absolute uncertainty of 0.344 t C ha^{-1} yr^{-1} was used for annual carbon stock changes under 4B1 and 4B2, as calculated by a Monte-Carlo analysis (Wüst-Galley et al. 2019). The uncertainty analysis considered variation in the following input parameters: carbon inputs from farmyard manure and plants, the extent of summer pastures, and monthly temperature, precipitation and evapotranspiration. For the Monte-Carlo analysis it was assumed that the extent of variation in input parameters is unchanged from one year to the next. By comparison, the range of annual SOC changes identified for 71 different treatments of Swiss agricultural long-term experiments is 1.87 t C ha^{-1} (Keel et al. 2019), suggesting that the calculated uncertainty might have been underestimated (Wüst-Galley et al. 2019).

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 23% as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 37.3% (see chp. 6.3.3), resulting in a combined uncertainty of 43.9%. Thus, the absolute uncertainties of the total organic soil emissions in 2018 are 41.21 kt C for 4B1 and 1.68 kt C for 4B2. By dividing those uncertainties with the total area of 4B1 and 4B2, respectively, the absolute uncertainties per hectare result in 0.116 t C ha^{-1} yr^{-1} for 4B1 and 0.047 t C ha^{-1} yr^{-1} for 4B2.

Overall uncertainties 4B1 and 4B2

The root sum squares of the above-mentioned three absolute uncertainties are 0.363 t C ha^{-1} yr^{-1} for 4B1 and 0.347 t C ha^{-1} yr^{-1} for 4B2. These absolute uncertainties were used to calculate relative emission factor uncertainties for 4B1 and 4B2 by dividing with the net carbon stock change per hectare of 4B1 and 4B2, respectively. In 2018, the total net carbon stock changes were 0.272 t C ha^{-1} for 4B1 and -0.241 t C ha^{-1} for 4B2 (calculated from CRF Table4.B). The resulting relative uncertainties are 133.1% for 4B1 and 144.0% for 4B2, respectively (see Table 6-5). In the same way the uncertainties for the year 1990 were calculated. They are 231.7% (4B1) and 89.0% (4B2).

6.5.3.2 Time-series consistency

Time series for category 4B Cropland are all considered consistent; they were calculated based on consistent methods and homogenous databases. Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

6.5.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

6.5.4.1 Carbon stocks in mineral soils

The initial SOC stocks for this submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.5.6.

6.5.4.2 Changes in living biomass

The biomass carbon pools were recalculated for the GHG inventory submission 2019 in the course of the Tier 3 approach for quantification of carbon stocks and carbon stock changes in agricultural soils (see chp. 6.5.2.3). As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector, i.e. same data source SBV (2019) and former editions.

6.5.4.3 Changes in soil carbon stocks

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2019). A comparison of SOC stocks and measured values from field experiments is made by Wüst-Galley et al. (2019).

In 2003 and 2018 increases in SOC stocks are exceptionally high (see Figure 6-9). These peaks might be explained by strongly reduced SOC decomposition in RothC caused by high soil moisture deficits (these summers were exceptionally warm and dry in Switzerland leading to high evapotranspiration relative to precipitation). Alternatively, the timing of the addition of plant carbon inputs from crops and manure into the soil might be important in determining SOC stock changes. Currently the highest carbon inputs from plants and manure coincide with the period of extreme topsoil moisture deficit. For two reasons however, it is unlikely that this is the main cause of SOC peaks in warm / dry years. Firstly, a change in the timing of manure applications (so that carbon inputs from manure and plants no longer coincide) had no significant effect on SOC changes. Secondly, for certain strata, namely those at risk of topsoil moisture deficit, permanent grassland also shows SOC peaks in the years 2003 and 2018, although grassland receives carbon inputs regularly throughout much of the year. Based on these results, we conclude that the SOC peaks in cropland are at least to a large extent an effect of lowered SOC decomposition due to high soil moisture deficits during these especially warm / dry years. Such model behaviour in RothC was also identified by Falloon et al. (2011). In 2003 and 2018, peak SOC values were obtained for cropland but not for permanent grassland. This can be explained by the distribution of these two land use types: Cropland is concentrated in regions prone to high topsoil moisture deficit (lowlands), whereas permanent grassland is distributed more evenly across the country, including wetter (upland) regions.

So far, changes in SOC were calculated as differences between annual mean stocks. The reported stock changes are strongly influenced by meteorological conditions and can mask more subtile changes due to agricultural management. Since the latter are of main interest in the context of GHG reporting, the data were also presented as 5-year running averages (cf. Figure 6-9).

The SOC pools measured at 29 cropland monitoring sites of the Swiss Soil Monitoring Network (NABO; see chp. 6.4.4) featuring mineral soils indicate no significant changes from 1990 to 2014 (Figure 6-10). The decline from the first to the second sampling campaign was identified as artefact introduced by the date of sampling; in the first campaign, samplings were conducted substantially later in the year compared with the remaining campaigns, which induced higher SOC contents and thus SOC pools. The range of the calculated SOC pools was large (20.6–88.4 t C ha^{-1}) with a mean of 46.7 t C ha^{-1}.

The monitoring scheme applied by NABO is able to detect relative changes in SOC stocks of roughly 3.3% per 10 years for mineral cropland soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC pools (mean ≈ 47 t ha^{-1}) this corresponds to a minimum detectable change of roughly 0.15 t C ha^{-1} yr^{-1} for SOC pools.

The mean change in SOC which was calculated with RothC for the years 1990–2018 was 0.037 ± 0.344 t C ha^{-1} yr^{-1} (area-weighted average change across three elevation zones ± absolute uncertainty based on a Monte Carlo analysis; see Figure 6-9 and chp. 6.5.3). In comparison, the modelled change is one order of magnitude smaller than the detectable change by NABO and suggests that modelled SOC pool changes agree with the repeated soil inventories in the NABO network.

The SOC pools for three additional cropland sites featuring organic soils ranged from 205 to 269 t C ha^{-1} in the first and from 141 to 236 t C ha^{-1} for the sixth sampling campaign (not included in Figure 6-10). Thus, SOC pools 0–20 cm of these sites declined by 14–63 t C ha^{-1} over a period of 30 years (however, the effective losses over the whole soil profiles are even higher due to decreasing depths of soil layers).

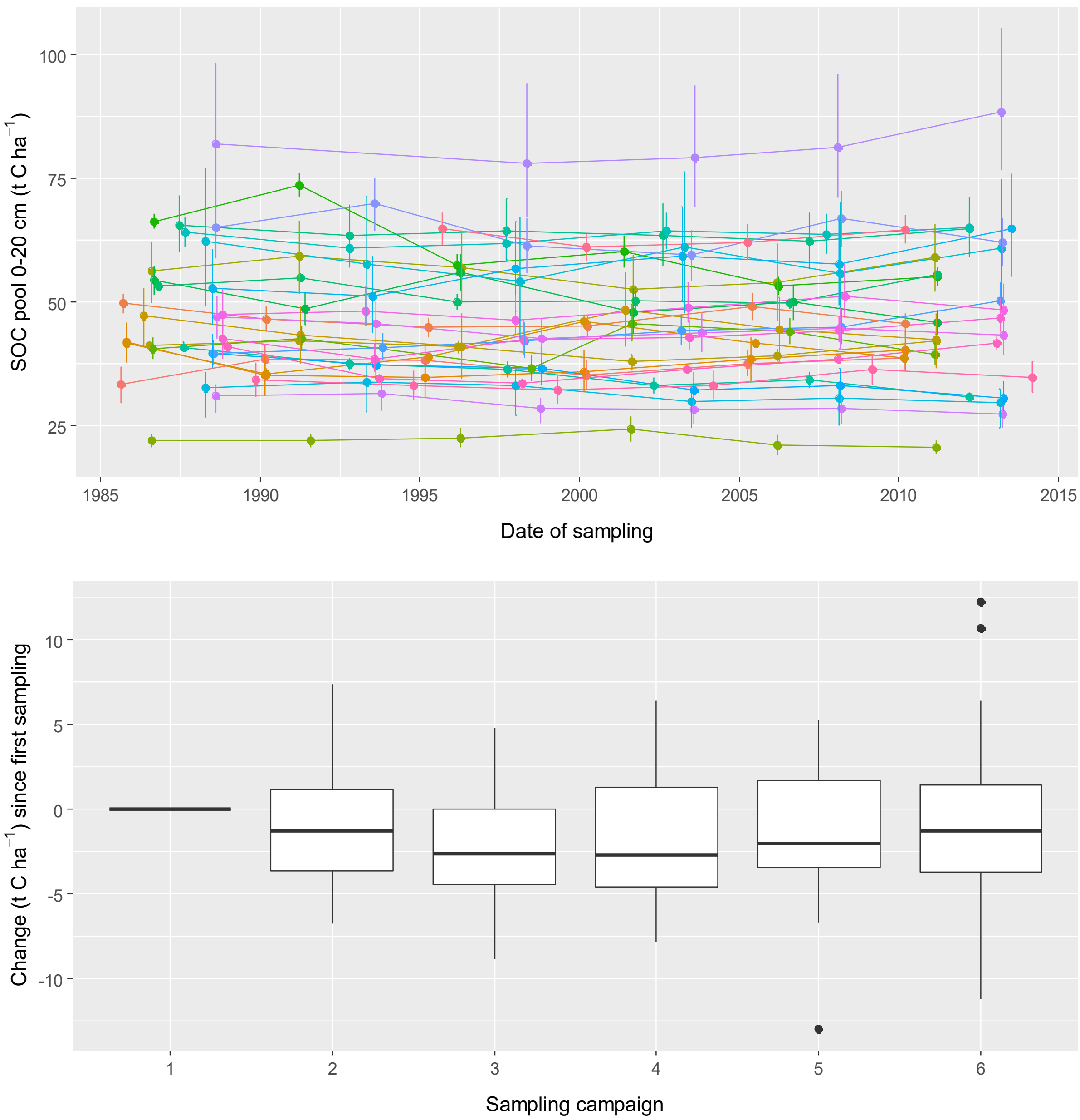


Figure 6-10 Measured SOC pools for topsoils (0–20 cm) and their changes for 29 NABO long-term monitoring sites featuring mineral soils and used as cropland during the time period 1985–2014. The elevation of the sites ranges from 324 to 945 m a.s.l. Top panel: SOC pools 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC pools since first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

6.5.4.4 Short-term land-use changes in arable rotations

Short-term land-use changes between "grassland" and cropland are to be expected for leys in arable rotations. However, leys were allocated to cropland by the Swiss Land Use Statistics (AREA) and were thus not considered grasslands in the common sense (i.e. permanent grassland). Furthermore, only long-term changes between cropland and grassland are considered relevant for carbon stock changes in soils. Since only long-term land-use changes are registered by the Swiss Land Use Statistics (AREA), carbon stock changes in soils associated with land-use changes between cropland and grassland and vice versa were adequately reported in the Swiss GHG inventory.

6.5.5 Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4B between the latest and the previous submission are additionally presented in chp. 10.1.2.4.

- 4B: Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).
- 4B: The biomass carbon pools were recalculated to include root biomass (as for living biomass on grassland). Additionally, net change of living biomass for the year 2017 was recalculated based on new available yield data (SBV 2019).
- 4B: Carbon stocks and carbon stock changes in mineral soils were recalculated. (1) All preliminary values for 2017 from the previous GHG inventory submission were replaced with newly-available data, including crop yields; (2) The time series of the excretion rate of volatile solids for llamas, alpacas and deer were updated in line with the excretion rates used in the Agriculture sector; (3) The time series of manure inputs from fattening pigs and broiler chickens were altered, as described in described in chp. 5.3.5; (4) In the previous submission the soil depth of some mountain soils had been underestimated, due to a mistake in the transfer of soil depth values from the input data to the model. This led to an underestimation of initial carbon stocks. In spite of this, the median initial carbon stock of the current submission is – at the national level – the same as that of the previous submission, due to the low proportion of cropland in mountainous regions. The four recalculations listed here result in a change of emissions in kt CO_2 eq of between -2 and 6 for the period 1990–2016 (mean: 2 kt CO_2 eq). For 2017, the recalculations led to a change of -50 kt CO_2 eq. This is due to the replacement of preliminary values for some input parameters (point (1) above) with newly-available data.

6.5.6 Category-specific planned improvements

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4B is subject to further evaluation.

A digital soil modelling project at Agroscope/Kompetenzzentrum Boden (funded by FOEN 2017–2020) builds on the outcomes of the recently completed national research programme "Sustainable Use of Soil as a Resource" (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

6.6 Category 4C – Grassland

6.6.1 Description

Table 6-27 Key categories in category 4C. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4C1	Grassland remaining grassland	CO2	L2, T2
4C2	Land converted to grassland	CO2	L1, L2, T1, T2

Swiss grasslands belong to the cold temperate wet climatic zone.

Carbon stocks in living biomass and carbon stocks in mineral and organic soils were considered.

Grasslands were subdivided into permanent grassland (CC31), shrub vegetation (CC32), vineyards, low-stem orchards ('Niederstammobst') and tree nurseries (CC33), copse (CC34), orchards ('Hochstammobst'; CC35), stony grassland (CC36), and unproductive grassland (CC37) (see Table 6-2 and Table 6-6).

In category 2 in CRF Table4.C, the land-use types CC32, CC33, CC34 and CC35 were merged under the notation 'woody' and CC36 and CC37 were merged under 'unproductive' (see Table 6-2).

In 2018, category 4C1 Grassland remaining grassland was a net source of 96.29 kt CO_2. Annual carbon stocks and carbon stock changes in living biomass are calculated for CC31. For CC32 to CC37, carbon stocks in living biomass are assumed to be in balance (i.e. no carbon stock changes occur). CO_2 emissions in category 4C1 were generated by carbon stock changes in living biomass (including changes of land-use categories among grasslands) and mostly by carbon mineralisation in organic soils under permanent grasslands (CC31), although only 0.6% of CC31 soils in Switzerland are organic soils (Table 6-7). Contributions of other Grassland remaining grassland categories (CC32-CC37) were of minor importance, although there is a noticeable gain in living biomass for shrub vegetation (CC32). The gain can be explained by abandoned pastures (CC31) that change to CC32 (approximately 1 kha per year, see Table 6-9).

Category 4C2 Land converted to grassland was a net source of 219.71 kt CO_2 in 2018. The highest individual contribution came from subcategory 4C2.1 Forest land converted to grassland being responsible for a net source of 419.58 kt CO_2. Most of this source was due to net changes in living biomass from deforestation. Subcategories 4C2.2 to 4C2.5 were net sinks due to sequestration of CO_2 in biomass and in mineral soils in the course of the conversion to grassland.

6.6.2 Methodological issues

For CC31, carbon in living biomass, carbon stocks and carbon stock changes in mineral soils were estimated by a Tier 3 approach using the model RothC (Wüst-Galley et al. 2019). The results were integrated in the GHG inventory by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone (see chp.6.5.2.3 for details regarding mineral soil). The difference in carbon stock between a specific year and the preceding year was reported as net change for living biomass and for mineral soil. For CC32 to CC37, constant carbon stocks in living biomass and in mineral soil are assumed (cf. Table 6-4).

6.6.2.1 Carbon in living biomass

Permanent grassland (CC31)

Permanent grasslands range in elevation from <300 m to 3000 m above sea level. Because both biomass productivity and soil carbon rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three elevation zones (cf. chp.6.2.2).

Standing stocks for permanent grasslands (t C ha^{-1}) were calculated as the annual cumulative yield (C_{yield}) of six differentially managed grasslands for three elevation zones. Total harvested biomass was adopted from annual statistics of the Swiss Farmers Union (SBV 2019 and former editions) and allocated to the below listed different grassland types and elevation zones based on standard yields from Richner et al. (2017) and area data from the Farm Structure Survey:

- extensive meadow
- less intensive meadow
- intensive meadow
- extensive pasture
- intensive pasture
- summer pasture

Table 6-28 shows the average C_{yield} 1990–2018 assuming a carbon fraction of 0.45 (Bolinder et al. 2007). Root biomass was estimated based an allometric function as described in Wüst-Galley et al. (2019).

The resulting area-weighted (across the three elevation zones) mean biomass stock for Swiss grassland over the inventory time period was 4.53 ± 0.06 (1 SD) t C ha^{-1}.

Carbon stock and carbon stocks changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990, see

Figure 6-11). The rationale for this approach is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years.

Table 6-28 Carbon stocks (t C ha^{-1}) and net carbon stock changes (gain/loss) (t C ha^{-1} yr^{-1}) in living biomass (including roots) of permanent grassland (CC31) reported as moving average over five years, stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; cf. chp. 6.2.2). Each value represents the mean of six grassland types in the period 1990-2018 (based on SBV 2019 and former editions and Richner et al. 2017, see also Wüst-Galley et al. 2019).

Living biomass	**Elev.**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
		CC31: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	5.88	5.86	5.84	5.81	5.79	5.77	5.75	5.75	5.75	5.73
Stock	2	5.38	5.37	5.35	5.33	5.31	5.30	5.30	5.30	5.30	5.31
Stock	3	3.31	3.30	3.30	3.29	3.29	3.29	3.29	3.29	3.30	3.30
Gain/loss	1	-0.02	-0.02	-0.02	-0.03	-0.02	-0.02	-0.02	-0.01	0.00	-0.01
Gain/loss	2	-0.01	-0.02	-0.02	-0.02	-0.02	-0.01	0.00	0.00	0.01	0.01
Gain/loss	3	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	0.01

Living biomass	**Elev.**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
		CC31: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	5.72	5.71	5.69	5.66	5.64	5.61	5.59	5.56	5.53	5.50
Stock	2	5.31	5.31	5.31	5.30	5.29	5.27	5.25	5.23	5.22	5.19
Stock	3	3.31	3.31	3.32	3.32	3.32	3.32	3.31	3.31	3.31	3.30
Gain/loss	1	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.02	-0.04
Gain/loss	2	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01	-0.02
Gain/loss	3	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Living biomass	**Elev.**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	
		CC31: carbon stock [t C ha^{-1}] and gain/loss in living biomass [t C ha^{-1} yr^{-1}]									
Stock	1	5.48	5.46	5.47	5.46	5.46	5.46	5.46	5.43	5.43	
Stock	2	5.19	5.18	5.20	5.19	5.21	5.21	5.22	5.20	5.21	
Stock	3	3.30	3.30	3.30	3.30	3.31	3.31	3.31	3.31	3.32	
Gain/loss	1	-0.02	-0.02	0.01	-0.02	0.01	-0.01	0.00	-0.02	0.00	
Gain/loss	2	-0.01	-0.01	0.02	-0.01	0.02	0.00	0.01	-0.02	0.00	
Gain/loss	3	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	

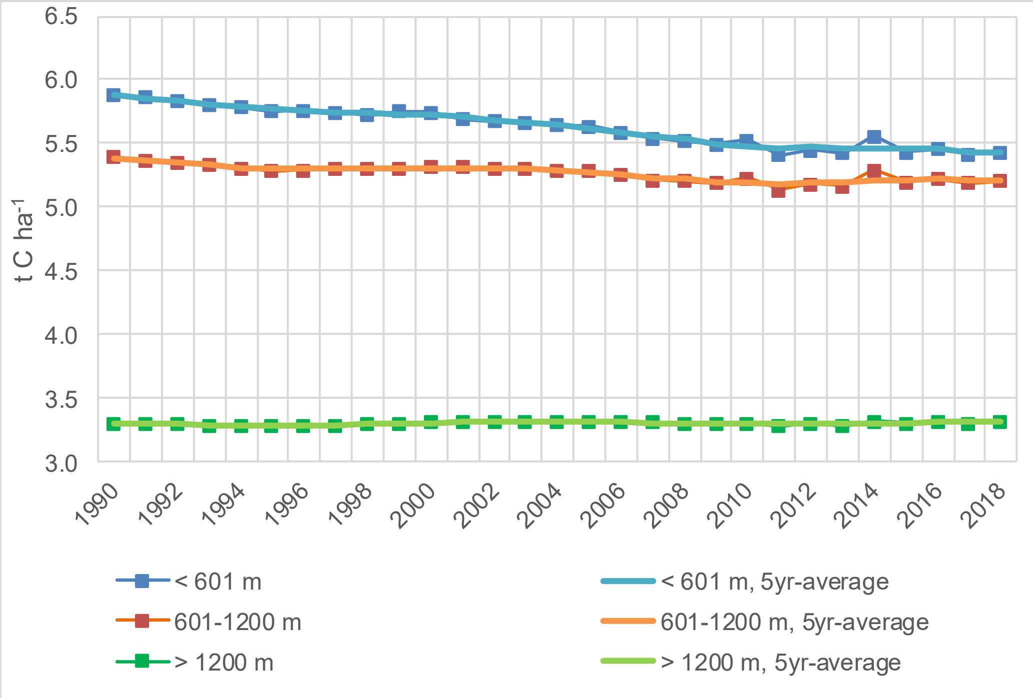


Figure 6-11 Carbon stocks in living biomass of permanent grassland (CC31) stratified for elevation zone and corresponding moving averages over five years.

Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of accurate data, the living biomass of shrub vegetation and copse was assumed to be equal to the living biomass of brush forest as described in chp. 6.4.2.8, where brush forest is assumed to contain 20.45 t C ha^{-1} (Düggelin and Abegg 2011).

Vineyards, low-stem orchards and tree nurseries (CC33)

Low-stem orchards are small fruit trees distinguished from CC35 ('orchards') by a maximum stem height of 1 m and a much higher stand density. Only low-stem orchards and vineyards are considered in the following because no stand densities for tree nurseries are available. This is justified because tree nurseries comprise only ca. 8% (1'378 ha tree nurseries, SFSO 2002) of the total area of CC33, i.e., 17'054 ha, 15'436 ha are vineyards (SFSO 2005) and 240 ha are low-stem orchards (Widmer 2006).

The standing carbon stock of living biomass per ha (Cl) for CC33 was therefore calculated as:

$$Cl = \left[\left(Cl_{vineyards} * area_{vineyards}\right) + \left(Cl_{low-stem\ orchards} * area_{low-stem\ orchards}\right)\right] / \left(area_{vineyards} + area_{low-stem\ orchards}\right)$$

Cl of vineyards (5.44 t C ha^{-1}) was calculated as the sum of the woody biomass (3.61 t C ha^{-1}) and the biomass in the grass layer (1.83 t C ha^{-1}).

Woody biomass for vineyards was calculated based on the mean stand density (5’556 vines ha^{-1}) and the mean carbon content in the woody biomass of one plant including roots (0.65 kg C; Ruffner 2005).

The mean carbon content of the grass layer in vineyards was calculated using the following information and assumptions: (1) Most vineyards in Canton Valais (around 5'000 ha) have no grass layer, in the other cantons the share of vineyards with grass understorey is very high (95%). Thus, it can be assumed that on the average 65% of the Swiss vineyards exhibit a grass layer. (2) The grass layer between the vine rows has a lower carbon content than permanent grassland. It is assumed that it is 50% less than the carbon content of CC31 (elevation <600 m, average of the period 1990–2018).

For small fruit trees on low-stem orchards, no literature value was found for biomass expansion factors. Therefore, the following assumptions were made: Diameter at breast height (DBH) of such trees was assumed to be 10 cm and the stem height was assumed to be 1 m. The bole shape of low-stem apple trees can be approximated by a cylinder shape.

Stem wood volume = $r^2 * \pi *$ height = $(5\text{ cm})^2 * 3.1 * 100\text{ cm} = 7.75\text{ dm}^3$

Based on expert knowledge (Kaufmann 2005), the percentage of branches was estimated as 100%, and the percentage of roots was estimated as 30% of the stem wood volume. This results in a BEF of 2.3. A wood density of 0.55 kg dm^{-3} (Vorreiter 1949) and the default IPCC carbon content of 50% (IPCC 2006, Volume 4, chp. 5.2.2.2) were assumed. With these assumptions the carbon content of a tree of the type low-stem (‘Niederstamm’) was calculated as follows:

C low-stem = stem wood volume * BEF * wood density * carbon content

= $7.75\text{ dm}^3 * 2.3 * 0.55\text{ kg/dm}^3 * 0.5 = 4.9$ kg C

The mean stand density of low-stem orchards was estimated as 2500 ha^{-1} (Widmer 2006), resulting in a Cl of 12.25 t C ha^{-1}.

The resulting carbon in living biomass (Cl) for CC33 is 5.57 t C ha^{-1}.

Orchards (CC35)

Orchards consists of larger fruit trees (‘Hochstammobst’) planted at a low density with grass understory. Cl of orchards trees was calculated as:

Cl biomass = (carbon per fruit tree [t C] * number of fruit trees / area orchards [ha]) + carbon in grass [t C ha^{-1}]

The carbon content of a large fruit tree with a DBH of 25–35 cm was calculated as follows:

C (Hochstamm) = Stem wood volume * KE-Factor = 225 kg C

where:

- Stem wood volume of an apple tree assuming a cylindrical stem with mean DBH of 30 cm and a stem height of 7 m amounts to 0.5 m^3, and
- KE-Factor [t C m^{-3}] = BEF * Density * carbon content = 0.45 (Wirth et al. 2004: 68, Table 16).

From the total fruit-growing area of 41’480 ha (SFSO 2005), the area of low-stem trees (240 ha, see CC33) was subtracted, and the remaining area of 41’240 ha was divided by the number of large fruit trees calculated as the mean of the counts in 1991 (3’616’301 trees) and 2001 (2’900’000 trees; SFSO 2002). This resulted in a mean stand density of 79 trees ha^{-1}. The resulting carbon stock in woody biomass of CC35 is thus 17.78 t C ha^{-1}. Because orchards typically have a grass understory, the biomass of CC31 was added to the woody biomass. The average biomass 1990–2018 of CC31 (cf. Table 6-28) was weighted with the area of CC35 in the three elevation zones (cf. Table 6-7) – resulting in 5.56 t C ha^{-1} – and added to the woody biomass to obtain a total carbon stock of 23.34 t C ha^{-1} for CC35.

Stony grassland (CC36)

Approximately 35% of the surface of CC36 (herbs and shrubs on stony surfaces) is covered by vegetation. No accurate data were available for this category. Therefore, the carbon stock of brush forest (20.45 t C ha^{-1}; cf. chp. 6.4.2.8; Düggelin and Abegg 2011) was multiplied by 0.35 to account for the 35% vegetation coverage. This results in a carbon stock for stony grassland of 7.16 t C ha^{-1}.

Unproductive grassland (CC37)

The category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, biomass data are currently available. Therefore, the area-weighted mean (cf. Table 6-7) of carbon stocks of permanent grasslands in the three elevation zones (cf. Table 6-28, average of the period 1990–2018) was assumed to be representative for the carbon stock on unproductive grassland CC37. Carbon in living biomass in unproductive grassland appeared to be 3.45 t C ha^{-1}.

6.6.2.2 Carbon in dead organic matter

Applying a Tier 1 approach carbon stocks in dead organic matter were not assessed.

6.6.2.3 Carbon in soils

Permanent grassland (CC31)

Mineral soils

Carbon stocks in grassland soil refer to a depth of 0–30 cm and were calculated based on Leifeld et al. (2003, 2005) as described in Wüst-Galley et al. (2019) and in chp. 6.5.2.3. Average stocks were calculated as weighted means using the location of permanent grassland, according to the AREA Land Use Statistics. The median soil organic carbon stock (0–30 cm, in 1975) for permanent grassland is 64.3 t C ha^{-1}. The variability of carbon stocks across the area is 19.3 t C ha^{-1} (1 SD). These carbon stocks were used to initialise the RothC model (see below and chp. 6.5.2.3) which was used to estimate carbon stocks from 1990 to 2018.

Switzerland used the soil carbon model RothC to estimate carbon stocks in mineral soil (0–30 cm) under permanent grassland for the period 1990 to 2018, as described in chp. 6.5.2.3 and in Wüst-Galley et al. (2019). Six differently managed permanent grassland types (as listed in chp. 6.6.2.1, covering over 99% of Swiss permanent grassland) were considered. Plant carbon inputs into the soil from grasslands were assumed to be constant, in accordance to the approach in Franko et al. (2011) and as detailed in Wüst-Galley et al. (2019). Mean carbon stock values calculated for permanent grasslands (CC31) are given in Table 6-29 .

Table 6-29 Area-weighted (using the relative surface of the six grassland types) carbon stock means (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in mineral soils (0-30cm) for permanent grassland (CC31), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; cf. chp. 6.2.2). Highlighted data for 1990 are displayed in Table 6-4. The resulting area-weighted (across the three elevation zones) mean carbon stock for permanent grassland over the inventory period is 62.80 ± 0.44 (1 SD) t C ha^{-1}.

Mineral		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
soil	Elev.	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	1	60.44	60.57	60.63	60.37	60.14	59.90	59.91	59.70	59.52	59.56
Stock	2	65.26	65.38	65.42	65.22	65.05	64.84	64.89	64.84	64.68	64.65
Stock	3	62.60	62.91	63.11	63.17	63.26	63.29	63.56	63.73	63.75	63.89
Net change	1	-0.02	0.13	0.05	-0.26	-0.24	-0.24	0.01	-0.20	-0.18	0.03
Net change	2	-0.13	0.12	0.04	-0.20	-0.17	-0.21	0.06	-0.06	-0.15	-0.03
Net change	3	0.15	0.31	0.20	0.06	0.09	0.03	0.27	0.18	0.02	0.14

Mineral		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
soil	Elev.	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	1	59.21	58.78	58.58	58.78	58.94	58.67	58.74	58.57	58.47	58.35
Stock	2	64.45	64.22	64.10	64.05	64.02	63.89	63.88	63.70	63.73	63.66
Stock	3	63.91	63.96	64.03	64.03	64.06	64.13	64.18	64.12	64.32	64.38
Net change	1	-0.35	-0.43	-0.20	0.20	0.16	-0.27	0.07	-0.17	-0.10	-0.11
Net change	2	-0.21	-0.22	-0.12	-0.05	-0.03	-0.13	-0.01	-0.18	0.02	-0.07
Net change	3	0.02	0.05	0.07	0.00	0.03	0.07	0.05	-0.06	0.21	0.05

Mineral		2010	2011	2012	2013	2014	2015	2016	2017	2018	
soil	Elev.	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	1	58.16	57.98	57.66	57.43	57.07	56.93	56.89	56.66	56.73	
Stock	2	63.56	63.41	63.16	63.06	62.81	62.60	62.50	62.32	62.22	
Stock	3	64.45	64.48	64.33	64.37	64.37	64.30	64.31	64.24	64.25	
Net change	1	-0.19	-0.18	-0.32	-0.22	-0.36	-0.14	-0.04	-0.23	0.07	
Net change	2	-0.10	-0.15	-0.25	-0.09	-0.25	-0.20	-0.10	-0.18	-0.10	
Net change	3	0.07	0.03	-0.15	0.04	0.00	-0.07	0.01	-0.07	0.02	

Organic soils

Soil carbon stocks in organic soils under permanent grassland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils without differentiation between cropland and grassland. The mean soil organic carbon stock (0–30 cm) of organic soils is 240 ± 48 t C ha^{-1} (uncertainty 20%).

Shrub vegetation (CC32) and Copse (CC34)
Due to the lack of more specific data, the average carbon stocks of CC31 for each elevation zone (see Table 6-29) in the period 1990–2018 were used:

- Elevation zone 1 (<601 m a.s.l.): 58.74 t C ha^{-1}
- Elevation zone 2 (601-1200 m a.s.l.): 63.99 t C ha^{-1}
- Elevation zone 3 (>1200 m a.s.l.): 63.91 t C ha^{-1}.

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha^{-1}.

Vineyards, low-stem orchards and tree nurseries (CC33)
No specific value for mineral soils under CC33 was available. As CC33 is only partially covered by grass understorey the mean soil organic carbon stock of cropland (CC21) (area-weighted mean across the three elevation zones 1990–2018) was taken: 50.58 t C ha^{-1} (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha^{-1}.

Orchards (CC35)
No specific value for mineral soils under orchards was available. As most orchard areas have grass understorey the average soil carbon content of permanent grassland (CC31) for the period 1990–2018 was taken, weighted with the area of CC35 per elevation zone: 59.79 t C ha^{-1} (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha^{-1}.

Stony grassland (CC36)
Soil organic carbon stocks under herbs and shrubs on stony surfaces were calculated according to the procedure described in chp. 6.6.2.1, i.e. it was assumed that not more than 35% of the area of CC36 is covered with vegetation and thus only 35% of the area bears a mineral soil while the remainder is bare rock. Land use of this category is mainly located at elevations >1200m a.s.l. The carbon stock of CC36 was calculated as average soil carbon content of permanent grassland (CC31) for the period 1990–2018, weighted with the area of CC36 per elevation zone, considering a 35% coverage:

Cs of CC36 = 0.35 * 63.90 t C ha^{-1} = 22.36 t C ha^{-1} (0–30 cm)

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha^{-1}. It was assumed that the small area covered by organic soils in CC36 (cf. Table 6-7), albeit entitled 'stony grassland', does not contain significant contributions from stones because bogs are free of stones as a matter of nature and fens usually contain, if any, only fine mineral sediments.

Unproductive grassland (CC37)
Unproductive grassland includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, soil carbon stock data are currently available. Therefore, the carbon stock of mineral soils was calculated as average soil carbon content of permanent grassland (CC31) for the period 1990–2018, weighted with the area of CC37 per elevation zone: 63.69 t C ha^{-1} (0–30 cm).

The mean soil organic carbon stock (0–30 cm) of organic soils is 240 t C ha^{-1}.

6.6.2.4 Changes in carbon stocks

6.6.2.4.1 Living biomass
For permanent grassland (CC31), the difference in carbon stock in living biomass (five-year moving average) between a specific year and the preceding year was reported as net change (gain or loss) as shown in Table 6-28. Applying a Tier 1 approach, changes in carbon stocks in living biomass were assumed to be in equilibrium for Grassland remaining grassland in the subcategories CC32–CC37.

6.6.2.4.2 Dead organic matter
Applying a Tier 1 approach, changes in carbon stocks of dead organic matter were assumed to be in equilibrium for Grassland remaining grassland.

6.6.2.4.3 Mineral soils: Permanent grassland (CC31)
The difference in carbon stock between a specific year and the preceding year was reported as net change for mineral soils (Table 6-29 and Figure 6-12). In Figure 6-12, carbon stocks changes are additionally presented as moving averages over five years (from year -2 to year +2, e.g. 1988–1992 for the year 1990). Interannual changes in carbon stocks mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. However, the 5-year averages are not used in the reporting. The mean annual carbon stock change in the inventory period for elevation zone 1 is -0.129 t C ha^{-1}, for elevation zone 2 is -0.109 t C ha^{-1} and for elevation zone 3 is +0.062 t C ha^{-1}. The average annual stock change across the inventory period (area-weighted across the three elevation zones) is -0.044 t C ha^{-1}. Annual carbon stocks in permanent grasslands on a per hectare basis deviate very little from the stocks predicted by linear regression across the inventory time period (i.e. accounting for the long-term trend); annual stocks vary by -0.9 to +0.55% or -0.56 to +0.32 t C ha^{-1} (data not shown).

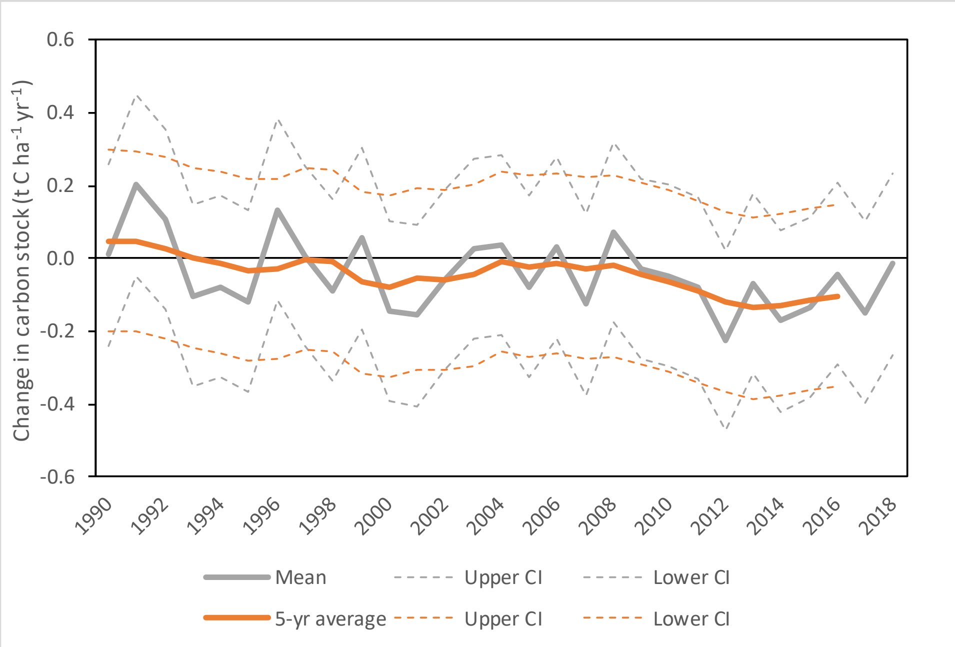


Figure 6-12 Annual carbon stock changes (t C ha^{-1} yr^{-1}) and corresponding 5-year moving averages in mineral soil (0-30 cm) for permanent grassland (CC31), area-weighted across three elevation zones, plus upper and lower confidence intervals (see chp. 6.6.3). The 5-year averages are displayed to highlight the trends; they are not used for the reporting.

6.6.2.4.4 Mineral soils: Remaining grassland subcategories (CC32-37)

A Tier 1 approach (changes in SOC are in equilibrium) was assumed for carbon stock changes in mineral soils in the subcategories CC32–37.

6.6.2.4.5 Organic soils

The annual net carbon stock change in organic soils on managed grassland (CC31, CC33 and CC35) was estimated as -9.52 t C ha^{-1} according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018). For extensively managed grasslands (CC32, CC34, CC36 and CC37) the emission from organic soils was estimated as 5.30 t C ha^{-1} yr^{-1} according to available domestic data (ART 2011b; Paul and Alewell 2018).

6.6.2.4.6 Land-use change

In the case of land-use change, the net carbon changes in biomass and soil of CC31, CC32, CC33, CC34, CC35, CC36, and CC37 were calculated as described in chp. 6.1.3.

6.6.2.5 N_2O emissions from grassland

N_2O emissions from drainage of organic soils (category 4(II)) on grassland were reported in the agriculture sector (CRF Table3.D).

The calculation of emissions for categories 4(III) and 4(IV) (direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils) is described in chp. 6.10.

6.6.2.6 Emissions from wildfires

Data on wildfires affecting Swiss grassland are obtained from cantonal authorities and are compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database; Pezzatti et al. 2019, http://www.wsl.ch/swissfire). Table 6-30 shows the annual burnt area from 1990 to 2018. The Swissfire database differentiates between 'grassland' and 'unproductive land'. As 'unproductive land' can partially cover the grassland categories CC32, CC34, CC36 and CC37 the sum of both categories was reported. Controlled burning is not a common practice in Switzerland. Therefore, all fires were assigned to wildfires.

The CH_4 and N_2O emissions were calculated using equation 2.27 in Volume 4 of IPCC (2006) with the following parameters:

- The mass of available fuel encompasses the carbon stock of living biomass (litter and dead wood carbon stocks were assumed to be zero for grassland). On average, the amount of living biomass amounted to 16.60 t biomass ha^{-1} (7.47 t C ha^{-1}). This value was derived from the carbon stocks of all grassland categories (CC31 to CC37) as an area-weighted mean using the geographical extensions in 1990 and a carbon fraction of 0.45.
- The fraction of the biomass combusted was 0.74 (IPCC 2006 Volume 4, Table 2.6, Savanna and Grassland).
- For CH_4 the default emission factor of 2.3 g (kg combusted biomass)$^{-1}$ and for N_2O, the default emission factor of 0.21 g (kg combusted biomass)$^{-1}$ was applied (IPCC 2006, Volume 4, Table 2.5, Savanna and Grassland).

The resulting annual CH_4 and N_2O emissions 1990–2018 on burnt areas in category 4C Grassland are shown in Table 6-30 and are reported in CRF Table4(V).

Table 6-30 Area of 4C Grassland affected by wildfires (WSL, Swissfire database) and resulting CH_4 and N_2O emissions.

Grassland	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Area burnt	ha	637.1	22.3	6.0	18.9	174.5	82.0	42.8	371.8	72.0	19.0
CH_4	t	18.0	0.6	0.2	0.5	4.9	2.3	1.2	10.5	2.0	0.5
N_2O	t	1.6	0.1	0.0	0.0	0.5	0.2	0.1	1.0	0.2	0.0

Grassland	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Area burnt	ha	21.8	7.5	257.2	137.9	4.3	19.5	14.3	97.8	29.2	4.0
CH_4	t	0.6	0.2	7.3	3.9	0.1	0.6	0.4	2.8	0.8	0.1
N_2O	t	0.1	0.0	0.7	0.4	0.0	0.1	0.0	0.3	0.1	0.0

Grassland	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018
Area burnt	ha	1.3	65.7	13.6	3.6	2.6	8.0	212.3	37.5	28.9
CH_4	t	0.0	1.9	0.4	0.1	0.1	0.2	6.0	1.1	0.8
N_2O	t	0.0	0.2	0.0	0.0	0.0	0.0	0.5	0.1	0.1

6.6.2.7 NMVOC emissions

Estimates for annual biogenic emissions of NMVOC (CRF Table4) for natural grassland in Switzerland are available in SAEFL (1996a). The value for natural grassland (unproductive vegetation) is 0.51 kt yr^{-1}.

6.6.3 Uncertainties and time-series consistency

6.6.3.1 Uncertainties

Activity data

Uncertainties of activity data of category 4C Grassland are described in chp. 6.3.3. For calculating the overall uncertainty of category 4C, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2020).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from both cropland and grassland (Leifeld and Fuhrer 2005). Data on biomass yields for different elevations and management intensities as assessed based on SBV (2019) and Richner et al. (2017) were based on many agricultural field experiments and have a high reliability. The absolute uncertainties per hectare, calculated with the implied emission factors of 2018, are 0.003 t C ha^{-1} yr^{-1} for 4C1 and 0.096 t C ha^{-1} yr^{-1} for 4C2.

Mineral soils

0.249 t C ha^{-1} yr^{-1} was used as absolute uncertainty for 4C1 and 4C2. This value was calculated by a Monte-Carlo analysis (Wüst-Galley et al. 2019), see chp. 6.5.3. By comparison, the range of annual SOC changes identified for 9 different treatments of Swiss agricultural long-term experiments is 0.51 t C ha^{-1} yr^{-1} (Keel et al. 2019), indicating that the calculated uncertainty is plausible.

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 23% as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 68.6% (see chp. 6.3.3), resulting in a combined uncertainty of 72.3%. Thus, the absolute uncertainties of the total organic soil emissions in 2018 are 37.9 kt C for 4C1 and 8.0 kt C for 4C2. By dividing those uncertainties with the total area of 4C1 and 4C2, respectively, the absolute uncertainties per hectare result in 0.030 t C ha^{-1} yr^{-1} for 4C1 and 0.086 t C ha^{-1} yr^{-1} for 4C2.

Overall uncertainties 4C1 and 4C2

The root sum squares of the above-mentioned three absolute uncertainties are 0.251 t C ha^{-1} yr^{-1} for 4C1 and 0.280 t C ha^{-1} yr^{-1} for 4C2. These absolute uncertainties were used to calculate relative emission factor uncertainties for 4C1 and 4C2 by dividing with the mean net carbon stock change per hectare of 4C1 and 4C2, respectively. In 2018, the total net carbon stock changes were -0.020 t C ha^{-1} for 4C1 and -0.645 t C ha^{-1} for 4C2 (calculated from CRF Table4.C). The resulting relative uncertainties are 1’224.7% for 4C1 and 43.5% for 4C2, respectively (see Table 6-5). In the same way the uncertainties for the year 1990 were calculated. They are 2’879.7% (4C1) and 55.4% (4C2).

Wildfires

For wildfires, the emission factor uncertainties of CH_4 and N_2O were set to 70% (identical to forest land, see chp. 6.4.3). The activity data uncertainty is 30% (see chp. 6.3.3).

6.6.3.2 Time-series consistency

Time series for category 4C Grassland are all considered consistent; they were calculated based on consistent methods and homogenous databases. Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

6.6.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

6.6.4.1 Carbon stocks in mineral soils

The initial SOC stocks for this submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2019). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.6.6.

6.6.4.2 Changes in living biomass

The biomass carbon pools for CC31 were recalculated in the course of the Tier 3 approach for quantification of carbon stocks and carbon stock changes in agricultural soils in the GHG inventory submission 2019. As far as possible, the input data for the simulations were consistent with input data in the Agriculture sector, i.e. same data source SBV (2019) and former editions.

6.6.4.3 Changes in soil carbon stocks

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2019). A comparison of SOC stocks and measured values from field experiments is made by Wüst-Galley et al. (2019).

The Swiss Soil Monitoring Network (NABO; see chp. 6.4.4) provided data from 31 monitoring sites identified as grassland according to the land-use definitions used for LULUCF (see chp. 6.2); thus, the selected sites included –in addition to meadows and pastures– also vineyards, orchards, and urban parks. SOC pools for the top 20 cm of these soils ranged from 25.3 to 142.1 t C ha^{-1} with a mean of 73.5 t C ha^{-1} (Figure 6-13). The highest pools were found for alpine pastures at high elevation. On average, a slight increase during the period 1985 to 2000 (sampling campaigns 1 to 3) and a slight decrease thereafter (campaigns 3 to 4) were observed for SOC. However, these minor changes were statistically non-significant. In addition, previous studies showed that the elevated SOC pools for the third sampling campaign must be considered as artefact induced by sub-optimal conditions during field work. From sampling campaigns 4 to 6, SOC pools remained stable. The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5% per 10 years for mineral grassland soils (minimum detectable change for about 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC pools (mean ≈

74 t ha^{-1}) this corresponds to a minimum detectable change of roughly 0.19 t C ha^{-1} yr^{-1} for SOC pools (or 0.21 t C ha^{-1} yr^{-1} if vineyards are excluded).

In conclusion, NABO data provide evidence that Swiss grassland mineral soils did not act as a significant net source or sink of carbon over the last 30 years.

The mean change in SOC which was calculated with RothC for the years 1990–2018 was -0.044 ± 0.249 t C ha^{-1} yr^{-1} (area-weighted average change across three elevation zones ± the absolute uncertainty based on a Monte Carlo analysis, see Figure 6-12 and chp. 6.6.3). In comparison, the modelled net change is two orders of magnitude smaller than the detectable change by NABO and suggests that modelled SOC pool changes agree with the repeated soil inventories in the NABO network.

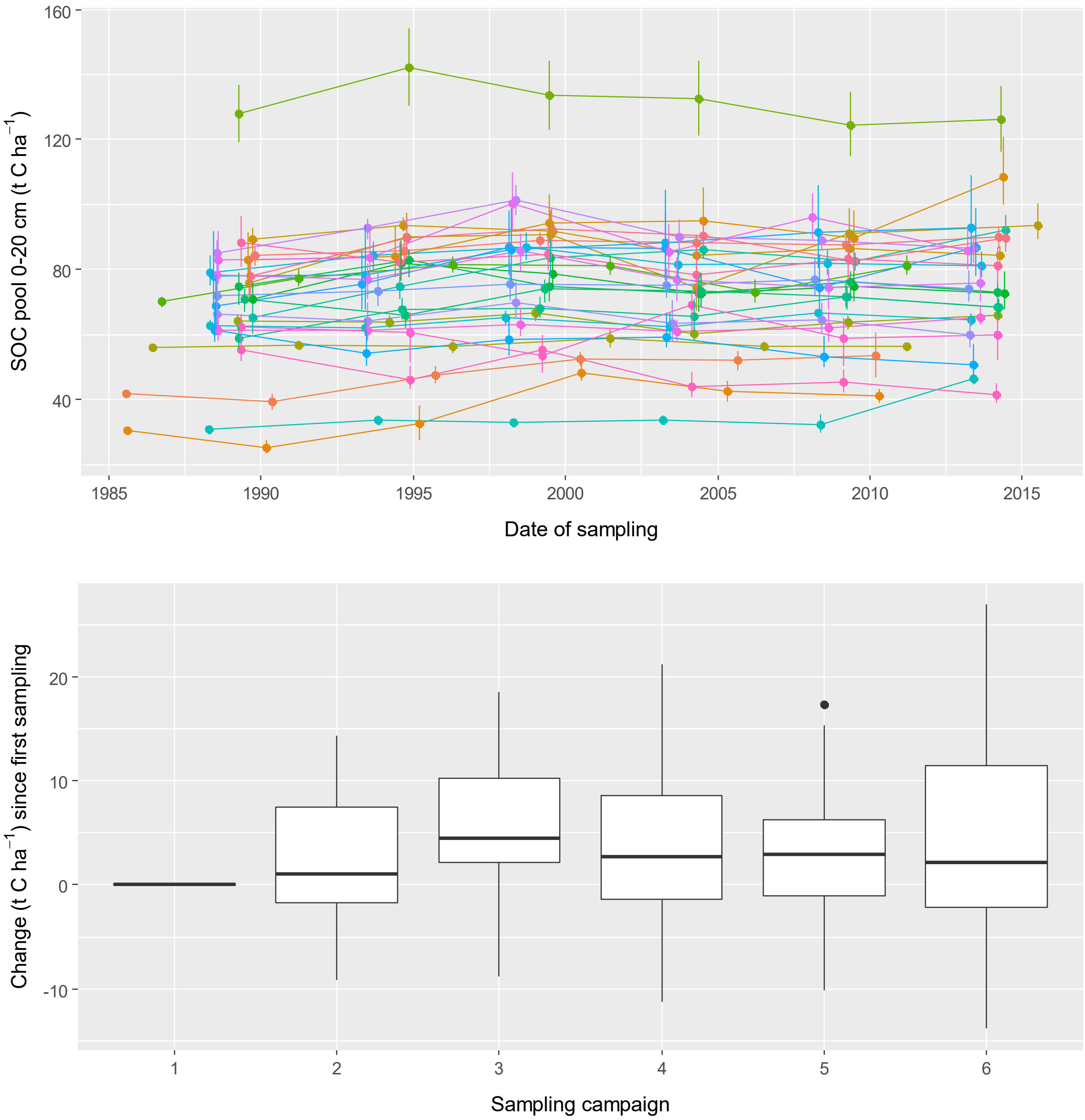


Figure 6-13 Measured SOC pools for topsoils (0–20 cm) and their changes for 31 NABO long-term monitoring sites used as grassland during the time period 1985–2014. The elevation of the sites ranges from 265 to 2400 m a.s.l. Top panel: SOC pools 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5% and 95% percentiles of bootstrap samples taking into account the variability in SOC contents of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC pools since first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

6.6.4.4 Short-term land-use changes between Grassland and Cropland

See chp. 6.5.4.4.

6.6.5 Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4C between the latest and the previous submission are additionally presented in chp. 10.1.2.4.

- 4C: Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).
- 4C: Carbon stocks and carbon stock changes in living biomass of permanent grassland (CC31) were recalculated and annual values are reported instead of constant values. Root biomass was estimated based on an allometric function as described in Wüst-Galley et al. (2019) instead of using values from ART (2011a). The new approach is considered more realistic and is consistent with the soil organic carbon modelling. Additionally, net change of living biomass for the year 2017 was recalculated based on new available yield data.
- 4C: The carbon stocks in living biomass for grassland subcategories CC33, CC35 and CC37 were adjusted to the recalculated mean carbon contents (over the period 1990–2018) of living biomass of CC31 (this submission, see above).
- 4C: Carbon stocks and carbon stock changes in mineral soils were recalculated for permanent grassland CC31. (1) All preliminary values for 2017 from the previous submission were replaced with newly-available data; (2) The time series of the excretion rate of volatile solids for llamas, alpacas and deer were updated in line with the excretion rates used in the Sector Agriculture; (3) The time series of manure input from fattening pigs and broiler chickens were altered, as described in described in chp. 5.3.5; (4) In the previous submission the soil depth of some mountain soils had been underestimated, due to a mistake in the transfer of soil depth values from the input data to the model. This led to an underestimation of initial carbon stocks. The median initial carbon stock (across the whole country) in the current submission is on average 6.3% higher than that reported in the previous submission. The effect of the recalculations on carbon stock changes is described in chp 10.1.2.4.
- 4C: The carbon stocks in mineral soils for grassland subcategories CC32 and CC34 to CC37 were adjusted to the recalculated soil organic carbon content of CC31 (this submission, see above). The carbon stock in mineral soils for grassland subcategory CC33 was adjusted to the recalculated soil organic carbon content of CC21 (this submission, see chp. 6.5.5).
- 4(V)C1: The area affected by wildfires in the Swissfire database was updated for the years 1998, 1999, 2005, 2009, 2011–2017 (Pezzati et al. 2019).
- 4(V)C1: For calculating the amount of available fuel consumed by wildfires recalculated carbon contents in living biomass for CC31, CC33, CC35, and CC37 (this submission, see above) were used.

6.6.6 Category-specific planned improvements

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4C is subject to further evaluation.

A digital soil modelling project at Agroscope/Kompetenzzentrum Boden (funded by FOEN 2017–2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

A study on GHG (CO_2, CH_4, N_2O) emissions from an intensively used fen under grassland management in the Rhine valley (canton Sankt Gallen; Agroscope, 2017–2022, financed by FOEN) will improve the robustness of country-specific emission factor estimates for grassland soils rich in organic matter in the medium term. A further objective of the study is to test if cover fills reduce peat oxidation and carbon emissions from managed organic soils.

6.7 Category 4D – Wetlands

6.7.1 Description

Table 6-31 Key categories of 4D Wetlands. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4D1	Wetland remaining wetland	CO2	L2

Carbon stocks in living biomass and carbon stocks in mineral and organic soils were considered.

Wetlands were subdivided into surface waters (CC41) and unproductive wetlands such as shore vegetation, fens or (raised) bogs (CC42) (see Table 6-2 and Table 6-6).

6.7.2 Methodological issues

6.7.2.1 Carbon in living biomass

Surface waters (CC41)
Surface waters have no carbon stocks by definition.

Unproductive wetland (CC42)
CC42 consists of (very) extensively managed grassland, bushes or tree groups. The pool of living biomass was estimated as 6.50 t C ha^{-1} (Mathys and Thürig 2010).

6.7.2.2 Carbon in soils

Surface waters (CC41)
The soil carbon stock for surface waters (CC41) is zero. However, for CC41 situated in areas with organic soil (see chp. 6.2.2 and Table 6-7), a soil carbon stock of 240 t C ha^{-1} (0–30 cm) was assumed. These surface waters were assumed to be shallow ponds as integrated parts of fens or bogs.

Unproductive wetland (CC42)
Land cover in CC42 includes bogs and fens protected by Federal Legislation (Swiss Confederation 1991a, 1994) as well as reed. More than 10% of the unproductive wetlands are located on organic soils (cf. Table 6-7). In this case the carbon stock in soils is 240 t C ha^{-1} (0–30 cm). Currently, no specific soil data are available for CC42 on mineral soils. As a first approximation, it was assumed that the soil carbon stock of unproductive wetlands is similar like in mineral soils of permanent grassland (CC31). Therefore, the averages 1990–2018 of CC31 (see chp. 6.6.2.3) were calculated and weighted with the area per elevation zone of CC42: 62.86 t C ha^{-1} (0–30 cm).

6.7.2.3 Changes in carbon stocks

Living biomass, Dead organic matter, Mineral soils
Applying a Tier 1 approach, carbon stocks in living biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Wetlands remaining wetlands.

Organic soils
The emission from organic soils under CC41 was assumed to be zero because the respective areas are not drained.

The emission from organic soils under CC42 was estimated to be 5.30 t C ha^{-1} yr^{-1} according to domestic data (ART 2011b; Paul and Alewell 2018). This value was used for weakly managed ecosystems such as fens and (very) extensively managed ecosystems such as raised bogs. Bogs and fens are protected to a large part by Federal Ordinances (Swiss Confederation 1991a, 1994) and drainage is not allowed any more. However, the impact of old drainages constructed before 1990 probably still triggers certain emissions.

Land-use change
In the case of land-use change, the net carbon changes in biomass and soil of both CC41 and CC42 were calculated as described in chp. 6.1.3.

For land converted to unproductive wetland (CC42) a conversion time of one year was chosen for the carbon stock change in living biomass and in dead organic matter (see Table 6-3). For carbon stock changes in wetland soils the conversion time is 20 years.

6.7.2.4 Non-CO_2 emissions from wetlands

No emissions were reported in category D in CRF Table4(I) (notation key “NO”). Input of nitrogen fertilisers to unproductive wetlands (CC42) is very unlikely as these areas represent mostly nature conservation areas (raised bogs, fens) protected by legislation (Swiss Confederation 1991a, 1994), where fertilising is prohibited.

An estimate of 0.43 kt CH_4 yr^{-1} emitted by reservoirs (flooded lands) was given by Hiller et al. (2014). The estimate encompasses 97 artificial lakes covering a total area of 10.6 kha. This emission is reported in category D.2 in CRF Table4(II).

N_2O emissions from drainage of organic soils was calculated for unproductive wetlands (CC42) and reported in category D.3 in CRF Table4(II) (labelled as “WL drained”). AD correspond to the total area of organic soils for subdivision "unprod wetland" (CC42) in CRF Table4.D.The emission factor of 1.6 kg N_2O-N ha^{-1} used is the default value given in the IPCC Wetlands Supplement (IPCC 2014a, Table 2.5) for shallow drained, nutrient-rich grassland.

The calculation of emissions for categories 4(III) and 4(IV) (direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils) is described in chp. 6.10.

6.7.3 Uncertainties and time-series consistency

6.7.3.1 Uncertainties 4D1

Activity data

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.3.

For calculating the overall uncertainty of 4D1, only the relevant emissions from organic soils were considered (Meteotest 2020).

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 72.2% both for 1990 and 2018. It was calculated on the basis of measurement data compiled by ART (2011b). The uncertainty of the activity data (area of organic soil) is 90.8% (see chp. 6.3.3).

6.7.3.2 Uncertainties 4D2

Activity data

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.3.

For calculating the overall uncertainty of 4D2, the relevant emissions from living biomass, mineral soils and organic soils were considered (Meteotest 2020).

Living biomass

The relative uncertainty in yield determination was estimated as 13% for biomass carbon from both cropland and grassland (Leifeld and Fuhrer 2005). The absolute uncertainty per hectare, calculated with the implied emission factors of 2018, is 0.142 t C ha^{-1} yr^{-1} for 4D2.

Mineral soils

Based on expert judgement, an uncertainty of 50% was chosen for the carbon stock changes calculated with the stock-difference approach in 4D2. The absolute uncertainty per hectare, calculated with the implied emission factor of 2018, is 0.342 t C ha^{-1} yr^{-1} for 4D2.

Organic soils

The uncertainty of the carbon stock change (emission factor) in organic soils is 72.2% calculated on the basis of measurement data compiled in ART (2011b) and the uncertainty of the activity data (area of organic soil) is 90.8% (see chp. 6.3.3), resulting in a combined uncertainty of 116.0%. Thus, the absolute uncertainties of the total organic soil emissions in 2018 are 1.230 kt C for 4D2. By dividing this uncertainty with the total area of 4D2, the absolute uncertainty per hectare results in 0.231 t C ha^{-1} yr^{-1} for 4D2.

Overall uncertainty 4D2

The root sum squares of the above-mentioned three absolute uncertainties is 0.437 t C ha^{-1} yr^{-1} for 4D2. This absolute uncertainty was used to calculate the relative emission factor uncertainty for 4D2 by dividing with the mean net carbon stock change per hectare of 4D2. In 2018, the total net carbon stock change was -2.123 t C ha^{-1} for 4D2 (calculated from CRF Table4.D). The resulting relative uncertainty is 20.6% for 4D2 (see Table 6-5). In the same way the uncertainty for the year 1990 was calculated: 23.8%.

Flooded lands (CH_4)

The emission factor uncertainty for CH_4 emitted by flooded lands can be very high (IPCC 2006, Volume 4, Appendix 3). As a best guess, a value of 70% was chosen for the CH_4 emission factor of 4(II)D2 (Table 6-5). The activity data uncertainty of flooded lands was set to 10% based on an expert judgment considering the methods used by Hiller et al. (2014) for estimating the area of reservoirs/flooded land.

Drainage of organic soils (N_2O; category 4(II))

For N_2O emissions from drainage of organic soils (category 4(II)), the emission factor uncertainty for shallow-drained, nutrient-rich grassland given in the Wetlands Supplement Guidelines (IPCC 2014a, Table 2.5) was used. It was calculated as arithmetic mean of the lower and upper bound uncertainty (66.9%; cf. Table 6-5). The respective activity data uncertainty is 48.8% (Meteotest 2020); it was calculated by combining the uncertainties of the area of organic soils (see chp. 6.3.3) for forest land (35.3%) and for wetlands (90.8%).

6.7.3.3 Time-series consistency

Time series for category 4D Wetlands are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.7.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

6.7.5 Category-specific recalculations

- 4D: Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).
- 4D: The carbon stock in mineral soils for unproductive wetlands (CC42) was adjusted to the recalculated average (1990–2018) of permanent grassland (CC31) (cf. chp.6.6.5).

6.7.6 Category-specific planned improvements

Two typing errors in CRF Table4(II)D.2 for the year 2018 will be corrected in the next submission. The area should read 10.60 kha and the amount of CH_4 emitted by reservoirs (flooded lands) should read 0.43 kt.

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4D is subject to further evaluation.

A digital soil modelling project at Agroscope/Kompetenzzentrum Boden (funded by FOEN 2017–2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

6.8 Category 4E – Settlements

6.8.1 Description

Table 6-32 Key categories in category 4E. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4E2	Land converted to settlements	CO2	L1, L2

Carbon stocks in living biomass and carbon stocks in mineral and organic soils were considered.

Settlements were subdivided into buildings/constructions (CC51), herbaceous biomass in settlements (CC52), shrubs in settlements (CC53), and trees in settlements (CC54) (see Table 6-2 and Table 6-6).

GHG emissions by biomass burning in settlements (category 4(V)E) do not occur.

6.8.2 Methodological issues

6.8.2.1 Carbon in living biomass

Buildings and constructions (CC51)
By default, buildings/constructions have no carbon stocks.

Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)
Carbon stocks in living biomass are: 9.54 t C ha^{-1} for CC52, 15.43 t C ha^{-1} for CC53, and 20.72 t C ha^{-1} for CC54 (Mathys and Thürig 2010: Table 7).

6.8.2.2 Carbon in soils

Buildings and constructions (CC51)
The carbon stocks in mineral and in organic soils for CC51 were assumed to be zero.

Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)
The carbon stock in mineral soils for CC52, CC53, and CC54 is 50.58 t C ha^{-1} (0–30 cm). This value corresponds to soil carbon stocks in mineral soils under cropland (see chp. 6.5.2.3.1) and was calculated as the area-weighted (across the three elevation zones) mean for 1990–2018.

For organic soils the carbon stock for CC52, CC53, and CC54 was assumed as 240 t C ha^{-1} (0–30 cm).

6.8.2.3 Changes in carbon stocks

Living biomass, dead organic matter, mineral soils

Applying a Tier 1 approach, changes in carbon stocks in biomass, in dead organic matter, and in mineral soils were assumed to be in equilibrium for Settlements remaining settlements.

Organic soils

On organic soils, the following emission factors were applied:

- 9.52 t C ha^{-1} yr^{-1} for CC52. This corresponds to the value used for cropland because CC52 areas are managed (gardens, parks) (Leifeld et al. 2003, 2005 and verified by ART 2009b and Paul and Alewell 2018).
- 5.30 t C ha^{-1} yr^{-1} for CC53 and CC54. This corresponds to the value used for extensively managed grasslands (ART 2011b; Paul and Alewell 2018).

Land-use change

In case of land-use changes from non-CC51 to CC51 on mineral or on organic soils a loss of 20% of the initial carbon stock was reported following IPCC 2006 (Volume 4, chp. 8.3.3.2). The reason for this is that 20% the soil organic matter is assumed to be lost as a result of disturbance, removal or relocation on these areas being sealed. This assumption is supported by paragraph 7 of the federal "Ordinance against deterioration of soils" (Swiss Confederation 1998) stating that the soil material excavated on a construction site must be treated in such a way that it can be used as a soil again. When the material is re-used (e.g. for re-cultivations) the fertility of the soil must not be affected. This regulation ensures that a large part of the soil organic matter is preserved on land converted to CC51.

Thus, equation 6.8 presented in chp. 6.1.3.2 was adjusted as follows if a=CC51:

$$deltaC_{s,i,b51} = [\ 0.2 * (0 - stockC_{s,i,b}\ ) / CT\ ] * A_{i,b51}$$

where:

$stockC_{s,i,b}$	carbon stock in soil (t C ha^{-1})
b	land-use category before conversion (CC = b ≠ 51)
b51	land use conversion from b to CC51
i	spatial stratum
$A_{i,b51}$	area of land (ha) converted from b to CC51 in the spatial stratum i (the sum of the areas converted within the last 20 years)
CT	conversion time (20 years; see Table 6-3).

In case of land-use changes from CC51 to non-CC51 categories, the regular stock-difference approach and gain-loss approach, respectively, according to chp. 6.1.3.2 and Table 6-3 was applied.

In the case of land-use change from or to CC52, CC53, and CC54, the net carbon changes in biomass and soil of CC52, CC53, and CC54 were calculated as described in chp. 6.1.3.2.

6.8.2.4 N_2O emissions from settlements

N_2O emissions associated with inputs from N in Settlements (category 4(I)E) were included in the Agriculture sector (category 3Da7 Other "Domestic use of inorganic fertilisers"; see chp. 5.5).

The calculation of emissions for categories 4(III) and 4(IV) (direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils) is described in chp. 6.10.

6.8.3 Uncertainties and time-series consistency

6.8.3.1 Uncertainties

Based on expert judgement, a value of 50% was chosen for the emission factor uncertainty in category 4E (Table 6-5).

Uncertainties of activity data of category 4E Settlements are described in chp. 6.3.3.

6.8.3.2 Time-series consistency

Time series for category 4E Settlements are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.8.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

6.8.5 Category-specific recalculations

- 4E: Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).
- 4E: The carbon stocks in mineral soils for non-sealed settlement areas (CC52, CC53, CC54) were adjusted to the recalculated average (1990–2018) of cropland (CC21) (cf. chp. 6.6.5).

6.8.6 Category-specific planned improvements

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017)

was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4E is subject to further evaluation.

A digital soil modelling project at Agroscope/Kompetenzzentrum Boden (funded by FOEN 2017–2020) builds on the outcomes of the recently completed national research programme “Sustainable Use of Soil as a Resource” (www.nfp68.ch/en). It addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.

6.9 Category 4F – Other land

6.9.1 Description

Category 4F – Other land is not a key category.

As shown in Table 6-2 and in Table 6-6 Other land (CC61) covers unmanaged, non-vegetated areas such as glaciers, rocks and shores.

6.9.2 Methodological issues

By definition, Other land has no carbon stocks. Coherently, changes in carbon stock in biomass, in dead organic matter, and in soils were assumed to be zero for Other land remaining other land.

In the case of land converted to other land, the net carbon changes in biomass and soil were calculated as described in chp. 6.1.3.

The calculation of emissions on land converted to other land for categories 4(III) and 4(IV) (direct N_2O emissions from nitrogen mineralisation in mineral soils and indirect N_2O emissions from managed soils) is described in chp. 6.10.

6.9.3 Uncertainties and time-series consistency

6.9.3.1 Uncertainties

Based on expert judgement, a value of 50% was chosen for the emission factor uncertainty in subcategory 4F2 (Table 6-5).

Uncertainties of activity data of category 4F Other Land are described in chp. 6.3.3.

6.9.3.2 Time-series consistency

Time series for category 4F Other land are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.9.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

6.9.5 Category-specific recalculations

- 4F: Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).

6.9.6 Category-specific planned improvements

No category-specific improvements are planned.

6.10 Categories 4(III) and 4(IV) – N_2O emissions

6.10.1 Description

Table 6-33 Key categories of 4(III) Direct N_2O from disturbance. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4III	Direct N2O from disturbance	N2O	L2

This chapter presents the methods for calculating direct (category 4(III)) and indirect (category 4(IV)) N_2O emissions from nitrogen (N) mineralisation in mineral soils. The source of nitrogen is N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils. As the approaches applied were not Tier 3, no N_2O immobilisation is reported.

- In category 4(III), direct N_2O emissions from nitrogen mineralisation associated with loss of soil organic matter are reported.
- In category 4(IV)2, indirect emissions of N_2O due to nitrogen leaching and run-off after mineralisation of soil organic matter are reported.

The following N_2O emissions were included in the Agriculture sector:

- Direct N_2O emissions on Cropland remaining cropland (no category registered in CRF Table4(III); see chp. 5.5) and on Grassland remaining grassland (category 4(III)C1; see chp. 5.5). In Switzerland, grassland is considered to be under agricultural management.

- Indirect N_2O emissions due to atmospheric deposition (category 4(IV)1; all land uses) and leaching and run-off on agricultural land (category 4(IV)2; Cropland remaining cropland and Grassland remaining grassland) (see chp. 5.3).

On productive forest land (CC12), small annual changes in carbon contents of mineral soils are reported that were calculated with the Yasso07 model (chp. 6.4.2.7). These changes were deliberately not considered for the calculation of N_2O emissions in categories 4(III) and 4(IV) as they are not associated with a land-use change or any change in management. Accordingly, N_2O emissions for subcategory 4A1 in CRF Table4(III) are reported as “NO”.

6.10.2 Methodological issues

Direct N2O emissions

Direct N_2O emissions (category 4(III)) as a result of the disturbance of mineral soils associated with change of land use or management of mineral soils were calculated according to IPCC (2006, vol. 4, chp. 11):

$$\text{Emission}(N_2O) = -\text{deltaCs} * 1 / (C{:}N) * EF1 * 44/28, \text{ if deltaCs} < 0 \qquad [\text{kt } N_2O]$$

where:

- deltaCs: soil carbon change induced by change of land-use or management [kt C]
- C:N: C to N ratio of the soil before the land-use change
- EF1: default emission factor = 0.01 kg N_2O-N (kg N)$^{-1}$, IPCC 2006 (Volume 4, Table 11.1).

deltaCs was calculated according to the methodology described in chp. 6.1.3.2. If deltaCs is zero or positive (carbon gain) there are no N_2O emissions provoked by the specific change of land-use or management.

The value of the C:N ratio is related to the land-use category before the change. For cropland and grassland the ratio is 9.8 according to Leifeld et al. (2007). This value was also used for mineral soils in wetlands (CC42) and unsealed settlement areas (CC 52, CC53, CC54). For forest land, the default value of C:N=15 was used (IPCC 2006, Volume 4, equation 11.8).

Indirect N2O emissions

The indirect N_2O emissions (category 4(IV)) as a result of N leaching and run-off after mineralisation of soil organic matter were calculated as follows using default emission factors (IPCC 2006, Volume 4, Table 11.3):

$$\text{Emission}(N_2O) = -\text{deltaCs} * Frac_{LEACH} / (C{:}N) * EF5 * 44/28, \text{ if deltaCs} < 0 \qquad [\text{kt } N_2O]$$

where:

- $Frac_{LEACH}$: fraction of mineralised N lost by leaching or run-off, see Table 6-34.
- C:N ratio as above for direct N_2O emissions

- EF5: default emission factor = 0.0075 kg N_2O-N (kg N)$^{-1}$, IPCC 2006 (Volume 4, Table 11.3).

If deltaCs is zero or positive (carbon gain) there are no N_2O emissions provoked by the specific change of land-use or management.

For calculating deltaCs, all land-use changes and conversions between land-use subcategories were taken into account.

Table 6-34 Fractions of mineralised N lost by leaching or run-off ($Frac_{LEACH}$), see also chp. 5.5.2.4.2.

	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
$Frac_{LEACH}$	--	0.206	0.206	0.206	0.206	0.206	0.206	0.204	0.202	0.201	0.199

	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
$Frac_{LEACH}$	--	0.197	0.195	0.193	0.191	0.189	0.188	0.186	0.184	0.182	0.180

	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018
$Frac_{LEACH}$	--	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178

6.10.3 Uncertainties and time-series consistency

6.10.3.1 Uncertainties

Emission factors categories 4(III) and 4(IV)

Relative uncertainties for the emission factors were estimated as the mean of the upper and the lower limit of the uncertainty ranges listed in IPCC (2006), Vol 4, Tables 11.1 and 11.3 (Table 6-5):

- Uncertainty 4(III) (EF1): 135.0%
- Uncertainty 4(IV) (EF5): 161.5%

Activity data category 4(III)

The uncertainty of the activity data for category 4(III) corresponds to the uncertainty of the amount of mineralised N. It was calculated as the combined uncertainty of:

- Uncertainty of the carbon stock losses in mineral soils: Land converted to settlements (4E2) is the main source in category 4(III). Therefore, the uncertainty of the area converted to settlements (4.6%; Table 6-5) and the uncertainty of the CO_2 emission factor (50.0%) were combined to estimate the uncertainty of the carbon stock loss: 50.2%.
- Uncertainty of the C:N ratio: The uncertainty of the C:N ratio for Forest land is used here. With a value of 15 and a 95%-range between 10 and 30 (IPCC 2006, Volume 4, equation 11.8) the mean uncertainty results in 66.7%.

The resulting uncertainty for AD of category 4(III) is 83.5%, calculated as $(50.2^2+66.7^2)^{0.5}$.

<u>Activity data for category 4(IV)2</u>

The uncertainty of the activity data for category 4(IV)2 is 85.8%. It is the combined uncertainty of the amount of leached N, which is calculated from the amount of mineralised N (uncertainty 83.5%, see category 4(III)) and $Frac_{LEACH}$ (uncertainty 20%, adopted from ART 2008a) (cf. Table 6-5).

6.10.3.2 Time-series consistency

Time series for categories 4(III) and 4(IV) N_2O emissions from nitrogen mineralisation are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.10.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

6.10.5 Category-specific recalculations

- 4(III), 4(IV): Activity data (areas) 1991–2017 were updated (see chp. 6.3.5).
- 4(III), 4(IV2): Activity data (loss of soil organic matter) were recalculated due to various recalculations of carbon stocks in mineral soils. In the case of a land-use change, the recalculated carbon stocks in mineral soils of cropland, grassland, wetlands and settlements (see chp.6.5.5, chp.6.6.5, chp.6.7.5, and chp.6.8.5) led to recalculations of carbon stock changes (following the stock-difference approach, see Table 6-3) and – in a next step – of resulting direct and indirect N_2O emissions.

6.10.6 Category-specific planned improvements

No category-specific improvements are planned.

6.11 Category 4G – Harvested wood products (HWP)

6.11.1 Description

Table 6-35 Key categories in category 4G. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
4G	HWP Harvested wood products	CO2	T1, T2

The data presented in this chapter are estimates of net emissions and removals from HWP due to annual losses and gains of carbon, respectively. Gains refer to annual carbon inflow to the HWP pool, losses refer to annual carbon outflow from the HWP pool.

The approach to calculate carbon stock changes in HWP corresponds to a production approach as described in Annex 12.A.1, Volume 4 of IPCC (2006). Changes in carbon stocks in Swiss forests are presented in chp. 6.4. The estimate covers all wood products originating from trees harvested in Switzerland (sawnwood, wood based panels, and paper and paperboard) that are processed in Switzerland and that are used for material (i.e. not for energetic) purposes.

The HWP pool also includes products made from domestic harvest that were exported and are in use in other countries. However, imported HWP are not included in the HWP pool.

To calculate carbon stock changes in HWP, product categories and half-lives were used following the methodologies described in IPCC (2006) and IPCC (2014). Further details and results are presented in FOEN (2020e).

6.11.2 Methodological issues

The same methodology was used for reporting under the UNFCCC and accounting under the Kyoto Protocol for HWPs in Switzerland consistent with paragraph 29 in the Annex to Decision 2/CMP.7, which states that “transparent and verifiable activity data for Harvested wood products categories are available, and accounting is based on the change in the Harvested wood products pool of the second commitment period, estimated using the first-order decay function”. Therefore, in this chapter the terminology of the Kyoto Protocol is used, i.e. it is referred to the activities Afforestation, Deforestation and Forest management (as defined in FOEN 2006h; see chp. 11.1.3).

For the estimation of carbon stocks and carbon stock change, the equations described in IPCC (2014: chp. 2.8) were used. A Tier 2 approach, first order decay, was applied for the product categories sawnwood, wood based panels, and paper and paperboard according to equation 2.8.5 in IPCC (2014).

- Emissions occurring during the second commitment period from HWPs removed from forests prior to the start of the second commitment period were also accounted for. The starting year used to estimate the delayed emissions from the existing pools is 1900.
- Emissions from the HWP pool accounted for in the first commitment period on the basis of instantaneous oxidation were excluded from the accounting for the second commitment period.
- Emissions from wood harvested for energy purposes were accounted on the basis of instantaneous oxidation (FOEN 2020e).
- HWP going to solid waste disposals were not included in the HWP pool for LULUCF, i.e. instantaneous oxidation is assumed. Some information on wood in solid waste disposals is given in the waste sector, see chp. 7.2.2.
- Imported HWP are not included in the HWP pool.
- Exported HWP were included in the calculation (notation key “IE” in CRF 4(KP-I)C, Forest management).

- The share of industrial roundwood (f_{IRW}) for the domestic production of HWP originating from domestic forests was calculated according to equation 2.8.1 in IPCC (2014). Exported round wood was not included in the calculation of HWP.
- For estimating the domestic HWP contribution of paper and paperboard, the feedstock factors f_{IRW} and f_{PULP} (see equation 2.8.2 in IPCC 2014) were applied according to equation 2.8.4 in IPCC (2014).
- For estimating the HWP contribution of paper and paperboard, the recovered wood pulp from recovered paper was excluded from the feedstock. For this purpose, the net consumption of recovered pulp was calculated from FAO data on production, export and import of recovered fibre pulp (see FOEN 2020e).
- Based on the available datasets it was not possible to differentiate between HWP from Afforestation and HWP from Forest management. Since Afforestation in Switzerland typically serves purposes other than timber production such as recreation, ground water protection, noise control, improvement of microclimate and air quality, biomass is not removed to enter the HWP pool. In case there is some wood of first thinnings in Afforestations since 1990, it is a negligable amount which is mostly left on the site or sometimes collected for energy purposes. Therefore, the amount of HWP from Afforestation was reported as not occurring ("NO") and all carbon stock changes in HWPs were reported under Forest management.
- The change in carbon stocks of HWPs was estimated separately for each product category and differentiating HWPs from Deforestation and from Forest management (including HWP from Afforestations) by applying equation 2.8.4 in IPCC (2014). Applying instantaneous oxidation to HWPs originating from Deforestation, the same results were obtained for changes in carbon stocks of HWP reported under the UNFCCC (CRF Table4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C).

6.11.2.1 Activity data

The time series are shown in CRF Table4.Gs2. The activity data are described in detail in FOEN (2020e):

- Data for the product categories sawnwood and wood panels are retrieved from FAOSTAT for the years 1961–1990 (http://www.fao.org/faostat/en/#data/FO, Forestry Production and Trade).
- Data for the product category paper and paperboard were based on FAOSTAT (Forestry Production and Trade).
- Data for recovered fibre pulp (production, import, export) were based on FAOSTAT (Forestry Production and Trade).
- In order to estimate the share of industrial roundwood originating from domestic forests, as feedstock for HWP production, data from national wood processing statistics and foreign trade statistics (see FOEN 2020e for details) were used.

In order to estimate carbon amounts in each HWP category and subcategory, default conversion factors were taken from IPCC (2014; Table 2.8.1) for the wood-based panels. For sawnwood, country-specific values measured by the wood industry and checked with the values in the NFI were used (Werner 2019):

- Coniferous sawnwood: 0.41 t/m^3
- Non-coniferous sawnwood: 0.59 t/m^3

6.11.2.2 Emission factors

Emission factors for specific product categories were calculated following eq. 2.8.5 in IPCC 2014 using default half-lives of 25 years for wood panels, 35 years for sawnwood and 2 years for paper products (Tab. 2.8.2 in IPCC 2014).

6.11.2.3 Results

Emissions and removals per product category are listed in Table 6-36. Figure 6-14 shows the resulting CO_2 emissions and removals.

Table 6-36 CO_2 emissions and removals from Harvested wood products (HWP) derived from sawnwood ($changeC_{HWP\text{-}sawnwood}$), panels ($changeC_{HWP\text{-}panels}$) and paper and paperboard ($changeC_{HWP\text{-}paper\ and\ paperboard}$), originating from Forest management, in kt CO_2 yr^{-1} (positive values refer to emissions, negative values refer to removals). HWPs originating from Deforestation were calculated using instantaneous oxidation; there are no HWPs from Afforestation (see main text).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	kt CO_2									
HWP	-1'168.8	-764.0	-556.4	-477.0	-358.6	-487.1	-302.1	-256.7	-308.9	-386.5
$changeC_{HWP\text{-}sawnwood}$	-662.3	-409.5	-230.2	-149.0	-92.1	-256.2	-141.2	-104.3	-186.2	-239.2
$changeC_{HWP\text{-}panels}$	-465.7	-376.2	-400.6	-370.4	-294.4	-236.9	-193.9	-165.7	-181.1	-165.8
$changeC_{HWP\text{-}paper\ and\ paperboard}$	-40.8	21.8	74.5	42.4	27.8	6.1	33.0	13.3	58.4	18.5

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	kt CO_2									
HWP	-723.0	-427.1	-301.0	-359.0	-581.6	-727.9	-543.1	-365.8	-433.2	-422.9
$changeC_{HWP\text{-}sawnwood}$	-363.8	-120.6	-54.5	-59.7	-214.2	-295.9	-285.3	-72.0	-191.1	-152.1
$changeC_{HWP\text{-}panels}$	-387.3	-306.0	-240.9	-271.9	-347.2	-417.2	-290.6	-253.7	-276.4	-293.3
$changeC_{HWP\text{-}paper\ and\ paperboard}$	28.1	-0.6	-5.6	-27.4	-20.3	-14.7	32.8	-40.0	34.2	22.5

	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt CO_2								
HWP	-457.5	-355.5	-134.4	56.9	-115.7	-100.1	-57.3	-24.0	-78.3
$changeC_{HWP\text{-}sawnwood}$	-141.8	-52.5	49.2	136.4	36.0	28.1	33.7	83.3	34.1
$changeC_{HWP\text{-}panels}$	-332.0	-297.3	-188.2	-123.7	-146.9	-143.8	-111.2	-120.6	-119.2
$changeC_{HWP\text{-}paper\ and\ paperboard}$	16.3	-5.6	4.6	44.3	-4.8	15.6	20.2	13.4	6.7

Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and panels; the share of paper and paperboard is relatively small (see Table 6-36). The production of sawnwood correlates with the domestic harvesting rate. Because of the strong reduction in the production of sawnwood since 2011, the relative contribution of panels to the HWP pool considerably increased (see Figure 6-14).

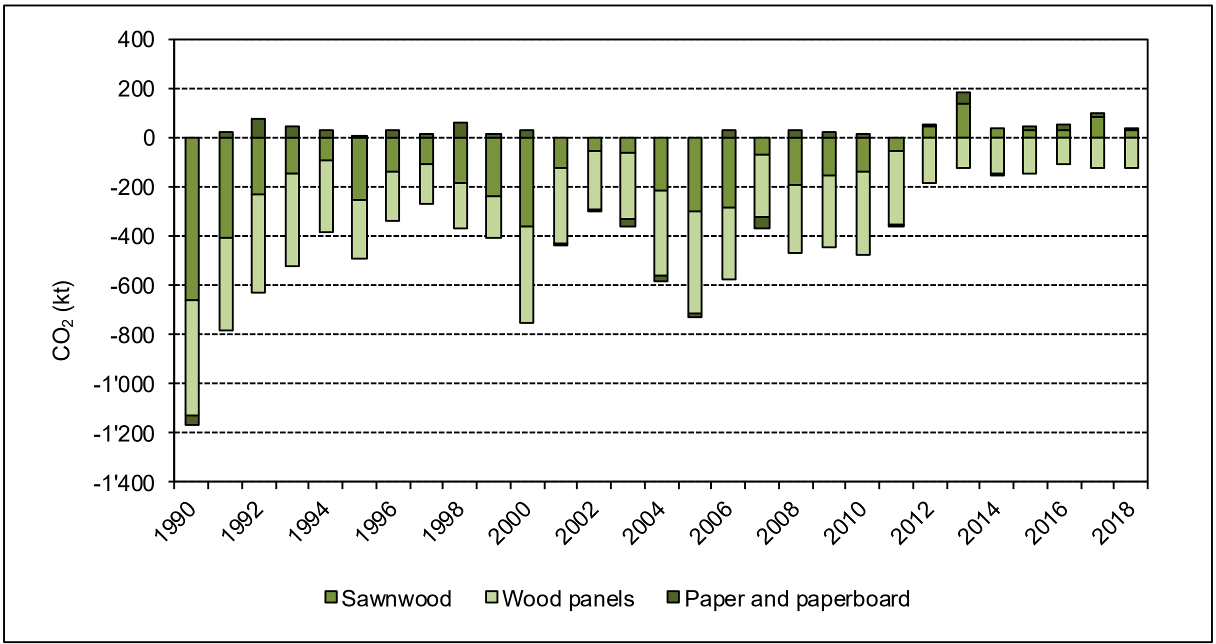


Figure 6-14 CO_2 emissions and removals from category 4G Harvested wood products originating from Forest management (KP) (in kt CO_2; positive values refer to emissions, negative values refer to removals).

6.11.3 Uncertainties and time-series consistency

6.11.3.1 Uncertainties

For category 4G HWP, the following information on relative uncertainty was used:

Activity data

A mean uncertainty of 11.2% (Table 6-5) was estimated based on the following expert judgements considering the type and reliability of data source:

- Roundwood harvest: 5% (national activity data from the Swiss Forestry Statistics, annual complete survey)
- Sawnwood production: 5% (national activity from survey on wood processing in sawmills, combined survey)
- Wood Panels production: 5 (national activity from survey in the wood industry)
- Paper and Paperboard production: 5% (activity data from FAOSTAT).
- Share of domestic wood used in the production of sawnwood, panels and paper: 10% (based on foreign trade statistics in the FAO database)

$$U_{HWP}AD = \sqrt{5^2 + 10^2} = 11.2\%, \text{ for all product categories.}$$

Conversion factors (emission factors)

The uncertainties of conversion factors used to calculate emission factors were based on the following sources:

- Wood density: 20%, expert judgement (country-specific measurements of the wood industry)
- Carbon contents in wood products: 10% (Lamlom and Savidge 2003, assessment of carbon content in wood; IPCC 2006, Volume 4, Table 12.6)
- Half-lives: 50% (default from IPCC 2006, Volume 4, Table 12.6).

The resulting uncertainty of the emission factor (carbon stock change) for HWP amounts to 54.8% (as shown in Table 6-5):

$$U_{HWP}\mathrm{EF} = \sqrt{20^2 + 10^2 + 50^2} = 54.8\%$$

Overall uncertainty 4G

The overall relative uncertainty of carbon losses and gains in HWP was thus calculated as:

$$U_{HWP}\mathrm{Combined} = \sqrt{11.2^2 + 54.8^2} = 55.9\%$$

6.11.3.2 Time-series consistency

Time series for category 4G Harvested wood products are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.11.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

No category-specific QA/QC activities were carried out.

6.11.5 Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4G between latest and previous submission are additionally presented in chp. 10.1.2.4.

- 4G: 1990–2017, for calculating paper production, the share of recovered fibre pulp was included for the first time (data on production, import and export from the FAO-database). Furthermore, the factor fIRW(i) (equation 2.8.4 in IPCC 2014) was applied in order to consider the amount of domestic pulp wood contained in recycled products. Consequently, the feedstock in paper and paper board decreased by more than 80%. This recalculation was performed in response to UNFCCC (2018, ID#KL.7).
- 4G: 1990–2017, the conversion factors for sawnwood (coniferous and non-coniferous) were updated with country-specific data. The new values are based on national measurements of the wood industry instead of default values from IPCC (2014).
- 4G: In the FAO-database 2009, the following input data were updated: Export of industrial roundwood (non-coniferous).
- 4G: In the FAO-database 2013, the following input data were updated: Export of pulp and paper.

- 4G: In the FAO-database 2016 and 2017, the following input data were updated: Production of industrial roundwood (coniferous and non-coniferous), particle boards and oriented strandboards (OSB).
- 4G: In the FAO-database 2017, the following input data were updated: Production of sawnwood (coniferous and non-coniferous), medium-density fibreboards/hardboards (MDF/HDF) and other fibreboards.
- 4G: 1990–2017, due to recalculations of AREA data and NFI data the split between HWP from Afforestation and from Forest management as well as the split between Deforestation and Forest management were also recalculated (this procedure resulted in minor changes).

6.11.6 Category-specific planned improvements

No category-specific improvements are planned.

7 Waste

Responsibilities for sector Waste	
Method updates	Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)
Author	Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)
EMIS database operation	Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest), Dominik Eggli (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest), Michael Bock (FOEN), Adrian Schilt (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)
Internal review	Adrian Schilt (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)

7.1 Overview

7.1.1 Greenhouse gas emissions

Within sector 5 Waste, emissions from five source categories are considered:

- 5A Solid waste disposal
- 5B Biological treatment of solid waste
- 5C Incineration and open burning of waste
- 5D Wastewater treatment and discharge
- 5E Other (no direct GHG emissions, but indirect GHG emissions reported in chp. 9)

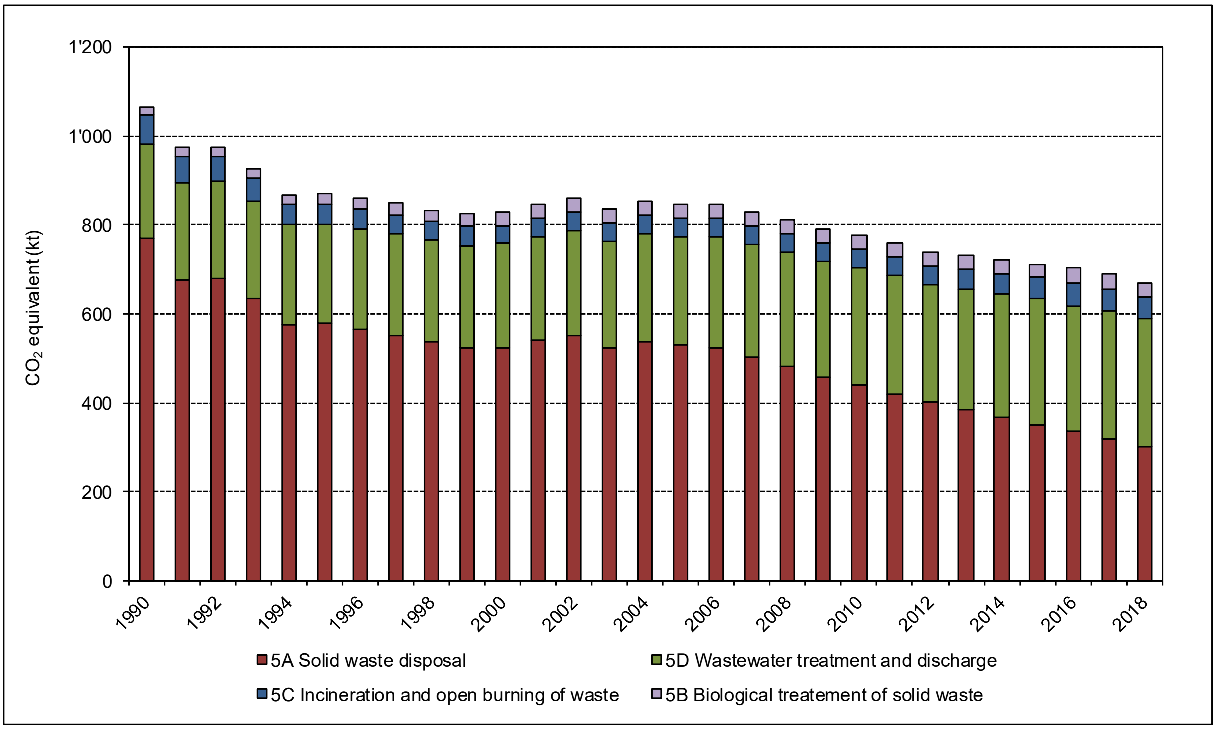


Figure 7-1 Switzerland's greenhouse gas emissions from sector 5 Waste. There are no direct greenhouse gas emissions from sector 5 E Other.

The total greenhouse gas emissions from sector 5 Waste show a decrease within the reporting period. 5A Solid waste disposal and 5D Wastewater treatment and discharge are the two dominant source categories. The former shows decreasing emissions, while the latter shows an increase in greenhouse gas emissions.

Table 7-1 Trend of total GHG emissions from sector 5 Waste in Switzerland.

Gas	1990	1995	2000	2005
	CO_2 equivalent (kt)			
CO_2	40	22	17	12
CH_4	921	742	699	712
N_2O	102	106	114	123
Sum	1064	870	830	846

Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	CO_2 equivalent (kt)									
CO_2	11	11	11	10	10	10	10	10	10	9
CH_4	648	632	615	598	585	574	560	550	537	521
N_2O	130	133	136	131	138	138	143	143	143	140
Sum	789	776	761	739	733	722	713	703	690	671

CH_4 is the most important greenhouse gas in sector 5 Waste over the entire reporting period. Nevertheless, CH_4 emissions have decreased.

The relative trends of the gases are shown in Figure 7-2.

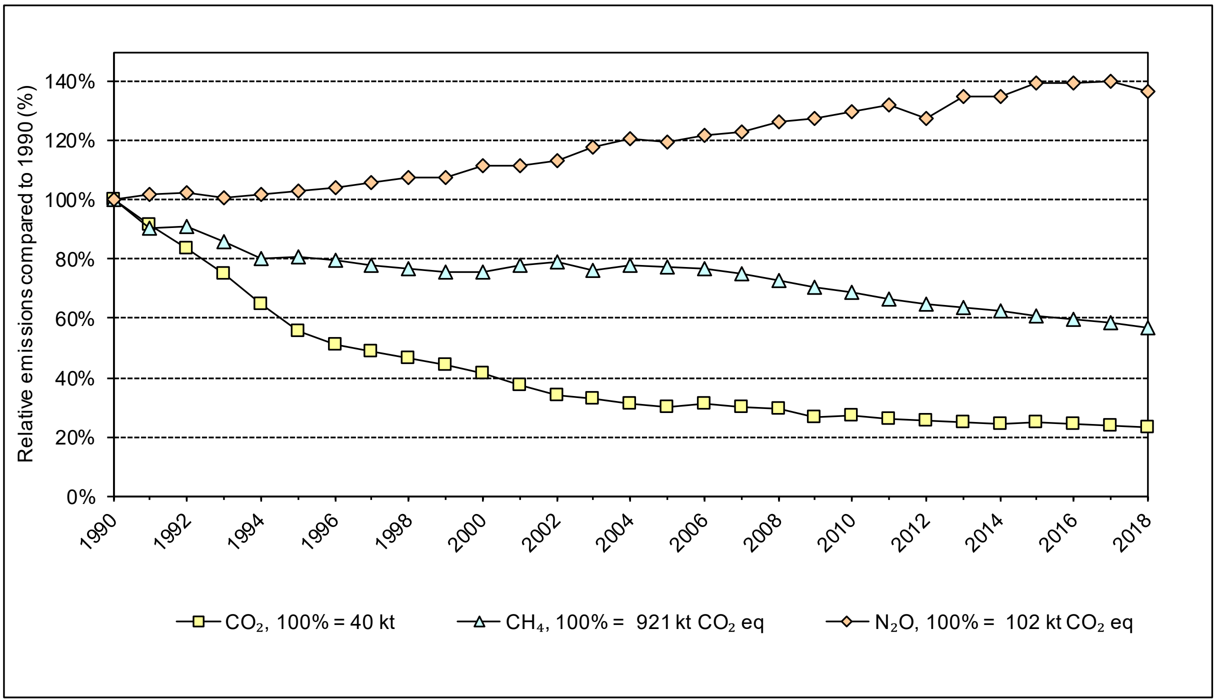


Figure 7-2 Relative trends of greenhouse gas emissions from sector 5 Waste. The base year 1990 represents 100%.

According to the 2006 IPCC Guidelines (IPCC 2006) all emissions from waste-to-energy, i.e. emissions resulting when waste material is used directly as fuel or converted into a fuel, are reported under sector 1 Energy (see also Figure 7-4). Therefore, the largest share of waste-related emissions in Switzerland is not reported under sector 5 Waste. This is illustrated in Figure 7-3 which provides an overview of all waste-related GHG emissions in Switzerland reported in chp. 7 and elsewhere in the NIR (see also Figure 7-4).

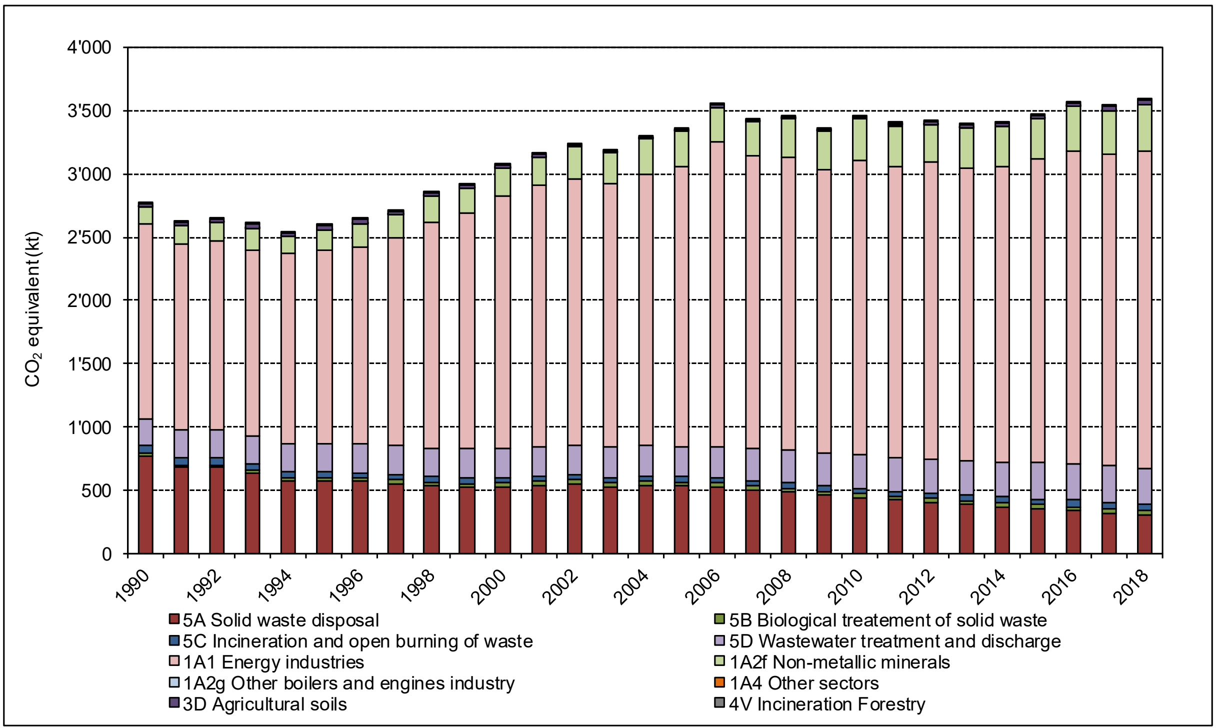


Figure 7-3 Total waste-related GHG emissions, reported in different sectors. The energetic use of waste-related biomass is not considered for this figure, as it predominantly leads to emissions of biogenic CO_2 (and only very minor emission of CH_4 and N_2O).

7.1.2 Overview of waste management in Switzerland

Goals and principles regarding waste management in Switzerland are stated in the Guidelines on Swiss Waste Management (BUS 1986), in the Waste Concept for Switzerland (SAEFL 1992) and in the ordinance regarding waste avoidance and waste management (Swiss Confederation 2015). The four principles are:

- The generation of waste shall be avoided as far as possible.
- Pollutants from manufacturing processes and in products shall be reduced as far as possible.
- Waste shall be recycled wherever this is environmentally beneficial and economically feasible.
- Waste shall be treated in an environmentally sound way. In the long term only materials of final storage quality shall be disposed of in landfills.

Figure 7-4 gives a general overview of the type of treatment and amounts of waste treated in the respective sectors in Switzerland, including waste imports and waste exports. Only waste fractions that are relevant for emissions are shown. The figure further illustrates where the processes related to the waste management system are reported in the NIR. The following details can be provided regarding the different sectors:

- **1 Energy:** In accordance with the 2006 IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities, where waste is used as an alternative fuel for energy production, are reported in 1A Fuel combustion. This applies to municipal solid waste incineration plants (MSWIP) and special waste incineration plants (SWIP), where energy is recovered (1A1a). MSWIP treat burnable municipal solid waste as well as sewage sludge, burnable construction waste and some special wastes. Cement industry uses conventional fossil fuels but also alternative fuels, which are special waste, dried sewage sludge, biomass as well as plastics collected separately or segregated from solid waste streams (1A2fi). The digestion of biomass in agricultural and industrial biogas facilities and of sewage sludge in wastewater treatment plants as well as the use of landfill gas are also reported in sector 1 Energy (source categories 1A1a, 1A2gviii and 1A4ci), as such biogas and sewage gas is used for combined heat and power generation. The energy production from renewable goods, such as the use of wood waste in wood-fired power stations, is reported under 1A1a, 1A2, 1A4ai and 1A4bi and 1A4ci.
- **3 Agriculture:** Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. In 2014, within sector 3 Agriculture only compost used as fertiliser was relevant for emissions (N_2O emissions as described in chp. 5.5.2.2, Table 5-23).
- **5 Waste:** Only emissions from waste management activities not used for energy production are reported under sector 5 Waste. Solid waste disposal does not occur anymore in Switzerland as incineration is mandatory for disposal of combustible waste since 2000. Emissions from composting are described under 5B1. Emissions related to digestion, but not directly related to energy production (such as the storage of digested biomass), are reported under 5B2. 5C Waste incineration and open burning of waste accounts for a small fraction only, consisting of illegal waste incineration, sewage sludge incineration, burning of residues in agriculture and private households as well as cremations. Special waste incineration without energy recovery, such as cable incineration or hospital waste incineration plants, no longer takes place in Switzerland and is thus crossed out in the figure. These waste fractions are nowadays incinerated in MSWIP and are therefore reported under sector 1 Energy. Emissions related to wastewater treatment are reported under 5D.

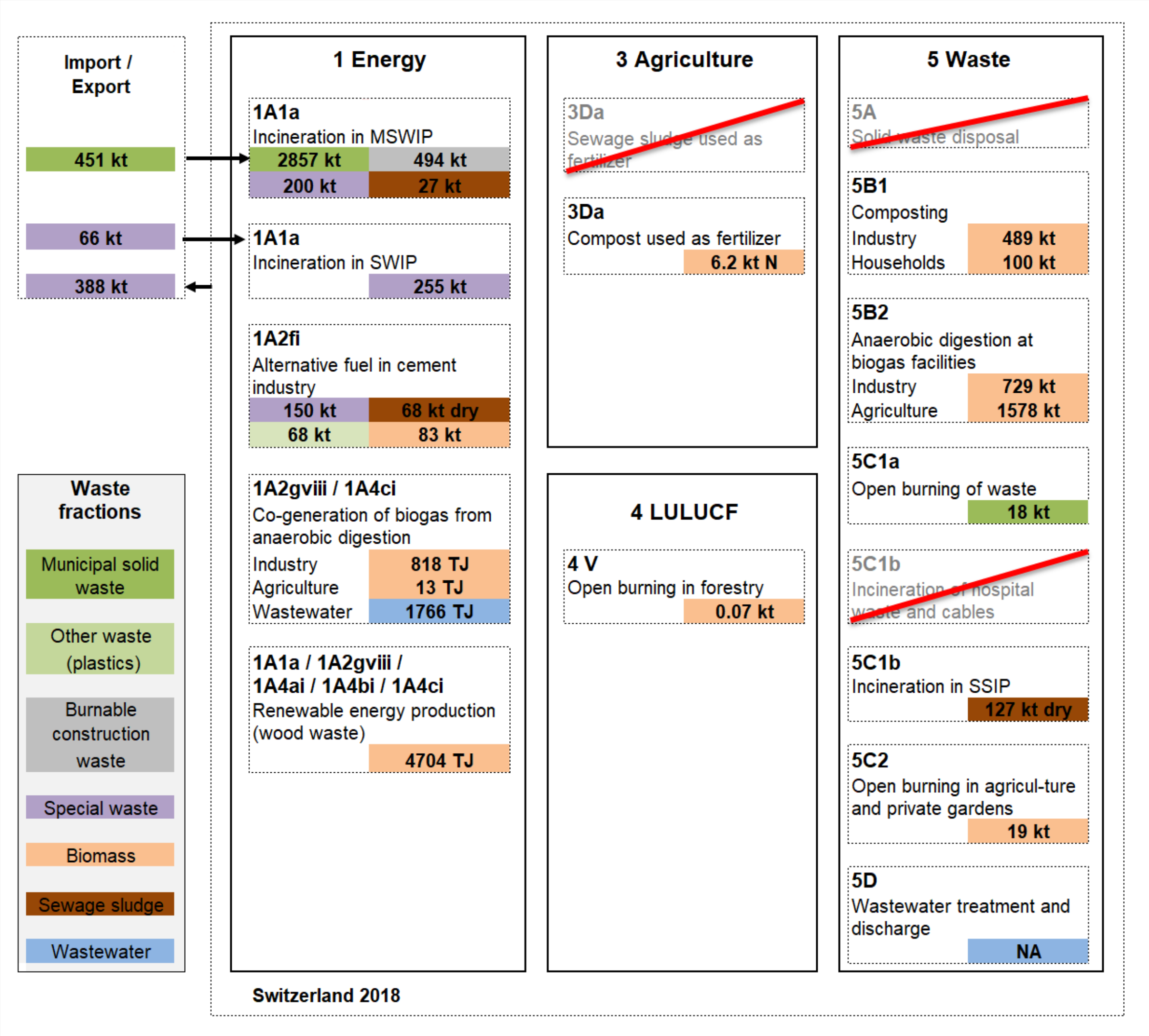


Figure 7-4 Overview on the type of treatment and amounts of waste treated in the respective sectors in Switzerland in 2018. Abbreviations: MSWIP: Municipal Solid Waste Incineration Plant, SWIP: Special Waste Incineration Plant, SSIP: Sewage Sludge Incineration Plant

Regarding the treatment and amounts of relevant waste types the following details can be provided (state in 2018, recycled amounts are not shown in Figure 7-4 because they are not relevant for emissions):

- **Municipal solid waste:** In Switzerland more than 50% of the municipal solid waste is collected separately and recycled (FOEN 2019h). The amount of waste incinerated includes imported MSW, mainly from neighbouring countries such as Germany, France, Austria and Italy. The import of waste into Switzerland needs to be authorized by the Federal Office for the Environment. A part of the separately collected plastic fractions from households and industry which cannot be recycled is used as an alternative fuel in the cement industry.
- **Construction waste:** More than 50% of the construction waste is recycled. About half of the recycling takes place at the construction sites, e.g. by reusing material left after breaking up the road cover. The other half is separated at the construction sites and recycled individually, e.g. used glass, metals, concrete etc. A minor amount of combustible construction waste is incinerated in MSWIP. The remaining, inert

construction waste is disposed of in landfills for inert waste (ERM 2016; Wüest & Partner 2015).

- **Special waste:** Special waste refers to a highly diverse waste fraction encompassing hospital wastes, batteries, electronic waste, hazardous industrial sludge, contaminated soils, solvents, chemicals etc. Special waste is either recycled, biologically treated, landfilled, burnt or exported for landfilling in foreign countries (FOEN 2019h). Only the amount of incinerated special waste is relevant for emissions (EMIS 2020/1A1a Kehrichtverbrennungsanlagen and EMIS 2020/1A1a Sondermüllverbrennungsanlagen). Some special waste is also used as an alternative fuel in the cement production (EMIS 2020/1A2f i Zementwerke Feuerung).
- **Sewage sludge:** Since 2009 sewage sludge is not used anymore as a fertiliser in agriculture. Such use has been prohibited due to the content of organic contaminants, heavy metals and other substances (see chp. 5.5.2.2.2). Therefore, all sewage sludge is incinerated, either in MSWIP or in SSIP without energy recovery (internal information provided by the waste section of FOEN). Dried sewage sludge is also used as an alternative fuel in the cement industry (EMIS 2020/1A2fi Zementwerke Feuerung).
- **Biomass:** The term biomass refers to a broad range of materials such as garden waste, grass, wood waste, liquid manure and production remains from the food industry or further fractions, depending on the process concerned. Biomass from agriculture, forestry and private gardens are burnt without energy recovery (EMIS 2020/5C2 & 4VA1 Abfallverbrennung Land- und Forstwirtschaft). Biomass is also digested or composted (in large-scale composting facilities or backyards). Quantities of biomass refer to wet matter. Biomass such as used wood or animal fat is used as an alternative fuel in the cement industry (EMIS 2020/1A2fi Zementwerke Feuerung). Compost is used as a fertiliser (see Table 5-23 “Other organic fertilisers”).

7.2 Source category 5A – Solid waste disposal

7.2.1 Source category description

Table 7-2 Key categories of 5A Solid waste disposal. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
5A	Solid waste disposal	CH4	L1, L2, T1, T2

Source category 5A1 Managed waste disposal sites comprises all emissions from managed solid waste landfill sites. As incineration is mandatory for combustible waste since 2000, inputs into managed solid waste landfill sites have dropped to zero. Remaining emissions thus stem from landfilling before 2000. Emissions from source category 5A2 Unmanaged waste disposal sites are included in source category 5A1 Managed waste disposal sites. This is motivated by the fact that in Switzerland to date no official unmanaged waste disposal sites exist. Although no reliable data is available, the effective quantity of waste not properly treated in landfills is estimated to be very small.

In Switzerland, less than four managed biogenic active landfill sites were equipped to recover landfill gas in 2018 (SFOE 2019a). While some landfill gas is used to generate heat only, the landfill gas is generally used in co-generation plants in order to produce electricity and heat. A small amount of the landfill gas is flared (Consaba 2016).

Emissions from the usage of landfill gas in combined heat and power units are reported in sector 1 Energy in source category 1A1a Public electricity and heat production (see Figure 3-20).

Table 7-3 Specification of source category 5A Solid waste disposal in Switzerland.

5A	Source category	Specification
5A1	Managed waste disposal sites	Emissions from managed solid waste landfill sites.
5A2	Unmanaged waste disposal sites	Officially no unmanaged waste disposal sites exist (included in 5A1)
5A3	Uncategorized waste disposal sites	Not ocurring in Switzerland

7.2.2 Methodological issues

Methodology (5A)

Emissions are calculated by a Tier 2 method based on the decision tree in the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 3, Fig. 3.1). The spreadsheet for the First Order Decay (FOD) model provided by IPCC (2006) has been applied and parametrised for Swiss conditions (FOEN 2017g).

The values for the parameter degradable organic carbon (DOC) are provided for each waste fraction (Table 7-4). For all waste types the IPCC default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, as most of the industrial waste deposited in Switzerland is assumed to be wood waste.

Table 7-4 Degradable organic carbon (DOC) values for fractions of different waste compositions (weight fraction, wet basis).

Waste composition	**IPCC default value**		**Country-specific parameters**	
(weight fraction, wet basis)	Range	Default	Swiss Value	Reference and remarks
Food waste	0.08-0.20	0.15	0.15	
Garden	0.18-0.22	0.2	0.2	
Paper	0.36-0.45	0.4	0.4	
Wood and straw	0.39-0.46	0.43	0.43	
Textiles	0.20-0.40	0.24	0.24	
Disposable nappies	0.18-0.32	0.24	NO	not relevant/no activity data
Sewage sludge	0.04-0.05	0.05	0.05	
Industrial waste	0.00-0.54	0.15	0.43	all waste wood

The methane generation rate [1/yr] is chosen according to wet temperate conditions (Table 7-5). For all waste types the IPCC default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, again based on the fact that most of it is assumed to be wood waste.

Table 7-5 Methane generation rate [1/yr] according to waste by composition for wet temperature conditions.

Waste composition	**IPCC default value**		**Country-specific parameters**	
(weight fraction, wet basis)	Range	Default	Swiss Value	Reference and remarks
Food waste	0.1–0.2	0.185	0.185	
Garden	0.06–0.1	0.1	0.1	
Paper	0.05–0.07	0.06	0.06	
Wood and straw	0.02–0.04	0.03	0.03	
Textiles	0.05–0.07	0.06	0.06	
Disposable nappies	0.06–0.1	0.1	NO	not relevant/no activity data
Sewage sludge	0.1–0.2	0.185	0.185	
Industrial waste	0.08–0.1	0.09	0.03	all waste wood

The general parameters are set as follows:

- DOCf (fraction of DOC dissimilated) = 0.5 (IPCC default value)
- Delay time (months) = 6 (IPCC default value)
- Fraction of methane (F) in developed landfill gas = 0.5 (IPCC default value)
- Conversion factor, C to CH_4 = 1.33 (IPCC default value)
- Oxidation factor (OX) = 0.1

The oxidation factor OX has been set to 0.1 according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 3), since it is standard practice in Switzerland to cover the landfills, e.g. with soil.

For the methane correction factors (MCF) for the different solid waste disposal site types IPCC default values are used. Between 1990 and 2015 (the IPCC spreadsheet has to be parametrised from 1950 to 2030/2050) waste distribution to the following three solid waste disposal site types has taken place (for both MSW and IW):

- Methane correction factor (MCF) for unmanaged, shallow solid waste disposal sites (SWDS) = 0.4 (IPCC default value)
- Methane correction factor (MCF) for unmanaged, deep SWDS = 0.8 (IPCC default value)
- Methane correction factor (MCF) for managed SWDS = 1 (IPCC default value)
- The other two MCF (managed, semi-aerobic and uncategorised) are not relevant because such SWDS are not occurring in Switzerland, i.e. no waste has been distributed to such sites.

The waste composition of MSW deposited has changed during the last 60 years (see Table 7-6).

Table 7-6 Composition of MSW going to solid waste disposal sites (BUS 1978, BUS 1984, FOEN 2014o).

Waste fraction	1950-1979	1980-1989	1990-1999	2000-2009	since 2010
Food	20.0%	26.5%	21.4%	26.6%	31.5%
Garden	8.0%	2.9%	1.6%	1.4%	1.7%
Paper	36.0%	30.6%	28.0%	21.0%	17.2%
Wood	4.0%	4.3%	5.0%	2.0%	1.8%
Textile	4.0%	3.1%	3.0%	3.0%	3.2%
Nappies	0.0%	0.0%	0.0%	0.0%	0.0%
Plastics, other inert	28.0%	32.6%	41.0%	46.0%	44.6%

With these parametrisations and the activity data for municipal solid waste (MSW), industrial waste (IW) and sewage sludge (SS) the amount of CH_4 generated in landfills is calculated. The amount of CH_4 recovered and used as fuel for combined heat and power generation or flared is then subtracted.

For combined heat and power generation and flaring, the emissions of other gases are considered to be proportional to the amount of CH_4 burnt (Table 7-7).

Long term storage of carbon in waste disposal sites, annual change in total long-term storage of carbon and annual change in total long-term storage of carbon in HWP has been calculated with the parametrised spreadsheet model provided by IPCC (2006) as well and is reported in CRF Table5 as memo item. As incineration is mandatory for combustible waste since 2000 in Switzerland and solid waste disposal activities have ceased there is no annual change since 2007.

Emission factors (5A)

Emission factors for CO_2, CH_4, CO, NMVOC and SO_2 are country-specific based on measurements and expert estimates, as documented in EMIS 2020/1A1 & 5A Kehrichtdeponien. CO_2 emissions from non-biogenic waste are included, while CO_2 emissions from biogenic waste are excluded from total emissions. Table 7-7 presents the emission factors used in 5A1.

Table 7-7 Emission factors for 5A1 Managed waste disposal sites in 2018.

5A1 Managed waste disposal sites	Unit	CO_2 biogen	CO_2 fossil	CH_4	NO_x	CO	NMVOC	SO_2
Direct emissions from landfill	t / t CH_4 produced	3.0	NA	1.0	NA	NA	NA	NA
Flaring	kg / t CH_4 burned	2750	NA	NA	1.0	17	NA	NA
Open burning	kg / t waste burned	571	523	6.0	2.5	50	16	0.75

Activity data (5A)

There are three kinds of activity data for 5A1 Managed waste disposal sites: Waste quantities disposed on landfills, direct CH_4 emissions and CH_4 flared.

For the calculation of these three kinds of activity data the amounts of MSW, IW and SS deposited on SWDS are relevant.

Table 7-8 Activity data in 5A1: Waste disposed on managed waste disposal sites (documented in EMIS 2020/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	Unit	1950	1960	1970	1980	1990	1995	2000	2005
Municipal solid waste (MSW)	kt	570.2	675.4	864.0	532.4	650.0	540.0	291.7	13.7
Construction waste (CW)	kt	9.9	10.5	36.0	84.8	150.0	60.0	53.9	1.4
Sewage sludge (SS)	kt (dry)	NO	NO	3.2	29.6	60.0	28.1	4.2	1.0
Open burned waste	kt	298.9	293.9	225.8	96.7	NO	NO	NO	NO
Total waste quantity	kt	879.0	979.8	1129.0	743.5	860.0	628.1	349.7	16.1

5A1 Managed waste disposal sites	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Municipal solid waste (MSW)	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Construction waste (CW)	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sewage sludge (SS)	kt (dry)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Open burned waste	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total waste quantity	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 7-8 documents the amounts of municipal solid waste, construction waste and sewage sludge disposed of on managed waste disposal sites since 1950 (as documented in EMIS 2020/1A1a & 5A Kehrichtdeponien). An increase of waste landfilled until 1970 can be observed. The decline of waste amounts landfilled afterwards is due to changes in the legislative framework, making incineration mandatory for disposal of combustible waste and banning the disposal of combustible waste on landfills from 1 January 2000. The amounts of combustible waste disposed of on managed waste disposal sites reached zero in 2009. Open burning of waste on SWDS has occurred in the past. By reason of legal requirements and regulations it is assumed that open burning did not take place since 1990 anymore (Consaba 2016) and is therefore NO in Table 7-8.

With these primary activity data total CH_4 emissions generated are calculated using the spreadsheet FOD model provided by IPCC (2006). For the calculation of direct CH_4 emissions, CH_4 flared and used in co-generation units is determined and subtracted from total CH_4 emissions (Table 7-9). The landfill gas recovered and used as fuel for co-generation units is reported under 1A1 Energy in accordance with the 2006 IPCC Guidelines (IPCC 2006). The sum of landfill gas flared and landfill gas used in co-generation units is reported as being recovered in CRF Table5.A.

The amount of CH_4 used in co-generation stems from the Swiss statistics of renewable energies (SFOE 2019a). The amount of landfill gas flared has been assessed in a separate investigation (Consaba 2016). The CH_4 flared has been estimated as follows:

- A list of all managed SWDS that are still operated or have been closed since 1990 was compiled.
- Their technical equipment was assessed and deduced (motors, torches, gas drainage, etc.).
- Four types of managed landfill sites according to their equipment and CH_4 management were distinguished:
    - landfills with gas recovery in combined heat and power generation, boiler and torch;
    - landfills with gas recovery or thermal treatment (boiler, torch, non-catalytic oxidation, flameless oxidation);
    - landfill gas recovery without methane elimination (biofilter, aerobiosation);
    - landfills without gas treatment (direct release).

- A survey was conducted in 14 managed SWDS and data on their operation mode has been collected.
- With these data the amounts flared in SWDS category a) and b) were estimated.
- The amount flared on all managed SWDS has been extrapolated considering the waste amounts deposited.
- A time series for the amount of methane torched relative to the total amount of CH_4 estimated with the Swiss FOD IPCC 2006 model (managed and unmanaged sites) has been calculated.

The amount flared is expressed as a percentage of CH_4 produced in all SWDS in Switzerland. The percentage flared varies between 5 and 15% since 1990.

Table 7-9 Activity data in 5A1: Direct CH_4 emissions, CH_4 flared and CH_4 used in combined heat and power (CHP) units (as documented in EMIS 2020/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	**Unit**	**1990**	**1995**	**2000**	**2005**
CH_4 direct emissions	kt	30.8	23.1	21.0	21.2
CH_4 flared	kt	1.8	5.3	5.6	3.4
CH_4 used in co-generation units (reported under 1A1a)	kt	4.9	12.1	11.3	4.1

5A1 Managed waste disposal sites	**Unit**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
CH_4 direct emissions	kt	18.3	17.6	16.8	16.0	15.3	14.7	14.1	13.4	12.8	12.1
CH_4 flared	kt	2.4	2.4	2.1	1.8	1.6	1.4	1.4	1.4	1.4	1.4
CH_4 used in co-generation units (reported under 1A1a)	kt	1.5	1.0	0.9	0.9	0.8	0.6	0.4	0.2	0.1	0.1

The CH_4 generated in landfill sites decreased since 1990 because waste quantities disposed of in landfills have been decreasing. Together with the relative increase of CH_4 recovery from 1990 until 2017 this is the reason for the pronounced trend of CH_4 emissions from source category 5A.

7.2.3 Uncertainties and time-series consistency

Uncertainty in CH_4 and CO_2 emissions from 5A Solid waste disposal

For lack of a detailed uncertainty analysis with the new FOD model, a combined uncertainty of 30% is assumed for the CH_4 emissions (EMIS 2020/1A1a & 5A Kehrichtdeponien).

Consistency: Time series for 5A Solid waste disposal are all considered consistent.

7.2.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

7.2.5 Category-specific recalculations

The following recalculations were implemented in submission 2020:

- 5A1a: The value reported for import of special waste for 2017 has changed in the annual national statistical report by the waste division of FOEN. However, the change is not visible in Figure 7-4 of the NIR since only values for the current submission year 2018 are depicted.
- 5A1 / 1A1a: For the year 2017, CH_4 use in CHP from solid waste disposal sites has decreased from 2.41 GWh to 1.81 GWh due to changes in the annual statistical report by SFOE.
- 5A: The shares of kitchen waste and garden waste within the deposited amounts of organic waste on solid managed waste disposal sites from 1950–1979 have been recalculated according to BUS 1978 (numbers for food and garden in Tab. 7-6). This leads to an increase in direct emissions of CH_4 from landfills of 0.8% in 1990 and 0.2% in 2017 (i. e. 254 t CH_4 and 22 t CH_4, respectively). AD for flaring also increases (by less than 1%).

7.2.6 Category-specific planned improvements

No category-specific improvements are planned.

7.3 Source category 5B – Biological treatment of solid waste

7.3.1 Source category description

Source category 5B – Biological treatment of solid waste is not a key category.

Source category 5B Biological treatment of solid waste comprises the process-related GHG emissions from composting and from digesting of organic waste.

Within 5B1 Composting two kinds of composting are distinguished, i.e. industrial composting and backyard composting. Industrial composting covers the emissions from centralized composting activities with a capacity of more than 100 tonnes of organic matter per year as well as the composting of organic material at the border of agricultural fields. Backyard composting in private households or communities is also common practice in Switzerland and therefore considered.

In 5B2 Anaerobic digestion at biogas facilities emissions occur from gas leakages as well as from digested matter (solid leftovers after completion of anaerobic microbial degradation of organic matter) which is being composted. The biogas is used for combined heat and power generation or upgraded and used as fuel.

In 5B Biological treatment of solid waste the emissions from the composting of digested matter as well as the CH_4 losses from biogas facilities and emerging from biogas upgrading are included. Emissions related to the use of biogas for combined heat and power generation as well as emissions from biogas upgrading are reported in sector 1 Energy source categories 1A2gviii Other and 1A4ci Agriculture/forestry/fishing (see Figure 3-20).

Table 7-10 Specification of source category 5B Biological treatment of solid waste.

5B	Source category	Specification
5B1	Composting	Process-related emissions from composting of organic waste
5B2	Anaerobic digestion at biogas facilities	Process-related emissions from digesting of organic waste

7.3.2 Methodological issues

7.3.2.1 Composting (5B1)

Methodology (5B1)

Emissions are calculated by a Tier 2 method based on the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.1 Biological treatment of solid waste).

Activity data and emission factors for industrial and backyard composting have been thoroughly reassessed in 2017 (Schleiss 2017), new data were gained and EMIS 2020/5B1 Kompostierung, which serves as basis for greenhouse gas emission estimates, has been revised accordingly.

Emission factors (5B1)

Emission factors used for source category 5B1 Composting are summarized in Table 7-11 and documented in detail in EMIS 2020/5B1 Kompostierung. Emission factors are country-specific and encompass CH_4, N_2O and NMVOC based on measured or estimated values reported in the literature.

Activity data (5B1)

Activity data for source category 5B1 Composting are shown in Table 7-12 and documented in detail in EMIS 2020/5B1 Kompostierung.

Activity data for industrial composting are based on waste surveys (Schleiss 2017). For 2013 reliable data on waste quantities are available (FOEN 2016m). All cantons were addressed and data on the amounts of organic waste quantities, according to their respective treatment option, have been collected. Data on waste quantities are also available from surveys in 1989, 1993 and 2000. Activity data between these years were interpolated. The time series were validated with further data sets from the years 2002 and 2010. After 1993 digesting of organic waste was also becoming a relevant treatment option and therefore respective amounts were subtracted. In addition, also waste wood quantities were subtracted, in order to get the amount of organic waste treated in industrial composting plants. As of 2014, activity data for industrial composting are adopted from the annual statistical reports by the inspectorate system for the composting and fermentation industry in Switzerland CVIS as recommended by Schleiss (2017).

Activity data for backyard composting were reassessed in 2017 (Schleiss 2017). Basically, amounts of organic waste composted in backyards are based on expert assessments and are derived from data from a small number of cities and villages. The experts took into account different parameters affecting waste amounts composted in backyards over time, i.e. urban or rural situation, communication e.g. by community authorities and incentive programmes, and on the availability of separate door-to-door collection of organic wastes. As of 2008, activity data for backyard composting are assumed to be constant as recommended by Schleiss (2017).

7.3.2.2 Anaerobic digestion at biogas facilities (5B2)

Methodology (5B2)

In source category 5B2 Anaerobic digestion at industrial and agricultural biogas facilities are considered. The produced biogas is used for combined heat and power generation or upgraded to natural gas quality. Accordingly, biogas upgrading is considered as a separate process in 5B2. However, emissions from the use of biogas as fuel for combined heat and power generation are reported under sector 1 Energy, in accordance with the 2006 IPCC Guidelines (IPCC 2006).

For the emissions from 5B2 Anaerobic digestion at biogas facilities, a Tier 2 method is used. While industrial and agricultural biogas facilities are separately considered, the same emission factors are used (see below). As mentioned above, emissions from biogas upgrading are estimated separately, based on the amount of biogas upgraded.

Emissions of greenhouse gases from industrial and agricultural biogas facilities are estimated using a constant emission factor for each biogas facility. This is based on an evaluation of measurement data for CH_4 losses that has shown that those losses are not dependent on the amount of substrate processed in a particular facility. Therefore, CH_4 emissions are calculated based on an emission factor per plant multiplied by the number of industrial and agricultural biogas facilities, respectively.

In contrast, emissions of air pollutants are calculated based on estimates from up to seven different process steps (such as pre-storage, primary and secondary digester, interim storage, maturing, handling of biogas etc.), as documented in EMIS 2020/1A1a & 5 B 2 Vergärung LW and EMIS 2020/1A1a & 5 B 2 Vergärung IG. However, as NMVOC and CO emissions from source category 5B are of biogenic origin, they are not considered for the calculation of indirect CO_2 emissions in chp. 9 Indirect CO_2 and N_2O emissions.

N_2O emissions from source category 5B2 are considered to be negligible according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.3), and are therefore set to zero.

Emission factors (5B2)

Table 7-11 presents the emission factors used in 5B2 Anaerobic digestion at biogas facilities. As documented in FOEN (2015n), the emission factor for CH_4 for anaerobic digestion at industrial and agricultural biogas facilities is based on investigations performed in the framework of the GHG emission compensation projects. Field measurements indicate that there is no correlation between the produced amount of biogas and the amount of biogas lost to the atmosphere. The investigated data show that on average each biogas facility loses 1.23 t CH_4 per year to the atmosphere. This value is used to estimate the emissions from industrial and agricultural biogas facilities in Switzerland.

The emission factor for losses of CH_4 from biogas upgrading is based on official regulations regarding maximal CH_4 leakage, as well as studies focussing on CH_4 emissions from biogas upgrading. Accordingly, regulations by the Swiss Gas and Water Association (SGWA 2016a) set an emission limit value (ELV) for CH_4 losses from biogas upgrading. In 1990, such losses were allowed to be 5% of the upgraded amount, in 2014 the limit was lowered to 2.5%. Measurements in a few biogas upgrade installations in 2007, 2013 and 2014 showed the following losses: 2007 one plant: 2.6%, 2013 one plant: 1%, 2014 three plants: 1.3%, 1.8%, and 3.5%. The measurements showed that the emission limits were respected (with the exception of one plant in 2014) and therefore Switzerland decided to set the losses from biogas upgrading to the ELV with the assumption of a linear improvement between the 1990 and the 2014 value. The continuous improvement seems plausible, as newer plants show fewer losses and values of less than 1%–2.5% are state of the art.

Activity data (5B2)

Activity data for 5B2 Anaerobic digestion at biogas facilities, as shown in Table 7-12, are based on data from the Swiss renewable energy statistics (SFOE 2019a). Relevant are the number of industrial and agricultural biogas facilities, as well as the total amount of biogas upgraded.

Table 7-11 Emission factors for 5B Biological treatment of solid waste in 2018.

5B Biological treatment of solide waste	Unit	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Composting (industrial)	g/t composted waste	1'000	50	NA	NA	300	NA
Composting (backyard)	g/t composted waste	1'000	50	NA	NA	300	NA
Digestion (industrial biogas facilities)	t/facility	1.23	NA	NA	NA	NA	NA
Digestion (agricultural biogas facilities)	t/facility	1.23	NA	NA	NA	NA	NA
Biogas up-grade	g/GJ	500	NA	NA	NA	NA	NA

Table 7-12 Activity data in 5B Biological treatment of solid waste.

5B Biological treatment of solide waste	Unit	1990	1995	2000	2005
Composting (industrial)	kt (wet)	240	360	519	526
Composting (backyard)	kt (wet)	110	155	180	170
Digestion (industrial biogas facilities)	number	NO	4	11	14
Digestion (agricultural biogas facilities)	number	102	76	68	72
Biogas up-grade	GJ	NO	NO	19'866	40'637

5B Biological treatment of solide waste	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Composting (industrial)	kt (wet)	532	530	532	534	536	492	445	523	512	489
Composting (backyard)	kt (wet)	130	120	110	100	100	100	100	100	100	100
Digestion (industrial biogas facilities)	number	21	22	28	26	26	25	26	27	28	28
Digestion (agricultural biogas facilities)	number	75	72	80	89	97	98	99	98	106	111
Biogas up-grade	GJ	85'008	121'627	168'170	236'074	277'700	337'403	408'222	442'708	456'665	473'538

To improve transparency the CH_4 and N_2O emissions of source category 5B Biological treatment of solid waste are shown on a completely disaggregated level in Table 7-13.

Table 7-13 CH_4 and N_2O emissions of 5B Biological treatment of solid waste.

5B Biological treatment of solide waste	Gas	Unit	1990	1995	2000	2005
Composting (industrial)	CH_4	t	240.2	360.3	519.3	526.2
	N_2O	t	12.0	18.0	26.0	26.3
Composting (backyard)	CH_4	t	110.0	120	130	140
	N_2O	t	5.5	6.0	6.5	7.0
Digestion (industrial)	CH_4	t	NO	4.9	13.6	17.2
Digestion (agricultural)	CH_4	t	125.5	93.5	83.6	88.6
Biogas up-grade	CH_4	t	NO	NO	15.7	28.0

5B Biological treatment of solide waste	Gas	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Composting (industrial)	CH_4	t	531.8	529.7	531.7	533.6	535.6	492.4	445.3	523.3	511.6	488.9
	N_2O	t	26.6	26.5	26.6	26.7	26.8	24.6	22.3	26.2	25.6	24.4
Composting (backyard)	CH_4	t	130.0	120.0	110.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	N_2O	t	6.5	6.0	5.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Digestion (industrial)	CH_4	t	25.9	27.1	34.5	32.0	32.0	30.8	32.0	33.2	34.5	34.5
Digestion (agricultural)	CH_4	t	92.3	88.6	98.4	109.5	119.4	120.6	121.8	120.6	130.5	136.6
Biogas up-grade	CH_4	t	51.3	70.9	94.7	128.0	144.7	168.7	204.1	221.4	228.3	236.8

7.3.3 Uncertainties and time-series consistency

Uncertainty in CH_4 emissions from composting and digestion

The uncertainty of all emission factors in source category 5B1 Composting is estimated at 30% for industrial composting and at 100% for backyard composting. The uncertainty of the related activity data is estimated at 30% for industrial composting and at 100% for backyard composting (EMIS 2020/5B1 Kompostierung).

For 5B2 Anaerobic digestion at biogas facilities the uncertainty takes into account the different process steps on one hand and emission factors on the other hand (EMIS 2020/1A1a & 5 B 2 Vergärung LW and EMIS 2020/1A1a & 5 B 2 Vergärung IG).

The overall uncertainty for 5B Biological treatment of solid waste for activity data as well as for emission factor is 30%.

Consistency: Time series for 5B Biological treatment of solid waste are all considered consistent.

7.3.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

7.3.5 Category-specific recalculations

The following recalculations were implemented in submission 2020:

- 5B1: For calculating activity data for 5B1 Composting, the annual report of the inspectorate of the national composting and fermentation industry has been used as source for the years 2014–2017 according to Schleiss (2017). This approach provides a more accurate reflection of inter-annual variability compared to the previously applied linear interpolation approach. Overall, the recalculated activity data are about 10% lower.

7.3.6 Category-specific planned improvements

- 5B: A research project in the framework of a joint research programme is investigating the CH_4 emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project (results expected in 2021) as appropriate.

7.4 Source category 5C – Incineration and open burning of waste

7.4.1 Source category description

Source category 5C – Incineration and open burning of waste is not a key category.

There is a long tradition in Switzerland to incinerate waste. The heat generated during the incineration has to be recovered if technically and economically feasible. In accordance with the 2006 IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities are dealt with in 1A1a Public electricity and heat production.

5C1 encompasses incineration of hospital wastes, illegal waste incineration, incineration of insulation material from cables, of sewage sludge and in crematoria.

5C2 consists of emissions from open burning of branches in agriculture and gardening. Natural agricultural and gardening residues consist of fallen fruit trees, part of diseased residue which are cut up, collected and burnt off-site. Field burning of agricultural residues does not occur in Switzerland. Emissions from open burning of natural residues in forestry are reported in LULUCF sector 4 V (chp. 6.4.2.13).

Table 7-14 Overview of waste incineration sources reported under 5C.

5C	Source category	Specification
5C1	Hospital waste incineration	Emissions from incinerating hospital waste in hospital incinerators
	Illegal waste incineration	Emissions from illegal incineration of municipal solid wastes at home. Emissions from waste incineration at construction sites (open burning)
	Insulation material from cables	Emissions from incinerating cable insulation materials
	Sewage sludge	Emissions from sewage sludge incineration plants
	Crematoria	Emissions from the burning of bodies in crematoria
5C2	Open burning of branches	Open burning of branches in agriculture and gardening.

7.4.2 Methodological issues

Methodology (5C)

Emissions are calculated using Tier 2 methods based on the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). In general, the GHG emissions are calculated by multiplying the waste quantity incinerated by emission factors. For crematoria, the GHG emissions are calculated by multiplying the number of cremations by emission factors.

For sewage sludge incineration plants the respective waste quantities are based on reliable statistical data (updated every two years until 2006). The emission factors are based on emission declarations from an incineration plant in 2002 that covered approximately one third of the Swiss capacities. Due to the lack of better or newer data these emission factors are kept constant since then and no improvement in flue gas cleaning standards is assumed.

For hospital waste incineration, illegal waste incineration and incineration of insulation material, the waste quantities used are based on expert estimates.

Emissions from burning of residues in agriculture and gardening are calculated using a Tier 1 method based on the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). Emission factors are taken from EMEP/CORINAIR (EMEP/EEA 2019 and EMEP/EEA 2002).

Indirect CO_2 emissions from fossil CO and NMVOC emissions from illegal waste incineration, insulation material from cables and hospital waste incinerations are documented in chp. 9 Indirect CO_2 and N_2O emissions.

Emission factors (5C)

Table 7-15 presents an overview of the emission factors for 5C for the latest inventory year.

Table 7-15 Emission factors for 5C Waste incineration and open burning of waste in 2018. Documentation/sources: EMIS 2020/5C1 and EMIS 2020/5C2, EMEP/EEA 2019 and EMEP/EEA 2002).

5C Waste incineration and open burning of waste	**CO_2** t/t	**CH_4** kg/t	**N_2O** g/t	**NO_x** kg/t	**CO** kg/t	**NMVOC** kg/t	**SO_2** kg/t
Hospital waste incineration	0.9	NA	60	1.5	1.4	0.3	1.3
Municipal waste incineration (illegal)	0.5	6.0	150	2.5	50	16	0.75
Industrial waste incineration	1.3	NA	NA	1.3	2.5	0.5	6.0
Sewage sludge incineration	NA	0.1	800	0.7	0.19	0.005	0.47
Open burning of natural residues in agriculture	NA	6.8	180	1.4	49	1.5	0.03
Open burning of natural residues in private households	NA	6.8	180	1.4	49	1.5	0.03
	CO_2 t/crem.	**CH_4** kg/crem.	**N_2O** g/crem.	**NO_x** kg/crem.	**CO** kg/crem.	**NMVOC** kg/crem.	**SO_2** kg/crem.
Cremation	NA	NA	NA	0.21	0.05	0.006	NA

Comments on CO_2 emission factors:

- For all waste incineration categories, only CO_2 emissions from non-biogenic waste are taken into account.
- Hospital waste incineration: The waste is mainly of fossil origin. The default value for the CO_2 emission factor is taken from SAEFL (2000). Since 2002, no emissions from hospital

waste incineration occur, as all hospital waste incinerator plants have been closed and hospital waste is incinerated in municipal solid waste incineration plants (accounted for in 1A1a).

- Illegal waste incineration: The CO_2 emission factor is estimated by using the same assumption as in case of MSW incineration: The C-content is based on the study by FOEN (2014l) and the fossil carbon fraction was determined by Rytec (2014). See also chp. 3.2.5.2 and detailed information in EMIS 2020/1A1a Kehrichtverbrennungsanlagen (pp. 5–7).
- Industrial waste (consists of cable insulation materials): The CO_2 emission factor is based on measurements of the flue gas treatment of a cable disassembling site where O_2 was measured in the flue gas. Assuming that the ratio of CO_2/O_2 is the same as in municipal solid waste incineration plants, a fraction of 7% of CO_2 results. Based on these assumptions, an emission factor of 1.3 kg/kg cable can be derived. Since 1995, no emissions from incinerating cable insulation materials occurred.
- Sewage sludge plants: As sewage sludge is biogenic waste, the emission factor for CO_2 is zero. It is assumed that the share of fossil fuel used during the start-ups is negligible.

Additional information on emission factors of all other (non-CO_2) gases:

- Hospital waste incineration: All emission factors are taken from SAEFL (2000).
- Illegal waste incineration: The emission factor for N_2O is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 5), the emission factors for CH_4, SO_2, NO_x, NMVOC from SAEFL (2000) and USEPA (1995a).
- Industrial waste (cable insulation materials): All emission factors are adopted from SAEFL (2000).
- Sewage sludge plants: For 1990 emission factors are taken from SAEFL (2000). From 2002 onwards constant emission factors are used, which are deduced from measurements (LHA 2004) taken at the largest sewage sludge incineration plant incinerating one third of Switzerland's sewage sludge. Between 1990 and 2002 the emission factors are interpolated. Emission factors for NMVOC, CO, SO_2 and CH_4 decrease due to gradual technical improvements.
- Crematoria: NMVOC and CO emissions were reduced by technical improvements. A large number of measurements were analysed (crematoria as well as other types of installations are obliged to monitor their emissions by the Swiss Federal Ordinance on Air Pollution Control (Swiss Confederation 1985) such that plant-specific emission factors are available for installations with retrofitted flue gas treatment as well as non-retrofitted installations. The emission factors are calculated as weighted averages of cremations taking place in retrofitted and non-retrofitted cremation plants (EMIS 2020/5C1 Krematorien).
- The emission factors of burning of branches in agriculture and gardening are calculated based on EMEP/EEA (2019) except for CH_4 und N_2O for which emission factors are based on EMEP/CORINAIR (EMEP/EEA 2002), see also documentation in EMIS 2020/5C2 & 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.
- General remark: In years with no specific data for activity data or emission factors the respective data are interpolated.
- General remark: Indirect CO_2 emissions from fossil CO and NMVOC emissions are reported in chp. 9 Indirect CO_2 and N_2O emissions.

Activity data (5C)

The activity data for 5C Waste incineration are the quantities of waste incinerated, see Table 7-16. Activity data for open burning are split into open burning of natural residues in agriculture as well as into open burning of natural residues in private households, while respective activity data in CRF Table5.C are aggregated.

Table 7-16 Activity data for the different emission sources within source category 5C Waste incineration and open burning of waste.

5C Incineration and open burning of waste	Unit	1990	1995	2000	2005
Hospital waste incineration	kt	15.0	8.8	2.5	NO
Municipal waste incineration (illegal)	kt	32.3	26.2	24.9	21.7
Industrial waste incineration	kt	7.5	NO	NO	NO
Sewage sludge incineration	kt (dry)	57.0	50.2	64.3	94.9
Open burning of natural residues in agriculture	kt	16.5	15.2	14.0	12.8
Open burning of natural residues in private households	kt	6.1	4.9	3.6	2.4
Total	kt	134.3	105.2	109.3	131.7
Cremation	Numb.	37'513	40'968	44'821	48'169

5C Incineration and open burning of waste	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Hospital waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Municipal waste incineration (illegal)	kt	20.7	21.0	20.3	20.3	19.9	19.3	19.3	19.0	18.3	17.9
Industrial waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sewage sludge incineration	kt (dry)	96.2	97.4	98.1	98.7	121.2	123.9	132.9	139.6	142.6	126.5
Open burning of natural residues in agriculture	kt	11.8	11.5	11.4	11.3	11.2	11.1	11.0	10.8	10.7	10.6
Open burning of natural residues in private households	kt	1.5	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
Total	kt	130.2	131.2	131.0	131.4	153.4	155.4	164.3	170.6	172.7	156.1
Cremation	Numb.	52'402	52'813	52'530	50'567	53'205	55'616	59'664	54'634	57'694	54'842

Hospital waste incineration: Does not occur anymore in specific hospital waste incineration plants since 2002. Such waste is nowadays incinerated in MSWIP and is therefore reported under sector 1 Energy. The amount of hospital waste burnt in 1990 stems from BUS (1988).

Illegal municipal waste incineration: As waste incineration outside incineration plants is forbidden in Switzerland, no data is available. Illegal incineration of waste e.g. in wood stoves, garden fires, construction sites etc. is decreasing due to surveillance by authorities but also by citizens that would report open burning. However, there still are cases of illegal waste incineration. It is assumed that 1% of all waste in Switzerland has been burnt illegally in 1990 and that this value linearly decreases to 0.25% in 2030 (and then remains constant).

Industrial waste incineration (cable insulation): Does not occur anymore since 1995. Such waste is nowadays incinerated in MSWIP and is therefore reported under sector 1 Energy. The amount burnt in 1990 is estimated by the amount reported by a company that was supposed to burn approx. 1/3 of all insulation material in Switzerland.

Sewage sludge incineration: Activity data for sewage sludge incineration for the years 1990, 1994, 1996, 1998, 2000, 2002, 2004 and 2006 stem from waste statistics by the FOEN. Since 2010, activity data are calculated as follows: The total amount of sewage sludge incurring in Switzerland is calculated assuming per capita sludge production of 26 kg per person and year based on the 2011 waste statistics and is applied from 2010 onwards (as recommended in EAWAG 2018). The amounts of sewage sludge burnt in MSWIP and used as alternative fuel in the cement industry are then subtracted from the total amount of sewage sludge and the remainder constitutes the activity data for sewage sludge incineration. Missing values for years between 1990 and 2010 are interpolated.

Open burning of natural residues: The amount of natural residues burnt openly has been estimated in a study (INFRAS 2014) as briefly described in the following. Open burning of such residues is regulated in the Ordinance on Air Pollution Control OAPC, Article 26b. In Switzerland, cantonal authorities are responsible for the implementation of the regulations of the OAPC. Since there is no nationwide data available for the activity data of open burning of natural residues, cantonal authorities have been interviewed. Based on the available statistics in many cantons on the number of permitted fires and sanctions due to non-permitted fires, the amount of burnt material in those cantons has been quantified. Since there also is a significant number of unreported cases, it has been assumed that the actual amount of material burnt is three times as large as the amount that has been approved by the authorities. Based on the numbers from the evaluated cantons an extrapolation to the amount burnt in Switzerland has been made. For the extrapolation the statistics on the harvesting of wood has been used (FOEN2012i). For the determination of a time series of natural residues burnt, elder experts with historical knowledge in agriculture and forestry have been interviewed. Furthermore, statistical data on agricultural and forestry activities has been used to estimate the potential of material available for burning at a certain time. With this approach a time series since 1900 has been compiled. Emissions from open burning of natural residues in forestry (5C2ii) are reported in LULUCF sector 4 V (chp. 6.4.2.13).

Cremations: Activity data is reported by the Swiss Cremation Association. These statistics are updated every year.

7.4.3 Uncertainties and time-series consistency

The uncertainty assessment, based on expert judgment, results in high uncertainties for CO_2 and CH_4 of 40% and 60% of emission estimates, respectively, and for N_2O in low uncertainty of 40% of emission estimates (see Table 1-10 for quantification of “low” and “high”).

Consistency: Time series for 5C Waste incineration and open burning of waste are all considered consistent.

7.4.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

7.4.5 Category-specific recalculations

The following recalculations were implemented in submission 2020:

- 5C1 (CO_2, N_2O): An error has been corrected in the amount of hospital waste (AD) incinerated in the year 1990 according to BUS (1988). The amount decreases linearly to 0 in the year 2002. Therefore all AD values for the years 1990 to 2001 have changed. AD has decreased by 50%.

7.4.6 Category-specific planned improvements

No category-specific improvements are planned.

7.5 Source category 5D – Wastewater treatment and discharge

7.5.1 Source category description

Table 7-17 Key categories of 5D Wastewater treatment and discharge. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
5D	Wastewater treatment and discharge	CH4	L1, L2, T1, T2
5D	Wastewater treatment and discharge	N2O	L2, T2

Source category 5D1 Domestic wastewater comprises all emissions from liquid waste handling and sludge from housing and commercial sources (including grey water and night soil). In Switzerland, municipal wastewater treatment (WWT) plants treat wastewater from single cities or several cities and municipalities together. Wastewater in general is treated in three steps:

1. Mechanical treatment
2. Biological treatment
3. Chemical treatment.

The treated wastewater flows into a receiving system (lake, river or stream). Pre-treated industrial effluents are also handled for final treatment in municipal WWT plants (see Figure 7-5). In the following, these are called "domestic WWT plants" according to the terminology of 5D1 Domestic wastewater.

Switzerland's wastewater management infrastructure – comprising about 850 WWT plants and 40'000–50'000 km of public sewers – is now practically complete (FOEN 2017l). The vast majority of WWT plants apply an anaerobic sludge treatment with sewage gas recovery, and use the sewage gas for heat production. About 290 WWT plants also apply combined heat and power (CHP) units. See also EMIS 2020/5D1 Wastewater Treatment Plants.

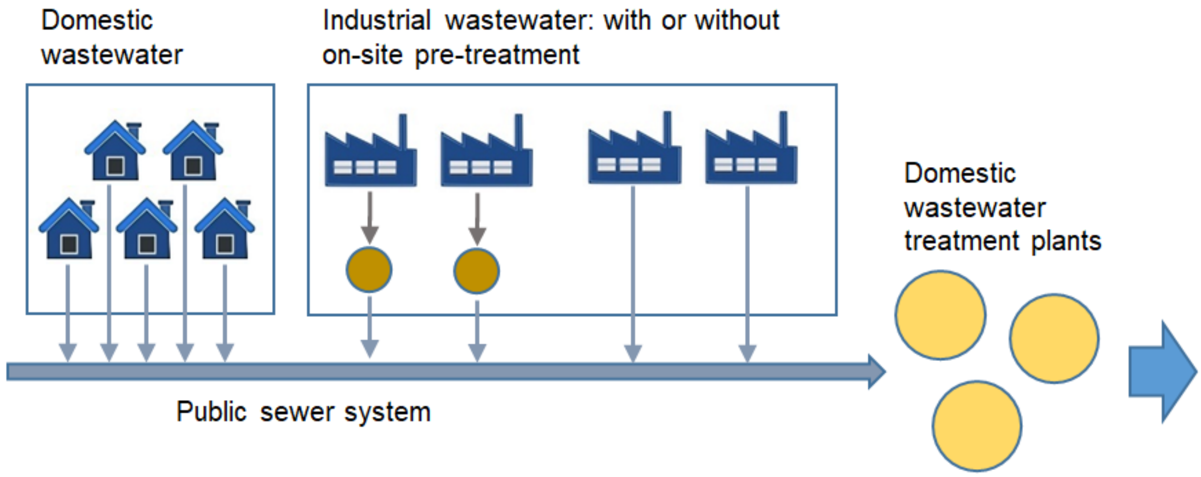


Figure 7-5 Graphical representation of domestic and industrial wastewater streams.

Source category 5D2 Industrial wastewater comprises all emissions from liquid waste handling and sludge from industrial processes such as food processing, textiles, car-washing places, electroplating plants, and pulp/paper production. These processes may result in effluents with a high load of organics. Depending on the contaminants, an on-site pre-treatment is necessary in order to reduce the load of pollutants in the wastewater to meet the regulatory standards (which are in place to preclude disruptions of the domestic WWT plants) and to reduce discharge fees. The on-site pre-treatment is generally anaerobic, in order to use the sewage gas as source for heat and power production. Currently, about 20 industrial WWT plants pre-treat wastewater before its discharge to the domestic sewage system, where the industrial wastewater is additionally treated together with domestic wastewater in domestic WWT plants (see Figure 7-5 and Figure 7-6). Due to this strong connection with domestic wastewater treatment, industrial wastewater is not identified as separate wastewater stream for the calculation of GHG emissions, but joined to the domestic wastewater treatment. For the calculation of emissions of other gases (NO_x, CO, NMVOC, SO_2), domestic and industrial wastewater streams are distinguished (i.e. different emission factors relative to population, see below). See also EMIS 2020/5D2 Pre-treatment of industrial wastewater.

Table 7-18 Specification of source category 5D Wastewater treatment and discharge.

5D	**Source category**	**Specification**
5D1	Domestic wastewater	Emissions from liquid waste handling and sludge from housing and commercial sources
5D2	Industrial wastewater	Emissions of precursors from handling of liquid wastes and sludge from industrial processes (emissions of CH_4 and N_2O are implemented in 5D1)
5D3	Other	Not occurring in Switzerland

Category 5D contains all direct emissions from wastewater handling, including direct emissions of sewage gas (leakage), torching and upgrading of sewage gas to natural gas quality (to be fed into the natural gas network and/or used as fuel). Emissions from the usage of sewage gas in combined heat and power (CHP) units and boilers (only heat production) are reported in sector 1 Energy in source category 1A2gviii Other (see Figure 3-19).

Wastewater treatment also leads to emissions reported in other categories, as illustrated in Figure 7-6. Emissions associated with sewage sludge drying are assumed to be negligible. The discharge of sewage sludge on agricultural soils has been phased out since 2003 and is generally forbidden since 2009. Therefore, this process is crossed out in Figure 7-6. The same applies to solid waste disposal on land (5A). All sewage sludge is incinerated either in municipal solid waste incineration plants (1A1a), sewage sludge incineration plants (5C) or used as alternative fuel in the cement industry (1A2f).

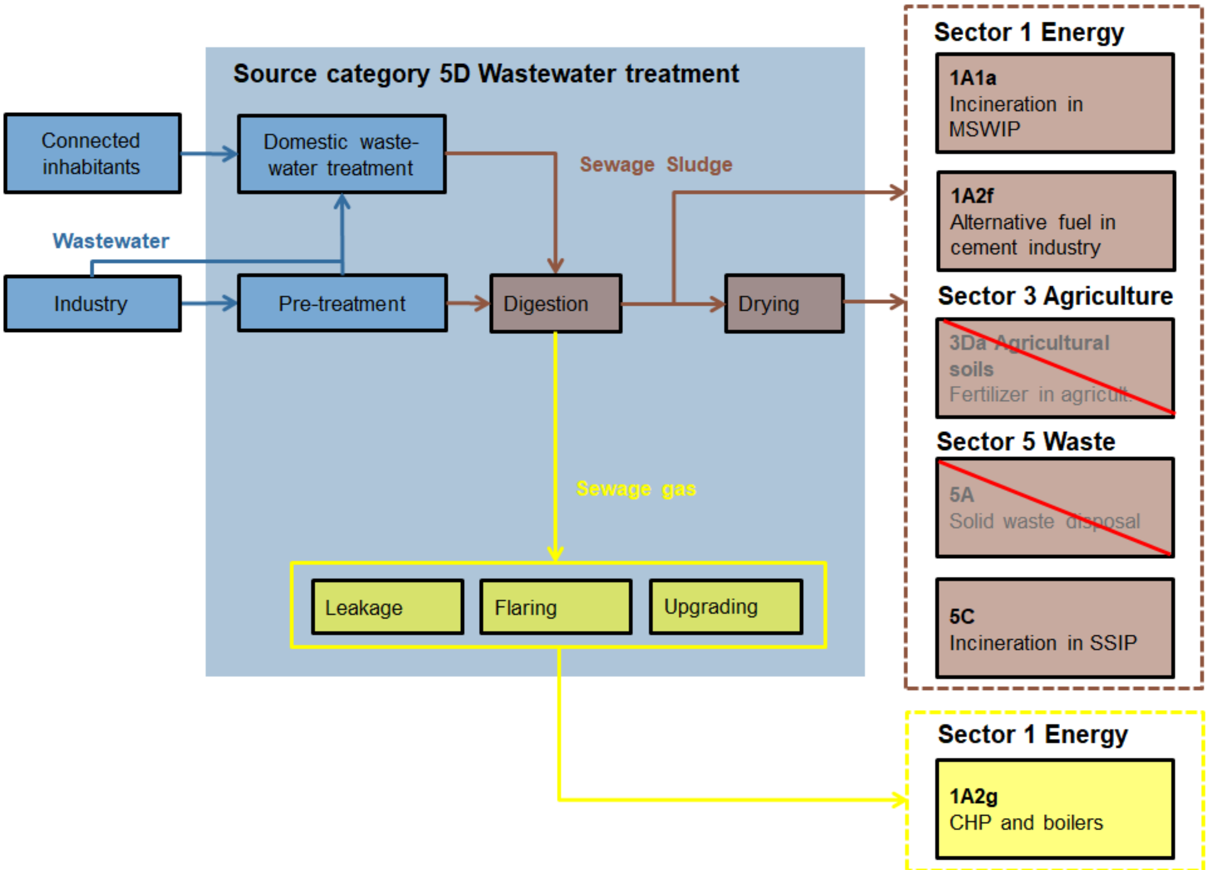


Figure 7-6 System boundaries of processes related to wastewater treatment. CHP = Combined heat and power generation. MSWIP = Municipal solid waste incineration plant. SSIP = Sewage sludge incineration plant.

7.5.2 Methodological issues

CH_4 emissions are calculated by a Tier 2 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Fig. 6.2 and Fig. 6.3).

N_2O emissions are calculated using a country-specific method according to IPCC (2006).

Details regarding the calculation of CH_4 and N_2O emissions are provided in the following.

7.5.2.1 CH_4 emissions

Methodology (5D, CH_4)

CH_4 emissions from wastewater treatment and discharge take into account emissions stemming from organically degradable material in wastewater and emissions related to sewage gas production (and recovery) from sewage sludge (in domestic as well as industrial installations). Accordingly, the contribution of industrial wastewater is taken into account in the calculation of CH_4 emissions from domestic wastewater by means of a correction factor for additional industrial biochemical oxygen demand (BOD) discharged into the domestic sewer system. Industries handling wastewater with high BOD usually use anaerobic digesters to produce sewage gas. The emissions related to sewage gas production (and recovery) during industrial pre-treatment of wastewater are also taken into account in the calculation of emissions from domestic WWT plants, because the underlying Swiss renewable energy statistics in Switzerland (see below) does not differentiate between sewage gas production in domestic and industrial WWT plants.

Accordingly, total CH_4 emissions from domestic and industrial wastewater treatment and discharge are calculated as the sum of two terms:

$$CH_{4,total} = CH_{4,wastewater} + CH_{4,sewage\ gas}$$

(1) Wastewater

In accordance with the 2006 IPCC Guidelines (IPCC 2006) the contribution of wastewater sewered to WWT plants is determined by:

$$CH_{4,wastewater} = EF_{wastewater} * T_{Plant} * TOW$$

$EF_{wastewater}$ corresponds to the emission factor (see below), T_{Plant} to the fraction of population connected to domestic WWT plants in each year and TOW to the total organically degradable material in the wastewater per year.

From all inhabitants (urban and rural) 90% were connected to WWT plants in 1990, and this percentage reached 97% in 2006, remaining constant thereafter. Switzerland reports emissions only from wastewater discharged to the public sewer system, without taking into account potential emissions from wastewater of unconnected inhabitants. However, emissions from the small fraction of wastewater not treated in WWT plants (since 2006 the wastewater from 3% of the population) are negligible. Federal law only permits alternative treatment systems in remote and sparsely populated regions. Some of such alternative systems treat wastewater very similar to centralized WWT plants, often under aerobic conditions. The sewage sludge from these small scale treatment installations is either dealt with by centralized WWT plants or MWIP (municipal waste incineration plants). Simpler systems are e.g. septic tanks with at least three chambers. However, the production of CH_4 in an anaerobic environment is strongly temperature dependent and significant CH_4 production is unlikely below 15°C due to the inactivity of methanogens (IPCC 2006). As in Switzerland alternative systems are typically buried, the wastewater reaches the rather constant temperature of the surrounding soil, approximately corresponding to the mean annual air temperature. At Grono, the warmest place in Switzerland, the mean annual temperature is 12.4°C. Accordingly, in alternative treatment systems the temperature of the wastewater is too low to produce substantial CH_4 emissions. CH_4 emissions from wastewater produced by inhabitants not connected to domestic WWT plants are thus considered insignificant and set to zero in the Swiss greenhouse gas inventory.

(2) Sewage gas

The CH_4 emissions resulting from sewage gas treatment (aiming at stabilizing the sewage sludge and producing sewage gas) are calculated based on a country-specific implied emission factor ($EF_{sewage\ gas}$, see below), which is normalized with population (P):

$$CH_{4,sewage\ gas} = EF_{sewage\ gas} * P$$

Emission factors (5D, CH_4)

(1) Wastewater

The wastewater of all connected inhabitants, i.e. virtually all wastewater generated in Switzerland, is sewered to WWT plants using closed sewer systems. The emission factor according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Equation 6.2) is represented by the product of the maximum CH_4 producing potential (B_o, default value 0.60 kg CH_4/kg BOD) and the methane correction factor (MCF) for the wastewater treatment and discharge system. For the wastewater sewered to centralized WWT plants, the 2006 IPCC Guidelines (IPCC 2006) propose that the MCF is zero (range 0.0–0.1) for well managed aerobic WWT plants. While WWT plants are generally well managed in Switzerland and mostly operated aerobically (with the exception of sewage sludge treatment, which is considered separately, see below), some CH_4 emissions may still occur. Therefore, the MCF is set to 0.05 (corresponding to the mid-value of the range of well managed aerobic WWT plants), which also brings total CH_4 emissions from WWT in Switzerland to similar values as estimated by Hiller et al. (2014) in their peer-reviewed study. This leads to the following constant emission factor:

$$EF_{wastewater} = B_0 * MCF = 0.60 \frac{kgCH_4}{kgBOD} * 0.05 = 0.03 \frac{kgCH_4}{kgBOD}$$

As mentioned above the maximum CH_4 producing capacity of the wastewater not treated in WWT plants is zero, as the wastewater has a temperature most likely too low to produce significant amounts of CH_4. Accordingly, the emission factor for wastewater not treated in WWT plants is zero and the corresponding emissions are zero, too.

(2) Sewage gas

To calculate the country-specific implied emission factor $EF_{sewage\ gas}$ for CH_4 emissions from sewage gas treatment the total sewage gas production (in domestic and industrial systems) is taken into account based on detailed Swiss renewable energy statistics in Switzerland (SFOE 2019a). These statistics provide the amount of sewage gas used in furnaces and CHP installations, as well as the amount of sewage gas upgraded to natural gas quality. It is assumed that 2% of the total amount of sewage gas is flared and 0.75% of the total amount is leaking. It is further assumed that the leakage of upgraded gas linearly decreases from 5%

in 1990 to 2.5% in 2014, remaining constant thereafter. The emission factor is adapted on a yearly basis due to the respective annual changes in population and the total production of sewage gas.

(3) Values of emission factors referred to the number of inhabitants

The CH_4 emission factors for 5D Wastewater treatment and discharge are summarized in Table 7-19.

Table 7-19 Country-specific CH_4 emission factors for source category 5D Wastewater treatment and discharge in 2018 referred to the number of inhabitants. Detailed information is given in EMIS 2020/5D1 5D2 Kläranlagen GHG (Wastewater Handling - Emissions of Nitrous Oxide (N_2O) and Methane (CH_4), Update to the 2006 IPCC Guidelines).

5D Wastewater treatment and discharge	**Unit**	**2018**
Population	in 1000	8'514
Emissions from WW sewered to WWT plants	kg CH_4/person/a	0.80
Emissions from WW not sewered to WWT plants	kg CH_4/person/a	NA
Emissons from losses during sludge treatment	kg CH_4/person/a	0.09

Activity data (5D, CH_4)

(1) Wastewater

In correspondence with the emission factor $EF_{wastewater}$ given above, the activity data is the fraction of population connected to domestic WWT plants (T_{plant}), as well as the total organically degradable material (*TOW*) in domestic and industrial wastewater. According to the 2006 IPCC Guidelines (IPCC 2006), TOW is calculated by

$$TOW = P * BOD * 0.001 * I * 365$$

TOW is given in kg BOD/yr (BOD: biochemical oxygen demand) and P is the population (see Table 7-20). For BOD the default value for Europe given by the 2006 IPCC Guidelines (IPCC 2006) is used for Switzerland (60 g/inhabitant/day). The parameter I corresponds to the correction factor for additional industrial BOD discharged into domestic sewers with default value 1.25. While the amount of sewage sludge removed from WWT plants is known, detailed information about its BOD content is not available. Therefore, the amount of BOD removed with sewage sludge is set to zero, in accordance with the default value given by the 2006 IPCC Guidelines (IPCC 2006).

Time series of the activity data are shown in Table 7-20.

(2) Sewage gas

As elaborated above, a per capita CH_4 emission factor ($EF_{sewage\ gas}$) is calculated for CH_4 emissions from separate sewage sludge treatment, and the respective activity data is population (Table 7-20).

7.5.2.2 N_2O emissions

Methodology (5D, N_2O)

Direct N_2O emissions from centralized WWT plants and N_2O emissions from wastewater effluent are calculated in accordance with the 2006 IPCC Guidelines (IPCC 2006).

(1) N_2O emissions from WWT plants

Direct N_2O emissions from WWT plants are determined with equation 6.9 of the 2006 IPCC Guidelines (IPCC 2006):

$$N_2O_{PLANTS} = EF_{PLANT} * P * T_{PLANT} * F_{IND-COM}$$

N_2O_{PLANTS} corresponds to the total N_2O emissions from WWT plants in kg N_2O/yr, P to the population, T_{PLANT} to the degree of utilization of modern, centralized WWT plants (%), $F_{IND\text{-}COM}$ to the correction factor for industrial (and commercial) co-discharged protein, and EF_{PLANT} to the emission factor from the plants.

(2) N_2O emissions from wastewater effluents

The following equation from the 2006 IPCC Guidelines (IPCC 2006) for the N_2O emissions from wastewater effluent is used:

$$N_2O_{EFFLUENT} = EF_{EFFLUENT} * N_{EFFLUENT} * 44/28$$

$N_2O_{Effluent}$ corresponds to the total N_2O emissions from effluents (kg N_2O/yr), $N_{EFFLUENT}$ to the total amount of nitrogen discharged to the aquatic environment (kg N/yr), and $EF_{EFFLUENT}$ to the emission factor for N_2O emissions from discharged wastewater (kg N_2O-N/kg N). The following equation allows for the calculation of the total amount of nitrogen in the wastewater ($N_{EFFLUENT}$, kg N/yr, IPCC 2006):

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON-CON} * F_{IND-COM}) - N_{SLUDGE} - N_{WWT}$$

P corresponds to the population, Protein to the annual per capita protein consumption (kg protein/inhabitant/yr), and F_{NPR} to the fraction of nitrogen in protein. $F_{NON\text{-}CON}$ is a factor accounting for non-consumed protein added to the wastewater. $F_{IND\text{-}COM}$ is a factor accounting for industrial (and commercial) co-discharged protein into the sewer system. N_{SLUDGE} is the amount of nitrogen removed with sewage sludge (kg N/yr), calculated as the product of sludge amount per year and its nitrogen concentration. The default value according to the 2006 IPCC Guidelines would be zero, but detailed data about sewage sludge removal as well as the nitrogen content of the sewage sludge is available for Switzerland (Külling et al. 2002a). In Switzerland sewage sludge is mostly burnt today in waste incineration plants and (cement) industry, previously it has also been used as fertiliser (now forbidden). N_{WWT} corresponds to the amount of nitrogen directly emitted by WWT plants in form of N_2O (N_2O_{Plants}, see calculation above).

Emission factors (5D, N_2O)

(1) N_2O emissions from WWT plants

The IPCC default emission factor is applied: EF_{PLANT} = 3.2 g N_2O/inhabitant/yr (IPCC 2006).

(2) N_2O emissions from wastewater effluents

The IPCC default emission factor is applied: $EF_{EFFLUENT}$ = 0.005 kg N_2O-N/kg N (IPCC 2006).

Activity data (5D, N_2O)

(1) N_2O emissions from WWT plants

The needed time-dependent and country-specific activity data are summarized in Table 7-20:

- Population (P)
- Degree of utilization of modern, centralized WWT plants (T_{PLANT})
- In addition, the following constant factor is used: Industrial (and commercial) co-discharged protein, within IPCC range: $F_{IND\text{-}COM}$ = 1.0 (EAWAG 2018)

(2) N_2O emissions from wastewater effluents

The time-dependent and country-specific activity data are also summarized in Table 7-20:

- Population (P)
- Annual per capita protein consumption (Protein) (SBV 2019)
- Mass of nitrogen contained in the removed sludge (N_{SLUDGE})

In addition, the following constant factors are used:

- Fraction of nitrogen in protein, IPCC default value: F_{NPR} = 0.16 kg N/kg protein (IPCC 2006).
- Factor accounting for non-consumed protein added to the wastewater, within IPCC range: $F_{NON\text{-}CON}$ = 1.0 (EAWAG 2018). This value is appropriate for Switzerland as it is illegal to discharge solid and liquid garbage with the wastewater, see Article 10 in the Waters Protection Ordinance, Swiss Confederation 1998a.
- Industrial (and commercial) co-discharged protein, IPCC default value: $F_{IND\text{-}COM}$ = 1.25 (IPCC 2006).

Table 7-20 Activity data for source category 5D Wastewater treatment and discharge (source EMIS 2020/5D1 Wastewater Treatment Plants and EMIS 2020/5D2 Pre-treatment of industrial wastewater).

5D Wastewater treatment and discharge	Unit	1990	1995	2000	2005
Population	persons in 1000	6'796	7'081	7'209	7'501
Fraction of population connected to wastewater treatment plants	%	90.0	93.7	95.4	96.8
Connected persons	persons in 1000	6'116	6'635	6'877	7'261
Protein consumption	kg/inhab./a	38	37	37	36
N removed with sludge (N_{sludge})	N in t/a	9'465	9'009	8'831	9'026
N directly emitted (N_{WWT})	N in t/a	12.5	13.5	14.0	14.8
Total org. degr. material (TOW)	t/a	186'041	193'842	197'346	205'340

5D Wastewater treatment and discharge	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Population	persons in 1000	7'801	7'878	7'912	7'997	8'089	8'189	8'282	8'373	8'452	8'514
Fraction of population connected to wastewater treatment plants	%	97.2	97.2	97.3	97.3	97.3	97.3	97.3	97.3	97.3	97.3
Connected persons	persons in 1000	7'583	7'657	7'698	7'781	7'871	7'968	8'058	8'147	8'224	8'284
Protein consumption	kg/inhab./a	38	38	39	37	37	37	37	36	36	36
N removed with sludge (N_{sludge})	N in t/a	8'965	8'909	8'948	9'044	9'148	9'261	9'366	9'470	9'561	9'631
N directly emitted (N_{WWT})	N in t/a	15.4	15.6	15.7	15.8	16.0	16.2	16.4	16.6	16.7	16.9
Total org. degr. material (TOW)	t/a	213'552	215'660	216'591	218'918	221'436	224'174	226'720	229'211	231'374	233'071

7.5.2.3 Other gases

The sewage gas production generates emissions of further gases from flaring: CO_2 (biogenic), NO_x, CO, NMVOC, and SO_2. The emissions are calculated by multiplying population (as activity data, see Table 7-20) with country-specific emission factors based on measurements and expert estimates, documented in EMIS 2020/5D1 Wastewater Treatment Plants and EMIS 2020/5D2 Pre-treatment of industrial wastewater. The emission factors used are summarized in Table 7-21.

Table 7-21 Emission factors of CO_2 (biogenic), CH_4, N_2O, NO_x, CO, NMVOC and SO_2 for 5D Wastewater treatment and discharge in 2017.

5D Wastewater treatment and discharge	CO_2 biog.	N_2O	CH_4	NO_x	CO	NMVOC	SO_2
	kg/person	g/person					
5D1 Domestic wastewater	0.41	39	888	0.56	0.28	0.011	0.003
5D2 Industrial wastewater	0.09	IE	IE	0.13	0.06	0.003	0.001

7.5.3 Uncertainties and time-series consistency

Uncertainty in CH_4 and N_2O emissions from 5D

7.5.3.1 CH_4 emissions

The default values of the 2006 IPCC Guidelines (IPCC 2006) are adopted to estimate the uncertainty of CH_4 emissions. The following specifications are given:

- Activity data: Uncertainties of the single factors U(population) = 5%, U(BOD) = 30%, U(I) = 20% lead to an aggregated uncertainty of U(AD) = 36%.
- CH_4 emission factor: Uncertainties of the single factors U(B_0) = 30%, U(MCF) = 10% (well managed plants) lead to an aggregated uncertainty of U(EF) = 32%.
- Combined uncertainty U(Em CH_4) = 48%.

7.5.3.2 N_2O emissions

By applying the default uncertainties of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, table 6.11) for the activity data (population, protein consumption etc.) a total uncertainty of 32% results.

For the emission factor the 2006 IPCC Guidelines provide default values, too. However, the range for $EF_{EFFLUENT}$ covers a range of 0.0005–0.25 kg N_2O-N/kg N (with default value 0.005 kg N_2O-N/kg N). If this range is interpreted as the 95% uncertainty interval, a symmetrised uncertainty of 2500% would result, which is not considered appropriate. The 2006 IPCC Guidelines (IPCC 2006) do not explain how to apply the range, wherefore the default uncertainty is not adopted. Instead, the uncertainty is based on expert judgments assuming a high uncertainty of N_2O emissions from 5D Wastewater treatment and discharge in Switzerland. By means of Table 1-10 this qualitative estimation corresponds to 150% for the combined uncertainty. This value is used for the uncertainty analyses in chp. 1.7.

Consistency: Time series for 5D Wastewater treatment and discharge are all considered consistent.

7.5.4 Category-specific QA/QC and verification

To check the quality of the assumptions and calculations for 5D Wastewater treatment and discharge and their accordance with the 2006 IPCC Guidelines, a review by Eawag (Swiss Federal Institute of Aquatic Science and Technology) has been performed in 2018 (EAWAG 2018).

The reviewers concluded that the calculations of N_2O emissions are carried out correctly as stated in the IPCC Guidelines and no methodological issues were detected. The emission factors used agree with the default values of the IPCC Guidelines and best practice. However the report recommended to adjust two factors ($F_{IND\text{-}COM}$ and $F_{NON\text{-}CON}$) and to calculate the total amount of sewage sludge via the per capita production. Concerning methane the review showed methodological differences from the IPCC Guidelines. They state that sewage gas usage in combination with energy recovery should be allocated to Sector 1 Energy and not Sector 5 Waste. All these recommendations have been implemented and lead to recalculations in submission 2019.

In chapter 8 of the report the reviewers also proposed additional methods which would describe the production and emission pathways of GHG more accurately. The aim is to develop methods based on the 2006 IPCC Guidelines that are refined for Switzerland. The methods are based on literature reviews, expert judgements and running monitoring campaigns performed by Eawag. The finalized proposals are pending until these campaigns have been concluded. An implementation of those findings and recommendations will then be considered (see chp. 7.5.6).

7.5.5 Category-specific recalculations

The following recalculations were implemented in submission 2020: Major recalculations which contribute significantly to the total differences emissions of sector 5D between latest and previous submission are presented also in chp. 10.1.2.5.

- 5D1 (CH_4 and N_2O): For 5D1 domestic wastewater treatment, activity data of combined heat and power generation (CHP) (years 2012 and 2014–2017) and boilers (years 2013–2017) have changed in the national statistical report on renewable energy by SFOE. Overall, the recalculated activity data are about 1% lower.
- 5D1 (CH_4 and N_2O): For 5D1 Domestic wastewater treatment, the data reported for total protein consumption in 2016 and 2017 have changed (by less than 1%) in the 2019 annual report by the Swiss Farmers Union (SBV).

7.5.6 Category-specific planned improvements

Currently, long-term and representative measurements of N_2O emissions from wastewater treatment plants in Switzerland are ongoing (EAWAG 2018). Results for estimating representative EF of N_2O for wastewater treatment are expected in 2022.

At the same time representative measurements of CH_4 and NH_3 emissions from wastewaster treatment plants in Switzerland are ongoing (Kupper et al. 2018b). Results for estimating representative EF of CH_4 for waste water treatment are expected in 2021.

After the succesfull finish of both projects it is planned to implement the findings in a future inventory and NIR.

7.6 Source category 5E – Other

7.6.1 Source category description

Source category 5E Other is not a key category.

The source category 5E Other comprises NMVOC and CO emissions from car shredding stemming from residues of fuels (gasoline, diesel) and motor oil in the tanks and motors of the shredded vehicles. Direct GHG emissions do not occur.

Table 7-22 Specification of source category 5E Other (car shredding)

5E	Source category	Specification
5E	Car shredding plants	Emissions from car shredding plants

7.6.2 Methodological issues

Methodology (5E)

For the emissions from car shredding a Tier 1 method is used.

Indirect CO_2 emissions from fossil CO and NMVOC emissions are described in chp. 9 Indirect CO_2 and N_2O emissions.

Emission factors (5E)

An emission factor of 100 g NMVOC per tonne of shredded vehicle is applied for the period 1990–1995. From 2000 onward, 200 g/t are used. Between 1995 and 2000 the values are linearly interpolated. The NMVOC emission factor are based on measurements at four plants in the years from 2002 to 2008 (EMIS 2020/5E Shredder Anlagen). For CO a constant emission factor is applied over the entire reporting period.

Table 7-23 CO and NMVOC emission factors for 5E Other (car shredding) in 2018.

5E Other waste	Unit	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Shredding	g/t scrap	NA	NA	NA	5	200	NA

Activity data (5E)

The waste quantities from 1990 to 1999 are provided by the Swiss Shredding Association. The data from 2000 to 2007 are taken from Swiss waste statistics. From then onwards the quantities are assumed to remain constant due to the lack of data (see also EMIS 2020/5E Shredder Anlagen).

Table 7-24 Activity data 5E Other (car shredding).

5E Other waste	Unit	1990	1995	2000	2005
Shredding	kt	280	300	300	300

5E Other waste	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Shredding	kt	300	300	300	300	300	300	300	300	300	300

7.6.3 Uncertainties and time-series consistency

Uncertainties of 20% for the emission factor and 10% for the activity data are assumed.

Consistency: Time series for 5E Other are all considered consistent.

7.6.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

7.6.5 Category-specific recalculations

No category-specific recalculations were carried out.

7.6.6 Category-specific planned improvements

No category-specific improvements are planned.

8 Other

Responsibilities for chapter Other	
Author & Method Updates	Michael Bock (FOEN)
EMIS data base operation	Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)
Annual updates (NIR text, tables, figures)	Beat Rihm (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest), Michael Bock (FOEN), Adrian Schilt (FOEN)
Internal review	Adrian Schilt (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN)

8.1 Overview

8.1.1 Greenhouse gas emissions

Within the sector 6 Other emissions from two sources are considered:

- Fire damage estates
- Fire damage motor vehicles

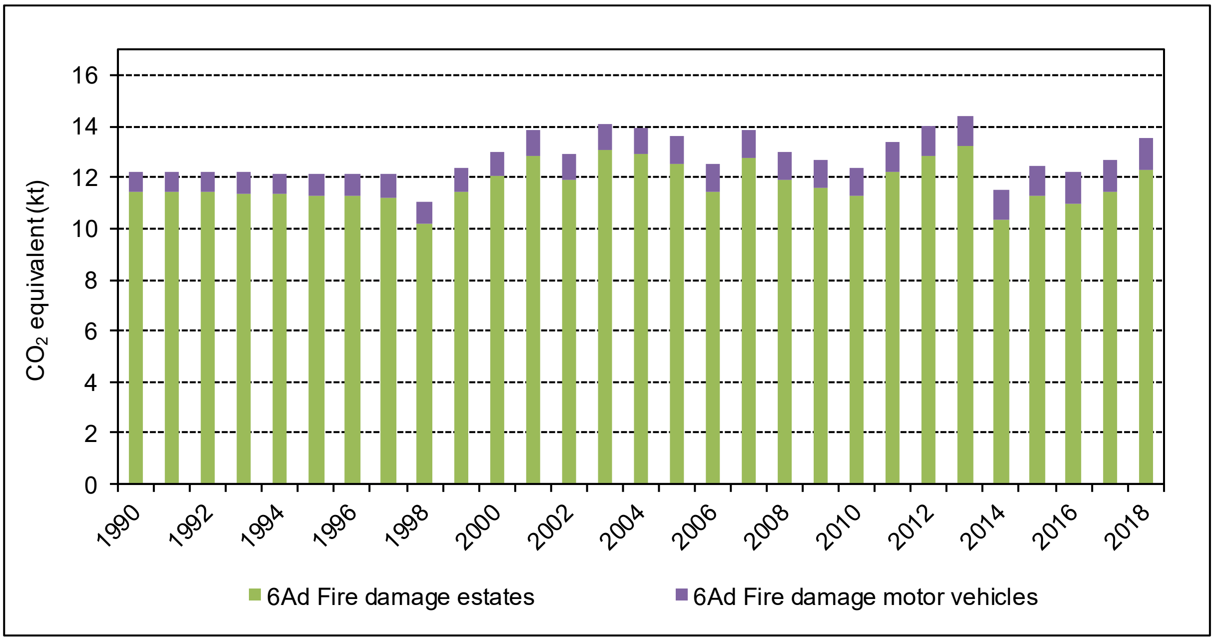


Figure 8-1 Switzerland's greenhouse gas emissions in sector 6 Other.

Table 8-1 Trend of total GHG emissions from sector 6 Other in Switzerland.

Gas	1990	1995	2000	2005
	CO_2 equivalent (kt)			
CO_2	11	11	12	12
CH_4	0.66	0.62	0.62	0.65
N_2O	0.60	0.54	0.54	0.57
Sum	12	12	13	14

Gas	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	CO_2 equivalent (kt)									
CO_2	12	11	12	13	13	10	11	11	12	12
CH_4	0.61	0.60	0.64	0.67	0.69	0.56	0.60	0.59	0.61	0.65
N_2O	0.52	0.51	0.55	0.58	0.60	0.47	0.51	0.50	0.51	0.55
Sum	13	12	13	14	14	12	12	12	13	14

In sector 6 Other Fire damage estates account for most of the emissions, the rest stems from Fire damage motor vehicles. The total greenhouse gas emissions of this sector show variations around 12 kt CO_2 eq during the reporting period. Consequently, sector 6 Other is an emission source of minor importance for the national total.

8.2 Source category 6 – Other

8.2.1 Source category description

Source category 6 - Other is not a key category.

The sources reported in source category 6 Other are shown in Table 8-2.

Table 8-2 Specification of source category 6 Other.

6	Source category	Specification
6Ad	Fire damage estates	Emissions from fires in buildings.
6Ad	Fire damage motor vehicles	Emissions from fires in motor vehicles.

8.2.2 Methodological issues

Methodology (6 Other)

CO_2 emissions are calculated by a Tier 1 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.1). Emission factors are country specific.

CH_4 emissions are calculated by a Tier 1 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study (FM Global 2010) (“OTH”, fire damage estates) and from EPA 1992 (“OTH”, fire damage motor vehicles).

N_2O emissions are calculated by a Tier 1 method based on the decision tree of the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study (FM Global 2010) ("OTH", fire damage estates). N_2O emissions from fire damages of motor vehicles have not been estimated.

The estimation of GHG emissions are based on damage sums and fires reported from insurance companies.

Emission factors (6 Other)

a) Fire damage estates

Emission factors for CO_2, CO, NO_x and SO_2 are country-specific based on measurements and expert estimates originally gained for illegal waste incineration. It is assumed that for fire damage in estates emission factors are the same as for illegal waste incineration (EMIS 2020/6Ad Brand- und Feuerschäden Immobilien).

The fraction between fossil and biogenic CO_2 emissions is assumed to remain constant since 2000 with 80% being fossil and 20% being biogenic CO_2 emissions. Before 2000, it is assumed that the fraction of fossil CO_2 emissions from burnt goods has been increasing linearly from 20% in 1950 to 80% in 2000. Hence, the interpolated emission factors for fossil CO_2 lay between 400 and 1500 t CO_2 / kt burnt good between 1950 and 2000, respectively. Vice versa, the emission factors for biogenic CO_2 lay between 1500 and 400 t CO_2 / kt burnt good between 1950 and 2000, respectively.

Indirect CO_2 emissions from fossil CO and NMVOC emissions are documented in chp. 9.

b) Fire damage motor vehicles

Emission factors for CO_2, CO, NO_x and SO_2 are country-specific based on measurements and expert estimates originally gained for the combustion of cable insulation materials, documented in EMIS 2020/6Ad Brand- und Feuerschäden Motorfahrzeuge.

The emission factor for CH_4 from fire damage in motor vehicles is based on EPA (1992), while N_2O emissions have not been estimated for this source category.

Indirect CO_2 emissions from fossil CO and NMVOC emissions are documented in chp. 9.

Table 8-3 Emission factors for fire damages in 2018 (EMIS 2020/6Ad).

6A Other	Unit	CO_2 biogenic	CO_2 fossil	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
6Ad Fire damage estates	t / kt burnt good	400	1'500	3	0.25	2	100	16	1
6Ad Fire damage motor vehicles	t / kt burnt good	NO	1'500	5	NE	1.3	2	2	5

Activity data (6 Other)

a) Fire damage estates

Since a methodological change for the NIR 2017 activity data are estimated yearly based on annually published information by the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF). VKF publishes the number of fire incidents in buildings each year and the total sum of monetary damage.

Statistical insurance data from 1992 to 2001 show that the average damage sum per fire incident in buildings amounts to approx. CHF 20’000. It is assumed that this corresponds to 780 kg of flammable material per case. It is further assumed that in average 50% of the material actually burns down during an incident because of the intervention of the fire brigade. Thus, an average amount of 400 kg of burnt material per fire case is estimated and held constant throughout the time series. With these assumptions, the amount of burnt material for each year can be estimated using the total sum of monetary damage published by VKF (EMIS 2020/6Ad Brand- und Feuerschäden Immobilien), divided by the average damage sum (CHF 20’000) and multiplied by the burnt material (400 kg) per fire incident. The resulting value of 8 kt is used for the year 1990. Additional statistical data published annually by the fire insurance association is available for the years 1996–2018. They are used to calculate the AD on an annual basis starting from 1996. Between 1990 and 1996 the AD were interpolated linearly.

b) Fire damage motor vehicles

Since a methodological change for the NIR 2017 activity data are estimated yearly based on vehicle numbers published annually by the Swiss Federal Statistical Office SFSO (EMIS 2020/6Ad Brand- und Feuerschäden Motorfahrzeuge).

Based on data from a Swiss insurance company with 25% market share in 2002, the number of reported cases of fire damage to vehicles was extrapolated to the total vehicle number in Switzerland. This results in one fire case per 790 vehicles for the year 2002. It is assumed that this ratio remains constant during the reporting period. By applying this ratio to the actual vehicle number published annually by the SFSO, the total number of vehicles with fire damages in Switzerland can be calculated for each year.

During a car fire incident, a car burns down only partially. It is assumed that approx. 100 kg of material burns down during a car fire. With these assumptions, the total number of material burnt can be calculated from the total number of car fire incidents in Switzerland.

Table 8-4 Activity data of burnt goods (documented in EMIS 2020/6Ad).

6A	Unit	1990	1995	2000	2005
6Ad Fire damage estates	kt	8.0	7.3	7.3	7.6
6Ad Fire damage motor vehicles	kt	0.48	0.52	0.58	0.64

6A	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
6Ad Fire damage estates	kt	7.0	6.8	7.4	7.8	8.0	6.3	6.8	6.6	6.9	7.4
6Ad Fire damage motor vehicles	kt	0.67	0.68	0.69	0.71	0.72	0.73	0.75	0.76	0.77	0.77

8.2.3 Uncertainties and time series consistency

Uncertainties of CO_2, CH_4 and N_2O emissions are estimated to be high (according to Table 1-10).

Consistency: Time series for 6Ad Fire damages are all considered consistent.

8.2.4 Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.2.3.

8.2.5 Category-specific recalculations

No category-specific recalculations were performed for the latest submission.

8.2.6 Category-specific planned improvements

No category-specific improvements are planned.

9 Indirect CO_2 and N_2O emissions

Responsibilities for chapter Indirect CO_2 and N_2O emissions	
Method updates	Adrian Schilt (FOEN)
Authors & sector experts	Sabine Schenker (FOEN), Adrian Schilt (FOEN)
EMIS database operation	Anouk-Aimée Bass (FOEN)
Annual updates (NIR text, tables, figures)	Felix Weber (INFRAS), Dominik Eggli (Meteotest)
Quality control (annual updates)	Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Rainer Kegel (FOEN), Adrian Schilt (FOEN)

9.1 Overview

In this chapter, indirect CO_2 emissions that result from the atmospheric oxidation of NMVOC and CO as well as indirect N_2O emissions that are induced by the deposition of NO_x and NH_3 are documented. While indirect CO_2 emissions reported in this chapter are accounted for in the national total, indirect N_2O emissions are not.

Indirect emissions of CO_2 and N_2O are shown in CRF Table6, together with the emissions of the precursor gases CH_4, CO, NMVOC, NO_x and NH_3. While all emissions of precursor gases are shown in both CRF Table6 and in the respective sectors, the indirect emissions of CO_2 and N_2O shown in CRF Table6 only represent emissions not already included in direct emissions in other sectors (in order to avoid double counting). Further, in the case of indirect CO_2 emissions, only carbon of fossil origin is considered. Accordingly, while e.g. NMVOC and CO of biogenic origin are shown as precursor gases in CRF Table6, they are not included for the calculation of indirect CO_2 emissions. Consequently, the implied emission factors may vary from sector to sector and also from year to year. Indirect CO_2 emissions resulting from the atmospheric oxidation of CH_4 are generally not considered.

Chapter 9.2 explains in detail the methodological issues to derive indirect CO_2 and N_2O emissions based on the emissions of the precursor gases NMVOC and CO, as well as NO_x and NH_3 from the different sectors. As an overview, the resulting indirect CO_2 emissions are shown in Table 9-1, as well as in Figure 9-1 and Figure 9-2. The resulting indirect N_2O emissions are shown in Table 9-2, as well as in Figure 9-3 and Figure 9-4.

Indirect CO_2 emissions are considered for both the uncertainty analysis (see chp. 1.6) and the key category analysis (see chp. 1.5).

Indirect N_2O emissions are neither considered for the uncertainty analysis (see chp. 1.6), nor for the key category analysis (see chp. 1.5).

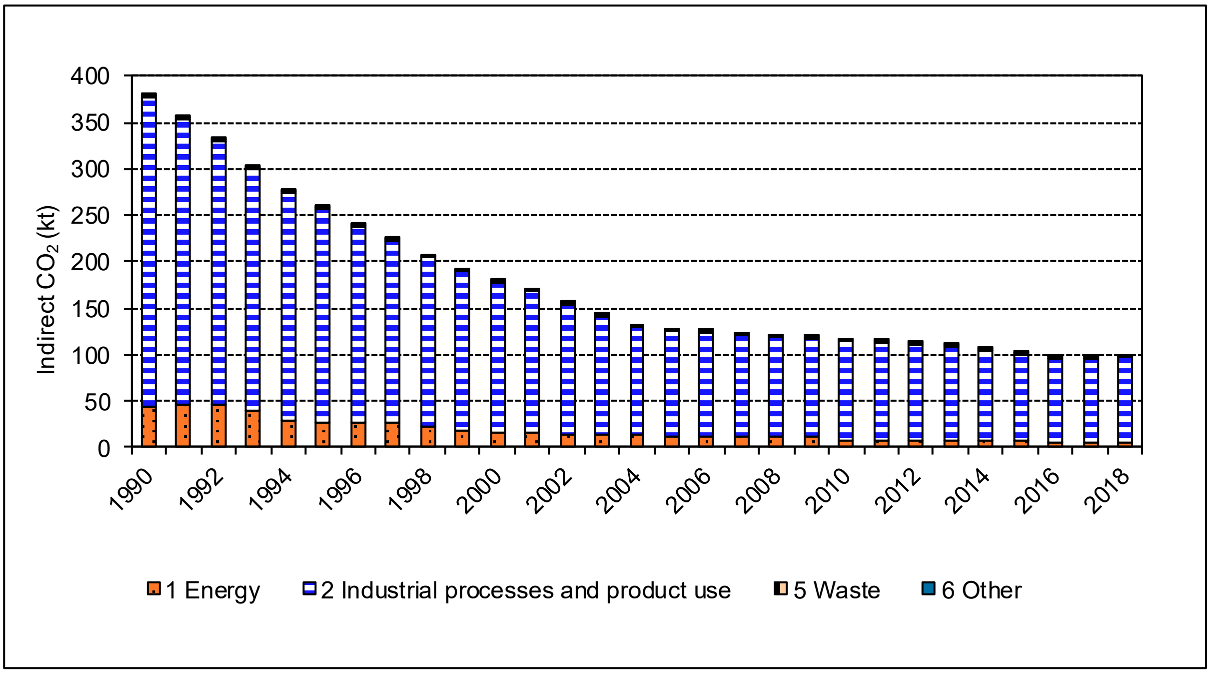


Figure 9-1 Switzerland's indirect fossil CO_2 emissions.

Table 9-1 Indirect fossil CO_2 emissions.

Indirect fossil CO_2 emissions by source category	1990	1995	2000	2005
	kt CO_2			
1 Energy	**44**	**28**	**17**	**13**
1B Fugitive emissions from fuels	44	28	17	13
2 Industrial processes and product use	**333**	**229**	**161**	**112**
2A Mineral industry	0.15	0.12	0.11	0.11
2B Chemical industry	1.7	0.80	0.56	0.58
2C Metal industry	3.4	2.4	2.2	1.3
2D Non-energy products from fuels and solvent use	201	125	87	48
2G Other product manufacture and use	124	98	70	61
2H Other	2.8	2.0	1.9	1.3
5 Waste	**2.0**	**1.6**	**1.6**	**1.4**
5C Waste incineration and open burning of waste	1.9	1.5	1.5	1.2
5E Other	0.064	0.10	0.13	0.13
6 Other	**1.0**	**1.0**	**1.1**	**1.2**
6Ad Fire damages	1.0	1.0	1.1	1.2
Total	**380**	**259**	**181**	**128**

Indirect fossil CO_2 emissions by source category	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt CO_2									
1 Energy	**11**	**8.2**	**8.1**	**8.2**	**8.3**	**8.1**	**6.9**	**6.1**	**5.8**	**5.7**
1B Fugitive emissions from fuels	11	8.2	8.1	8.2	8.3	8.1	6.9	6.1	5.8	5.7
2 Industrial processes and product use	**106**	**106**	**105**	**103**	**100**	**96**	**93**	**90**	**90**	**91**
2A Mineral industry	0.11	0.12	0.12	0.11	0.10	0.10	0.092	0.095	0.094	0.094
2B Chemical industry	0.41	0.51	0.47	0.45	0.47	0.42	0.48	0.44	0.58	1.06
2C Metal industry	0.85	0.93	1.05	0.81	0.80	0.77	0.67	0.63	0.65	0.64
2D Non-energy products from fuels and solvent use	46	46	44	43	42	38	36	34	35	34
2G Other product manufacture and use	57	57	56	57	55	55	54	53	54	54
2H Other	2.0	2.3	2.5	2.1	2.0	2.0	1.9	1.0	1.0	1.1
5 Waste	**1.29**	**1.3**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**	**1.1**
5C Waste incineration and open burning of waste	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.97
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
6 Other	**1.1**	**1.0**	**1.1**	**1.2**	**1.2**	**1.0**	**1.0**	**1.0**	**1.1**	**1.1**
6Ad Fire damages	1.1	1.0	1.1	1.2	1.2	1.0	1.0	1.0	1.1	1.1
Total	**120**	**117**	**115**	**114**	**111**	**106**	**102**	**98**	**98**	**99**

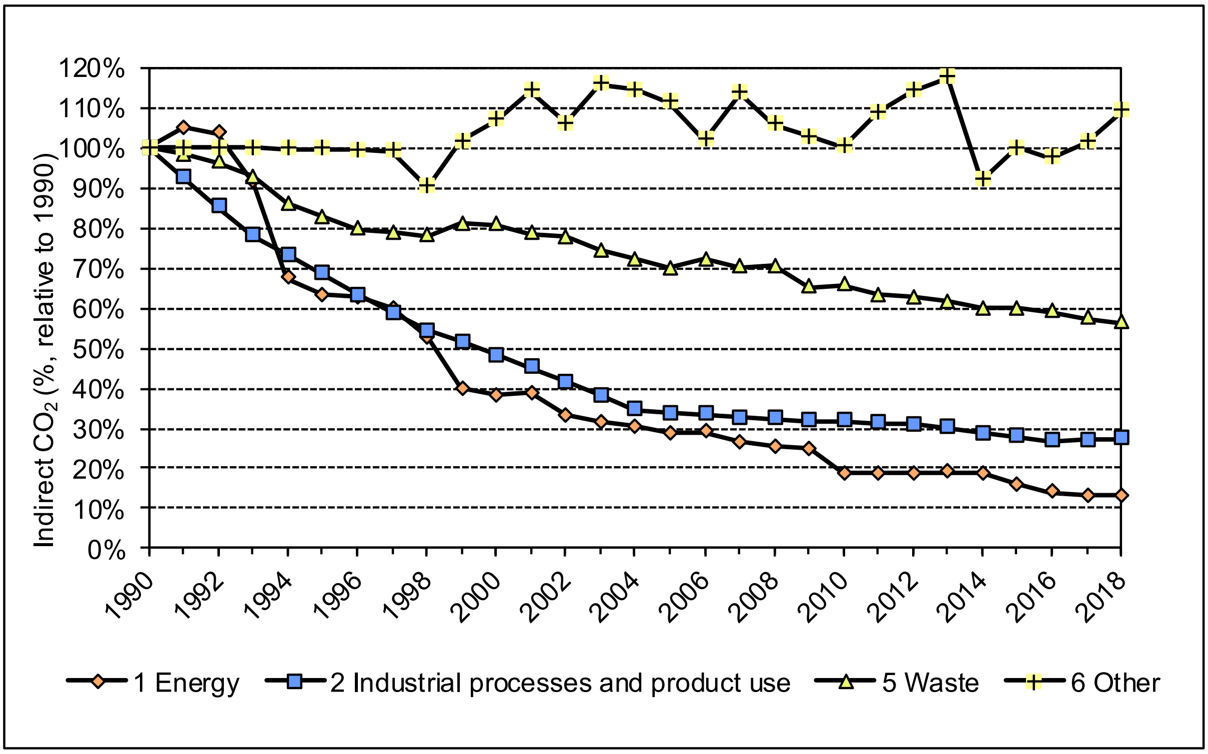


Figure 9-2 Relative trends of the indirect fossil CO_2 emissions by sector. The base year 1990 represents 100%.

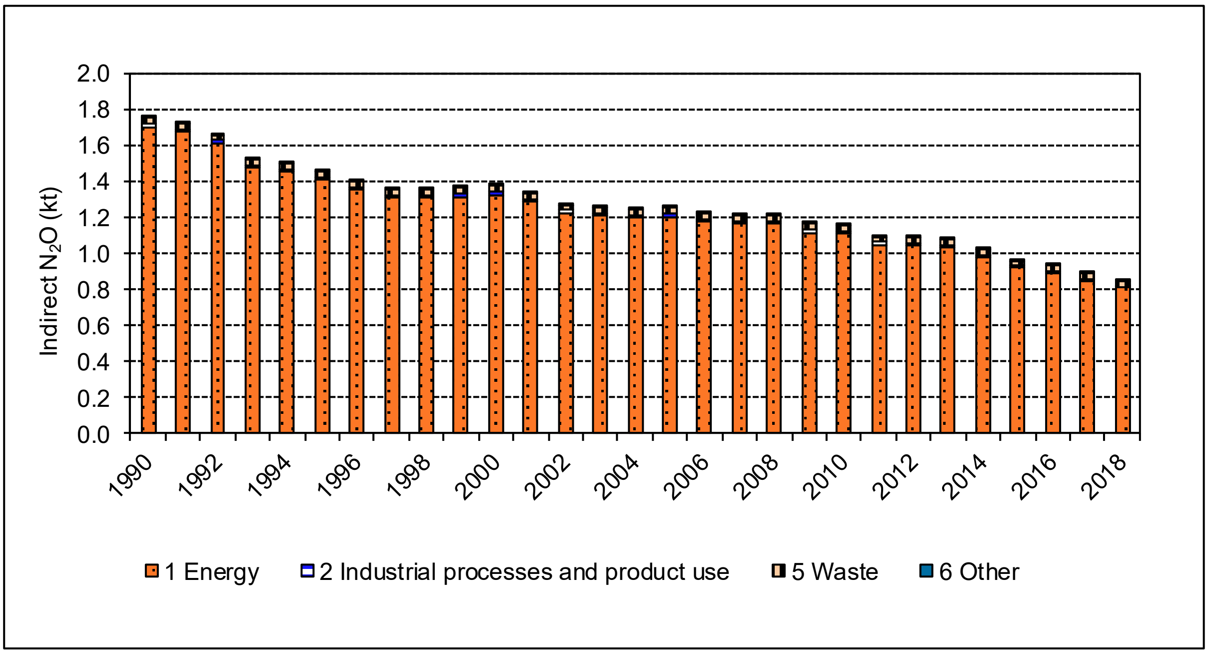


Figure 9-3 Switzerland's indirect N_2O emissions.

Table 9-2 Indirect N_2O emissions.

Indirect N_2O emissions by source category	1990	1995	2000	2005
	kt N_2O			
1 Energy	**1.7**	**1.4**	**1.3**	**1.2**
1A Fuel combustion activities	1.7	1.4	1.3	1.2
1B Fugitive emissions from fuels	0.0025	0.0038	0.0038	0.0035
2 Industrial processes and product use	**0.018**	**0.014**	**0.017**	**0.015**
2A Mineral industry	0.00021	0.00017	0.00015	0.00016
2B Chemical industry	0.0014	0.0012	0.0012	0.0011
2C Metal industry	0.0038	0.0023	0.0024	0.0025
2G Other product manufacture and use	0.0069	0.0068	0.0080	0.0081
2H Other	0.0054	0.0037	0.0051	0.0034
5 Waste	**0.033**	**0.030**	**0.031**	**0.032**
5A Solid waste disposal	0.020	0.015	0.014	0.014
5B Biological treatement of solid waste	0.0059	0.0086	0.012	0.012
5C Waste incineration and open burning of waste	0.0040	0.0030	0.0026	0.0026
5D Wastewater handling and discharge	0.0033	0.0034	0.0035	0.0036
6 Other	**0.00020**	**0.00018**	**0.00018**	**0.00019**
6Ad Fire damages	0.00020	0.00018	0.00018	0.00019
Total	**1.7**	**1.5**	**1.4**	**1.3**

Indirect N_2O emissions by source category	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt N_2O									
1 Energy	**1.1**	**1.1**	**1.0**	**1.0**	**1.0**	**0.98**	**0.92**	**0.89**	**0.84**	**0.81**
1A Fuel combustion activities	1.1	1.1	1.0	1.0	1.0	0.98	0.92	0.89	0.84	0.81
1B Fugitive emissions from fuels	0.0014	0.0014	0.0012	0.0010	0.0009	0.0011	0.00065	0.00004	0.00003	0.00003
2 Industrial processes and product use	**0.013**	**0.012**	**0.013**	**0.012**	**0.010**	**0.011**	**0.010**	**0.009**	**0.010**	**0.009**
2A Mineral industry	0.00017	0.00018	0.00017	0.00016	0.00016	0.00016	0.00015	0.00015	0.00015	0.00015
2B Chemical industry	0.0012	0.0012	0.0011	0.0011	0.0008	0.0009	0.0007	0.0009	0.0010	0.0004
2C Metal industry	0.0020	0.0026	0.0028	0.0026	0.0026	0.0027	0.0027	0.0026	0.0026	0.0027
2G Other product manufacture and use	0.0047	0.0035	0.0031	0.0033	0.0027	0.0025	0.0023	0.0024	0.0026	0.0029
2H Other	0.0052	0.0043	0.0056	0.0047	0.0040	0.0051	0.0040	0.0030	0.0035	0.0029
5 Waste	**0.032**	**0.032**	**0.032**	**0.032**	**0.032**	**0.032**	**0.031**	**0.033**	**0.032**	**0.032**
5A Solid waste disposal	0.012	0.012	0.011	0.011	0.011	0.010	0.0096	0.0092	0.0088	0.0083
5B Biological treatement of solid waste	0.013	0.014	0.014	0.014	0.015	0.015	0.014	0.016	0.016	0.016
5C Waste incineration and open burning of waste	0.0025	0.0026	0.0025	0.0025	0.0028	0.0028	0.0029	0.0030	0.0030	0.0028
5D Wastewater handling and discharge	0.0039	0.0040	0.0040	0.0041	0.0041	0.0042	0.0042	0.0043	0.0043	0.0043
6 Other	**0.00019**	**0.00018**	**0.00020**	**0.00021**	**0.00021**	**0.00017**	**0.00018**	**0.00018**	**0.00019**	**0.00020**
6Ad Fire damages	0.00019	0.00018	0.00020	0.00021	0.00021	0.00017	0.00018	0.00018	0.00019	0.00020
Total	**1.2**	**1.2**	**1.1**	**1.1**	**1.1**	**1.0**	**0.96**	**0.94**	**0.89**	**0.85**

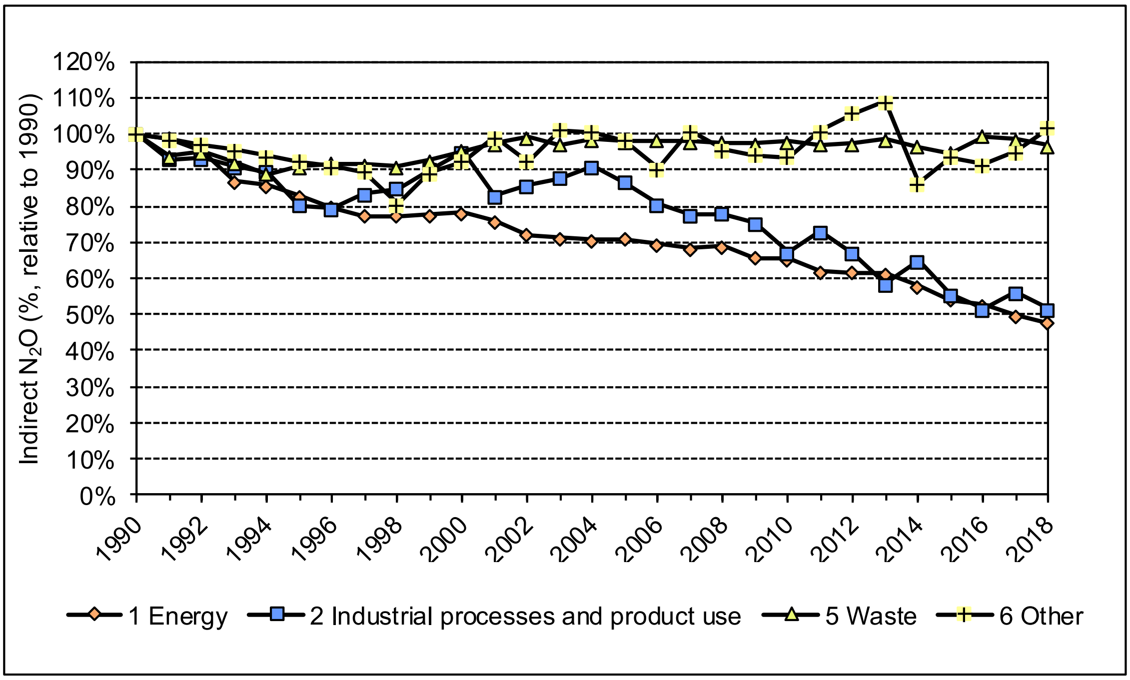


Figure 9-4 Relative trends of the indirect N_2O emissions by sector. The base year 1990 represents 100%.

9.2 Methodological issues

9.2.1 Methodological issues to derive indirect CO_2 emissions

Table 9-3 Key categories of indirect CO_2 emissions. Combined KCA results, level for 2018 and trend for 1990–2018, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC Category	GHG	Identification Criteria
2	Indirect CO2 emissions	CO2	L2, T1, T2

Indirect CO_2 emissions from the atmospheric oxidation of NMVOC are calculated based on the stoichiometric conversion (carbon content fraction multiplied by the molecular weight of carbon dioxide divided by the molecular weight of carbon). Thereby, a constant carbon content of NMVOC of 60% is assumed, based on the 2006 IPCC Guidelines (IPCC 2006). Indirect CO_2 emissions from the atmospheric oxidation of CO are also calculated based on the stoichiometric conversion (molecular weight of carbon dioxide divided by the molecular weight of carbon monoxide). Thus, indirect CO_2 emissions (Em) result from the following equations:

$$Em_{CO2,\ indirect\ from\ NMVOC} = Em_{NMVOC,\ fossil} * 0.6 * 44/12$$

$$Em_{CO2,\ indirect\ from\ CO} = Em_{CO,\ fossil} * 44/28$$

Activity data for the calculation of indirect CO_2 emissions

Activity data to calculate indirect CO_2 emissions consists of NMVOC and CO emissions as reported in each individual sector and source category, carefully excluding NMVOC and CO emissions of biogenic origin and emissions already included as direct (CO_2) emissions (e.g. when using an oxidation factor of 100%). For the different sectors and source categories, the situation is as follows:

1A Energy: Since according to the 2006 IPCC Guidelines (IPCC 2006) emission factors in source category 1A Energy are based on the assumption of complete oxidation (100%), CO_2 resulting from the atmospheric oxidation of CO and NMVOC emitted from this source category is already accounted for in the corresponding emission factors for direct CO_2 emissions. The respective emissions are thus implicitly reported as direct CO_2 emissions in 1A and no indirect CO_2 emissions from 1A Energy are reported (see chp. 3.2.4.4.1).

1B Fugitive emissions from fuels: CO_2 resulting from the atmospheric oxidation of NMVOC and CO emitted from source category 1B is reported as indirect CO_2 emissions unless it is already accounted for implicitly as direct CO_2 emissions in 1B (chp. 3.3). For 1B, Table 9-4 illustrates in which processes CO and NMVOC emissions occur, and whether the related CO_2 emissions are reported as indirect CO_2 emissions or implicitly as direct CO_2 emissions. In summary, all CO_2 resulting from the atmospheric oxidation of CO emitted from 1B is implicitly included in 1B as direct CO_2 and is therefore not reported as indirect CO_2.

CO_2 resulting from the atmospheric oxidation of NMVOC emitted from 1B is reported as indirect CO_2, except for CO_2 from source category 1B2c, where an oxidation factor of 100% is applied to calculate direct CO_2 emissions.

Table 9-4 Sources of indirect CO_2 emissions from source category 1B Fugitive emissions from fuels. Only relevant source categories are shown.

Source categories: Fugitive emissions		CO	NMVOC
Oil (1B2a)	Transport (1B2aiii)	NO	CO_2 resulting from NMVOC reported as indirect CO_2
	Refining/storage (1B2aiv)		
	Distribution of oil products (1B2av)		
Natural gas (1B2b)	Production (1B2bii)	NO	CO_2 resulting from NMVOC reported as indirect CO_2
	Transmission and storage (1B2biv)		
	Distribution (1B2bv)		
	Other leakage (1B2bvi)		
Venting and flaring (1B2c)	Flaring Oil (1B2ci)	CO_2 resulting from CO included in direct CO_2 emissions (CO_2 EF assumes 100% oxidation)	CO_2 resulting from NMVOC included in direct CO_2 emissions (CO_2 EF assumes 100% oxidation)
	H_2 Production refinery (1B2ci)	NO	NO
	Flaring from gas production (1B2cii)		CO_2 resulting from NMVOC included in direct CO_2 emissions (CO_2 EF assumes 100% oxidation)

2 Industrial processes and product use: Except for NMVOC emissions from the cracker reported in source category 2B8b Ethylene, CO and NMVOC emissions from 2C1 Secondary steel production, electric arc furnaces and CO emissions from anodes in source category 2C3 Primary aluminium production, none of the CO_2 emissions resulting from the atmospheric oxidation of NMVOC and CO emitted from sector 2 are already considered under the direct CO_2 emissions of this sector. The CO_2 emissions from the cracker reported in source category 2B8b Ethylene are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, these NMVOC emissions are not accounted for as indirect CO_2 emissions from sector 2 IPPU. The CO_2 emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of both CO and NMVOC are not accounted for as indirect CO_2 emissions. For CO emissions from 2C3 Primary aluminium production full oxidation of the anodes is assumed and these emissions are therefore not included in the indirect emissions (see chp. 4.4.2.2). On the other hand the NMVOC emissions from 2C3 Primary aluminium production originate solely from the production of the electrodes at the plants. Therefore, they have to be considered for the calculation of indirect CO_2 emissions.

In addition, before indirect CO_2 emissions are calculated, biogenic NMVOC and CO need to be subtracted from the total NMVOC and CO emissions from sector 2. Biogenic NMVOC and CO emissions occur in the source categories 2H2 Food and beverages industry and 2G4 Other (tobacco consumption only), see chp 4.2.

In source categories 2D3a and 2G4 direct CO_2 emissions from post-combustion of NMVOC as well as indirect CO_2 emissions from oxidation of NMVOC in the atmosphere occur. The CO_2 emissions from the NMVOC that are destroyed in post-combustion facilities are reported in the respective source categories 2D3a and 2G4. These NMVOC are not part of the reported NMVOC emissions of source categories 2D3a and 2G4 which are used to calculate indirect CO_2 emissions.

3 Agriculture and 4 LULUCF: NMVOC and CO emissions from the sectors 3 Agriculture and 4 LULUCF are of biogenic origin. Accordingly, no indirect CO_2 emissions are reported for these sectors.

5 Waste: NMVOC and CO emissions from sector 5 Waste contain fossil and biogenic shares. Only CO_2 resulting from the atmospheric oxidation of fossil NMVOC and CO is reported as indirect CO_2. Emissions of fossil NMVOC and CO stem from the following processes:

- Landfills with open burning: Partly fossil, 0 since 1990.
- Illegal waste incineration: Partly fossil, fossil share is assumed to be the same as for waste incinerated in MWIP, see chp. 7.4 Incineration and open burning of waste (5C1).
- Insulation material from cables: See chp. 7.4 Incineration and open burning of waste (5C1), 0 since 1995.
- Hospital waste incineration: See chp. 7.4 Incineration and open burning of waste (5C1), 0 since 2002.
- Shredding: See chp. 7.6 Other.

6 Other: NMVOC and CO emissions from sector 6 Other contain fossil and biogenic shares. Only CO_2 resulting from the atmospheric oxidation of fossil NMVOC and CO is reported as indirect CO_2. Emissions of fossil NMVOC and CO stem from the following processes:

- Fire damage estate: The share of fossil CO and NMVOC emission is assumed to be equal to the share of fossil CO_2 emissions, which is 80% since the year 2000, see chp. 8.2 (6Ad).
- Fire damage motor vehicles: The share of fossil CO and NMVOC emission is assumed to be 100%, see chp. 8.2 (6Ad).

9.2.2 Methodological issues to derive indirect N_2O emissions

Indirect N_2O emissions are estimated using a country-specific method according to a study of indirect N_2O emissions induced by nitrogen deposition in Switzerland (Bühlmann 2014, Bühlmann et al. 2015). In this study, ecosystem-specific emission factors for indirect N_2O resulting from nitrogen deposition were developed, based on a comprehensive literature survey. Thereby, the land cover types forests, grassland and wetlands were distinguished. In a next step, the ecosystem-specific emission factors were combined with a highly-resolved nitrogen deposition map of Switzerland as well with the geo-referenced dataset of the Swiss Land Use Statistics (allowing for the localisation and estimation of spatial extent of the different ecosystems). This resulted in detailed and spatially resolved indirect N_2O emissions for Switzerland. To facilitate a simple application in the greenhouse gas inventory, the resulting total emissions were used to come up with a total emission factor expressed as indirect N_2O-N per N-deposition (deposited in form of NO_x or NH_3, see also chp. 5.3.2.4). The resulting total emission factor is in the order of 2.5% and slightly varies with time as the shares of the different ecosystems are not constant over time. Based on this country-specific emission factor, higher indirect N_2O emissions result compared to the emissions that would result by applying the 2006 IPCC Guidelines (IPCC 2006, see also Bühlmann et al. 2015).

To calculate indirect N_2O emissions induced by the deposition of NO_x and NH_3 according to Bühlmann (2014) and Bühlmann et al. (2015), total N-deposition is needed. It is derived from NO_x (which is always reported in NO_2 equivalents) and NH_3 emissions using the stoichiometric conversion according to the following equation:

$$\text{Mass-N} = \text{Mass-NO}_{2,eq} * 14/46 + \text{Mass-NH}_3 * 14/17$$

Activity data for the calculation of indirect N_2O emissions

The activity data to calculate indirect N_2O emissions from a specific sector corresponds to the NO_x and NH_3 emissions reported in the respective source categories. However, the following exceptions need to be considered:

- Indirect N_2O emissions from sector 3 Agriculture are reported in the respective sector together with direct N_2O emissions (chp. 5.3.2.5.4 Volatilisation of NH_3 and NO_x from manure management systems, chp. 5.5.2.3 Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (3Db1) and chp. 5.5.2.4 Indirect N_2O emissions from leaching and run-off from managed soils (3Db2)).
- For sector 6, the only indirect N_2O emissions to be considered are those resulting from NO_x emissions in source category 6Ad Fire damages. All other indirect N_2O emissions are included in sector 3 Agriculture together with direct N_2O emissions.

9.2.3 Uncertainties and time series consistency

Indirect CO_2 emissions are included in the uncertainty analysis, but indirect N_2O emissions are not included.

Uncertainties of indirect CO_2 emissions are based on respective uncertainties of NMVOC and CO emissions. Uncertainties of NMVOC emissions are estimated based on AD and EF uncertainties as documented in Switzerland's Informative Inventory Report 2020 (FOEN 2020b). The estimated uncertainties distinguish between fossil and biogenic shares. Uncertainties of CO emissions are estimated based on AD uncertainties documented in Switzerland's Informative Inventory Report 2020 (FOEN 2020b) and EF uncertainties are based on expert judgements and uncertainties provided by the EMEP/EEA Guidebook.

Combined uncertainties of indirect CO_2 emissions amount to 17% for indirect CO_2 emissions from sector 1 Energy, 114% for indirect CO_2 emissions from sector 2 IPPU, 47% for indirect CO_2 emissions from sector 5 Waste and 76% for indirect CO_2 emissions from sector 6 Other.

Consistency: Time series for indirect CO_2 and N_2O emissions are all considered consistent.

9.2.4 Category-specific QA/QC and verification

The same QA/QC and verification procedures are conducted as for NMVOC, CO, NO_x and NH_3 related source categories in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.

9.2.5 Category-specific recalculations

- See NMVOC related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.
- See CO related recalculations reported in chp. 4 Industrial processes and product use, 7 Waste and 8 Other.
- See NO_x and NH_3 related recalculations reported in chp. 3 Energy, 4 Industrial processes and product use, 7 Waste and 8 Other.

9.2.6 Category-specific planned improvements

No category-specific improvements are planned.

10 Recalculations and improvements

Responsibilities for chapter Recalculations and improvements	
Overall responsibility	Regine Röthlisberger (FOEN)
Authors & annual updates (NIR text, tables, figures)	Regine Röthlisberger (FOEN), Andreas Schellenberger (FOEN), Chloé Wüst (Agroscope), Daniel Bretscher (Agroscope), Nele Rogiers (FOEN), Michael Bock (FOEN)
EMIS database operation	Adrian Schilt (FOEN)
Quality control (annual updates)	Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), sector experts

10.1 Explanations and justifications for recalculations and responses to the review process

The implementation of recommendations and encouragements from the UNFCCC review process are listed in chp. 10.1.1. Additionally, major recalculations are presented in chp. 10.1.2. In the relevant sectoral chapters, also minor recalculations are listed and a brief explanation for each is provided. A list with all recalculations and specifics of the recalculations is compiled by the EMIS experts and available to the reviewers on demand (partly in German).

10.1.1 Recommendations and encouragements from ERT and their implementation

The report of the in-depth review of the inventory submission of April 2019 was available in its draft version (UNFCCC 2020). Therefore, only some of the drafted recommendations could be addressed and implemented in time for this submission. Table 10-1 shows those recommendations that were implemented in the latest submission.

Table 10-1 Implementation of recommendations from the in-depth review in 2019 (based on draft review report, UNFCCC 2020).

ID	classification	Assumed Recommendation from Draft ARR 2019	Answer including reference to chapter in NIR
General			
G.3	CPR	The ERT recommends that Switzerland correct the references regarding the values of the CPR and the assigned amount to document FCCC/IRR/2016/CHE.	In chp. 12.5, the reference has been changed accordingly to FCCC/IRR/2016/CHE, cited as UNFCCC 2017a.
Energy			
E.3	1.A.1.a Public electricity and heat production – other fuels – CH4 (E.3, 2017) (E.10, 2016) (E.10, 2015) Transparency	Addressing. The notation key has been changed to "NE" in CRF table 1.A(a)s1 and for category 1.A.1.a.iv (other fossil fuels). In addition, an explanation has been included in the 2019 NIR (section 3.2.5.2.1) specifying that these emissions are insignificant; however, in CRF table 9 (row 7), the Party still reports the emissions as "not occurring", instead of as "insignificant". During the review, the Party confirmed that the explanation provided in CRF table 9 will be updated accordingly in the next submission.	CRF table 9 has been changed accordingly.
E.8	1.A.3.b Road transportation – liquid and gaseous fuels – N2O (E.20, 2017) Accuracy	During the review, the Party further explained that in the 2019 submission, cold-start N2O emissions were estimated using a workaround with the COPERT values (NIR, p.160). However, the "Handbook of emission factors" has been further developed over the past few years, and the EFs for cold-start N2O emissions were included only in the HBEFA handbook in 2019. Therefore, Switzerland will recalculate cold-start	Cold start emissions are now estimated with the road transportation model and N2O emissions have been recalculated for the entire time series. The cold start emission factors have been estimated based on the emission factors provided by the EMEP Guidebook and implemented in the road transportation model (see NIR chp. 3.2.9.2.2, 3.2.9.5 and Annex 3.1.3).
IPPU			
I.3	2.C.1 Iron and steel production – CO2 (I.14, 2017) Comparability	However, emissions from limestone used in cupola furnaces are still included under category 2.A.4.d (other process uses of carbonates – other). During the review, the Party explained that it will reallocate the emissions from limestone use in cupola furnaces to category 2.C.1 (iron and steel production) in its next submission.	Emissions from limestone use in cupola furnaces of iron foundries are reported under 2C1, as recommended by the ERT (NIR chp. 4.4.2.1 and 4.4.5).
I.8	2.A.1 Cement production – CO2	The ERT recommends that Switzerland clarify in its NIR the assumptions on CaO and MgO contents of clinker used in the base EF which forms the basis for the country-specific EF.	The description in NIR chp. 4.2.2.1 has been adjusted in order to further clarify the country-specific EF.
I.11	2.D.3 Other (non-energy products from fuels and solvent use) – CO2	The ERT recommends that Switzerland improve the transparency of the reporting of CO2 emissions from post-combustion of NMVOC emissions by including sufficient information on the EFs and methodology used for the estimation.	The description in NIR chp. 4.5.2.2 has been adjusted in order to provide additional information regarding methodology and EF.
Agriculture			
A.9	3.C Rice cultivation – CH4	The ERT recommends that Switzerland correct the error in CRF table 3.C regarding the harvested area of upland rice.	The error in the CRF tables has been corrected.
A.10	3.G Liming – CO2	The ERT Recommends that Switzerland document in the NIR how expert judgement has been sourced to estimate AD on the use of limestone and dolomite	The description of the activity data for liming has been revised accordingly (NIR chp. 5.8.2.2)
A.11	3.G Liming – CO2	The ERT recommends that Switzerland provide a brief explanation in the documentation box in CRF table 3.G on why dolomite use in 1993 is reported as "NO".	A comment has been added to the documentation box.
LULUCF			
L.4	4.A Forest land – CO2 (L.9, 2017) Transparency	[…] The ERT noted that this explanation should be included in the NIR to enhance the explanation on how stumps after cutting are included in the dead organic matter pool.	The required information was provided in chp. 6.4.2.1 (section "Data available in the NFI"), chp. 6.4.2.6, and NIR Table 6-16, among others.
L.6	Land representation	The ERT recommends that Switzerland correct the reporting of other land and unmanaged land in the CRF table 4.1 to ensure consistency between the NIR and the CRF tables.	In Switzerland, all land is considered managed except for land-use category Other land. Based on footnote (3) to CRF table 4.1, Parties may report unmanaged land under the individual unmanaged land use categories (Forest land, Grassland, Wetlands) or as total area of unmanaged land area. As no unmanaged land is occurring apart from Other land, the notation key NO is used for unmanaged Forest Land, unmanaged Grassland, and unmanaged Wetlands. The category Total unmanaged land (the sum of unmanaged Forest land, unmanaged Grassland and unmanaged Wetlands) is not applicable and the notation key NA is used in the corresponding row and column.
L.7	4.A Forest land – CO2	The ERT recommends that Switzerland correct the typographical errors in table 6-16.	The typographical errors in NIR Table 6-16 were corrected.
L.8	4.A Forest land – CO2	The ERT recommends that Switzerland either include trees with a diameter at breast height of <12 cm with branches, foliage and roots, and non-tree understory vegetation, including shrubs, ferns, grasses, sedges and herbs in the estimates of living biomass, deadwood, and litter, or provide justification as to why these small trees and non-tree vegetation are not included in the calculation of living biomass, deadwood and litter.	The description in chp. 6.4.2.1 was adjusted, providing additional information with regard to trees <12 cm diameter.
Waste			
W.6	5.C Incineration and open burning of waste – CH4 and N2O	The ERT recommends that the Party align the reporting on the sewage sludge between the agriculture and waste sectors. In particular, the ERT recommends that the Party explain the observed inconsistency, according to which the last year of sewage sludge application to agricultural soils was 2008, while the first year when all sewage sludge was incinerated was 2010.	Description in NIR chp. 7.1.2 has been adjusted in order to consistently report use of sewage sludge as fertilizer.

10.1.2 Major recalculations and improvements implemented in the latest submission

In this chapter, the most important recalculations are presented. The figures show the differences between emissions in submission 2019 (previous) and submission 2020 (latest). Explanations are provided for source categories that underwent recalculations larger than 2% of the corresponding source category emissions and resulted in absolute changes larger than 5 kt CO_2 eq (approx. 0.01% of the national total emissions) for the Energy, IPPU, Agriculture and Waste sector, and larger than approx. 100 kt CO_2 eq for the LULUCF and the KP-LULUCF sector. Additional recalculations and corrections of minor errors, which had a smaller impact than the above thresholds, are listed in the relevant sectoral chapters.

There was one recalculation in the IPPU sector which was larger than 0.5% of the national total emissions. A large chemical plant discovered a previously unnoticed source of N_2O emissions in its niacin production unit and reported the emissions to the FOEN. Plant-specific emission factors were determined based on exhaust measurements and emissions are estimated based on production data reaching back to 1990. These emissions are now reported under 2B10 Other chemical production and explain the substantial increase in N_2O emissions in the IPPU sector (Figure 10-4).

10.1.2.1 Energy

The total changes in emissions in the energy sector due to all recalculations are shown in Figure 10-1 for CO_2, Figure 10-2 for CH_4 and Figure 10-3 for N_2O. The largest recalculations in the energy sector resulted from the re-allocation of energy consumption between 1A2 and 1A4 and the implementation of the revisions to the road transportation model, which had an impact on CH_4 and N_2O emissions in 1A3b. All other recalculations had an impact that was smaller than 5 kt CO_2 eq (see Figure 10-1, Figure 10-2, Figure 10-3).

- 1A2gviii/1A4ai/1A4ci: In previous submissions, the fuel consumption for grass drying, which is reported in 1A4ci, was assumed to be part of the energy consumption of industry in the overall energy statistics. Based on recent inquiries with the SFOE, the energy consumption for grass drying is considered part of the energy consumption of commercial, agriculture and statistical difference. Therefore, the re-allocation of the energy consumption from industry to commercial, agriculture and statistical difference leads to an increase of energy consumption in 1A2gviii Other Boiler and Engines Industry and a corresponding decrease in 1A4ai Commercial/institutional as seen in Figure 10-1. In addition, the energy consumption of greenhouses, which was not estimated in previous submissions, is now allocated to 1A4ci Agriculture/forestry/ fishing instead of being lumped into 1A4ai Commercial/institutional. While this has no impact on energy consumption and emissions of 1A4 Other sectors, energy consumption and emissions increase in 1A4ci Agriculture/forestry/fishing and decrease by the same amount in 1A4ai Commercial/institutional. The re-allocation was made in order to better reflect the emissions in the agriculture sector. However, it has no impact on total energy consumption and emissions.
- 1A3b: The road transportation model was updated, including a new version of the emission factor database HBEFA 4.1 (see description in chp. 3.2.9.2.2), which had a marked impact on non-CO_2 emissions. The new version of the transport model has updated emission factors for CH_4 and N_2O based on a much larger data base that became available in recent years, and the road transportation model now also includes cold start N_2O emissions. The complete time series were recalculated and resulted mostly in increased CH_4 emissions of up to 12 kt CO_2 eq and increased N_2O emissions of up to 55 kt CO_2 eq (see 1A3 in Figure 10-2 and Figure 10-3 and chp. 3.2.9.5).

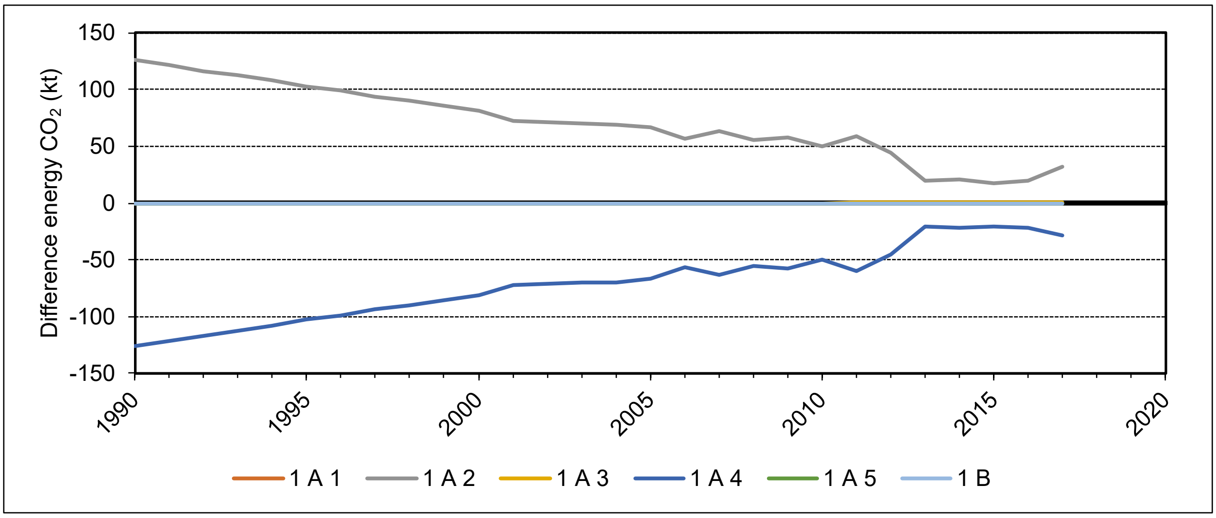


Figure 10-1 Differences in CO_2 emissions (in kt CO_2) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

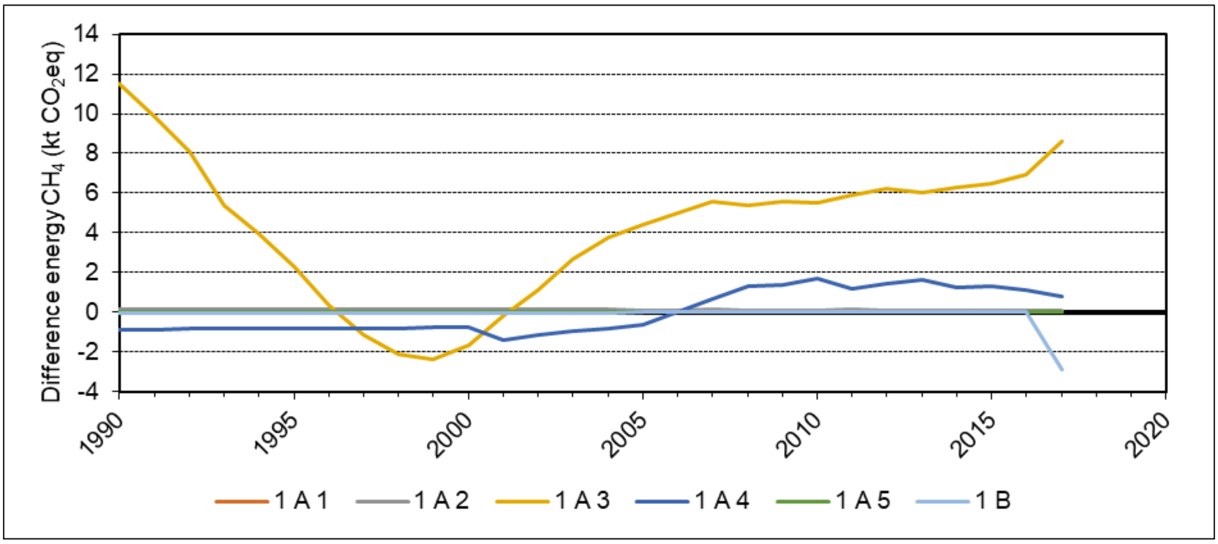


Figure 10-2 Differences in CH_4 emissions (in kt CO_2 eq) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

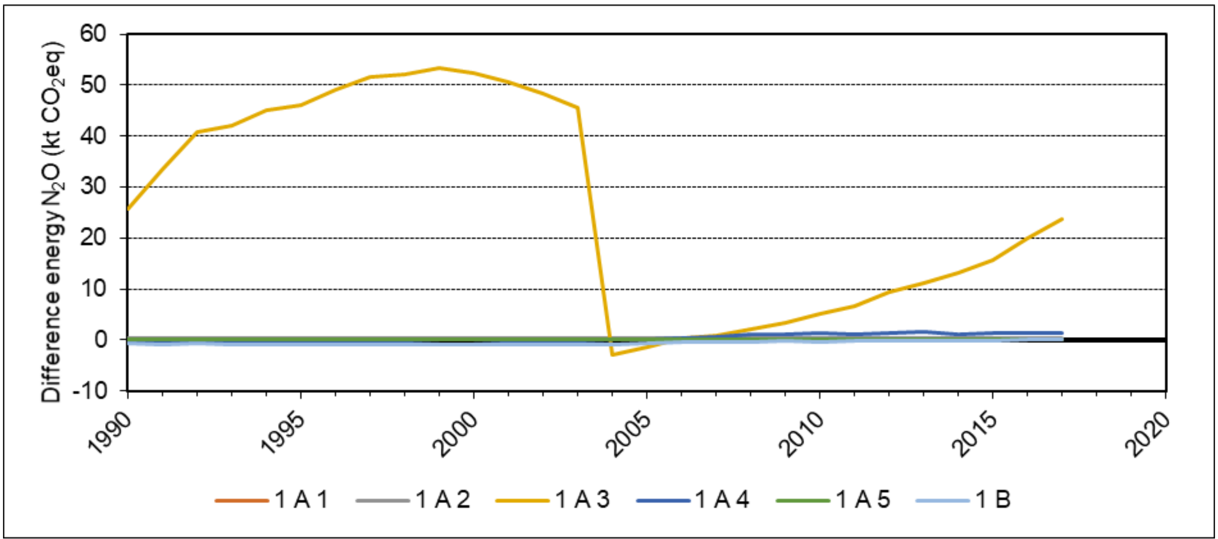


Figure 10-3 Differences in N_2O emissions (in kt CO_2 eq) between the latest and the previous submission for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.2 Industrial processes and other product use

The total changes in emissions in the IPPU sector due to all recalculations are shown in Figure 10-4 for CO_2, CH_4, and N_2O, and in Figure 10-5 for HFCs, PFCs, SF_6, and NF_3.

There is a huge increase of 400 to 700 kt CO_2 eq in N_2O emissions due to a newly discovered source of N_2O in 2B10 Other chemical – Niacin production (see chp. 4.3.2.5). In addition, there was also an update of the CO_2 EF for niacin production, resulting in an increase of CO_2 emissions in the range from 5 to 9 kt CO_2 eq.

Use of PFC and SF_6 in 2E Electronics industry has been modelled with revised emission factors from 2019 Refinement of 2006 IPCC Guidelines. This led to increases in PFC emissions of up to 10 kt CO_2 eq and increases in SF_6 emissions of up to 16 kt CO_2 eq (see chp. 4.6.2 and 4.6.5). Also, adjustments based on updated information regarding service activities and recycling of HFC-134a in mobile air-conditioning and the split of refrigerants between stationary air-conditioning and heat pumps led to revised estimates of HFC emissions in 2F Product uses as substitutes for ODS. Recalculated HFC emissions are up to 5 kt CO_2 eq higher in the time period from 1995 to 2005 and between 5 to 10 kt CO_2 eq lower in the time period 2015 to 2017 (see chp. 4.7.2.1 and 4.7.5).

All other recalculations had an impact that was smaller than 5 kt CO_2 eq (see Figure 10-4 and Figure 10-5).

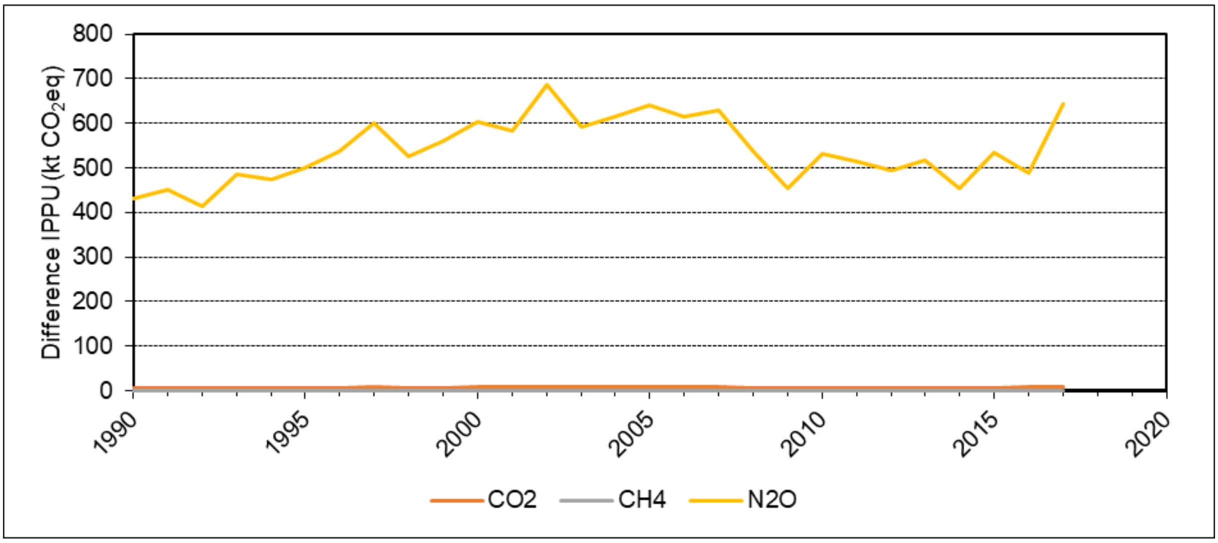


Figure 10-4 Differences in CO_2, CH_4, and N_2O emissions (in kt CO_2 eq) between the latest and the previous submission for sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

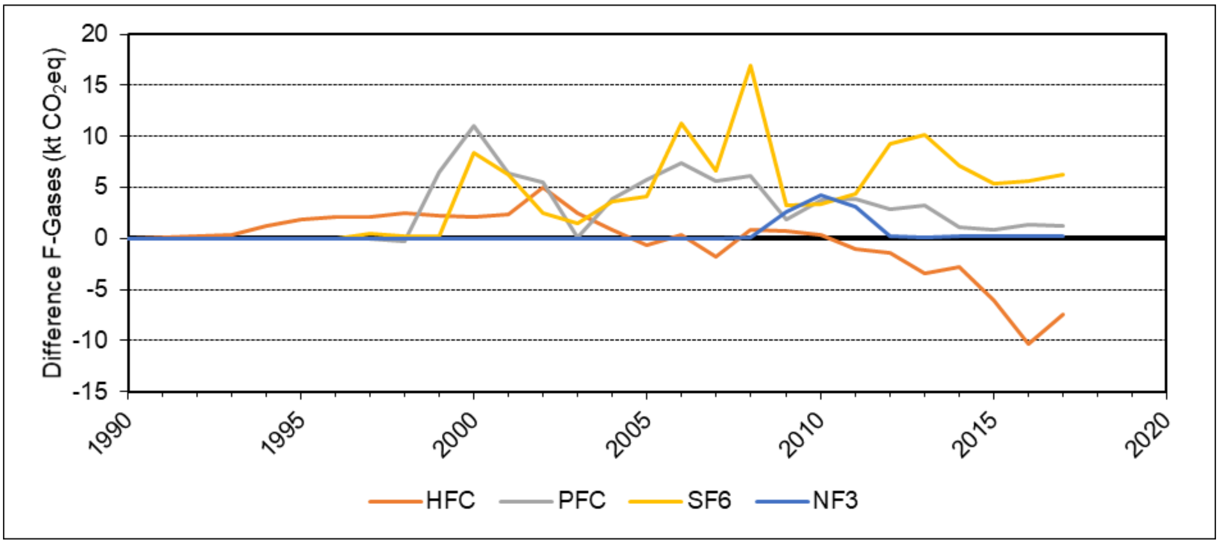


Figure 10-5 Differences in HFC, PFC, SF_6 and NF_3 emissions (in kt CO_2 eq) between the latest and the previous submission for the sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.3 Agriculture

The total changes in emissions in the Agriculture sector due to all recalculations are shown in Figure 10-6 for CO_2, CH_4, and N_2O, and for the most important recalculations aggregated for all greenhouse gases in Figure 10-7. The largest recalculations resulted from the revision of the animal turnover rates for fattening pigs and broilers (see chp. 5.2.5), and from adjustments in the amount of direct and indirect N_2O emissions from N mineralised in association with loss of soil carbon due to new data on N mineralisation in cropland and grassland (revision of the Tier 3 methodology in the LULUCF sector; see chp. 5.5.5).

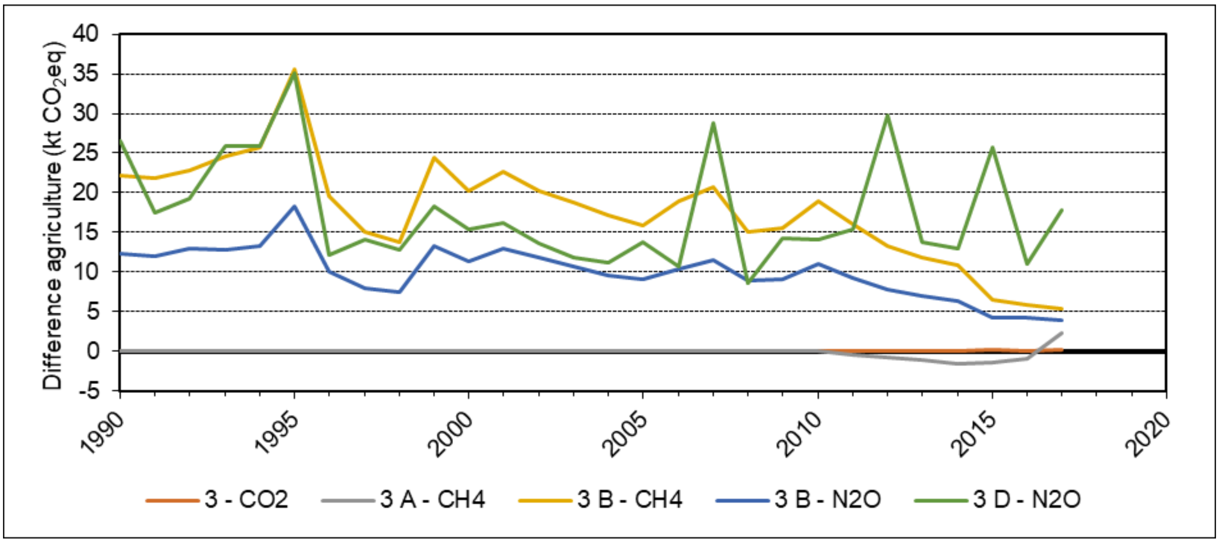


Figure 10-6 Differences in CO_2, CH_4, and N_2O emissions (in kt CO_2 eq) between the latest and the previous submission for sector Agriculture. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

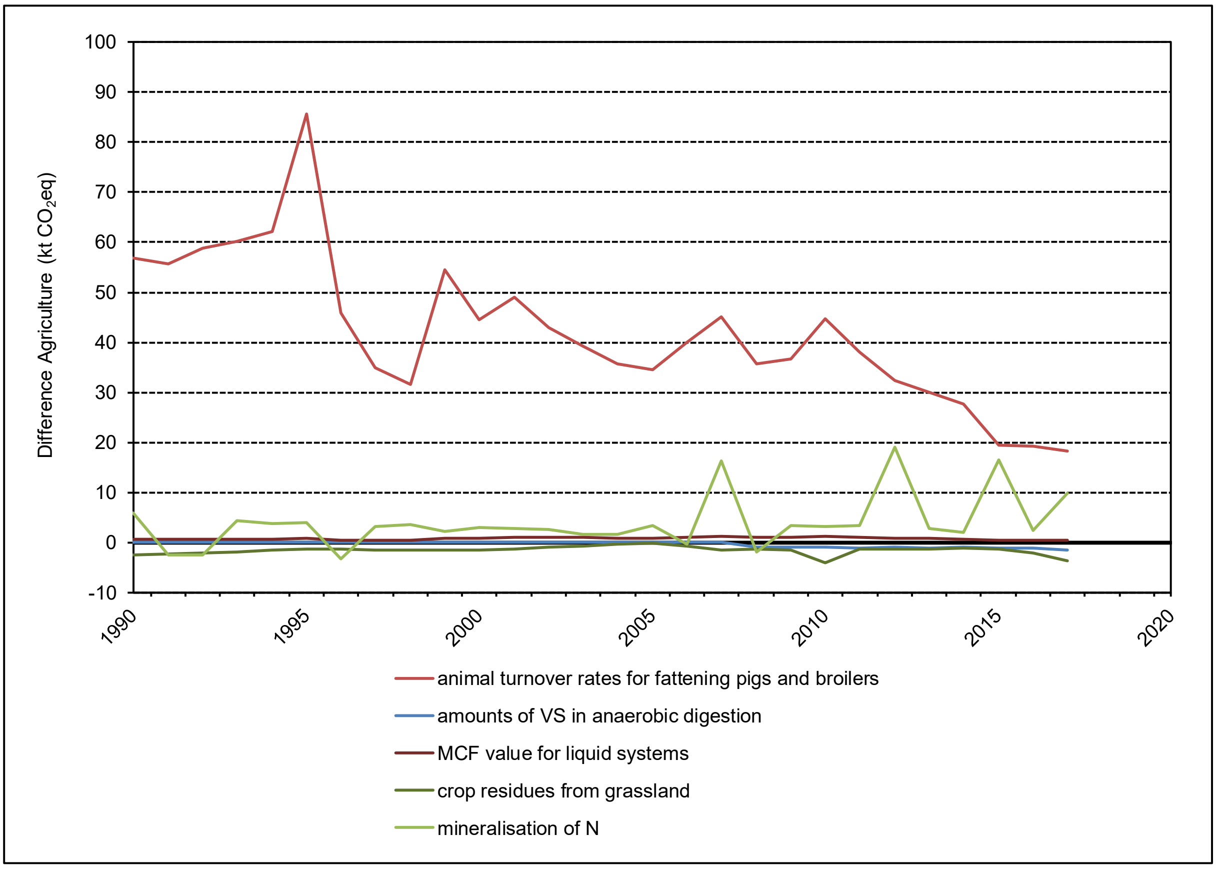


Figure 10-7 Differences in overall GHG emissions (in kt CO_2 eq) between the latest and the previous submission for sector Agriculture due to the most important recalculations. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission. Note that due to the successive implementation of the different recalculations the amounts are not always exact but must be understood as approximations.

- Emissions from "Fattening Pigs over 25 kg" and "Broilers" were revised for all years due to a new assessment of animal turnover rates in stables. The impact on overall emissions in kt CO_2 equivalents per year is approximately: 1990: +56.9; 2017: +18.2; mean 1990–2017: +42.1 (including emissions from 3A, 3B and 3D).
- Emissions of N_2O from 3Da5 “N in mineral soils that is mineralized/immobilized in association with loss of soil C“ were recalculated for the years 1990–2017 due to revised estimates of mineralised nitrogen (AD). The impact on overall emissions in kt CO_2 equivalents is approximately: 1990: +6.0; 2017: +9.8; mean 1990–2017: +3.9.

  All other recalculations had an impact that was smaller than 5 kt CO_2 eq (see Figure 10-6 and Figure 10-7 and the respective sub-chapters in chp. 5).

10.1.2.4 Land Use, Land-Use change and Forestry

Recalculations with an overall impact of approximately >|100| kt CO_2 eq are assessed quantitatively. The remaining recalculations are described qualitatively in the respective chp. 6.X.5.

Overall changes in emissions by sources and removals by sinks in the LULUCF sector due to all recalculations realised for the latest submission are shown in Figure 10-8. The overall pattern of the net emissions and removals remains unchanged (Figure 10-22). The seesaw pattern of the deviation of CO_2 eq net emissions and removals between the latest and the previous submission (range from 36.3 kt CO_2 eq in 2016 to 549.8 kt CO_2 eq in 1990) is controlled by major recalculations in subcategories 4A, 4B, 4C, and 4G (Figure 10-9).

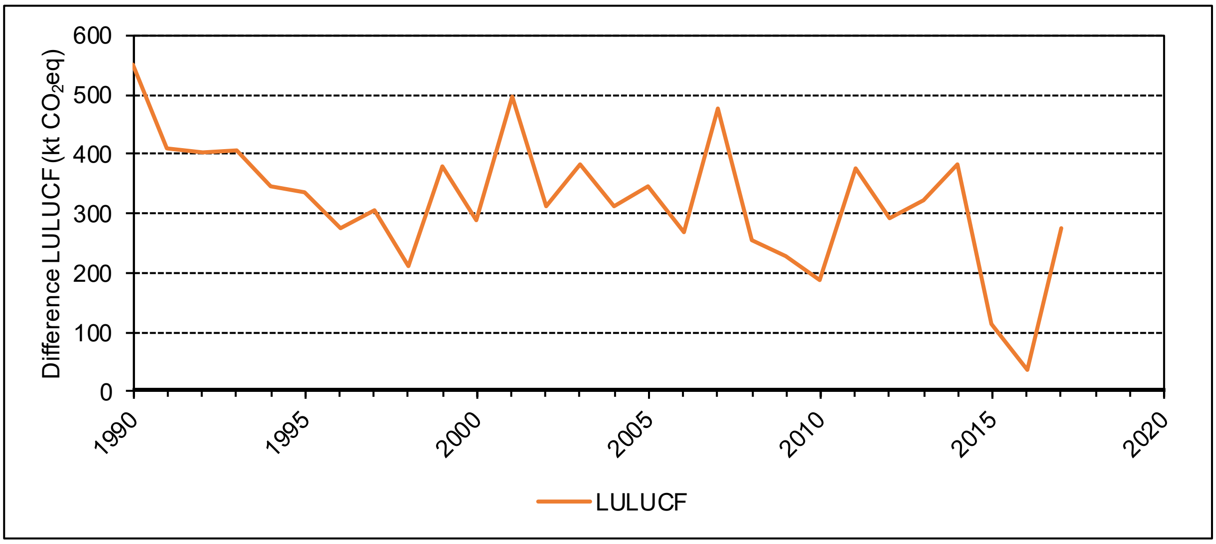


Figure 10-8 Differences in GHG emissions and removals (in kt CO_2 eq) between the latest and the previous submission for the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

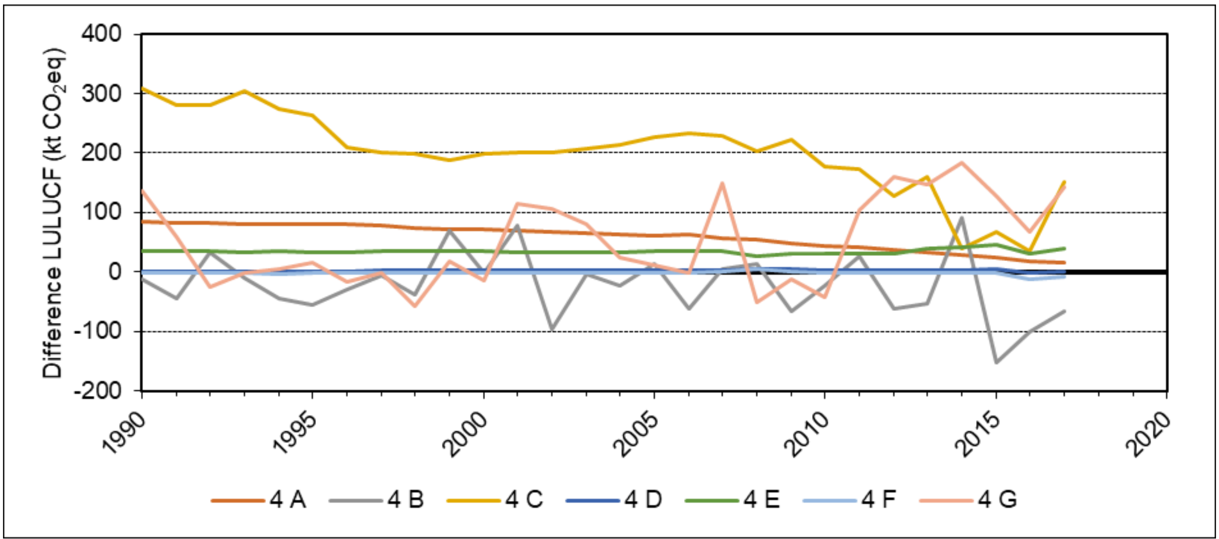


Figure 10-9 Differences in GHG net emissions and net removals (in kt CO_2 eq) between the latest and the previous submission for subcategories 4A-4G in the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

In category 4A Forest land the following recalculation was mainly responsible for the differences shown in Figure 10-9.

- 4A2: Litter carbon stocks for CC12 and CC13 were recalculated (see chp. 6.4.5): The recalculated litter carbon stocks are generally lower in elevations <600m and significantly higher in elevations >1200 m than those in the previous submission, leading to lower net removals in the litter pool of category 4A2 compared to the previous submission (Figure 10-10; difference almost steadily falling from 145.9 kt CO_2 eq in 1990 to 108.2 kt CO_2 eq in 2017).

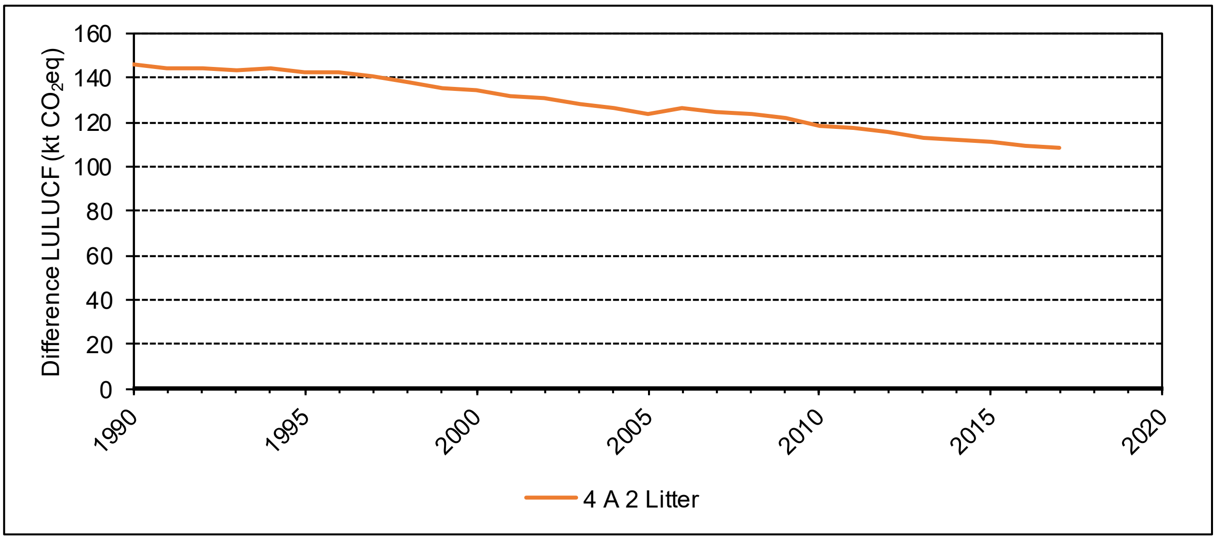


Figure 10-10 Differences in net removals (in kt CO_2 eq) between the latest and the previous submission for subcategory 4A2 Net carbon stock change in litter on Land converted to Forest Land (CO_2). Positive values refer to lower net removals in the latest submission compared to the previous submission.

In category 4B Cropland one major recalculation changed overall CO_2 eq net emissions and removals and enhanced the pronounced seesaw pattern of the deviation between the latest and the previous submission (Figure 10-9).

- 4B1: Carbon stocks and carbon stock changes in living biomass of Cropland were recalculated for the period 1990–2017 to include root biomass (see chp. 6.5.5). Additionally, net change of living biomass for the year 2017 was recalculated based on new available yield data (SBV 2019). The impact on net emissions and removals in kt CO_2 eq in category 4B1 is shown in Figure 10-11 separated for gains in living biomass and losses in living biomass. The combined deviation of CO_2 eq net emissions and removals between the latest and the previous submission ranges from -131.7 kt CO_2 eq in 2015 to 103.2 kt CO_2 eq in 2014 (mean -10 kt CO_2 eq).

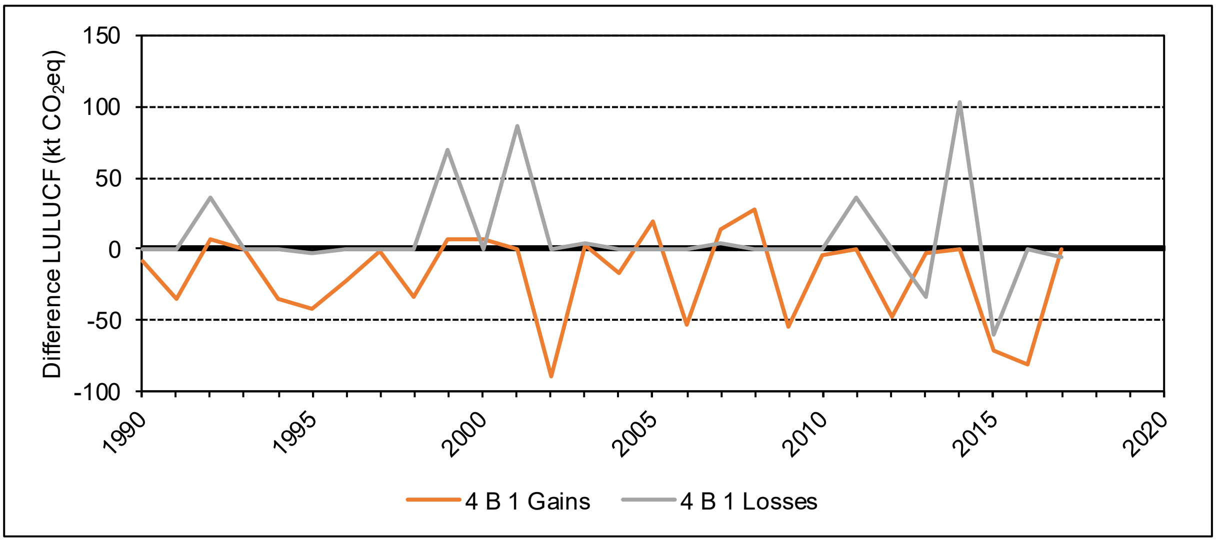


Figure 10-11 Differences in net emissions and net removals (in kt CO_2 eq) between the latest and the previous submission for subcategory 4B1 Gains in living biomass on Cropland remaining Cropland (CO_2) and subcategory 4B1 Losses in living biomass on Cropland remaining Cropland (CO_2). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

In category 4C Grassland two major recalculations controlled the changes in CO_2 eq net emissions and removals between the latest and the previous submission (Figure 10-9).

- 4C1: Carbon stocks and carbon stock changes in living biomass of permanent grassland (CC31) were recalculated for the period 1990–2017 (see chp. 6.6.5). Annual values were reported for the first time. Additionally, net change of CC31 living biomass for the year 2017 was recalculated based on new available yield data. Carbon stocks in living biomass for grassland subcategories CC35, CC35, and CC37 were adjusted to the recalculated CC31 data. The impact on net emissions and removals in kt CO_2 eq in category 4C1 is shown in Figure 10-12 separated for gains in living biomass and losses in living biomass. Impacts on net emissions and removals in kt CO_2 eq are between -89.0 and 58.3 kt CO_2 eq across the inventory time period The combined deviation of CO_2 eq net emissions and removals between the latest and the previous submission ranges from -82.0 kt CO_2 eq in 2014 to 39.4.2 kt CO_2 eq in 1993 (mean -3 kt CO_2 eq).

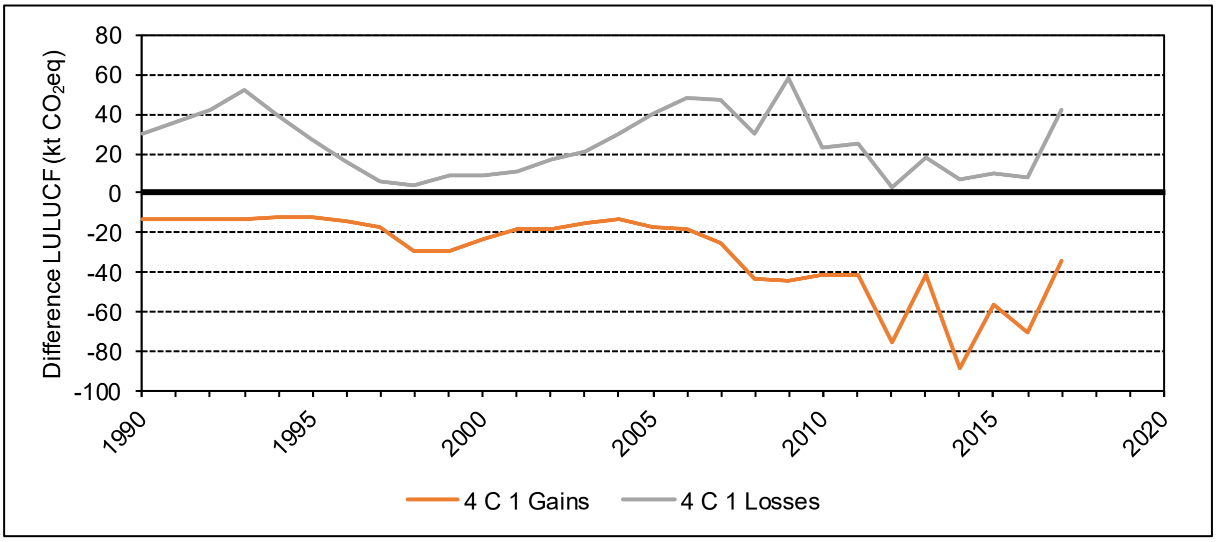


Figure 10-12 Differences in net emissions and net removals (in kt CO_2 eq) between the latest and the previous submission for subcategory 4C1 Gains in living biomass on Grassland remaining Grassland (CO_2) and subcategory 4C1 Losses in living biomass on Grassland remaining Grassland (CO_2). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

- 4C1: Carbon stocks and carbon stock changes in mineral soils of permanent grassland (CC31) were recalculated for the period 1990–2017, in part because the initial carbon stocks of some mountain soils had been underestimated in the previous submission (see chp. 6.6.5). Carbon stocks in mineral soils for grassland subcategories CC32 and 34 to CC37 / subcategory CC33 were adjusted to the recalculated CC31 / CC21 data. The recalculations led to a difference between the net emission estimates in the previous and latest submissions in kt CO_2 eq of between +170.0 (2014) and +302.9 (1990) across the inventory period (mean: 213 kt CO_2 eq; Figure 10-13). The trends of the emissions and removals of the previous and current submissions remain similar (Figure 10-14).

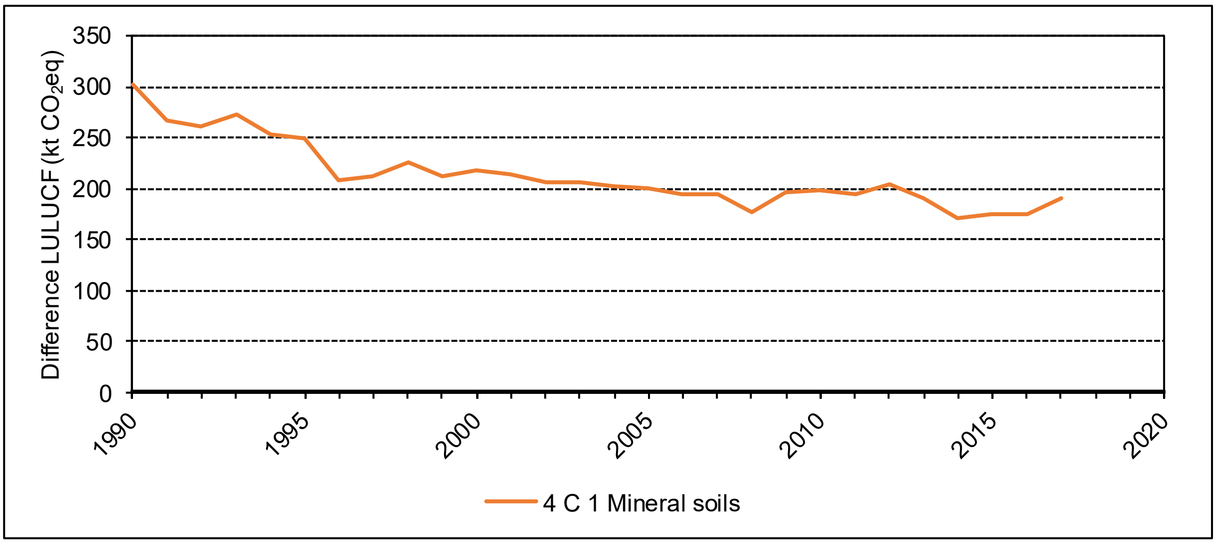


Figure 10-13 Differences in net emissions (in kt CO_2 eq) between the latest and the previous submission for the subcategory 4C1 Net carbon stock change in mineral soils on Grassland remaing Grassland (CO_2). Positive values refer to higher emissions/lower removals in the latest submission compared to the previous submission.

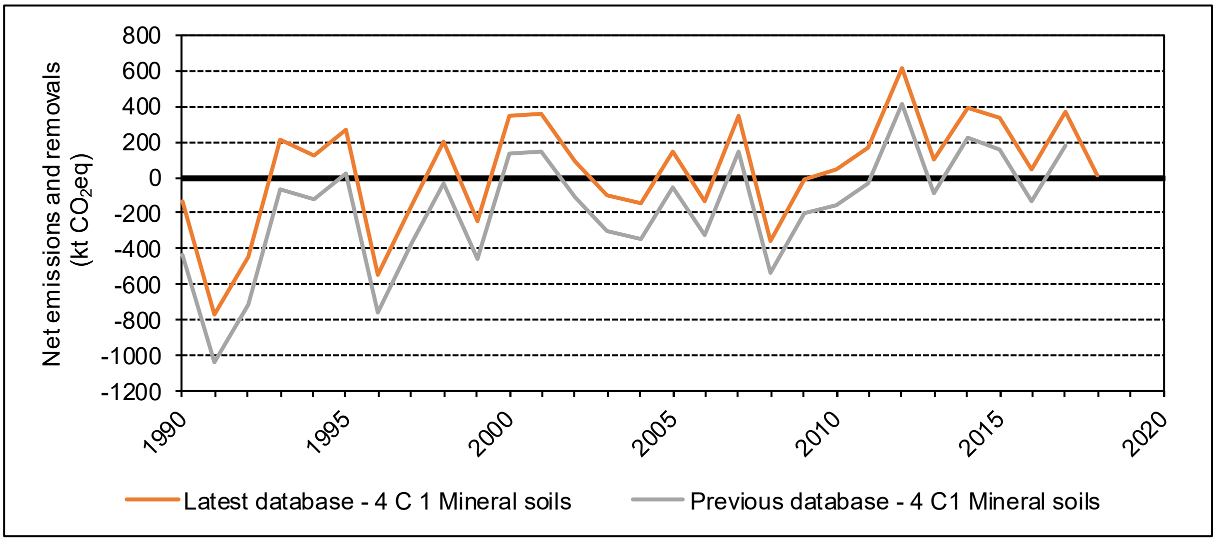


Figure 10-14 Net emissions and removals (in kt CO_2 eq) of the latest and previous submissions for subcategory 4C1 Net carbon stock change in mineral soils on Grassland remaining Grassland. Positive values refer to net emissions and negative values to net removals.

In category 4G Harvested Wood Products several recalculations controlled the changes in CO_2 eq net emissions and removals (cf. chp 6.11.5). Major recalculations which enhanced the pronounced seesaw pattern of the deviation between the latest and the previous submission (Figure 10-9) are:

- 4G1a sawnwood: The conversion factors for sawnwood (coniferous and non-coniferous) were recalculated with country-specific data. Furthermore, the production of sawnwood in 2017 was updated in the FAO database. The recalculations led to a difference between the net emissions estimates in the previous and latest submissions in kt CO_2 eq of between 6.1 (2013) and 89.5 (2017) across the inventory period (mean: 35 kt CO_2 eq), see Figure 10-15.
- 4G1b, recalculations for wood panels led to a difference between the net emissions and removals estimates in the previous and latest submissions in kt CO_2 eq of between -77.7 (2017) and 7.9 (2009) across the inventory period. In most years, however, only small changes resulted, see Figure 10-15.
- 4G2, paper and paperboard: For calculating paper production, the share of recovered fibre pulp was included for the first time. Furthermore, the factor f_{IRW} was applied for the first time in order to consider the amount of domestic pulp wood contained in recycled products. Consequently, the feedstock in paper and paper board decreased by more than 80%. This recalculation in response to UNFCCC (2018, ID#KL.7) led to a difference between the net emissions and removals estimates in the previous and latest submissions in kt CO_2 eq of between -88.8 (2008) and 171.6 (2014) across the inventory period (mean: 20 kt CO_2 eq). Recalculations in 4G2 shaped the pattern of overall differences in net emissions and net removals between the latest and the previous submission for category 4G, see Figure 10-15.

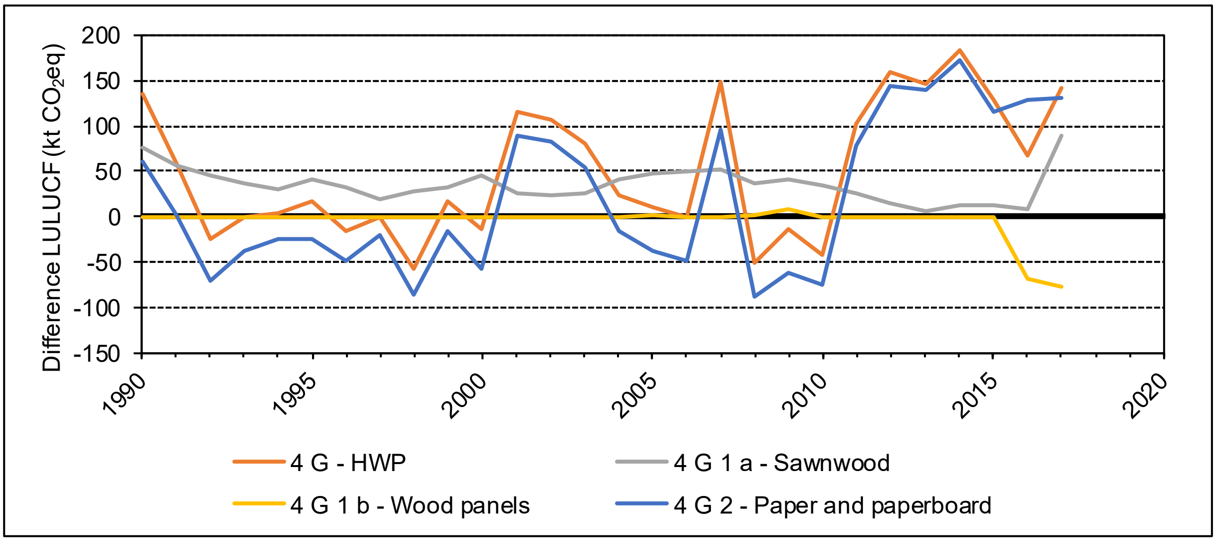


Figure 10-15 Differences in net emissions and net removals (in kt CO_2 eq) between the latest and the previous submission for subcategory 4G Harvested Wood Products (HWP) broken down for subcategory 4G1a Sawnwood (CO_2), subcategory 4G1b Wood panels (CO_2), and subcategory 4G2 Paper and paperboard (CO_2). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

10.1.2.5 Waste

The total changes in emissions in the Waste sector due to all recalculations are shown in Figure 10-16 for CO_2, CH_4, and N_2O. All recalculations had an effect of less than 15 kt CO_2 eq, which corresponds to less than 0.03% of total emissions. The largest recalculations due to the correction of a transcription error found in the estimate of hospital waste incineration in category 5C for the year 1990 led to a decrease of emissions of almost 15 kt CO_2 eq in 1990 (see chp. 7.4.5). Based on data from an archived publication on waste disposal (BUS 1978), AD for 5A Solid waste disposal were changed for the time period from 1950 to 1979, leading to a corresponding increase in CH_4 emissions of 6 kt CO_2 eq in 1990 and a diminishing effect over time (see chp. 7.2.5). All other recalculations had an impact of less than 5 kt CO_2 eq (see Figure 10-16).

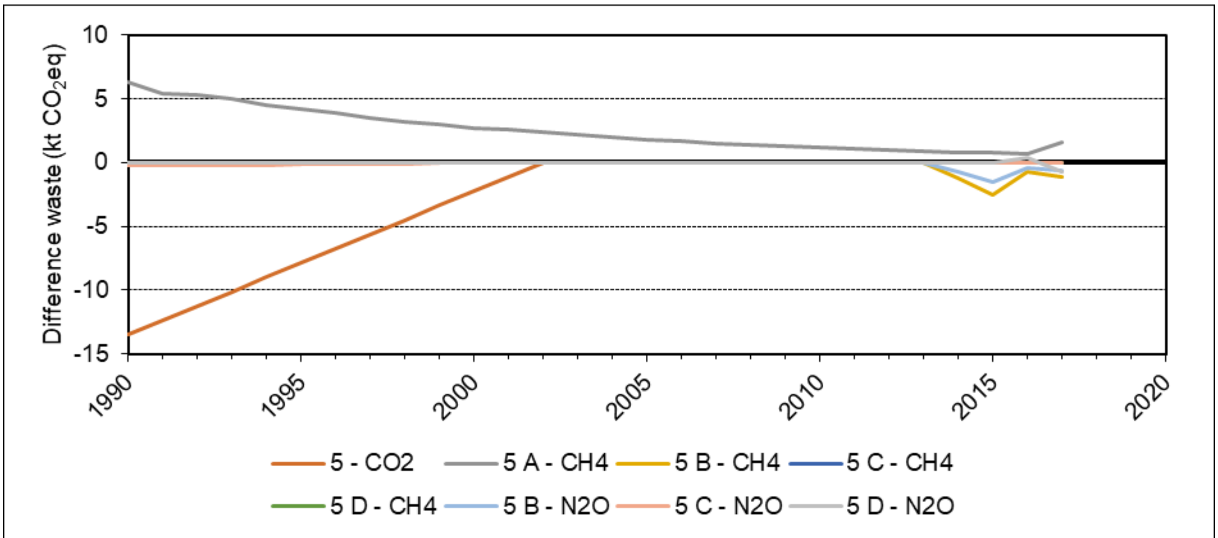


Figure 10-16 Differences in CO_2, CH_4, N_2O emissions (in kt CO_2 eq) between the latest and the previous submission for sector Waste. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.6 Other

No recalculations were carried out in sector Other.

10.1.2.7 Indirect CO_2 Emissions

The total changes in indirect CO_2 emissions due to all recalculations are shown in Figure 10-17. The recalculations are dominated by changes in emissions of precursor gases in source categories 2D3a and 2G4 (see chp. 4.5.5 and 4.8.5), with emission changes ranging from -23 kt CO_2 eq to +9 kt CO_2 eq.

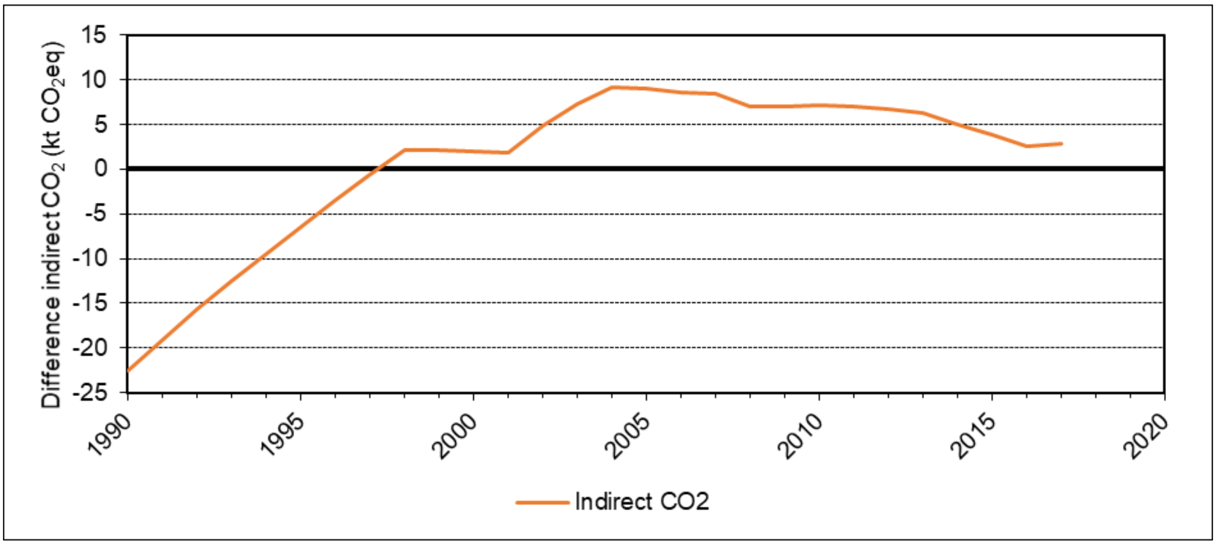


Figure 10-17 Differences in indirect CO_2 emissions (in kt CO_2 eq) between the latest and the previous submission. Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission.

10.1.2.8 KP- LULUCF Inventory

Recalculations with an overall impact of >|100| kt CO_2 eq are assessed quantitatively.

No Kyoto-specific methodological modification was made. All category-specific recalculations in categories 4A (chp. 6.4.5) and 4G (chp. 6.11.5), including the update of the activity data 1991–2017 (chp. 6.3.5), are relevant for the KP-LULUCF inventory. Figure 10-18 shows the differences in net emissions and net removals for KP-LULUCF resulting from the recalculations. The overall pattern of the net emissions and removals remains unchanged (Figure 10-23).

For Forest management, the recalculation in 4G HWP was mainly responsible for the differences in net emissions and removals, see chp. 10.1.2.4 and Figure 10-15. Afforestation and Deforestation were hardly affected by recalculations.

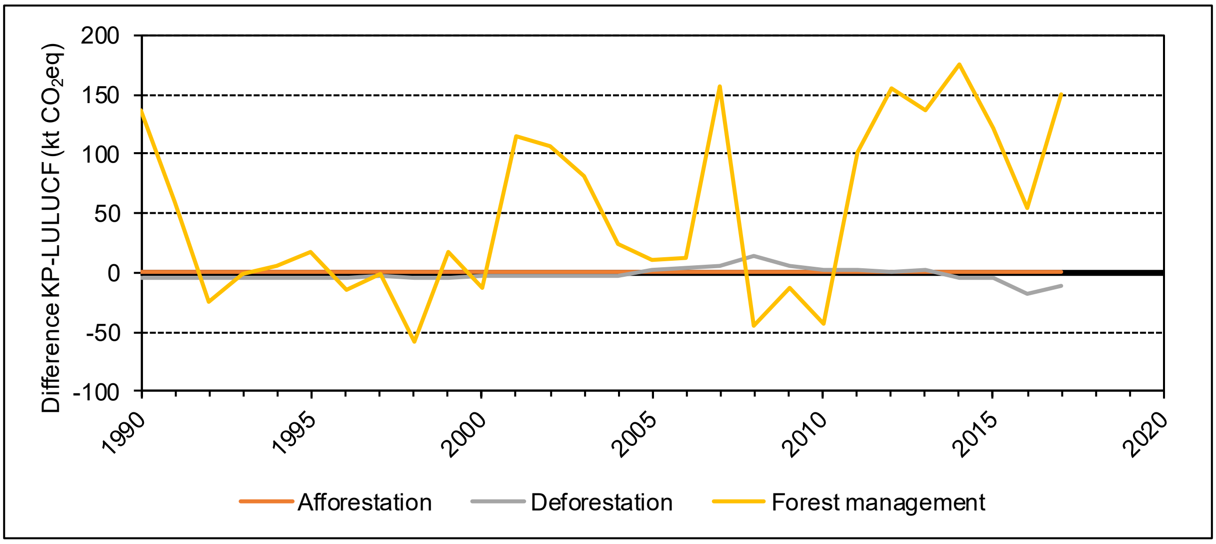


Figure 10-18 Differences in net emissions and net removals (in kt CO_2 eq) between the latest and the previous submission for Afforestation, Deforestation (Kyoto Protocol Art. 3.3), and Forest management (Kyoto Protocol Art. 3.4). Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

10.2 Implications for emission levels

Table 10-2 and Table 10-3 show the aggregated effect of all recalculations on the emission estimates for the base year 1990 and for the year 2017.

Table 10-2 Implications of recalculations for emission levels in 1990. Emissions (excluding indirect CO_2) are shown for the previous submission (FOEN 2019) and the latest submission. The difference refers to absolute values (Latest - Previous).

Emissions for 1990	CO_2			CH_4			N_2O			F-Gases			Sum of all gases		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)														
1 Energy	40'900	40'900	0.0	644.9	634.1	10.7	317.6	292.3	25.3				41'862	41'826	36.0
2 IPPU	3'155	3'149	5.4	1.8	1.8	0.0	604.3	171.9	432.4	253.5	253.5	0.0	4'014	3'576	437.8
3 Agriculture	48.9	48.9	0.0	4'476	4'453	22.2	2'302	2'263	38.7				6'826	6'766	60.9
4 LULUCF	-2'019	-2'571	552.1	29.6	29.6	-0.1	54.4	56.7	-2.3				-1'935	-2'484	549.7
5 Waste	40.2	53.7	-13.5	921.1	914.7	6.4	102.5	102.7	-0.3				1'064	1'071	-7.4
6 Other	11.0	11.0	0.0	0.7	0.7	0.0	0.6	0.6	0.0				12.2	12.2	0.0
Total including LULUCF	**42'136**	**41'592**	**544.0**	**6'074**	**6'034**	**39.2**	**3'381**	**2'887**	**493.8**	**253.5**	**253.5**	**0.0**	**51'844**	**50'767**	**1'077**
	101.3%	***100.0%***	***1.3%***	***100.6%***	***100.0%***	***0.6%***	***117.1%***	***100.0%***	***17.1%***	***100.0%***	***100.0%***	***0.0%***	***102.1%***	***100.0%***	***2.1%***
Total excluding LULUCF	**44'154**	**44'162**	**-8.1**	**6'044**	**6'005**	**39.3**	**3'327**	**2'831**	**496.1**	**253.5**	**253.5**	**0.0**	**53'779**	**53'252**	**527.3**
	100.0%	***100.0%***	***0.0%***	***100.7%***	***100.0%***	***0.7%***	***117.5%***	***100.0%***	***17.5%***	***100.0%***	***100.0%***	***0.0%***	***101.0%***	***100.0%***	***1.0%***

Emissions for 1990	HFC			PFC			SF_6			NF_3		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)											
2 IPPU	0.0	0.0	0.0	116.5	116.5	0.0	137.0	137.0	0.0	0.0	0.0	0.0

Table 10-3 Implications of recalculations for emission levels in 2017. Emissions (excluding indirect CO_2) are shown for the previous submission (FOEN 2019) and the latest submission. The difference refers to the absolute values (Latest - Previous).

Emissions for 2017	**CO_2**			**CH_4**			**N_2O**			**F-Gases**			**Sum of all gases**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)														
1 Energy	35'977	35'974	2.9	280.3	273.7	6.6	245.9	220.5	25.3				36'503	36'468	34.9
2 IPPU	2'136	2'129	7.4	2.9	2.9	0.0	681.7	38.6	643.0	1'740	1'740	0.4	4'561	3'910	650.8
3 Agriculture	47.8	47.6	0.2	4'048	4'040	7.6	2'011	1'989	21.6				6'107	6'077	29.5
4 LULUCF	-1'383	-1'658	275.1	13.9	13.9	0.0	44.1	45.5	-1.3				-1'325	-1'599	273.8
5 Waste	9.6	9.6	0.0	536.8	536.4	0.4	143.5	144.8	-1.3				689.9	690.8	-0.9
6 Other	11.5	11.5	0.0	0.6	0.6	0.0	0.5	0.5	0.0				12.6	12.6	0.0
Total including LULUCF	**36'799**	**36'514**	**285.6**	**4'882**	**4'868**	**14.7**	**3'127**	**2'439**	**687.3**	**1'740**	**1'740**	**0.4**	**46'548**	**45'560**	**988.0**
	100.8%	***100.0%***	***0.8%***	***100.3%***	***100.0%***	***0.3%***	***128.2%***	***100.0%***	***28.2%***	***100.0%***	***100.0%***	***0.0%***	***102.2%***	***100.0%***	***2.2%***
Total excluding LULUCF	**38'182**	**38'172**	**10.5**	**4'868**	**4'854**	**14.7**	**3'083**	**2'394**	**688.7**	**1'740**	**1'740**	**0.4**	**47'873**	**47'159**	**714.2**
	100.0%	***100.0%***	***0.0%***	***100.3%***	***100.0%***	***0.3%***	***128.8%***	***100.0%***	***28.8%***	***100.0%***	***100.0%***	***0.0%***	***101.5%***	***100.0%***	***1.5%***

Emissions for 2017	**HFC**			**PFC**			**SF_6**			**NF_3**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)											
2 IPPU	1'504	1'512	-7.4	32.0	30.8	1.2	202.9	196.5	6.3	0.80	0.54	0.3

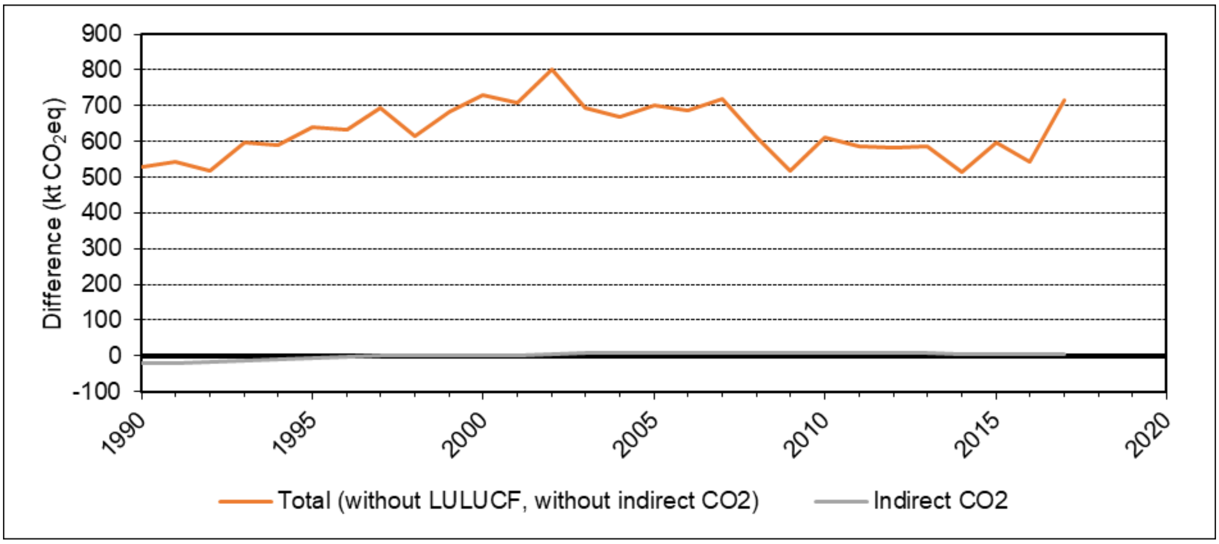


Figure 10-19 Implications of recalculations for the national total emissions (excluding LULUCF). The implications of recalculations for indirect CO_2 (in kt CO_2 eq) are shown separately (see also Figure 10-17). Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission. For the implications of recalculations for LULUCF and KP-LULUCF see Figure 10-8 and Figure 10-18, respectively.

Figure 10-19 shows the aggregated effect of all the recalculations on national total emissions without LULUCF. The effect of the recalculations ranges from 500 kt to 800 kt CO_2 eq corresponding to 1 to 1.5% of annual total emissions. The largest contributions to the total effect stem from a newly discovered source of N_2O in 2B10 Other chemical production.

The aggregated effect of all recalculations on total net emissions and net removals from LULUCF are shown in Figure 10-8.

To further visualize the aggregated effect of all the recalculations, the following figures compare total emissions as reported in the previous and the latest submission in absolute terms (instead of showing differences as in the figures above): Total emissions (without LULUCF, without indirect CO_2) in Figure 10-20, total indirect CO_2 emissions in Figure 10-21, total net emissions and net removals from LULUCF in Figure 10-22, and total net emissions and net removals from KP-LULUCF in Figure 10-23.

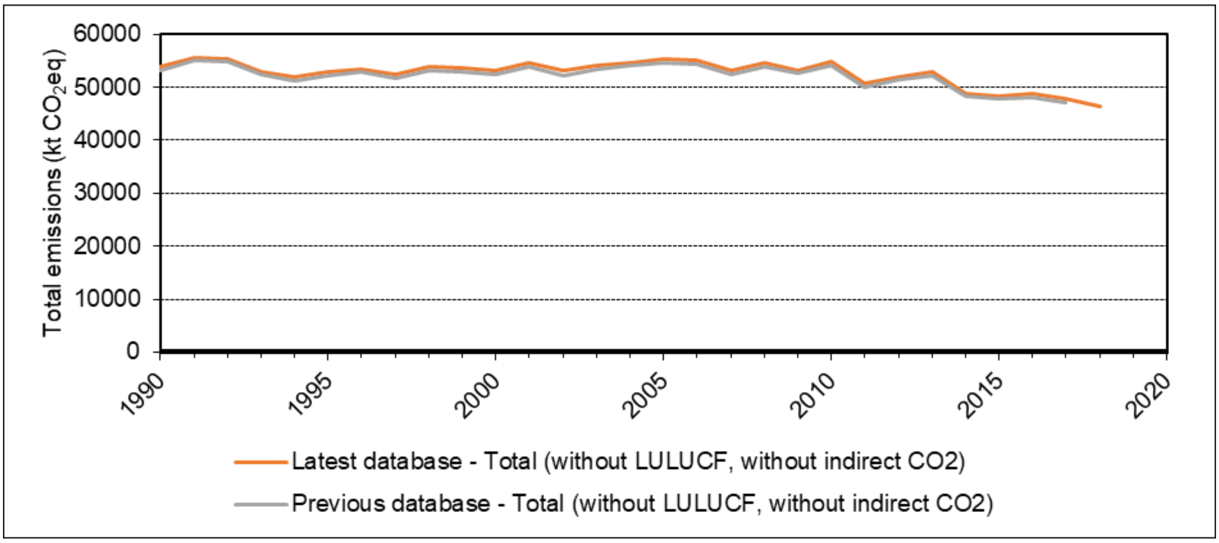


Figure 10-20 Comparison of total emissions (without LULUCF, without indirect CO_2) as reported in the previous and the latest submission.

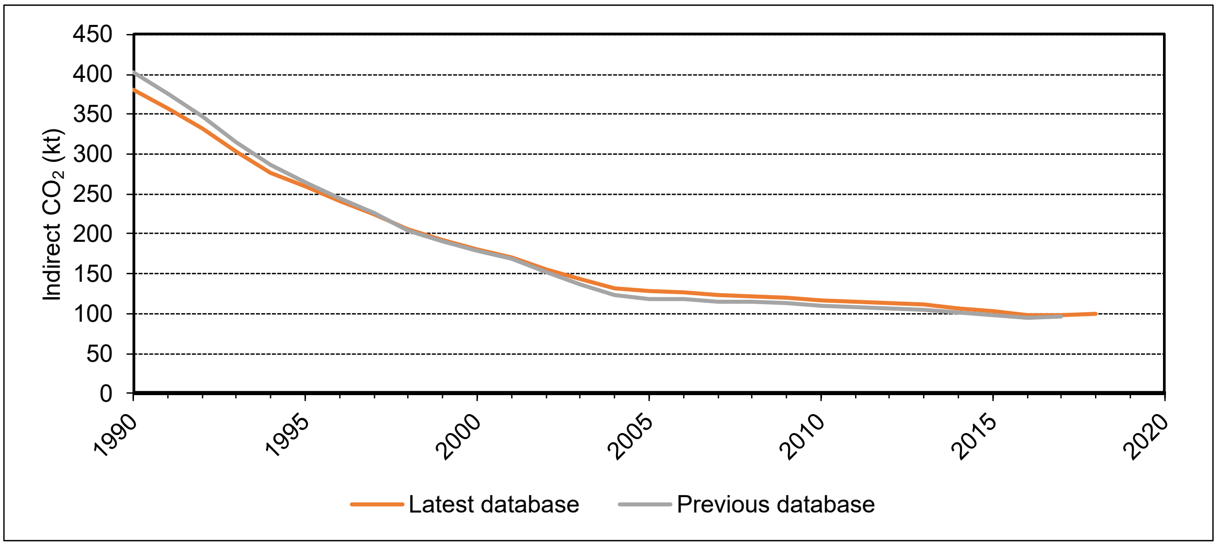


Figure 10-21 Comparison of total indirect CO_2 emissions as reported in the previous and the latest submission.

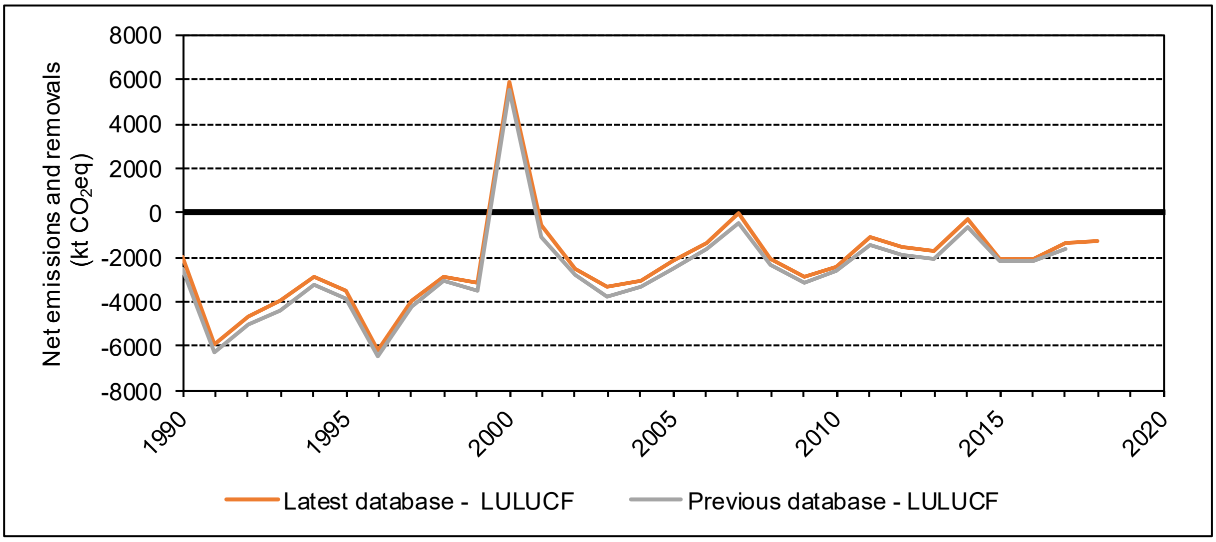


Figure 10-22 Comparison of net emissions (positive values) and net removals (negative values) from LULUCF as reported in the previous and the latest submission.

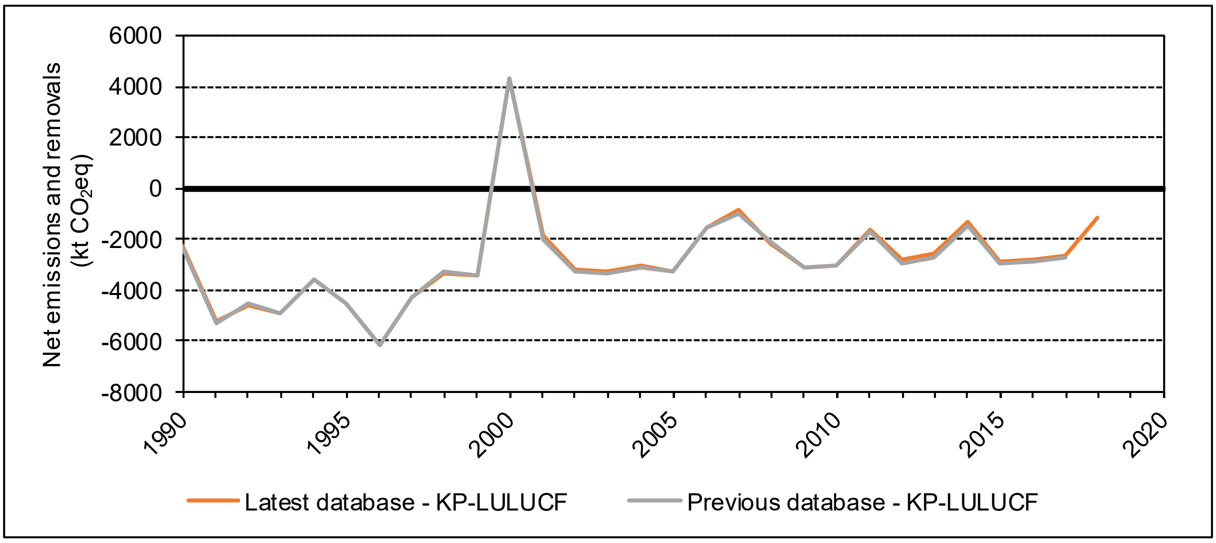


Figure 10-23 Comparison of net emissions (positive values) and net removals (negative values) from KP-LULUCF as reported in the previous and the latest submission.

10.3 Implications for emissions trends, including time series consistency

As recalculations are applied to the entire time series (as appropriate), time series consistency is maintained. The emission trend 1990–2017 has only slightly changed (see Table 10-4).

Table 10-4 Estimated emission trends 1990–2017, calculated based on national total emissions excluding indirect CO_2 as shown in the previous and the latest submission (for additional details see Table 10-2 and Table 10-3).

Trend	1990		2017		Change 1990/2017	
	Latest	Previous	Latest	Previous	Latest	Previous
	CO_2 equivalent (kt)				%	
Total including LULUCF	51'844	50'767	46'548	45'560	-10.2%	-10.3%
Total excluding LULUCF	53'779	53'252	47'873	47'159	-11.0%	-11.4%

10.4 Planned improvements, including in response to the review process

- 1B2ai Fugitive emissions from oil transport: Due to the fact that we use the tier 1 CH_4 emission factor of 5.4 * 10^{-6} Gg per 1000 m^3 oil transported by piplines as published in the IPCC Guidelines 2006 (table 4.2.4), there is an overestimation of CH_4 emissions from oil transportation. This emission factor refers to pipelines above ground as used in Noth America. As in Switzerland the pipelines for oil transportation are all under ground, there is no emission of CH_4 from this process. This will be corrected for the next submission 2021.
- 2F1: Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- 2F1: Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO_2 compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).
- 3B Manure management: An expert peer review of manure management is planned for summer 2020. Results will be implemented in future greenhouse gas inventories as appropriate.
- 3D Starting in 2020, FOEN funds the development and evaluation of a process-oriented model for N_2O emissions in agricultural soils subject to common Swiss management practices.
- 4: The suitability of newly available satellite data for land area representation in Switzerland is being evaluated.
- 4A: The implementation of the soil model Yasso07 to improve the accuracy in the estimates of temporal changes and turnover rates in the soil carbon, litter, and dead wood pools will be further developed.
- 4B, 4C: Starting in 2019, FOEN funds the development and evaluation of a process-oriented model for N_2O emissions in agricultural soils subject to common Swiss management practices.
- 4B, 4C, 4D, 4E: Price et al. (2017) created a nationwide model for tree biomass in Switzerland (both inside and outside of forest), using structural information available from

airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land use combination categories where tree biomass has either not been included or only roughly estimated until now. The suitability of the obtained data for reporting in categories 4B, 4C, 4D, and 4E, respectively, is subject to evaluation. The methodological approach is pursued with the overall objective to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland.

- 4B, 4C, 4D, 4E: A digital soil modelling project at Agroscope (funded by FOEN 2017–2020) addresses the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. A LULUCF module aims at improving the estimates of soil carbon contents in Swiss non-forest soils.
- 4C: A study on GHG (CO_2, CH_4, N_2O) emissions from an intensively used fen under grassland management in the Rhine valley (Agroscope, 2017–2022, financed by FOEN) will improve the robustness of country-specific emission factor estimates for grassland soils rich in organic matter in the medium term.
- 5B Biological treatment of solid waste: A research project in the framework of a joint research programme is investigating the CH_4 emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project as appropriate.
- 5D Wastewater treatment and discharge: Two research projects, aiming at deriving country-specific emission factors for CH_4 and N_2O from wastewater treatment plants, are on-going. Results will be implemented in the greenhouse gas inventory after completion of the projects as appropriate.

PART 2

11 KP-LULUCF

Responsibilities for chapter KP-LULUCF (Kyoto Protocol - Land use, and land-use change and forestry)	
Overall responsibility	Nele Rogiers (FOEN)
Authors & sector experts	Nele Rogiers (FOEN), Markus Didion (WSL), Esther Thürig (WSL)
Annual updates (NIR text, tables, figures)	Nele Rogiers (FOEN), Dominik Eggli (Meteotest)
Quality control (annual updates)	Markus Didion (WSL), Andreas Schellenberger (FOEN)
Internal review	Markus Didion (WSL)

Switzerland has chosen to account over the entire second commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (FOEN 2016c, FOEN 2016d). In addition to the mandatory submission of the inventory years of the second commitment period, data for the years 1990–2012 are available. Switzerland accounts for the mandatory activity Forest management under Article 3, paragraph 4, of the Kyoto Protocol (FOEN 2016c). Switzerland applies the condition of direct human-induced in relation to Afforestation and Deforestation very strictly for both activities (see chp.11.1.3, FOEN 2010d, FOEN 2010h). CRF NIR-1 shows the activity coverage, the carbon pools and the greenhouse gas sources reported for the mandatory activities under Article 3, paragraph 3 and for Forest management under paragraph 4, of the Kyoto Protocol. Detailed information on completeness of the activity coverage and reported pools is given in chp. 11.3.1.2. The areas and change in areas between the previous and the latest inventory year are shown in CRF NIR-2. CRF NIR-3 summarizes the results of the KCA for LULUCF activities under the Kyoto Protocol.

An overview of net annual CO_2 eq emissions and removals of activities under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4, of the Kyoto Protocol is shown in Figure 11-1 and Table 11-1. Annual removals from Afforestation and Deforestation fluctuate (Figure 11-2), which can mainly be attributed to the changes in their respective areas (see Table 11-2 for activity data). The relative changes in the area of managed forest are comparatively low and fluctuations in the annual net changes in Forest management can primarily be explained by changes in the losses from the (1) living biomass pool, (2) dead wood pool and (3) litter pool (Table 11-1). The extraordinary high emissions of the Forest management sector in 2000 and the small removals in the following year 2001 originate from winter storm “Lothar” at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007. Peak values in 2006 and 2007 resulted in small removals from Forest management. Because harvesting rates started to decline in 2008 (Table 6-18) due to the international and domestic economic framework conditions, removals from Forest management are increasing since 2008 with a clear year-to-year variability. The small net removals in 2011, 2014 and 2018 are due to comparably high harvesting rates and above-average losses in the litter pool (related to climatic circumstances). Fluctuations in the Harvested wood products (HWP) pool are mainly caused by changes in the production of sawnwood and panels (see Table 6-36 and Figure 6-14). The contribution of paper and paperboard to changes in HWP fluctuates over the years.

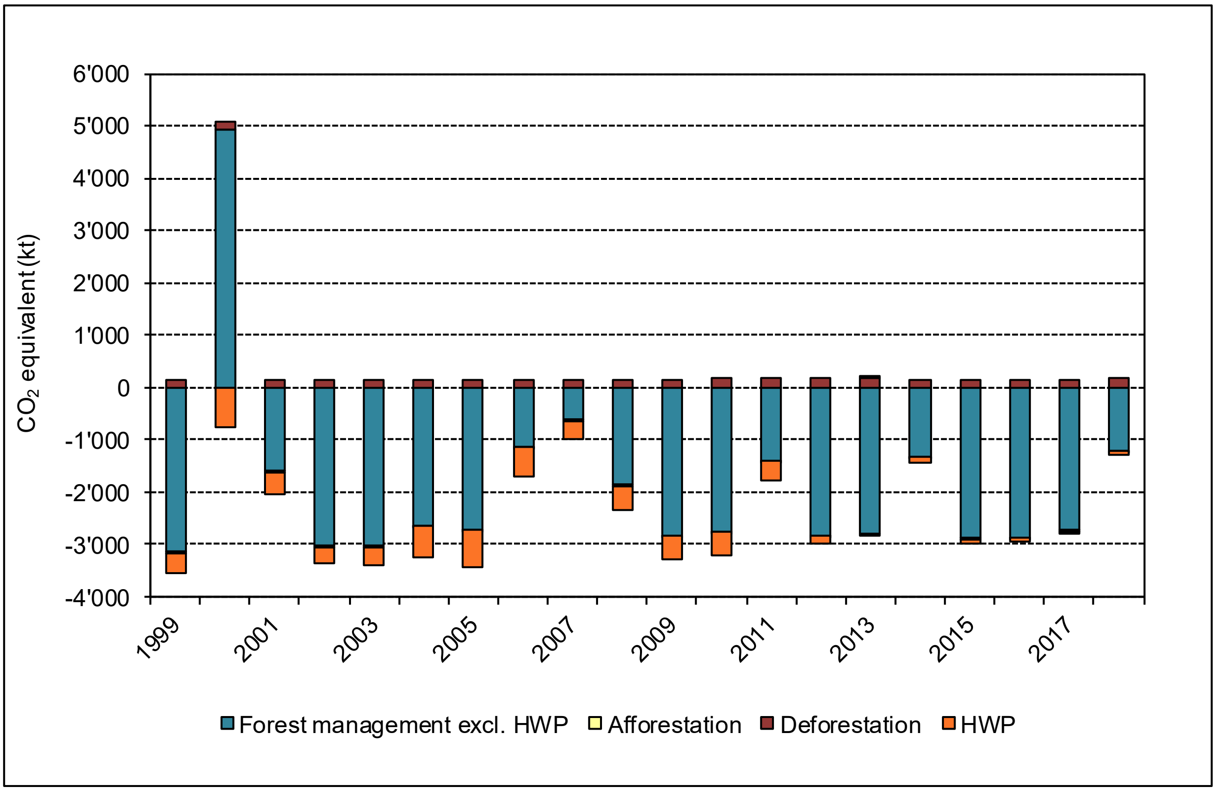


Figure 11-1 GHG emissions (positive sign) and removals (negative sign). Shown are data for Afforestation (too small to be distinguishable) and Deforestation under Article 3, paragraph 3, Forest management excluding HWP and HWP under Article 3, paragraph 4.

Table 11-1 Net CO_2 eq emissions (positive sign) and removals (negative sign) for activities accounted for under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4, of the Kyoto Protocol, selected years. Abreveations are explained in chp. 6.1.3.2 except for $loss_{drainage\ and\ LUC}$ (N_2O), $loss_{LUC}$ (N_2O), $loss_{drainage}$ (N_2O): N_2O emissions associated with drainage and/or land-use change (LUC); C_{l_ag}: carbon in above-ground living biomass; C_{l_bg}: carbon in below-ground living biomass; C_{s_m}: carbon in mineral soil; C_{s_o}: carbon in organic soil; C_{HWP}: carbon in HWP; $loss_{biomburn}$: CH_4 and N_2O emissions from biomass burning. Values correspond to data in CRF 4(KP) and CRF 4(KP-I)B.1.

Greenhouse gas source and sink activities	1990	1995	2000	2005
	kt CO_2 equivalent			
A. Article 3.3 activities	**83.38**	**105.67**	**122.87**	**133.58**
A.1. Afforestation and Reforestation incl. N_2O; 4(KP)	-2.97	-14.69	-19.19	-22.92
Afforestation <= 20 yr	-2.98	-14.70	-19.21	-22.93
Afforestation > 20 yr	NO	NO	NO	NO
$loss_{drainage\ and\ LUC}$ (N_2O)	0.003	0.01	0.01	0.02
A.2. Deforestation incl. N_2O; 4(KP)	86.35	120.36	142.06	156.50
Deforestation excl. N_2O	86.24	119.64	140.67	154.41
$loss_{LUC}$ (N_2O)	0.11	0.72	1.38	2.09
B. Article 3.4 activities	**-2'327.76**	**-4'596.93**	**4'211.75**	**-3'428.59**
B.1. Forest management; 4(KP)	-2'327.76	-4'596.93	4'211.75	-3'428.59
$gainC_{l\_ag}$	-9'759.92	-9'698.26	-9'729.58	-9'764.72
$gainC_{l\_bg}$	-2'749.43	-2'751.16	-2'763.58	-2'776.74
$lossC_{l\_ag}$	8'870.63	6'792.32	13'984.51	8'468.04
$lossC_{l\_bg}$	2'682.95	2'006.50	3'903.23	2'463.09
$changeC_h$	22.34	-244.11	-87.85	-699.09
$changeC_d$	-251.80	-225.22	-371.05	-387.28
$changeC_{s\_m}$	-3.71	-4.24	-7.72	-9.68
$changeC_{s\_o}$	1.08	1.09	1.09	1.10
$changeC_{HWP}$	-1'168.82	-487.06	-722.96	-727.87
Forest management excl. CH_4 and N_2O; 4(KP-I)B.1	-2'356.71	-4'610.15	4'206.10	-3'433.14
$loss_{biomburn}$ (CH_4 and N_2O)	28.80	13.08	5.51	4.41
$loss_{drainage}$ (N_2O)	0.15	0.15	0.15	0.15
B.2. Cropland management	NA	NA	NA	NA
B.3. Grazing land management	NA	NA	NA	NA
B.4. Revegetation	NA	NA	NA	NA

Greenhouse gas source and sink activities	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kt CO_2 equivalent									
A. Article 3.3 activities	**135.17**	**141.41**	**143.74**	**144.98**	**146.27**	**129.28**	**117.06**	**109.93**	**135.59**	**148.54**
A.1. Afforestation and Reforestation incl. N_2O; 4(KP)	-25.47	-23.79	-21.60	-20.80	-19.82	-17.65	-19.18	-18.94	-18.58	-16.15
Afforestation <= 20 yr	-25.49	-23.09	-20.80	-18.55	-16.94	-15.83	-15.22	-14.65	-14.27	-14.05
Afforestation > 20 yr	NO	-0.72	-0.80	-2.26	-2.90	-1.82	-3.97	-4.30	-4.31	-2.10
$loss_{drainage\ and\ LUC}$ (N_2O)	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
A.2. Deforestation incl. N_2O; 4(KP)	160.64	165.20	165.34	165.79	166.10	146.93	136.25	128.87	154.17	164.69
Deforestation excl. N_2O	157.97	162.49	162.59	162.99	163.26	144.08	133.40	126.03	151.32	161.83
$loss_{LUC}$ (N_2O)	2.67	2.71	2.75	2.80	2.83	2.85	2.84	2.83	2.85	2.86
B. Article 3.4 activities	**-3'243.70**	**-3'198.49**	**-1'747.90**	**-2'954.60**	**-2'739.69**	**-1'435.20**	**-2'973.65**	**-2'920.35**	**-2'751.26**	**-1'278.37**
B.1. Forest management; 4(KP)	-3'243.70	-3'198.49	-1'747.90	-2'954.60	-2'739.69	-1'435.20	-2'973.65	-2'920.35	-2'751.26	-1'278.37
$gainC_{l\_ag}$	-10'190.63	-10'198.98	-10'208.00	-10'217.02	-10'227.64	-10'243.42	-10'248.70	-10'273.54	-10'284.78	-10'293.86
$gainC_{l\_bg}$	-2'915.79	-2'919.04	-2'922.33	-2'925.62	-2'929.42	-2'934.72	-2'936.88	-2'944.88	-2'948.82	-2'952.19
$lossC_{l\_ag}$	8'614.79	9'092.87	9'016.22	8'286.79	8'537.96	8'758.03	8'150.30	8'016.60	8'391.39	9'281.55
$lossC_{l\_bg}$	2'573.94	2'733.38	2'712.36	2'504.18	2'587.68	2'657.79	2'478.06	2'447.05	2'552.63	2'801.65
$changeC_h$	-428.26	-900.63	317.14	-110.81	-373.86	598.78	-30.00	99.88	-164.40	166.51
$changeC_d$	-470.99	-543.46	-304.47	-351.59	-384.94	-149.44	-280.31	-206.60	-268.49	-197.49
$changeC_{s\_m}$	-8.93	-9.53	-10.70	-10.45	-10.68	-11.19	-10.62	-10.69	-10.68	-11.01
$changeC_{s\_o}$	1.11	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.15	1.15
$changeC_{HWP}$	-422.92	-457.49	-355.53	-134.43	56.90	-115.71	-100.14	-57.27	-23.97	-78.34
Forest management excl. CH_4 and N_2O; 4(KP-I)B.1	-3'247.68	-3'201.77	-1'754.18	-2'957.82	-2'742.86	-1'438.73	-2'977.14	-2'928.29	-2'755.98	-1'282.03
$loss_{biomburn}$ (CH_4 and N_2O)	3.82	3.12	6.13	3.07	3.01	3.38	3.34	7.78	4.56	3.51
$loss_{drainage}$ (N_2O)	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16
B.2. Cropland management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B.3. Grazing land management	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B.4. Revegetation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

CRF accounting ("Information table on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol") gives an overview of the CO_2 eq emissions and removals from Afforestation and Deforestation under Article 3, paragraph 3 and Forest management under Article 3, paragraph 4.

In 2018, Forest management in Switzerland caused removals of -1'278.37 kt CO_2 eq. The debit incurred from activities under Article 3.3 is 148.54 kt CO_2 eq (Table 11-1).

11.1 General information

The inventory datasets on which the calculations are based are described in chp. 6.2, 6.3 (Swiss Land Use Statistics AREA) and 6.4.2.1 (National Forest Inventory NFI).

Methodological issues and assumptions concerning the calculation of activity data and emission factors used for the reporting under Article 3, paragraphs 3 and 4, of the Kyoto Protocol follow the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) as described in chp. 6.4.2, and the KP-Supplement (IPCC 2014).

11.1.1 Definition of forest and any other criteria

The forest definition used under the Kyoto Protocol is defined in Switzerland's first Initial Report (FOEN 2006h, Sect. E) and it is still valid for the second commitment period (FOEN 2016c; see also chp. 6.4.1 in this submission). Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20% and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ. The selected parameters are listed in CRF NIR1.

Some source categories were explicitely excluded from the land-use category Forest land, although they may partly fulfil the requirements of the Swiss forest definition used under the Kyoto Protocol (see chp. 6.2.1, Table 6-6; chp. 6.4.1 and FOEN 2006h section E). Those are:

- Vineyards, Low-Stem Orchards, Tree nurseries, Copses and Orchards in the land-use category Grassland;
- Cemeteries and public parks in the land-use category Settlements.

11.1.2 Elected activities under article 3, paragraph 4, of the Kyoto Protocol

Switzerland only accounts for the mandatory activity Forest management under Article 3, paragraph 4, of the Kyoto Protocol (FOEN 2016c). In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), additions to the assigned amount resulting from Forest management under Article 3, paragraph 4, are capped. This cap for the second commitment period amounts to 15'037'884 t CO_2 eq for the entire commitment period 2013–2020 (FOEN 2016d).

11.1.3 Description of how the definitions of each activity under article 3.3 and each elected activity under article 3.4 have been implemented and applied consistently over time

The definitions of Afforestation, Deforestation and Forest management are published in Switzerland's Initial Report (see FOEN 2006h, Sect. E and F). These definitions are still valid for the second commitment period (FOEN 2016c). Switzerland applies the condition of direct human-induced in relation to Afforestation and Deforestation very strictly for both activities (see FOEN 2010d, FOEN 2010h).

For the notation of activities under article 3.3 and article 3.4 of the Kyoto Protocol, the first character is capitalised (see chp. 6.1.3.1): Afforestation, Deforestation and Forest management.

Afforestation

Afforestation is the conversion to forest of an area not fulfilling the definition of forest for a period of at least 50 years if the definition of forest in terms of minimum area (625 m^2) is fulfilled, and the conversion is a direct human-induced activity (FOEN 2006h).

Natural forest regeneration following the abandonment of subalpine pastures is not considered to be a direct human-induced activity. Only conversions to forest land which can clearly be attributed as direct human-induced from aerial photographs (SFSO 2019; see also chp. 6.3.1) are considered as Afforestation under the Kyoto Protocol. Examples of direct human-induced conversions to forest land (Afforestations) are shown in FOEN (2010h).

Deforestation

Deforestation is the permanent conversion of areas fulfilling the definition of forest in terms of minimum forest area (625 m^2) to areas not fulfilling the definition of forest as a consequence of direct human influence (FOEN 2006h).

Temporary removals of () trees (e.g. of strips or clusters for the construction of high-voltage power lines, cable-car lines, maintenance roads along railway lines and highways) are not reported as Deforestation under the Kyoto Protocol because in those cases the forest stand has to be re-established. In the NFI, small areas <25m wide (eg. unsurfaced storage yards located next to a forest road) or strips that are clear of trees (eg. unpaved forest roads <6 m wide) or areas where trees are maintained at a certain lower height (e.g. under power lines) are considered as forest if they are not clearly separable from the surrounding forested land (Lanz et al. 2019). After approximately 12 years (see chp. 6.3.1) it is possible to check if deforestations or other land-use changes have been correctly classified. The classification of all land-use changes classified as Deforestation under the Kyoto Protocol were screened (Sigmaplan 2012a). Based on Table CRF 4(KP-I)A.2, in the reporting year 77% of all these Kyoto Deforestations were still deforested after 29 years, whereas 23% were temporary removals of tree cover, which should be classified as "management interventions" rather than as real land-use changes. As no reclassification was done, the area of Deforestations reported under the Kyoto Protocol Art. 3.3 is in fact an overestimation. Accordingly, emissions are overestimated since implied emission factors for Deforestations are higher than for Forest management (see CRF 4(KP-I)A.2 for Deforestations and CRF 4(KP-I)B.1 for Forest management). The area of the current land-use after Deforestation is given as information item in CRF 4(KP-I)A.2. Since no additional activities besides Forest management are elected under Art. 3.4, only the activity data are given and no information on changes in carbon stocks is provided.

Reforestation

Reforestation does not occur in Switzerland (FOEN 2006h, Sect. E; see also chp. 11.4.1).

Forest management

Forest management includes all activities serving the purpose of fulfilling the Federal Law on Forests (Swiss Confederation 1991, Art. 1c), i.e. the obligation to conserve forests and to ensure forest functions – such as wood production, protection against natural hazards, preservation of biodiversity, purification of drinking water, and maintenance of recreational value – in a sustainable manner.

11.1.4 Description of precedence conditions and/or hierarchy among 3.4. activities and how they have been consistently applied in determining how land was classified.

Since Switzerland only accounts for Forest management from the activities of Article 3, paragraph 4, of the Kyoto Protocol, the hierarchy among 3.4 activities does not affect Swiss reporting.

11.2 Land-related information

11.2.1 Spatial assessment unit used for determining the area of the units of land

The spatial assessment unit for the submission of the KP-reporting tables covers the entire territory of Switzerland, i.e. 4'129.052 kha (see chp.6.3.1; Table 6-8).

All activity data for reporting the activities under the Kyoto Protocol are retrieved from the Swiss Land Use Statistics (SFSO 2019; see also chp. 6.3.1). The Swiss Land Use Statistics AREA (SFSO 2006a) uses a georeferenced sample grid with a grid size of 100 m by 100 m. To each grid point a specific combination category (see Table 6-2) is assigned.

11.2.2 Methodology used to develop the land transition matrix

The methodology used to develop the land transition matrix is described in detail in chp. 6.2.3.

11.2.3 Maps and/or database to identify the geographical locations and the system of identification codes for the geographical locations

All Afforestations and Deforestations are accounted for under Article 3, paragraph 3 and are not reported under Forest management under Article 3, paragraph 4. Afforestations older than the conversion period of 20 years are still reported under Afforestation: “Total for Activity

A.1” in CRF 4(KP-I)A.1 equals the cumulated afforestated areas since 1990 as shown in Table 11-2 and CRF NIR-2. The area of deforestations displayed under “Total for activity A.2” in CRF 4(KP-I)A.2 encompasses the cumulated area of deforestations since 1990 (see also Table 11-2 and CRF NIR-2). However, only the cumulated area of deforestations of the last 20 years are relevant to calculate changes in carbon stocks (Table 6-3).

The calculation of changes in carbon stocks is described in chp. 11.3.1.1. The changes in areas between the activities under Article 3, paragraph 3 and Article 3, paragraph 4 are listed in CRF NIR-2.

The area under Forest management is subdivided into productive forests (CC12) and unproductive forests (CC13; for a description see chp. 6.4.2.8). Productive forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions and tree species composition (see chp. 6.2.2 and Figure 6-4). Therefore, Switzerland has been stratified into five National Forestry Inventory production regions (L1: Jura, L2: Central Plateau, L3: Pre-Alps, L4: Alps, L5: Southern Alps), three elevation zones (Z1: <601 m, Z2: 601-1200 m, Z3: >1200 m) and two soil types (mineral soils and organic soils). In the reporting tables, the stratification of the activity data into production region (L) and elevation level (Z) is indicated in the column “Subdivision”.

Area reported under Afforestation, Deforestation and Forest management

Land Use Statistics (AREA) data allow to clearly separate between the land areas subject to a specific activity. Absolute and cumulated activity data since 1990 of Afforestations, Deforestations and Forest management are listed in Table 11-2. The total country area amounts to 4'129'052 ha (Table 6-8).

Table 11-2 Activity data for activities under Article 3, paragraphs 3 and 4, selected years. Data for Afforestation and Deforestation and values representing the area under Forest management were derived from the Swiss Land Use Statistics (AREA) (SFSO 2006a, 2019). See also CRF NIR-2.

	Unit	1990	1995	2000	2005
Afforestation area	kha	0.26	0.12	0.06	0.05
Cumulated area of Afforestation since 1990	kha	0.26	1.28	1.66	1.95
Deforestation area	kha	0.31	0.35	0.38	0.39
Cumulated area of Deforestation since 1990	kha	0.31	1.92	3.77	5.71
Forest management area	kha	1'210.66	1'221.64	1'229.13	1'235.99

	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Afforestation area	kha	0.05	0.04	0.04	0.04	0.07	0.07	0.06	0.05	0.04	0.04
Cumulated area of Afforestation since 1990	kha	2.15	2.20	2.24	2.29	2.35	2.42	2.48	2.53	2.58	2.62
Deforestation area	kha	0.38	0.39	0.39	0.39	0.38	0.33	0.30	0.28	0.33	0.38
Cumulated area of Deforestation since 1990	kha	7.25	7.64	8.03	8.42	8.80	9.13	9.43	9.71	10.05	10.42
Forest management area	kha	1'244.00	1'245.63	1'247.23	1'248.83	1'250.79	1'253.46	1'256.10	1'258.57	1'260.58	1'262.30

Afforestation

Activity data for Afforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2019; see also chp. 6.3.1). A detailed description of the identification of Afforestations fulfilling the Kyoto definition is provided in FOEN (2010h).

Deforestation

Data for Deforestations are derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2019; see also chp. 6.3.1). A detailed description of the identification of Deforestations under the Kyoto Protocol from the AREA dataset is given in FOEN (2010d) and Sigmaplan (2010a).

Not all changes from a forest combination category (afforestation CC11, productive forest CC12 and unproductive forest CC13) to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. The following criteria are used to identify conversions from a forest combination category to a non-forest combination category, which are not classified as Deforestations under the Kyoto Protocol Art. 3.3 (FOEN 2010d):

1. Non-permanent conversions are due to common forest management practices, natural dynamics or hazards:

- Tree loss is temporally limited, i.e., areas with loss of tree biomass, but where a change in land use cannot be identified: Natural regeneration, which is a common practice in Swiss forest management, is expected, but could not yet be recognized on the aerial photograph at the time the AREA survey (see chp. 6.3.1) was conducted. Also, in the NFI methodology (Lanz et al. 2019) “forest aisles” under power lines are explicitly classified as forests (see also chp. 11.1.3). Further, data in the information item of CRF 4(KP-I)A.2 show that although the aspect of "temporal limitiation" was considered when classifying Deforestations, at the end approximately 20% of these Kyoto Deforestations were in fact "short-term reduction of crown coverage" and should have been classified as "management interventions" rather than as real land-use changes (see chp. 11.1.3; Sigmaplan 2012a).
- Tree loss is spatially limited, i.e., conversion is caused by an alteration of the surrounding stand, but the change does not affect the tree cover at the sample point: this criterion applies also to the case of a Swiss-specific silvo-pastoral system of grasslands with tree cover. It is very difficult for interpreters of aerial photographs to determine this land use/land cover correctly. In fact, these points could be attributed to two coequal land-use types: agricultural area (NOLU04 2XX) and forest area (NOLU04 3XX; cf. Table 6-6). Land cover on these points is in general open forest (NOLC04 44), linear woods (NOLC04 46) or cluster of trees (NOLC04 47; cf. Table 6-6). When tree vegetation on these grasslands becomes denser over time, land owners remove single trees every now and then. This management practice can lead to the fact that an interpreter of aerial photographs reclassifies the sample point into a different land-use type during a later survey (i.e. change from forest area NOLU04 3XX to agricultural area NOLU04 2XX), although in reality no LUC took place on these sites; and, moreover, all elements of the Kyoto forest definition are still fulfilled (see Table 2 in FOEN 2010d).

2. Conversions of combination categories (see Table 6-2 and Table 6-6) which do not meet the definition of Deforestation as defined under the Kyoto Protocol and in Switzerland’s Initial Report (FOEN 2006h):

- Areas smaller than the minimum area of 625 m2.
- Areas with a reduction in forest cover on the grid point but still fulfilling the Kyoto definition of forest, i.e. having the potential to reach 3 m at maturity in situ.

3. No change in land use took place: reduction of tree cover without land-use change; former land use was mainly pasture

4. Tree loss is not direct human-induced: Conversion due to natural hazards and dynamics.

The four criteria were applied to the land-use change data of the AREA survey (see chp. 6.2.2) for calculating annual values of the respective area (e.g. the cumulative area 0.980 kha in 2016, see Table 11-6).

It was ensured that the criteria and the application to identify conversions which do not correspond to Deforestations under the Kyoto Protocol do not result in inconsistencies in the estimates of changes in carbon stocks on the converted areas. If a sample point in the AREA dataset is not classified as Kyoto Deforestation, it remains classified as Forest management. The classification under Forest management implies that carbon stocks on these areas are based on NFI data (see chp. 6.4.2.1). Thus, carbon stock changes are reflected in the implied emission factors in the reporting tables and are completely accounted for.

Forest management

Since all forests in Switzerland are subject to certain forest management practices, the area under the activity Forest management corresponds to the forest area (see FOEN 2006h, Sect. E; FOEN 2016c) as derived from the Swiss Land Use Statistics (AREA; SFSO 2006a, 2018; see also chp. 6.3). Changes in pools for the following geographical locations are reported:

- productive forest remaining productive forests (CC12 remaining)
- productive forest converted to unproductive forests (CC12 to CC13)
- unproductive forest remaining unproductive forests (CC13 remaining)
- unproductive forest converted to productive forests (CC13 to CC12).

Forest land is expanding in Switzerland (see “Forest management area” in Table 11-2). The land-use change matrix (Table 6-9) shows that these conversions are mainly occurring on former grasslands (CC3X to CC12 or to CC13). The main reason is natural forest regeneration in the Alpine area due to the abandonment of land. Evidence for this process is provided, for example, by Rigling and Schaffer (2015), Brändli (2014), SWI (2009), and Gehrig-Fasel et al. (2007).

11.3 Activity-specific information

11.3.1 Methods for carbon stock change and GHG emission and removal estimates

11.3.1.1 Description of the methodologies and the underlying assumptions used

Emission factors for Afforestations, Deforestations and Forest management were accounted for following the methodology described in chp. 6.1.3.2. The methodological approach is based on the details provided in Table 6-3, and on equations 6.1-6.8 and it is displayed in detail for each carbon pool in Table 11-4. Annual values for carbon stocks and carbon stock changes in the pools of living biomass, dead wood, litter and soil carbon of Afforestations (CC11), productive forests (CC12) and unproductive forests (CC13) are displayed in Table

6-4, Table 6-18, and Table 6-21. All working steps and data required to reproduce the calculation of emission factors in the reporting tables are summarized in FOEN (2020d).

Separation of above- and below-ground living biomass

Carbon stock of total living biomass can be separated into above- and below-ground components using the ratios listed in Table 11-3. Under the UNFCCC aggregated pools were reported, under the Kyoto Protocol the pools were reported separately. For Forest management the stratified ratios shown in Table 11-3 were used. For Afforestation and Deforestation the domestic mean value (0.30) was used.

Table 11-3 Root-to-shoot ratios to separate total living biomass into above- and below-ground living biomass. The ratios are retrieved from the NFI (Brändli 2010: Table 95).

NFI region	Elevation [m]	Root-to-shoot ratios for living trees
1	<601	0.22
	601-1200	0.27
	>1200	0.35
2	<601	0.22
	601-1200	0.24
	>1200	0.40
3	<601	0.23
	601-1200	0.28
	>1200	0.37
4	<601	0.25
	601-1200	0.30
	>1200	0.40
5	<601	0.28
	601-1200	0.32
	>1200	0.40
Switzerland	<601	0.23
	601-1200	0.27
	>1200	0.39
	average	0.30

Table 11-4 Application of the methodolgy described in equations 6.1-6.8 in chp. 6.1.3.2 and in Table 6-3 for calculating carbon stock changes for the Kyoto activities Afforestations (CC11) younger than 20 years (≤ 20 yr) and older than 20 years (>20 yr), Deforestations, and Forest management appearing in four types as defined by land use and land-use change, respectively (CC12 remaining, CC13 remaining, CC12 to CC13, i.e. conversions from CC12 to CC13, and CC13 to CC12, i.e. conversions from CC13 to CC12). In the case of Deforestation to buildings and constructions (i.e. a land-use change from C1X to CC51), changes in carbon stock of mineral soils and of organic soils are accounted for by reducing the carbon stock by 20% (see chp. 6.8.2.3). A conversion time (CT) of 20 years was applied for all pools except for the loss of living biomass, litter and dead wood after Deforestation (CT=1 year). Subscripts used: l = living biomass, h = litter, d = dead wood, s_m = mineral soil, s_o = organic soil, i = spatial stratum, a = land-use-type after the conversion, b = land-use-type before the conversion. CC11 (Afforestation), CC12 (productive forests) and CC13 (unproductive forests) refer to the specific combination category (see Table 6-2).

	Living Biomass	Litter	Dead Wood	Mineral Soil	Organic Soil
Afforestation CC11 ≤ 20 yr	gain-loss gainC$_{l,i,CC11}$ - lossC$_{l,i,CC11}$	stock-difference, CT=20 (stockC$_{h,i,CC11}$ - stockC$_{h,i,b}$)/CT = 0	stock-difference, CT=20 (stockC$_{d,i,CC11}$ - stockC$_{d,i,b}$)/CT = 0	stock-difference, CT=20 (stockC$_{s_m,i,CC11}$ - stockC$_{s_m,i,b}$)/CT	gain-loss changeC$_{s_o,i,CC11}$
Afforestation CC11 > 20 yr	gain-loss gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$	gain-loss changeC$_{h,i,CC12}$	gain-loss changeC$_{d,i,CC12}$	gain-loss changeC$_{s_m,i,CC12}$	gain-loss changeC$_{s_o,i,CC12}$
Deforestation	stock-difference, CT=1 (stockC$_{l,i,a}$- stockC$_{l,i,CC12}$)/CT	stock-difference, CT=1 (stockC$_{h,i,a}$ - stockC$_{h,i,CC12}$)/CT	stock-difference, CT=1 (stockC$_{d,i,a}$ - stockC$_{d,i,CC12}$)/CT	stock-difference, CT=20 C1X to CC51: 0.2 * (stockC$_{s_m,i,CC51}$ - stockC$_{s_m,i,CC1X}$)/CT = 0.2 * (0 - stockC$_{s_m,i,CC1X}$)/CT C1X to other: (stockC$_{s_m,i,a}$ - stockC$_{s_m,i,CC1X}$)/CT	stock-difference, CT=20 C1X to CC51: 0.2*(stockC$_{s_o,i,CC51}$ - stockC$_{s_o,i,CC1X}$)/CT = 0.2 * (0 - stockC$_{s_o,i,CC1X}$)/CT C1X to other: gain-loss; changeC$_{s_o,i,CCXX}$
Forest management CC12 remaining	gain-loss gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$	gain-loss changeC$_{h,i,CC12}$	gain-loss changeC$_{d,i,CC12}$	gain-loss changeC$_{s_m,i,CC12}$	gain-loss changeC$_{s_o,i,CC12}$
Forest management CC13 remaining	gain-loss gainC$_{l,i,CC13}$ - lossC$_{l,i,CC13}$ = 0	gain-loss changeC$_{h,i,CC13}$ = 0	gain-loss changeC$_{d,i,CC13}$ = 0	gain-loss changeC$_{s_m,i,CC13}$ = 0	gain-loss changeC$_{s_o,i,CC13}$
Forest management CC12 to CC13	stock-difference, CT=20 (stockC$_{l,i,CC13}$ - stockC$_{l,i,CC12}$)/CT	stock-difference, CT=20 (stockC$_{h,i,CC13}$ - stockC$_{h,i,CC12}$)/CT	stock-difference, CT=20 (stockC$_{d,i,CC13}$ - stockC$_{d,i,CC12}$)/CT = (0 - stockC$_{d,i,CC12}$)/20	stock-difference, CT=20 (stockC$_{s_m,i,CC13}$ - stockC$_{s_m,i,CC12}$)/CT = 0	gain-loss changeC$_{s_o,i,CC13}$
Forest management CC13 to CC12	gain-loss gainC$_{l,i,CC12}$ - lossC$_{l,i,CC12}$	stock-difference, CT=20 (stockC$_{h,i,CC12}$ - stockC$_{h,i,CC13}$)/CT	stock-difference, CT=20 (stockC$_{d,i,CC12}$ - stockC$_{d,i,CC13}$)/CT = stockC$_{d,i,CC12}$/20	stock-difference, CT=20 (stockC$_{s_m,i,CC12}$ - stockC$_{s_m,i,CC13}$)/CT = 0	gain-loss changeC$_{s_o,i,CC12}$

Reforestation

Reforestation does not occur in Switzerland (FOEN 2006h, Sect. E).

Afforestation ≤ 20 years: units of land not harvested since the beginning of the commitment period

Living biomass

- Gain and loss in living biomass of Afforestations (gross growth and cut and mortality) was taken from the study by Thürig and Traub (2015). Values are available for two elevation levels (Table 6-4).

Litter and dead wood

- On Afforestations, carbon stocks in litter and dead wood were assumed to be zero (IPCC 2006, chp. 4.3.2; see chp. 11.3.1.2 for details). Applying the stock-difference calculation approach (conversion time = 20 years; Table 11-4), calculated changes in the litter and dead wood pool on Afforestations are zero since there is no litter and no dead wood neither on Afforestations (land-use after conversion) nor on any other land-use types outside of forests (land-use before conversion; Table 6-4).

Soil carbon

- Mineral soils: In the case of a land-use change to Afforestations, the difference in soil carbon stocks between land use before and after the conversion was calculated. A conversion time of 20 years was applied.
- For organic soils, emissions due to drainage were calculated as described in chp. 6.4.2.10 and chp. 11.3.1.2.

Afforestation >20 years: units of land harvested since the beginning of the commitment period

After 20 years, afforestated areas are subject to common forest management practices and the first thinnings and treatments are conducted. These afforestated areas are, however, not reclassified to the activity Forest management: all afforestations after 1990 are consistently reported under Afforestation under Article 3.3 (CRF 4(KP-I)A.1; see chp. 11.2.3). Emissions and removals for the carbon pools of Afforestations older than 20 years were calculated using the carbon stock changes of productive forests (CC12; see methodological description under Forest management) since nearly all of the afforestations (99.9% of CC11 changed into CC12; see Table 6-9) develop into productive forests.

Deforestation

The differences in carbon stock of living biomass, litter and dead wood between Forest land and the land-use type after the conversion were immediately accounted for after Deforestation (conversion time = 1 year). Losses in mineral and organic soil carbon stocks due to disturbance caused by Deforestation and conversion to CC51 (buildings and constructions) were accounted for by reducing the carbon stock by 20% of the orginial carbon stock following the proposal of IPCC 2006 (Volume 4, chp. 8.3.3.2) over a conversion period of 20 years (see Table 11-4 and chp. 6.8.2.2).

Forest management

Living biomass

- Gain in living biomass (gross growth) of productive forests was used for “CC12 remaining” (Table 6-18). Gain of unproductive forests was used for “CC13 remaining” and is assumed to be zero (see chp. 6.4.2.8; Table 6-4).
- Losses in living biomass reflects yearly cut and mortality in productive forests “CC12 remaining” (CC12 in Table 6-18). Unproductive forests are not systematically harvested (see description in chp. 6.4.2.8. Thus losses of unproductive forests “CC13 remaining” are assumed to be zero (CC13 in Table 6-4). Moreover, since yearly harvesting amounts from forest statistics (FOEN 2017d) are distributed over the productive forests, total harvesting in forests was accounted for under “CC12 remaining”.
- For the conversions between different forest combination categories (“CC13 to CC12” and “CC12 to CC13”) the method is chosen in such a way that no potential carbon losses could be underestimated: For areas which changed from “CC12 to CC13” the difference in carbon stocks of living biomass was considered and a net loss in carbon stock of living biomass is reported. In the case of a conversion from “CC13 to CC12” a gain-loss approach was applied, since applying a stock-difference approach would lead to a considerable sink in carbon stock of living biomass in this type of Forest management.

Litter, dead wood and soil

- For productive forests “CC12 remaining”, yearly values for changes in carbon stocks of litter, dead wood and soil were used (Table 6-21). The estimates were obtained from simulations with Yasso07 (see chp. 6.4.2.7). For unproductive forests “CC13 remaining”, yearly changes in litter and dead wood and soil carbon stock were assumed to be zero (chp. 6.4.2.8).
- For the conversions between different forest combination categories (“CC13 to CC12” and “CC12 to CC13”) the differences in carbon stocks of dead wood, litter and soil carbon were taken into account. Carbon stocks of litter, dead wood and soils on CC13 are described in chp. 6.4.2.8 and shown in Table 6-4. For litter and dead wood, the conversion “CC12 to CC13” leads to a net loss in carbon stock, in the case of a conversion “CC13 to CC12”, a net gain is reported. Calculated carbon stock changes in mineral soils were zero since carbon stocks in mineral soils of CC12 and CC13 are the same.
- For organic soils, emissions due to drainage were calculated as described in chp. 6.4.2.10.

Differences in accounting for “Forest categories 4A1 and 4A2” under the UNFCCC and Forest management under the Kyoto Protocol Art. 3.4

Under the Kyoto Protocol Art. 3.4, natural forest regeneration is reported under Forest management as productive forest (CC12) or unproductive forest (CC13) as soon as the KP definition of forest is fulfilled (CRF NIR-1 and chp. 11.1.1). Changes within the activity Forest management are reported under the Kyoto Protocol in the combination categories “CC12 to CC13” and “CC13 to CC12”.

Under the UNFCCC, all changes in land use from non-forest land to forest land are reported in the land-use category 4A2 for a conversion time of 20 years. For further details and a quantitative comparison (area budget) see chp. 11.3.2.2.

11.3.1.2 Justification when omitting any carbon pool or GHG emissions/removals from activities under article 3.3 and elected activities under article 3.4

CRF NIR-1 summarizes the activity coverage and the carbon pools reported. When using the Tier 1 approach (IPCC 2006 Volume 4, chp. 1.3; IPCC 2014 chp. 2.3.1) assuming a specific carbon pool to be in balance, the carbon pool is indicated as not reported (NR) or as not estimated (NE) in CRF 4(KP-I)A.1 and 4(KP-I)B.1 (since notation key NR is not available in these tables).

This is the case for litter and dead wood under Afforestation ≤ 20 years. Also for all pools of unproductive forests, no changes are reported.

Changes in carbon pools not reported – Afforestation ≤ 20 years: litter and dead wood

Applying the stock-difference calculation approach (cf. Table 11-4), calculated changes in the litter and dead wood pools after Afforestation under 20 years are zero (see chp. 6.4.2.9), since carbon stock in litter and dead wood is assumed to be zero on Afforestations (land-use after conversion; IPCC 2006, Volume 4, chp. 4.3.2) and also on all other land-use types outside of forests (land-use before conversion; Table 6-4).

A Tier 1 approach for these pools for Afforestations under 20 years was applied because a) Afforestation is not a key category (see chp. 11.6.1) and b) because the relatively small carbon stock changes in these pools do not justify the (financial) effort to collect higher quality data without jeopardizing the resources for key categories (see Figure 4.1 in Volume 1 of IPCC 2006). Verifiable information to justify this approach is provided here:

- Changes in litter after afforestation: Under the Kyoto Protocol, changes in the litter pool after Afforestations were not reported. In an experiment by Zimmermann and Hiltbrunner (2012) litter accumulation of an afforestation with Norway Spruce was determined 40 years after afforestation. The authors found accumalation rates of 0.17-0.20 t C ha-1 yr-1. Other studies show even higher accumlation rates, e.g., 0.24-0.34 t C ha-1 yr-1 for afforestations with Norway spruce in the Southern Alps (Thuille and Schulze 2006), 0.24 t C ha-1 yr-1 for afforestation with ash and maple (Alberti et al. 2008) and 0.36 t C ha-1 yr-1 for Scotch pine (Vesterdal et al. 2002). In Finnish forests, Karhu et al. (2011) found that over 18 years the mean annual rate of carbon accumulation in the litter was 0.28 Mg ha-1 for Scots pine and 0.15 Mg ha-1 for birch.
- Based on a literature overview, Jandl et al. (2007) argued that the accumulation of a forest floor layer in, e.g., a conifer forest, results in a carbon sink. The authors concluded that after afforestation, forest floors accumulate carbon quickly. A long-term consequence of afforestation is the gradual incorporation of carbon in the carbon pool of the mineral soil. Guidi et al. (2014) found that the carbon stocks in the organic layers were affected by land-use change, with more carbon stored under early-stage forest compared with grassland abandoned 10 years ago, and highest carbon stocks were found under the old forest dominated by Fagus sylvatica and Picea abies.
- Changes in dead wood after afforestation: no changes in the dead wood pool after afforestations were reported. Zimmermann and Hiltbrunner (2012) showed that 40 years after afforestation with Norway Spruce, dead wood volume amounted to 10.4 t C ha-1. This corresponds to an annual increase of carbon stored in the dead wood of 0.26 t C ha-1 yr-1 for afforestations with Norway Spruce.
- Besides the results of the case studies listed above, a reasoning based on sound knowledge of likely system responses (Grassi and Blujdea 2011) was provided: At stand level, the pools dead wood and litter of afforestation on cropland and grassland cannot be a source, especially if the previous land use did not have perennial woody biomass. On afforestations, tree growth is assumed to follow an exponential pattern, which can also be assumed for the accumulation of litter and dead wood.

Note that for Afforestations older than 20 years, estimates of carbon stock changes in dead wood, litter and soil were reported.

Changes in carbon pools not reported – Unproductive forests

A description of unproductive forests and the reasoning why the living biomass, litter, dead wood and soil pools were reported to be in equilibrium and thus not a source is given in detail in chp. 6.4.2.8.

Based on the fact that unproductive forest land only covers 8-9% of the area under Forest management (CRF 4(KP.I)B) and based on the description of these stands in chp. 6.4.2.8, emissions or removals of any of the pools of unproductive forests do not account for more than 2530% of the activity Forest management. Based on the decision tree in Fig. 4.1 in IPCC (2006; Volume 1, chp. 4.1.2) and Fig 1.2 note 4 in IPCC (2006; Volume 1) that "a subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category", Switzerland decided to not jeopardize the resources for other key categories and hence used a Tier 1 approach. Thus no changes in the carbon pools of living biomass, litter, dead wood and mineral soil of unproductive forest areas are reported

Greenhouse gas sources reported

- Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or had been established on drained areas. Abegg (2017) estimated that 3% of organic soils in forest land is or has been subject to drainage. CO_2 emissions due to drainage are calculated as described in chp. 6.4.2.10. N_2O emissions from drainage of organic soils were calculated as described in chp. 6.4.2.11.

Greenhouse gas sources reported as “included elsewhere (IE)”

- Emissions from biomass burning on Afforestations and unproductive forests were reported under Forest management, subdivision productive forests (CC12). In this way, emissions were not underestimated, since the carbon stock (available fuel) in productive forests is higher than the carbon stocks of Afforestations and unproductive forests. Moreover, this approach reflects reality quite well since fires on Afforestations or in unproductive forests are rather unlikely to occur (see chp. 6.4.2.12).
- Biomass burning on areas under Forest management: CO_2 emissions were reported as “IE”. The reported losses of living biomass and dead wood are covered by NFI data and thus the values reported in the reporting tables Table4.A and 4(KP-I)B.1 include these losses. Emissions of CH_4 and N_2O were reported. The calculation of these emissions is described in chp. 6.4.2.12.

Greenhouse gas sources reported as “not occurring (NO)”

- Fertilisation of forests is prohibited by the Swiss forest law and adherent ordinances (Swiss Confederation 1991, 1992). Additionally, the “Ordinance on Chemical Risk Reduction“ (Swiss Confederation 2005) prohibits the application of fertilisers, including liming, in forests. Thus, emissions from fertilisation on Afforestations and Forest management were reported as “not occurring”.
- HWP from Afforestation: Since land under Afforestation in Switzerland typically serves purposes other than timber production, biomass is not removed for products entering the HWP pool. In case there is some wood of first thinnings in Afforestations since 1990, it is mostly left on the site or sometimes collected for energy purposes (i.e. it could be assessed as instantaneous oxidation). Therefore, the amount of HWP from Afforestation was reported as not occurring (“NO”) and all carbon stock changes in HWPs were reported under Forest management (see chp. 6.11.2). HWP from Deforestation was accounted for on the basis of instantaneous oxidation “IO”.

11.3.1.3 Information on whether or not indirect and natural GHG emissions and removals were factored out

No anthropogenic GHG emissions and removals from elevated CO_2 concentrations, indirect nitrogen deposition or the dynamic effects of the age structure resulting from LULUCF activities under Article 3, paragraphs 3 and 4 prior to 01 January 1990 were factored out.

The IPCC does not give specific methods for factoring out these effects. Besides this, there are no reliable country-specific data available. Investigations on elevated CO_2 concentrations on growth showed complex relationships in the mid-term. Some species showed an increase others a decrease and some no change in growth (Bader et al. 2013). Opposing patterns are also reported regarding the effect of nitrogen deposition: A positve effect of N deposition on growth was found by e.g. Spiecker (1999) and Jarvis and Linder (2000). Other studies (e.g., Hyvönen et al. 2008; Högberg et al. 2006; Braun et al. 2010; Gschwantner 2006; Meining et al. 2008) indicate that N-deposition, while leading to soil acidification, can cause a reduction in growth. Such acidification processes are widely detected in Swiss forest soils (Braun and Flückiger 2012).

11.3.1.4 Changes in data and methods since the previous submission (recalculations)

No recommendations and encouragements were documented during the in-depth review in 2019 (UNFCCC 2020) and all former recommendations and encouragements were resolved (see chp. 10.1.1, Table 10-1). Methodological improvements for Forest land in the LULUCF and the KP-LULUCF sectors are listed in chp. 6.4.5 and in chp. 6.11.5 and are quantitatively assessed in chp. 10.1.2.4 and in chp. 10.1.2.8. No Kyoto-specific methodological modification was made.

11.3.1.5 Uncertainty estimates

Uncertainty estimates of activity data are discussed in detail in chp. 6.1.5, chp. 6.3.3 and are shown in Table 6-10.

A detailed description of the determination of the emission factor uncertainty for Forest land, which is also assigned to the activity Forest management, can be found in chp. 6.4.3. Uncertainty estimates of LULUCF emission factors are shown in Table 6-5, and deduced overall uncertainties for the reported activities under the Kyoto Protocol are composed in Table 11-5: 46.7% for Afforestations (associated UNFCCC category: 4A2), 50.2% for Deforestations (associated UNFCCC category: mainly 4E2) and 46.7% for Forest management (associated UNFCCC category: 4A1).

Lands fulfilling the definition of forest (see chp. 11.1.1) were accounted for under Forest management. Accordingly, the area under Forest management resulting from natural regeneration is attributed the uncertainty of Forest management.

Table 11-5 Uncertainty estimates of activity data (Table 6-10) and emission factors (Table 6-5) and the overall uncertainty of activities reported under the Kyoto Protocol Article 3.3 and Article 3.4.

Activity under KP	Associated category in UNFCCC inventory (chp. 6.3)	Activity data uncertainty	Emission factor uncertainty [%]	Combined uncertainty
		%	%	%
Afforestation	4A2 Land converted to forest land	1.5	46.7	46.7
Deforestation	mainly 4E2 Land converted to settlements	4.6	50.0	50.2
Forest management	4A1 Forest land remaining forest land	1.1	46.7	46.7

11.3.1.6 Information on other methodological issues

N_2O emissions as a result of the disturbance associated with land-use conversion (Deforestation) were reported in CRF 4(KP-II)3. The emissions were calculated according to the methodology described in chp. 6.10.

11.3.1.7 The year of the onset of an activity, if after 2013

The starting year of the activities reported can directly be derived from the land-use change matrix (Table 6-9), from which a continuous time series was derived (Table 11-2).

11.3.2 Category-specific QA/QC and verification

In chp. 6.4.4 category-specific QA/QC and verification items for forest land are described. The general QA/QC measures are described in chp. 1.2.3.

11.3.2.1 Changes in soil carbon stock under Afforestation

The assumption that soils are acting as small sinks under Afforestation is supported by Jandl et al. (2007) who reviewed several studies on the effect of different forest management systems (including afforestations) on soil carbon sequestration and concluded that a long-term consequence of afforestation is the gradual incorporation of carbon in the mineral associated soil carbon pool.

11.3.2.2 Comparison of the forest areas reported in the reporting tables

A direct comparison of the areas reported in the reporting tables under the Convention Forest land remaining forest land (CRF Table4.A) and under Forest management under the Kyoto Protocol (CRF 4(KP-I)B.1) is not possible due to the different structure of these reporting tables and due to different reporting requirements:

- Conversions to Forest land which are not human-induced (natural regneration) were not accounted for as Afforestations under the Kyoto Protocol. These areas were reported under KP Art. 3.4 Forest management in CRF 4(KP-I)B.1 as soon as the definition of Forest was fulfilled. Under the Convention, these afforestations were reported under land-use category 4A2 with a conversion time of 20 years.
- Afforestations under the Kyoto Protocol which are older than 20 years were consistently reported under Art. 3.3 (sub-division >20 years in CRF 4(KP-I)A.1: units of land harvested since the beginning of the commitment period). Thus, there is no reclassification of the units of lands reported under Art. 3.3. In contrast, under the UNFCCC, afforestations older than 20 years were reallocated to the land-use category 4A1 Forest land remaining forest land.
- Not all changes from a forest combination category (CC11, CC12, CC13) to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. (see chp. 11.2.3). These areas remained under the Kyoto Protocol Art. 3.4 activity Forest management and were included in the areas as reported in CRF 4(KP-I)B.1.
- Reporting of land-use changes LUC: Since only the KP activity Forest management is accounted for under KP Art. 3.4, changes from other KP activities to Forest land were not reported seperately, but were reported under Forest management (CC12 or CC13) as soon as the KP definition of forest was fulfilled. Only conversions within the activity Forest

management were reported under the Kyoto Protocol, i.e. CC12 to CC13 and CC13 to CC12. Under the UNFCCC, land-use change to forest land were reported in category 4A2.

In Meteotest (2020) the reported activity data for the inventory year 2018 were examined and compared (Table 11-6). The differences in the reporting tables Table4.A, 4(KP-I)A.1 and 4(KP-I)B.1 can be explained and the resulting budget of areas reported under the Convention and the Kyoto Protocol is identical. For the next submission, the area comparison will be updated.

Table 11-6 Area budget (in kha) of KP-LULUCF and LULUCF under the UNFCCC in the year 2018 for forest land (Meteotest 2020).

Activity	Table, Cells	area UNFCCC kha	area KP kha	Check Difference kha	remarks
All Forest Land					
Forest Management	4(KP-I)B.1, D11		1'262.297		a)
Afforestations <= 20 years	4(KP-I)A.1, C29		1.075		b)
Afforestations > 20 years	4(KP-I)A.1, C13		1.543		c)
Total area KP			1'264.914		
Non-Kyoto loss of forest cover			-1.060		d)
Forest Land UNFCCC	4.A, C10	1'263.854			e)
Total		1'263.854	1'263.854	0.000	
Afforestation, CC11					
UNFCCC	4.A, C32+C36+C40 +C44+C48	1.075			f)
KP (<= 20 years)	4(KP-I)A.1, C29		1.075	0.000	g)

Remarks:

a) Forest management consists of CC12 and CC13 areas fulfilling the criteria of the KP.

b) Afforestations are afforested areas since 1990 cumulated over 20 years at most.

c) Afforestations "older than 20 years" (>20 years) comprise the area that has been afforested since more than 20 years. In the UNFCCC tables these areas belong to 4A1 (both CC12 and CC13).

d) The non-Kyoto loss of forest cover is the part of the total area of forest loss (reported under UNFCCC) not fulfilling the definition of Deforestations according to the Kyoto Protocol (see NIR Chapter 11.2.3). For the comparison this area must be subtracted from the KP forest area. It is an annual value (not cumulated) calculated for each year in the period under consideration on the basis of the AREA survey data (chp. 6.2.2).

e) The Total forest land in CRF Table4.A covers productive forests (CC12), unproductive forests (CC13) and afforestations (CC11). It is congruent with the forest area derived from the aerial photos of the AREA survey (NIR Chapter 6.2.2).

f) The CC11 area under the UNFCCC can be derived from CRF Table4.A.2 by summing up the afforestation categories.

g) The cumulated (20 years) CC11 area of KP and UNFCCC are congruent.

11.3.2.3 Impact of forest management on changes in carbon stocks in litter and soil

Accounting for forest management impacts on carbon storage in litter and soil in Swiss productive forests with Yasso07

To estimate carbon stocks and carbon stock changes in the reported litter and soil pools, Switzerland uses the carbon cycling model Yasso07 (Didion et al. 2012, Didion 2019; chp. 6.4.2.7). Yasso07 requires information on carbon inputs from dead organic matter (i.e. non-woody inputs, including foliage and fine roots, woody inputs, including standing and lying dead wood and dead roots) and climate (annual monthly temperature and precipitation). The carbon inputs are obtained for each plot in the NFI that is simulated with Yasso07. The NFI plots were repeatedly measured since the first inventory in 1985 and, hence, observed changes in the volume of living and dead biomass reflect, among other, the site-specific impact of forest management practices. Based on harvesting statistics and allometric relationships, the production of dead wood (incl. dead roots, stems, stumps and branches) and litter from living trees (i.e. controlled by forest management) and as harvest residues were estimated.

Thus, the Yasso07 model reflects the impact of forest management practices: effects of common forest management on carbon stocks in litter (including non-woody and woody material) and soil were fully accounted for in the GHG inventory (Didion et al. 2014a).

Literature Review

A detailed screening of the available scientific literature on the impact of forest management on carbon stock changes in litter and soils is provided in Didion (2014). The majority of studies indicated no significant effect of forest management on soil carbon stocks with the exception of clearcutting (e.g. Jandl et al. 2007). Since silvicultural practices in Switzerland are regulated by law and exclude intensive management options such as clearcuts, fertilisation or liming (Swiss Confederation 1991, 1992), no or only minor forest management impacts on soil carbon stocks can be expected. The production of litter is directly affected by silvicultural practices since the removal of trees results in harvest residues and in a decrease in the amount of remaining foliage (e.g. Van Miegroet and Olsson 2011). Generally, the impact of forest management on litter production is temporary and losses of litter carbon can be rapidly replaced (Nave et al. 2010).

11.4 Article 3.3.

Net CO_2 eq removals from Afforestation and CO_2 eq emissions from Deforestation under Article 3, paragraph 3 differ by one order of magnitude (Figure 11-2, Figure 11-3). Since carbon from living biomass is immediately removed after clear-cutting, deforestation can be seen as a process where carbon is lost over a very short time. In contrast, afforestation is a slow process where carbon is sequestered and accumulated over decades. CO_2 emissions on organic soils under Afforestation are due to former drainage (see chp. 11.3.1.2). Figure 11-2 shows net CO_2 eq removals and emissions from Afforestation and CO_2 eq emissions from Deforestation for the period 1999 until the latest inventory year. Associated data for selected years are listed in Table 11-1.

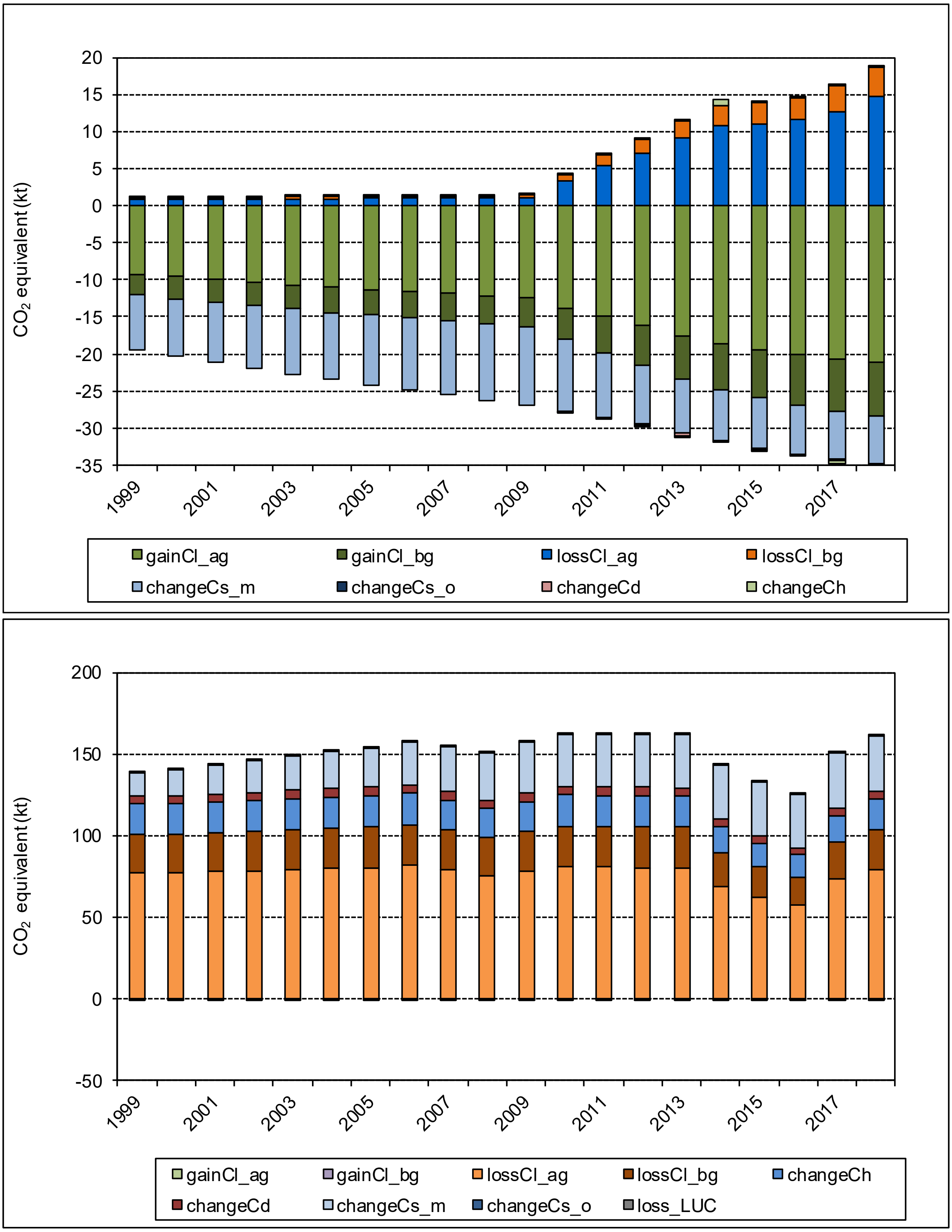


Figure 11-2 Net CO_2 eq removals (negative sign) and CO_2 eq emissions (positive sign) from Afforestation under Article 3, paragraph 3 (upper panel) and emissions from Deforestation under Article 3, paragraph 3 (lower panel) shown per carbon pool. For abbreviations see Table 11-1 and chp. 6.1.3.2. Note the different scale of the y-axis in both graphs.

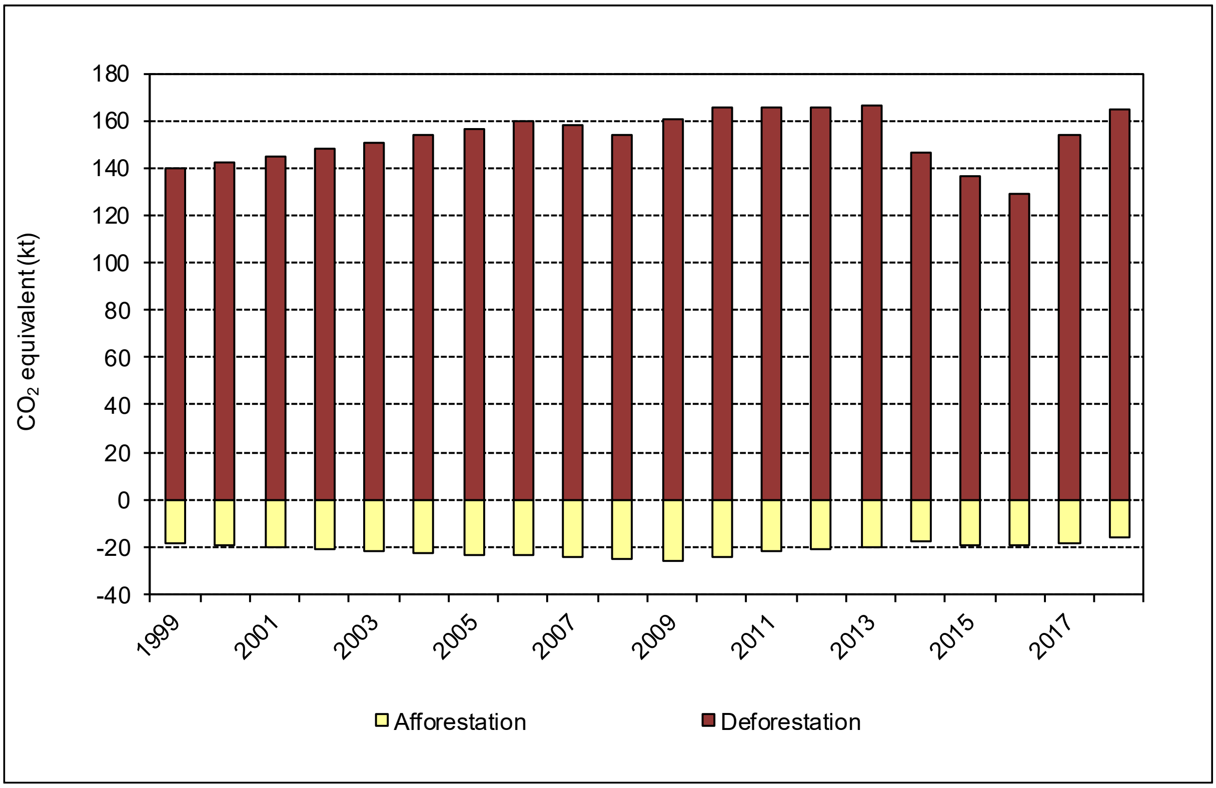


Figure 11-3 Net CO_2 eq removals (negative sign) of Afforestations under Article 3, paragraph 3 and CO_2 eq emissions (positive sign) of Deforestations under Article 3, paragraph 3.

11.4.1 Information that demonstrates that activities under Article 3.3. began on or after 01 January 1990 and before December 2020 and are direct human-induced.

The Swiss definitions of Afforestation and Deforestation only consider direct human-induced activities (see FOEN 2006h, Sect. E and FOEN 2010d).

Reforestation

For more than 100 years, the area of forest in Switzerland has been increasing (see chp. 11.5.2). A decrease in forest area as a result of deforestation is not possible, since deforestation is strongly regulated by the Federal Law on Forests (Swiss Confederation 1991). Therefore, reforestation of areas not forested for a period of at least 50 years does not occur in Switzerland (FOEN 2006h, Sect. E). Switzerland only considers Afforestation and Deforestation under Article 3, paragraph 3.

Afforestation

Switzerland is very restrictive in reporting Afforestations under the Kyoto Protocol and only reports planted forests under Afforestation (see chp. 11.1.3; FOEN 2010h).

The annual rate of all afforested areas since 1990 is assessed based on AREA data (chp. 6.3; chp. 11.1.3; FOEN 2010h). For reporting under the Kyoto Protocol, afforested areas since 1990 always remain in the Afforestation category. Therefore, the area in this activity has been increasing since 1990 (see Table 11-2).

Afforestations older than 20 years are subject to common forest management practices including harvesting (see chp. 11.3.1.1). These areas are reported as a subcategory in CRF 4(KP-I)A.1.

Deforestation

In Switzerland, direct human-induced Deforestation is subject to authorization (Swiss Confederation 1991, Art. 5). Deforestation is only allowed for projects with public interests and in these cases, the deforestation has to be compensated by an afforestation of equal area (FOEN 2010h).

For details concerning the classification of Deforestations under the Kyoto Protocol see chp. 11.2.3. Only deforestation events carried out after 01 January 1990 are considered. For reporting under the Kyoto Protocol, deforested areas since 1990 remain in the Deforestation category. Therefore, the area in this category has been increasing since 1990 (see Table 11-2). Since Switzerland only accounts for KP Art. 3.4 activity Forest management, these deforested areas are not accounted for under another KP Art. 3.4 activity.

11.4.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from Deforestation

The Swiss definition of Deforestation only covers permanent conversions from Forest land to non-forest land. In the process of the interpretation of land conversions based on AREA data (chp. 11.2.3), the definition is implemented by applying the criteria discussed in chp. 11.2.3. This approach was verified by Sigmaplan (2012a).

The criteria distinguish between permanent conversions and transient situations like harvesting or forest disturbance followed by forest re-establishment. Construction of e.g. pipelines and power supply lines within a forest area are transient situations (see chp. 11.1.3 and 11.2.3; Brändli 2010). As described in FOEN (2010d), these non-permanent conversions are not classified as Deforestation under the Kyoto Protocol.

11.4.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

The AREA survey provides a detailed overview of land-use changes with regard to land cover and land use (see chp. 6.2 and 6.3). Temporal changes of land cover can lead to a reclassification in AREA from a forest combination category to a non-forest combination category. However, not all changes from Afforestation CC11, productive forest CC12, or unproductive forest CC13 to a non-forest combination category correspond to the definition of Deforestation according to the Kyoto Protocol Art. 3.3. Explicit criteria were developed (cf. FOEN 2010d and chp. 11.2.3) to identify which conversions from a forest combination category to a non-forest combination category do not correspond to Kyoto Deforestation under the Kyoto Protocol.

11.4.4 Information related to the natural distrubances provision under Article 3.3

Switzerland does not apply the provision of exclusion of natural disturbances for Afforestation and reforestation under Article 3, paragraph 3, of the Kyoto Protocol (FOEN 2016c).

11.4.5 Information on Harvested wood products under Article 3.3

The calculation of carbon stock changes in Harvested wood products (HWP) is described in chp. 6.11. The change in carbon stocks was estimated differentiating HWPs originating from Deforestation and from Forest management. Based on the available datasets it was not possible to differentiate between HWP from Afforestation (if available, it is a negligible amount) and HWP from Forest management. Thus, HWP from Forest management also covers HWP from Afforestation.

Applying instantaneous oxidation to HWP originating from Deforestations, identical results are obtained for changes in carbon stocks of HWP reported under the UNFCCC (CRF Table4.Gs1) and under the Kyoto Protocol (CRF 4(KP-I)C) as shown in Table 6-36.

11.5 Article 3.4

CO_2 eq emissions and removals differentiated for the reported carbon pools and net CO_2 eq emissions and removals of KP Article 3, paragraph 4 activity Forest management for the period 1999 until the latest inventory year are shown in Figure 11-4. Associated data for selected years are listed in Table 11-1. The annual fluctuations of net CO_2 eq emissions and removals from Forest management are described at the start of chp. 11in the text accompanying Figure 11-1.

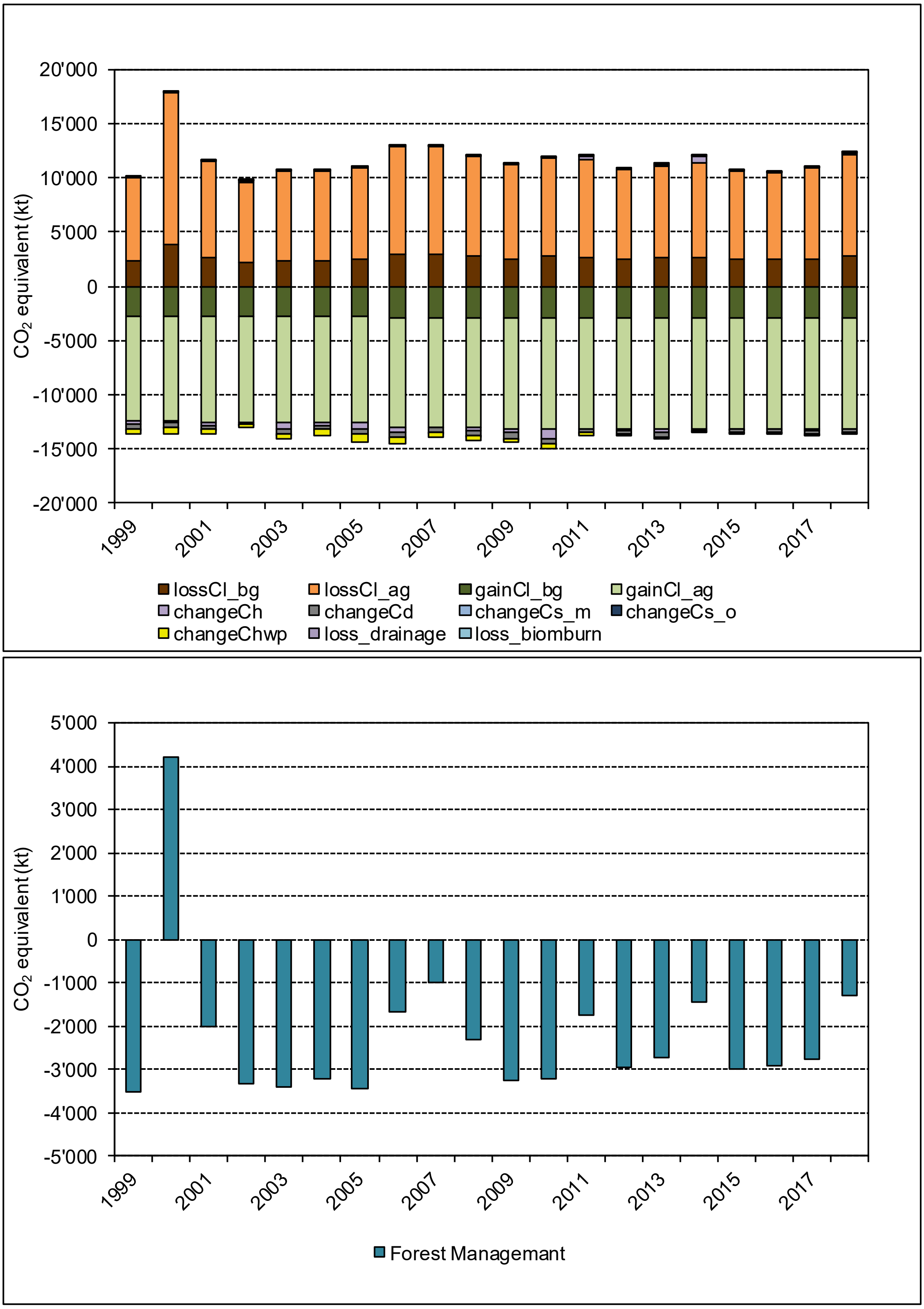


Figure 11-4 CO_2 eq emissions (positive sign) and CO_2 eq removals (negative sign) broken down for the reported carbon pools under Forest management (upper panel) and net CO_2 eq emissions and removals from Forest management (lower panel). For abreviations see Table 11-1 and chp. 6.1.3.2. Note the different scale of the y-axis in both graphs.

11.5.1 Information that demonstrates that activities under Article 3.4. have occurred since 1 January 1990 and are human-induced

According to the Federal Act on Forest, the extent and the spatial distribution of the total forest area in Switzerland has to be preserved (Swiss Confederation 1991, Art. 1) and thus, any change of the forest area has to be authorized. All Swiss forests are under continuous observation of the Swiss Forest Service and monitored by the NFI. Therefore, all forests in Switzerland are subject to forest management and reported under Forest management under Article 3, paragraph 4 of the Kyoto Protocol (FOEN 2006h, Sect. F).

11.5.2 Information relating to Forest management

There is a long tradition of forest protection in Switzerland. The first federal Forest Act came into force in 1876, but it only covered the higher-elevation regions. Its aimed to put a halt to the depletion of forests, to manage the remaining forest areas in a sustainable way, and to promote afforestation. The Forest Act of 1902 covered the whole country. The Forest Act as well as an increasing economic development, resulted in an increase of the forest area in Switzerland by nearly 50% compared to the mid-19th century (Figure 11-5). Also the growing stock increased significantly due to changes in forest management practices. The revised Forest Act (Swiss Confederation 1991) that came into force in 1993, reaffirmed the long-standing Swiss tradition of preserving both forest area and forest ecosystem functions and services. It prescribes sustainable forest management, prohibits clearing, and bans deforestation unless it is replaced by an equal area of afforested land or an equivalent measure to improve biodiversity.

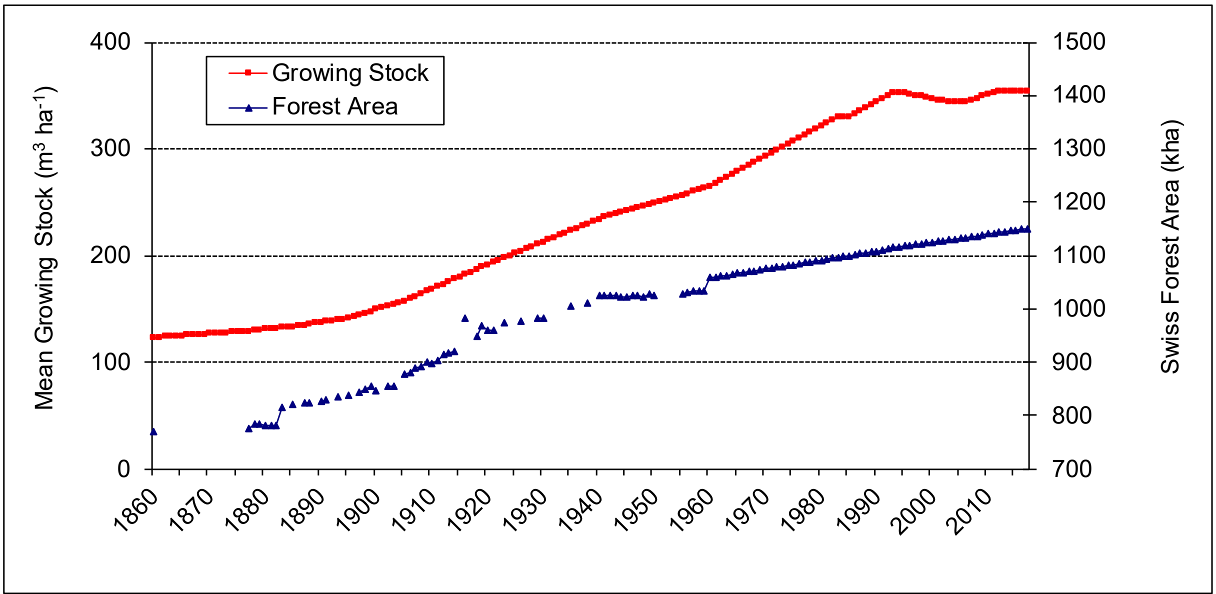


Figure 11-5 Historical mean growing stock (m^3 ha^{-1}) and forest area (kha) in Switzerland.

In 2004, the Swiss National Forest Programme was published, outlining an action plan for the period 2004–2015 (SAEFL 2004b). It specifies five priority objectives: (1) the forests' protective function is guaranteed, (2) the economic viability of the forestry sector is improved, (3) the value-added chain for wood is strengthened, (4) biodiversity is conserved and (5) forest soils, trees and drinking water are not threatened. These objectives encompass that

CO_2 removals by sinks and emissions by sources in the forests shall be recognized in terms of compliance with the Kyoto Protocol while making better use of the potential of forests for timber production and fuel wood through economic incentives and implementing new technologies.

In November 2006, the Swiss government communicated in its Initial Report to the UNFCCC that Switzerland will account for Forest management under Article 3.4 of the Kyoto Protocol (FOEN 2006h). In the second commitment period of the Kyoto Protocol, the accounting of Forest management is mandatory for all Parties.

To implement the objectives of the National Forest Programme (SAEFL 2004b), FOEN has formulated its Wood Resource Policy first initiated in 2008 (FOEN 2008h), updated in 2014 and 2017 (FOEN 2017j). With this Wood Resource Policy the Swiss Confederation formulated a separate Wood Action Plan, which is coordinated with the Forest Policy 2020 (FOEN 2013l), climate policy, energy policy and regional policy. As the lead agency in this process, the FOEN actively promotes the cooperation between these sectoral policy areas, the Swiss forestry and timber sector, and the cantons. The aim of the Wood Resource Policy is to ensure that wood from Swiss forests is supplied, processed and used in a way that is sustainable and resource-efficient. By this means, it makes a major contribution to forest, climate and energy policy. With its three priority areas of ‘optimised cascade use’, ‘climate-appropriate building and refurbishment’ and ‘communication, knowledge transfer and cooperation’, the Wood Action Plan supports the implementation of the Wood Resource Policy (FOEN 2017j). Upon evaluation of the first (2009–2012) and second phase (2013–2016), the Wood Resource Policy has been updated and the Wood Action Plan extended until 2020. In 2017, a new programme phase of the Wood Action Plan started (2017–2020). Its focus and relationship to other policy instruments are described above.

11.5.2.1 Conversion of natural forest to planted forest

Not applicable. Switzerland did not choose to apply the concept of carbon equivalent forests (see CRF 4(KP-I)B.1.2).

11.5.2.2 Forest management reference level (FMRL)

Switzerland’s Forest management reference level (FMRL) is documented in FOEN (2011l). The Swiss FMRL is inscribed in the appendix to the annex to Decision 2/CMP.7 and amounts to +0.220 Mt CO_2 eq. yr^{-1}. The FMRL was subject to a technical assessment. Based on the technical assessment report (UNFCCC 2011a) and applying guidance of IPCC (2014), a technical correction of Switzerland’s FMRL was implemented in FOEN (2015) as described in FOEN (2016: chp. 11.5.2.3). The last technical correction was reported and described in detail in FOEN (2019; chp. 11.5.2.4) and Thürig et al. (2019b).

11.5.2.2.1 Description and implementation of the BAU harvesting scenario

Switzerland’s BAU in FOEN (2011l) is based on Switzerland’s Wood Resource Policy (FOEN 2008h), which is reflected in Switzerlands’ Forest Policy (FOEN 2013l). This policy states that a harvesting level equal to the “potential sustainable wood supply” of 8.2 mio m^3 merchantable timber should be reached in Swiss Forests until 2020. Switzerland’s Wood Resource Policy from 2008 has been elaborated based on exploring several scenarios from two scientific studies: (1) Switzerland’s Potential Sustainable Wood Supply (FOEN 2008h; Switzerland’s PSWS was calculated in Hofer and Altwegg 2008 and refined in Hofer et al. 2011) and (2) Wood Market Model (Pauli and Thees 2009). A linear extrapolation of historical data (1990–2007) supported the increase of harvesting rates to this level.

The implementation of the BAU defined in FOEN (2011l) was elaborated in the first and second technical correction (FOEN 2015, FOEN 2016d and FOEN 2019, Thürig et al. 2019b, respectively), describing an exponential pathway to reach the harvesting level of 8.2 Mio m^3 in 2020. After 2020, harvesting amount was assumed to remain constant.

Merchantable wood and assortments into semi-finished products

In Switzerland’s Wood Resource Policy (FOEN 2008h) the targeted annual harvesting amount was formulated as “merchantable wood”. However, it was not further specified how “merchantable wood” is assigned to the different assortments. The assignment into the different assortments was therefore based on the mean distribution observed in the harvesting statistics 2005–2009 (Table 6-17; calculated as described in FOEN 2019g).

BAU harvesting volume: regional distribution and harvesting of brances

The BAU scenario aims at reaching 8.2 million m^3 merchantable timber by 2020 following an exponential increase of harvesting being realized in all NFI-Production regions of Switzerland. While the Central Plateau (Figure 6-4) remains the largest provider of coniferous timber, this amount cannot be further increased, because harvesting already exceeds increment resulting in decreasing growing stock and conifer proportion (see chp. 1.2 and 3.1 in FOEN 2015q). Thürig et al. (2019b) showed that the BAU scenario of increasing the harvesting amount to 8.2 million m^3 merchantable timber can only be realized by intensifying harvesting in other production regions in Switzerland.

Further, based on recent harvesting statistics (Table 6-17), it was approximated that 35% of all branches of deciduous trees are removed from the forest (Thürig et al. 2019b).

Mortality equals “background level for natural disturbances”

Mortality was adjusted to amount to 16.34% of the total mean cut and mortality (“losses in living biomass”) from 1990–2009. This corresponds to the Swiss “background level for natural disturbances” (FOEN 2016c).

11.5.2.3 Information on the main factors generating the accounted quantity

The reason for differences between the FMRL and the annually reported carbon balance of Forest management is mainly due to short-time fluctuations in annual harvesting rates. However, the difference between the mean carbon balance of Forest management over the periode 2013–2018 (-2.35 Mt CO_2 eq based on Table 11-1) and the corrected FMRL (-2.49 Mt CO_2 eq; Table 11-7) is very small.

It must be mentioned, that in the next submission the FMRL will undergo a technical correction and the reported emissions and removals will be subject to a recalculation. Thus, reported values and also the accounted quantity will change until values will be finalized at the end of the commitment period.

11.5.2.4 Technical correction Forest management reference level

For this submission no improvements leading to a technical correction of the FMRL were implemented.

Switzerland decided not to provide technical corrections of the FMRL on an annual basis, but to correct the FMRL periodically. The last technical correction was reported and described in detail in FOEN (2019: chp. 11.5.2.4) and in Thürig et al. (2019b). In order to reflect the most recent scientific knowledge, data availability and model versions and to ensure methodological consistency between the FMRL and reporting for Forest management, the next technical correction of the FMRL will be reported in Switzerland's GHG inventory submission in 2021.

The impact of all technical corrections of the FMRL made since FOEN (2011l) on carbon stock changes in living biomass, dead wood, litter and soil organic carbon in Swiss Forests are summarized in Table 11-7. The technical correction from the previous submission is still valid. It is the difference between the FMRL submitted in February 2011 (FOEN 2011l) and the corrected values for the FMRL published in FOEN (2019) and amounts to -2.71 Mt CO_2 eq yr^{-1}.

Table 11-7: Summary of the technical correction of the FMRL. Values from FMRL as defined in FOEN (2011l), corrected values as described in FOEN (2015) and updated in FOEN (2016d) after the in-country review and corrected values as described in this submission (FOEN 2019) are listed per pool or source. Abbreviations as used in chp. 6.1.3.2 and in Table 11-1.

Pool (Mt CO_2 eq yr^{-1})	**FMRL FOEN 2011**	**FMRLcor FOEN 2016d**	**FMRLcor FOEN 2019**
$changeC_l$	0.48	-0.33	-0.73
$changeC_h$, $changeC_d$, $changeC_s$	-0.05	-0.59	-0.88
$changeC_{HWP}$	-0.21	-0.78	-0.89
non-CO_2-GHG from controlled burning	IE (in 5C2)	0.01	0.005
Total FMRL	**0.22**	**-1.69**	**-2.49**

11.5.2.5 Information related to the natural disturbance provision under Article 3.4

11.5.2.5.1 Application of the provision of natural disturbances

As indicated in Switzerland's Second Initial Report (FOEN 2016c, FOEN 2016d), Switzerland intends to apply, in the case of significant magnitude events, the provision of natural disturbances for units of lands under Forest management during the second commitment period in accordance with decision 2/CMP.7. In cases or events in which emissions from natural disturbances are higher than the nationally established threshold value and in which all other requirements defined in 2/CMP.7 and IPCC (2014) are met, Switzerland will evaluate and decide whether the technical effort would be justified to exclude them.

Between 2013 and the reporting year, no natural disturbances causing emissions exceeding the upper confidence interval (background level plus margin) occurred. Thus, no emissions from natural disturbances were excluded for those inventory years.

11.5.2.5.2 Technical correction of the background level and margin

The background level and margin have been reviewed and are reported in the update of Switzerland's Second Initial Report under the Kyoto Protocol (FOEN 2016d).

There is no technical correction of the background level and margin so far.

11.5.2.6 Information on Harvested wood products under Article 3.4

Methodology, estimates and uncertainties of carbon stock changes in the HWP pool are described in chp. 6.11. The same methodology was applied for reporting HWP from Forest land under the UNFCCC and accounting for HWP from Forest management under the Kyoto Protocol. A time series for changes in the HWP pool is shown in Table 6-36 and Figure 6-14. An overview of emissions and removals resulting from the HWP pool from Forest management is presented in Table 11-1 and Figure 11-1.

11.5.3 Information relating to Cropland management, Grazing Land management, Revegetation and Wetland drainage and rewetting if elected, for the Base Year

Not applicable.

11.5.4 Information that demonstrates that emissions and removals resulting from elected Article 3, paragraph 4 activities are not accounted for under activities under Article 3, paragraph 3

This information is requested in the Annex to 15/CMP.1 paragraph 9(c). The reporting of Forest management under Article 3, paragraph 4 is clearly separated from the reporting of the activities under Article 3, paragraph 3.

Units of lands with ARD (Afforestation, Reforestation and Deforestation) activities, are reported under Article 3, paragraph 3. These areas always remain under Article 3, paragraph 3. Afforestations older than 20 years are accounted for based on emission factors of mature forests under Forest management. These units of lands are reported in CRF 4(KP-I)A.1 and not under Forest management. Thus, there is no double counting of units of lands under article 3, paragraph 3 to Article 3, paragraph 4.

11.5.5 Information that indicates to what extend removals from Forest management offset the debit incurred under Article 3, Paragraph 3

This information will only be available at the end of the commitment period.

11.6 Other information

11.6.1 Key category analysis for Article 3.3 and 3.4 activities

The results of the Approach 1 key category analysis including LULUCF for the reporting year are shown in Table 1-4 (by emissions) and summarized in Table 1-9. The method is explained in chp. 1.5. The smallest UNFCCC category, considered key based on an Approach 1 level assessment is “3B1-3B4 Manure management, N_2O” with a contribution of 135.33 kt CO_2 eq.

The following LULUCF activities under the Kyoto Protocol are listed in CRF NIR-3 because their associated LULUCF categories in the UNFCCC inventory are key categories under the level or trend assessment:

- Forest management (-1’203.69 kt CO2; subtotal without HWP in CRF 4(KP-I)B.1) encompasses net CO2 removals from Forest management excluding HWP, biomass burning and drainage (see Table 11-1) and is a key category under the Kyoto Protocol because its absolute contribution is higher than the smallest category considered key in the UNFCCC inventory. This activity is associated with the UNFCCC category Forest land remaining forest land. Since the total Swiss forest is considered as managed, there is a good agreement between the activity under the Kyoto Protocol and the UNFCCC category. According to Table 1-9 the UNFCCC category ”Forest land remaining forest land“ is both level and trend key category under Approaches 1 and 2 assessments in the reporting year.
- Afforestation and Reforestation (-16.15 kt CO2; CRF 4(KP)) encompasses net CO2 removals and is not a key category under the Kyoto Protocol because its absolute contribution is substantially lower than the smallest category considered key in the UNFCCC inventory. The associated UNFCCC category Land converted to Forest Land includes converted areas after natural regenerations due to abandonment of land, which are not reported as Afforestation under the Kyoto Protocol. The UNFCCC category Land converted to forest Land is level key category under Approaches 1 and 2 assessments and trend key category under Approach 2 in the reporting year (Table 1-9).
- Deforestation (161.83 kt CO2; CRF 4(KP)) encompasses net CO2 emissions and is a key category under the Kyoto Protocol because its contribution is higher than the smallest UNFCCC category considered key. The associated UNFCCC category is Land converted to settlements, but only a part of this UNFCCC category represents the activity Deforestation under the Kyoto Protocol (see chp. 11.2.3). The UNFCCC category Land converted to settlements is level key category under Approach 1 and 2 assessment in the reporting year (Table 1-9).
- Harvested wood products (-78.34 kt CO2; CRF 4(KP-I)C) is not a key category under the Kyoto Protocol because its absolute contribution is lower than the smallest UNFCCC category considered key. The same method is used for the calculation of HWP under the UNFCCC and the KP. According to Table 1-9 the UNFCCC category ”HWP“ is trend key category category under Approaches 1 and 2 assessments in the reporting year.

11.7 Information relating to Article 6

Switzerland does not host Joint Implementation projects.

12 Information on accounting of Kyoto units

Responsibilities for chapter Information on accounting of Kyoto units	
Overall responsibility	Stefan Meier (FOEN), Regine Röthlisberger (FOEN)
Authors	Stefan Meier (FOEN), Regine Röthlisberger (FOEN)
Sector expert	Susanne Riedener (FOEN)
Internal review	Michael Bock (FOEN), Susanne Riedener (FOEN)

12.1 Background information

The Swiss Emissions Trading Registry completed the go-live process and got fully operational with the International Transaction Log (ITL) on 4 December 2007.

The user interface is located on the Swiss Emissions Trading Registry website (https://www.emissionsregistry.admin.ch). Switzerland uses the CR registry software, which has been developed by Lippke & Wagner GmbH. Switzerland cooperates with Monaco regarding registry issues.

The following registry systems' reporting includes the Standard Electronic Format (SEF) tables and the standard independent assessment report (SIAR) tables in accordance with sections E and G of the annex to decision 15/CMP.1.

12.2 Summary of information reported in the SEF tables

The Standard Electronic Format reports for units with applicable commitment period 1 (CP1), and with applicable commitment period 2 (CP2) for 2019, have been submitted to the UNFCCC Secretariat electronically.

Overview of CP1 units

By the end of 2019, 241'826'246 Assigned Amount Units (AAUs) were held in the Swiss Emissions Trading Registry (Table 12-1). In addition, 4'210'465 Emission Reduction Units (ERUs), 9'280'880 Removal Units (RMUs), 23'935'068 Certified Emission Reductions (CERs), and 114'793 Temporary Certified Emission Reductions (tCERs) were held in the Swiss Emissions Trading Registry. As all CP1 units in Party and Entity holding accounts have been carried over in 2017, there will not be any more changes in CP1 holdings.

Table 12-1 Total quantities of CP1 Kyoto Protocol units by account type at the end of 2019 (SEF table 4)

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	NO	NO	NO	NO	NO	NO
Entity holding accounts	NO	NO	NO	NO	NO	NO
Article 3.3/3.4 net source cancellation accounts	172'587	NO	1'013'340	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Other cancellation accounts	4'796'312	3'651'820	NO	7'896'871	114'793	NO
Retirement account	236'857'347	558'645	8'267'540	16'038'197	NO	NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	241'826'246	4'210'465	9'280'880	23'935'068	114'793	NO

Overview of CP2 units

By the end of the reporting year 2019, a total balance of 5’794’523 AAUs, 78’336’356 ERUs, and 33’810’851 CERs were held in the Swiss Emissions Trading Registry, of which 154’276 ERUs and 7’474’766 CERs have been voluntarily cancelled (Table 12-2).

Table 12-2 Total quantities of CP2 Kyoto Protocol units by account type at the end of 2019 (SEF table 4)

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	NO	NO	NO	1'979'955	NO	NO
Entity holding accounts	NO	78'182'080	NO	24'356'130	NO	NO
Retirement account	NO	NO	NO	NO	NO	NO
Previous period surplus reserve account	5'794'523					
Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Voluntary cancellation account	NO	154'276	NO	7'474'766	NO	NO
Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation account	NO					
Article 3.7 ter cancellation account	NO					
tCER cancellation account for expiry					NO	
lCER cancellation account for expiry						NO
lCER cancellation account for reversal of storage						NO
lCER cancellation account for non-submission of certification report						NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	5'794'523	78'336'356	NO	33'810'851	NO	NO

12.3 Discrepancies and notifications

Switzerland’s reports on discrepancies (R-2), Clean development mechanism (CDM) notifications (R-3), non-replacements (R-4) including reversal of storage and failure of certification and invalid units (R-5) have been uploaded on the UNFCCC Submission Portal.

During the reported year 2019, the Swiss Emissions Trading Registry had no discrepancies, no CDM notifications, no non-replacements including reversal of storage and failure of certification and no invalid units. Therefore, the SIAR tables R-2, R-3, R-4 and R-5 are empty and no actions and changes have been taken to address discrepancies.

12.4 Publicly accessible information

In accordance to section E of the annex to decision 13/CMP.1 the Swiss Emissions Trading Registry makes non-confidential information available to the public via webpage or user-interface.

Non-confidential information is publicly available on the Swiss Emissions Trading Registry website https://www.emissionsregistry.admin.ch. The report 'Accounts' in the Public Information menu provides a list of open accounts in the national registry. The national allocation plan is accessible under 'Allocation' in the Public reports menu. The 'Surrendering Obligation', and 'Surrendered units' per operator are also publicly accessible. The report ‘Issued Attestations” lists all the issued attestations originating from domestic emission-reduction projects.

Data of transfers and holdings of individual accounts are considered as business secrets and the disclosure may prejudice their competitiveness. Information on acquiring and transferring units of companies (as legal persons) is therefore regarded as personal data. Article 19 of the Federal Act on Data Protection (FADP, SR 235.1 Bundesgesetz vom 19. Juni 1992 über den Datenschutz (DSG)) enacts that federal bodies may disclose personal data if there is a legal basis for doing so or if there is an overriding public interest. In the present case these conditions are not fulfilled. Therefore, the registry of Switzerland cannot make the information on acquiring and transferring accounts publicly available and considers them as confidential. The Representative identifier (13/CMP.1 Annex paragraph 45 (d)), as well as all information according to 13/CMP.1 Annex paragraph 45 (e) are also considered as confidential. Therefore, this information is not publicly available. A statement on which information is considered as confidential can be found on the website https://www.emissionsregistry.admin.ch under the Public Information menu.

All other information referred to in paragraphs 44 to 48 to the annex to decision 13/CMP.1 are made publicly available by the Swiss Emissions Trading Registry, if they are not covered by the above mentioned articles.

Information related to Article 6 projects is publicly accessible on the website http://www.bafu.admin.ch/ji-e. Switzerland does not host Joint Implementation (JI)-projects and therefore no issuance of ERUs has taken place.

12.5 Calculation of the Commitment Period Reserve (CPR)

The commitment period reserve and the assigned amount for the second commitment period is defined based on the *Report to facilitate the calculation of the assigned amount pursuant to Article 3, paragraphs 7bis, 8 and 8bis, of the Kyoto Protocol for the second commitment period 2013–2020 (Switzerland's Initial Report under the Kyoto Protocol, 2nd CP)* (FOEN 2016c), and the update to the report following the review (FOEN 2016d). According to the final review report (UNFCCC 2017a), Switzerland's assigned amount for the second commitment period is 361'768.524 kt CO_2 equivalent. The commitment period reserve is 325'591.672 kt CO_2 equivalent.

12.6 KP-LULUCF accounting

Switzerland chose to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol.

13 Information on changes in National Registry

Responsibilities for chapter Information on changes in National Registry	
Overall responsibility	Stefan Meier (FOEN)
Internal review	Susanne Riedener (FOEN)

Table 13-1 Changes in the national registry in accordance with §32 decision 15/CMP.1

Annual Submission Item	Reporting
15/CMP.1 annex II.E paragraph 32.(a): Change of name or contact	No change in the name or contact information of the registry administrator occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(b): Change of cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c): Change of the database or the capacity of National Registry	No change fo the database or to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d): Change of conformance to technical standards	No change in the registry's conformance to technical standards occurred for the reported period.
15/CMP.1 annex II.E paragraph 32.(e): Change of discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f): Change of Security	A new registry software version was installed on the PROD environment in July 2019, which included updated SW-components. No further details are provided for confidentiality reasons. However, it may be made available to the ERT upon approval of a specific request.
15/CMP.1 annex II.E paragraph 32.(g): Change of list of publicly available information	No change to the list of publicly available information occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(h): Change of Internet address	No change of the registry Internet address occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(i): Change of data integrity measures	No change of data integrity measures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(j):	No change of test results occurred during the reporting period.

14 Information on minimization of adverse impacts in accordance with Article 3, Paragraph 14

Responsibilities for chapter Information on minimization of adverse impacts in accordance with Article 3, Paragraph 14	
Overall responsibility	Adrian Schilt (FOEN)
Authors	Gabriela Blatter (FOEN), Patrick Renz (SECO), Dina Spörri (FOEN), Antonia Sutter (SDC)
Internal review	Regine Röthlisberger (FOEN)

The Convention (Art. 4 §8 and §10) and its Kyoto Protocol (Art. 2 §3 and Art. 3 §14) commit Parties to strive to implement climate policies and measures in such a way as to minimize adverse economic, social and environmental impacts on developing countries when responding to climate change.

Context

Switzerland strives to design climate change policies and measures in a way as to ensure a balanced distribution of mitigation efforts by implementing climate change response measures in all sectors and for different gases. Indirectly, this approach is deemed to minimise also potential adverse impacts on concerned actors (including developing countries). Given Switzerland's size and share in international trade (mainly with the European Union), it is not assumed that Swiss climate change policies have any significant adverse economic, social or environmental impacts in developing countries. Additionally, the policies and measures are very much compatible and consistent with those of the European Union in order to avoid trade distortion, non-tariff barriers to trade and to set similar incentives. All major legal reform projects in Switzerland are to be accompanied by impact assessments, inter alia including evaluation of trade-related issues. This approach strives for climate change response measures which are least trade distortive and do not create unnecessary barriers to trade. Consistently, Switzerland notifies all proposed non-tariff measures having a potential impact on trade to the World Trade Organisation.

Impact assessments of legal reform projects are accompanied by a broad internal and external consultation process, inter alia inviting competent and potentially affected actors to provide advice on economic, social and environmental aspects of proposed policies and measures. The open public consultation process, together with regular policy dialogues with other countries guarantee that domestic and foreign stakeholders can raise concerns and issues related to new policy initiatives, including those concerns about possible adverse impacts on other countries.

Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities

Environmental policy in Switzerland, including climate change policies, is guided by the polluter pays principle, as enshrined in the Swiss Federal Act on the Protection of the Environment (Swiss Confederation, 1983). Accordingly, the internalisation of external costs and adequate price signals are key aspects of Switzerland's climate change policy.

Regarding greenhouse gas emissions, market-based instruments – such as e.g. the Swiss emissions trading scheme, the supplemental use of international carbon credits from the Clean Development Mechanism or the CO_2 levy on heating and process fuels – are important measures to put a price on emissions of greenhouse gases that are then reflected in market prices and thus internalizing externalities.

Regarding fiscal incentives, tax and duty exemptions and subsidies, price-based measures are recognised as essential instruments for promoting the efficient use of resources and to reduce market imperfections. In 2001, Switzerland introduced a heavy vehicle charge. It is applied to passenger and freight transport vehicles of more than 3.5 tonnes gross weight. The impact of the heavy vehicle charge was most clearly reflected by changes in traffic volume (truck-kilometres), but also in reduced air pollution, a renewal of the heavy vehicle fleet and an increase of load per vehicle, i.e. fewer trucks transported more goods. Two thirds of the revenues are used to finance major railway infrastructure projects (such as the base tunnels through the Alps), and one third is transferred to the cantons. The Swiss Federal Office for Spatial Development annually publishes a report analysing all external effects of transport (including costs and benefits). The most recent estimates for 2016 correspond to total external costs of transport of about 2.3 billion Swiss francs (external costs related to climate contributing about 200 million Swiss francs), of which slightly less than one billion Swiss francs are covered by the heavy vehicle charge (ARE 2019).

In 2008, Switzerland introduced the CO_2 levy on heating and process fuel to set an incentive for a more efficient use of fossil fuels, promote investment in energy-efficient technologies and the use of low-carbon or carbon-free energy sources. Companies, especially those with substantial CO_2 emissions from use of heating and process fuels, may apply for exemption from the CO_2 levy on heating and process fuels, provided the company commits to emission reductions. The company has to elaborate an emission reduction target based on the technological potential and economic viability of various measures within the company. While the proceeds from the CO_2 levy on heating and process fuels were initially to be fully refunded to the Swiss population (on a per capita basis) and to the Swiss economy (in proportion to wages paid), a parliamentary decision of June 2009 earmarked a third of the revenues from the CO_2 levy on heating and process fuels for CO_2 relevant measures in the buildings sector. As of 1 January 2018, the funds for the national buildings refurbishment programme are limited to a maximum of 450 million Swiss francs per year (previously 300 million Swiss francs per year).

As analysed in detail in two studies, the overall economic impact of the Swiss climate policy is considered to be very small (Ecoplan 2009; FOEN 2010k). In general, Switzerland does not subsidise fossil fuels. However, depending on the definition, there are some policies in place that may be regarded as fossil fuel subsidies, but these policies are only applicable to small amounts of fossil fuels consumed in Switzerland. At the federal level, a few tax exemptions and reductions provide limited support to users of fossil fuels. Farmers, foresters, fishermen and the fuel use of snow cats are exempt from the mineral oil tax that is normally levied on sales of mineral oils, while public transport companies benefit from a reduced rate. These mineral oil tax exemptions in the specific sectors are listed in appendix 3 of the Swiss Federal Council's subsidy report (Swiss Federal Council 2008). Moreover, the mineral oil tax refunds in the agriculture sector was subject to an examination by the Swiss Federal Audit Office. In the respective report published in August 2018, the Swiss Federal Audit Office recommends the preparation of a legislative revision to abolish the mineral oil tax refunds in the agriculture sector (economic support for agriculture should be provided entirely in the form of direct payments)[12]. Some vehicles are also exempt from the performance-related heavy vehicle charge, e.g. agricultural vehicles, vehicles used for the concessionary transport of persons or vehicles for police, fire brigade, oil and chemical emergency unit, civil protection and ambulances.

Worldwide subsidies for fossil fuels are estimated at 300 billion to 500 billion US dollars per year, depending on the level of energy prices. This huge market distortion does not only produce severe fiscal problems for the countries concerned, it also poses a major obstacle for enhanced investments in energy efficiency measures and renewable energies. Switzerland as a founding member of the Friends of Fossil Fuels Subsidy Reform supports the gradual and sustained phasing out of fossil fuel subsidies and the reduction of unnecessary market distortions. Furthermore, Switzerland contributes to the World Bank development project ESMAP (Energy Sector Management Assistance Program). This programme offers technical assistance for states that want to reform their fossil fuel subsidies. The 2016 Annual Report of ESMAP is also supported by Switzerland and provides the analytical basis for the implementation of such reforms.

Removing subsidies associated with the use of environmentally unsound and unsafe technologies

Switzerland does not subsidise the use of environmentally unsound and unsafe technologies.

Cooperating in the technological development of non-energy uses of fossil fuels, and supporting developing country Parties to this end

Switzerland does not support any activities linked to the technological development of non-energy uses of fossil fuels in developing countries.

Cooperating in the development, diffusion, and transfer of less-greenhouse-gas-emitting advanced fossil fuel technologies, and/or technologies, relating to fossil fuels, that capture and store greenhouse gases, and encouraging their wider use; and facilitating the participation of the least developed countries and other non-Annex I Parties in this effort

Switzerland is an active participant in the negotiations for a plurilateral Environmental Goods Agreement (EGA) at the World Trade Organisation with the aim to liberalise environmental goods, including the diffusion and transfer of less-greenhouse-gas-emitting advanced fossil fuel technologies.

Furthermore, Switzerland is supporting the improvement and refit of inefficient gas-fired power plants in developing countries and advocates the use of the most efficient technologies available. Several Swiss universities conduct research in the field of carbon capture and storage and cooperate with other research institutions, companies and universities primarily in Europe and northern America to further develop the technology. Currently, Switzerland is not supporting any least developed countries and other developing

12 https://www.efk.admin.ch/images/stories/efk_dokumente/publikationen/_wirtschaft_und_verwaltung/wirtschaft_und_landwirtschaft/17500/17500BE_WiK_e.pdf

countries in the development of fossil fuel-fired power plants with carbon capture and storage technology, because Switzerland is of the view that the technology is not sufficiently mature and cost effective yet.

Strengthening the capacity of developing country Parties for improving efficiency in upstream and downstream activities relating to fossil fuels, taking into consideration the need to improve the environmental efficiency of these activities

Switzerland supports through different projects the enhancement of efficiency in industrial production, i.e. ‘cleaner production’. These cleaner production projects promote eco-efficient means of production and better working conditions attained through technological improvements and behavioural changes in both management and staff in industrial companies and services. The resulting rise of economic and environmental efficiency and improved competitiveness is gained through the systematic optimisation of energy use, processing of raw material, more efficient use of resources and thus better protection of the environment.

Furthermore, there is a rising awareness and demand by consumers for environmentally sound products. In order to alleviate potential adverse economic impacts of corresponding national measures Switzerland promotes and supports the development of international standards, especially with regard to the sustainable use of natural resources (including agricultural commodities), e.g. through the creation of sustainability standards, financial incentives and favourable framework conditions in developing countries.

Assisting developing country Parties which are highly dependent on the export and consumption of fossil fuels in diversifying their economies

Most developing and transition countries have, in recent years, taken important steps towards trade liberalisation, in order to align their trade policies with international trade agreements. The Swiss State Secretariat for Economic Affairs supports these efforts, because a multilaterally acknowledged and respected set of regulations for international transactions not only strengthens trade as such, but also creates more potent and legally secure markets to the benefit of all players.

The measures taken by the Swiss State Secretariat for Economic Affairs are aimed at creating the necessary conditions for earning additional income in the beneficiary countries and thereby contribute directly to the alleviation of poverty. The Swiss State Secretariat for Economic Affairs is focusing on three areas of intervention along the value chain: (1) enabling framework conditions for trade, (2) international competitiveness, and (3) improving market access.

Regarding market access, trade between developing and industrial countries is often insufficiently developed respectively not diversified enough. On one hand, in some developing countries there is still a lack of necessary production capacities, quality standards, transport infrastructure and know-how; on the other hand, tariff and non-tariff barriers to trade make direct access to markets more difficult.

Switzerland promotes access to Swiss markets by granting preferential tariffs on products from developing and emerging countries. In addition, the Swiss State Secretariat for Economic Affairs runs programmes for promoting imports to Switzerland and the rest of Europe. Easing market entry for products from disadvantaged countries is an important contribution to the promotion and diversification of trade, the increase of export revenues and thus to the economic development of the partner countries. Switzerland supports developing and transition countries in the following areas:

- Generalised system of preferences;
- Swiss Import Promotion Program (www.sippo.ch);
- Promotion and strengthening of private voluntary social and environmental standards based on international multi-stakeholder approaches, such as Better Cotton, 4C (Common Code for the Coffee Community), Roundtable for Sustainable Biofuels, etc.

Finally, Switzerland is a strong supporter of the Extractive Industries Transparency Initiative. Switzerland acts based on the firm conviction that an efficient use of natural resources is an important driving force for sustainable economic growth, contributing to sustainable development and poverty reduction. The sustainable management of natural resources – as supported by the Extractive Industries Transparency Initiative principle and criteria including regular publication and audit of revenues – is key to mobilise the funds for diversification strategies.

Changes compared to the previous submission

There are no fundamtental changes compared to the previous submission.

Annexes

Annex 1 Key category analysis (KCA)

Table A – 1 Overview over all categories included in the KCA (level of disaggregation) and summary of Switzerland’s combined KCA for the year 2018 including LULUCF categories, sorted by NFR code (first column). L1 = level, approach 1; T1 = trend, approach 1; L2 = level, approach 2; T2 = trend, approach 2.

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	**IPCC Category**	**GHG**	**Identification Criteria**
1A1	Energy industries: biomass	CH4	
1A1	Energy industries: biomass	N2O	
1A1	Energy industries: Gaseous fuels	CH4	
1A1	Energy industries: Gaseous fuels	CO2	L1, T1
1A1	Energy industries: Gaseous fuels	N2O	
1A1	Energy industries: Liquid fuels	CH4	
1A1	Energy industries: Liquid fuels	CO2	L1, T1
1A1	Energy industries: Liquid fuels	N2O	
1A1	Energy industries: Other fuels	CO2	L1, L2, T1, T2
1A1	Energy industries: Other fuels	N2O	
1A1	Energy industries: Solid fuels	CH4	
1A1	Energy industries: Solid fuels	CO2	
1A1	Energy industries: Solid fuels	N2O	
1A2	Manufacturing industries and construction: Biomass	CH4	
1A2	Manufacturing industries and construction: Biomass	N2O	
1A2	Manufacturing industries and construction: Gaseous fuels	CH4	
1A2	Manufacturing industries and construction: Gaseous fuels	CO2	L1, L2, T1, T2
1A2	Manufacturing industries and construction: Gaseous fuels	N2O	
1A2	Manufacturing industries and construction: Liquid fuels	CH4	
1A2	Manufacturing industries and construction: Liquid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction: Liquid fuels	N2O	
1A2	Manufacturing industries and construction: Other fuels	CH4	
1A2	Manufacturing industries and construction: Other fuels	CO2	L1, T1, T2
1A2	Manufacturing industries and construction: Other fuels	N2O	
1A2	Manufacturing industries and construction: Solid fuels	CH4	
1A2	Manufacturing industries and construction: Solid fuels	CO2	L1, T1, T2
1A2	Manufacturing industries and construction: Solid fuels	N2O	
1A3a	Civil aviation: Liquid fuels	CH4	
1A3a	Civil aviation: Liquid fuels	CO2	T1
1A3a	Civil aviation: Liquid fuels	N2O	
1A3b	Road transportation: Gasoline	CH4	T1, T2
1A3b	Road transportation: Gasoline	CO2	L1, T1
1A3b	Road transportation: Gasoline	N2O	T1, T2
1A3b	Road transportation: Biomass	CH4	
1A3b	Road transportation: Biomass	N2O	
1A3b	Road transportation: Gaseous fuels	CH4	
1A3b	Road transportation: Gaseous fuels	CO2	
1A3b	Road transportation: Gaseous fuels	N2O	
1A3b	Road transportation: Diesel	CH4	
1A3b	Road transportation: Diesel	CO2	L1, L2, T1, T2
1A3b	Road transportation: Diesel	N2O	T1
1A3c	Railways: Biomass	CH4	
1A3c	Railways: Biomass	N2O	
1A3c	Railways: Liquid fuels	CH4	
1A3c	Railways: Liquid fuels	CO2	
1A3c	Railways: Liquid fuels	N2O	
1A3d	Domestic navigation: Biomass	N2O	
1A3d	Domestic navigation: Biomass	CH4	
1A3d	Domestic navigation: Liquid fuels	CH4	
1A3d	Domestic navigation: Liquid fuels	CO2	
1A3d	Domestic navigation: Liquid fuels	N2O	
1A3e	Other transportation: Gaseous fuels	CH4	
1A3e	Other transportation: Gaseous fuels	CO2	
1A3e	Other transportation: Gaseous fuels	N2O	

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	**IPCC Category**	**GHG**	**Identification Criteria**
1A4a	Commercial: Biomass	CH4	
1A4a	Commercial: Biomass	N2O	
1A4a	Commercial: Gaseous fuels	CH4	
1A4a	Commercial: Gaseous fuels	CO2	L1, T1
1A4a	Commercial: Gaseous fuels	N2O	
1A4a	Commercial: Liquid fuels	CH4	
1A4a	Commercial: Liquid fuels	CO2	L1, T1
1A4a	Commercial: Liquid fuels	N2O	
1A4b	Residential: Biomass	CH4	T1, T2
1A4b	Residential: Biomass	N2O	
1A4b	Residential: Gaseous fuels	CH4	
1A4b	Residential: Gaseous fuels	CO2	L1, L2, T1, T2
1A4b	Residential: Gaseous fuels	N2O	
1A4b	Residential: Liquid fuels	CH4	
1A4b	Residential: Liquid fuels	CO2	L1, T1, T2
1A4b	Residential: Liquid fuels	N2O	
1A4b	Residential: Solid fuels	CH4	
1A4b	Residential: Solid fuels	CO2	
1A4b	Residential: Solid fuels	N2O	
1A4c	Agriculture and forestry: Biomass	CH4	
1A4c	Agriculture and forestry: Biomass	N2O	
1A4c	Agriculture and forestry: Gaseous fuels	CH4	
1A4c	Agriculture and forestry: Gaseous fuels	CO2	
1A4c	Agriculture and forestry: Gaseous fuels	N2O	
1A4c	Agriculture and forestry: Liquid fuels	CH4	
1A4c	Agriculture and forestry: Liquid fuels	CO2	L1, T1
1A4c	Agriculture and forestry: Liquid fuels	N2O	
1A5	Other (military): Biomass	CH4	
1A5	Other (military): Biomass	N2O	
1A5	Other (military): Liquid fuels	CH4	
1A5	Other (military): Liquid fuels	CO2	
1A5	Other (military): Liquid fuels	N2O	
1B2	Oil and natural gas energy production	CH4	L1, T1, T2
1B2	Oil and natural gas energy production	CO2	
1B2	Oil and natural gas energy production	N2O	
1	Indirect CO2 emissions	CO2	
2A1	Cement production	CO2	L1, L2, T1, T2
2A2	Lime production	CO2	
2A3	Glass production	CO2	
2A4	Other process uses of carbonates	CO2	
2B10	Chemical industry other	CO2	
2B10	Chemical industry other	CH4	
2B10	Chemical industry other	N2O	L1, L2, T1, T2
2B2	Nitric acid production	N2O	
2B5	Carbide production	CH4	
2B5	Carbide production	CO2	
2B8	Petrochemical and carbon black production	CO2	
2C1	Iron and steel production	CO2	
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFC	T1
2C4	Magnesium production	SF6	
2C7	Other	CO2	
2D	Non-energy products from fuels and solvent use	CO2	
2E1	Semiconductor	PFC	
2E1	Semiconductor	SF6	
2E1	Semiconductor	HFC	

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES			
Code	**IPCC Category**	**GHG**	**Identification Criteria**
2E3	Photovoltaics	NF3	
2E5	Other electronic	PFC	
2F1	Refrigeration and air conditioning	HFC	L1, L2, T1, T2
2F1	Refrigeration and air conditioning	PFC	
2F2	Foam blowing agents	HFC	T2
2F4	Aerosols	HFC	
2F5	Solvents	HFC	
2G	Other product manufacture and use	CO2	
2G	Other product manufacture and use	HFC	T2
2G	Other product manufacture and use	PFC	
2G	Other product manufacture and use	N2O	T2
2G	Other product manufacture and use	SF6	L1, L2
2H	Other	CO2	
2	Indirect CO2 emissions	CO2	L2, T1, T2
3A	Enteric Fermentation	CH4	L1, L2, T1, T2
3B1-3B4	Manure management	CH4	L1, L2
3B1-3B4	Manure management	N2O	L1, L2
3B5	Indirect N2O emissions from manure management	N2O	L1, L2, T2
3Da	Direct emissions from managed soils	N2O	L1, L2
3Db	Indirect emissions from managed soils	N2O	L1, L2, T1, T2
3G	Liming	CO2	
3H	Urea application	CO2	
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T2
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2
4B2	Land converted to cropland	CO2	
4C1	Grassland remaining grassland	CO2	L2, T2
4C2	Land converted to grassland	CO2	L1, L2, T1, T2
4D1	Wetland remaining wetland	CO2	L2
4D2	Land converted to wetland	CO2	
4E1	Settlements remaining settlements	CO2	
4E2	Land converted to settlements	CO2	L1, L2
4F2	Land converted to other land	CO2	
4G	HWP Harvested wood products	CO2 biog.	T1, T2
4II	Drainage and rewetting	CH4	
4II	Drainage and rewetting	N2O	
4III	Direct N2O from disturbance	N2O	L2
4IV	Indirect N2O	N2O	
4V	Biomass burning	N2O	
4V	Biomass burning	CH4	
5A	Solid waste disposal	CO2	
5A	Solid waste disposal	CH4	L1, L2, T1, T2
5B	Biological treatment of solid waste	CH4	
5B	Biological treatment of solid waste	N2O	
5C	Incineration and open burning of waste	N2O	
5C	Incineration and open burning of waste	CO2	
5C	Incineration and open burning of waste	CH4	
5D	Wastewater treatment and discharge	CH4	L1, L2, T1, T2
5D	Wastewater treatment and discharge	N2O	L2, T2
5	Indirect CO2 emissions	CO2	
6	Other sources	N2O	
6	Other sources	CH4	
6	Other sources	CO2	
6	Indirect CO2 emissions	CO2	

Annex 2 Assessment of uncertainty

A2.1 Detailed results of Approach 1 uncertainty analysis

The table on the next pages shows the detailed results of Approach 1 uncertainty analysis. The structure of the table is identical to Table 3.2 of the 2006 IPCC Guidelines (IPCC 2006, vol. 1, chp. 3). For explanations to the columns see pp. 3.30–3.32 in vol. 1 of IPCC (2006).

Table A – 2 Results of Approach 1 uncertainty analysis including the LULUCF sector, overall results are presented at the bottom of the last part of the table (corresponding to Table 3.2 of Volume 1, Chapter 3 of the IPCC 2006 Guidelines). The uncertainty analysis includes indirect CO_2 emissions.

IPCC Source category					Gas	Base year emissions or removals	Year 2018 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2018	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
						kt CO2 eq	kt CO2 eq	%	%	%	-	%	%	%	%	%
1A1	1. Energy	A. Fuel combustion activities	1. Energy industries	Biomass	CH4	0.47	0.22	10.00	28.28	30.00	2.10E-08	3.62E-06	4.18E-06	1.02E-04	5.91E-05	1.40E-08
				Gaseous F.	CH4	0.11	0.23	5.00	29.58	30.00	2.29E-08	2.56E-06	4.36E-06	7.58E-05	3.08E-05	6.69E-09
				Liquid F.	CH4	0.52	0.17	0.69	30.00	30.01	1.31E-08	5.28E-06	3.30E-06	1.58E-04	3.20E-06	2.51E-08
				Solid F.	CH4	0.13	-	5.00	29.58	30.00	-	2.19E-06	-	6.49E-05	-	4.21E-09
				Gaseous F.	CO2	243.40	511.40	5.00	0.88	5.08	3.31E-03	5.76E-03	9.79E-03	5.07E-03	6.92E-02	4.82E-03
				Liquid F.	CO2	685.81	339.08	0.69	0.08	0.69	2.69E-05	4.86E-03	6.49E-03	3.96E-04	6.30E-03	3.98E-05
				Other F.	CO2	1'491.55	2'482.50	5.00	9.22	10.49	3.33E-01	2.28E-02	4.75E-02	2.11E-01	3.36E-01	1.57E-01
				Solid F.	CO2	49.13	-	5.00	5.06	7.12	-	8.13E-04	-	4.12E-03	-	1.70E-05
				Biomass	N2O	22.58	14.73	10.00	79.37	80.00	6.81E-04	9.17E-05	2.82E-04	7.28E-03	3.99E-03	6.89E-05
				Gaseous F.	N2O	0.13	0.27	5.00	79.84	80.00	2.31E-07	3.05E-06	5.19E-06	2.44E-04	3.67E-05	6.07E-08
				Liquid F.	N2O	1.11	0.24	0.69	80.00	80.00	1.85E-07	1.36E-05	4.65E-06	1.09E-03	4.51E-06	1.19E-06
				Other F.	N2O	24.33	11.50	5.00	79.84	80.00	4.15E-04	1.82E-04	2.20E-04	1.46E-02	1.56E-03	2.15E-04
				Solid F.	N2O	0.24	-	5.00	79.84	80.00	-	3.92E-06	-	3.13E-04	-	9.80E-08
1A2			2. Manufacturing industries and construction	Biomass	CH4	4.31	1.97	10.00	28.28	30.00	1.72E-06	3.35E-05	3.78E-05	9.48E-04	5.34E-04	1.18E-06
				Gaseous F.	CH4	0.48	0.98	5.00	29.58	30.00	4.24E-07	1.09E-05	1.88E-05	3.21E-04	1.33E-04	1.21E-07
				Liquid F.	CH4	4.59	1.22	0.69	30.00	30.01	6.54E-07	5.27E-05	2.33E-05	1.58E-03	2.26E-05	2.50E-06
				Other F.	CH4	0.77	0.55	5.00	29.58	30.00	1.32E-07	2.35E-06	1.05E-05	6.97E-05	7.40E-05	1.03E-08
				Solid F.	CH4	0.31	0.22	5.00	29.58	30.00	2.14E-08	9.20E-07	4.22E-06	2.72E-05	2.98E-05	1.63E-09
				Gaseous F.	CO2	1'091.14	2'204.73	5.00	0.88	5.08	6.15E-02	2.42E-02	4.22E-02	2.13E-02	2.99E-01	8.96E-02
				Liquid F.	CO2	3'974.32	1'740.60	0.69	0.08	0.69	7.10E-04	3.24E-02	3.33E-02	2.64E-03	3.23E-02	1.05E-03
				Other F.	CO2	192.36	438.19	5.00	9.22	10.49	1.04E-02	5.21E-03	8.39E-03	4.80E-02	5.93E-02	5.82E-03
				Solid F.	CO2	1'274.70	396.54	5.00	5.06	7.12	3.91E-03	1.35E-02	7.59E-03	6.84E-02	5.37E-02	7.56E-03
				Biomass	N2O	5.16	14.82	10.00	79.37	80.00	6.90E-04	1.98E-04	2.84E-04	1.57E-02	4.01E-03	2.64E-04
				Gaseous F.	N2O	0.58	1.17	5.00	79.84	80.00	4.29E-06	1.28E-05	2.24E-05	1.02E-03	1.58E-04	1.07E-06
				Liquid F.	N2O	13.35	10.61	0.69	80.00	80.00	3.54E-04	1.77E-05	2.03E-04	1.42E-03	1.97E-04	2.04E-06
				Other F.	N2O	2.32	6.76	5.00	79.84	80.00	1.44E-04	9.11E-05	1.30E-04	7.27E-03	9.16E-04	5.37E-05
				Solid F.	N2O	6.14	1.87	5.00	79.84	80.00	1.10E-05	6.58E-05	3.58E-05	5.26E-03	2.53E-04	2.77E-05
1A3a			3. Transport; Domestic aviation	Kerosene	CH4	0.17	0.10	0.96	60.00	60.01	1.84E-08	8.72E-07	1.96E-06	5.23E-05	2.66E-06	2.74E-09
				Kerosene	CO2	252.55	114.98	0.96	0.16	0.97	6.15E-06	1.98E-03	2.20E-03	3.12E-04	2.99E-03	9.04E-06
				Kerosene	N2O	2.06	0.94	0.96	150.00	150.00	9.78E-06	1.60E-05	1.80E-05	2.40E-03	2.45E-05	5.77E-06

Table A – 2 (continued)

IPCC Source category					Gas	Base year emissions or removals	Year 2018 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2018	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
						kt CO2 eq	kt CO2 eq	%	%	%	-	%	%	%	%	%
1A3b	1. Energy	A. Fuel combustion activities	3. Transport; Road transportation	Gasoline	CH4	108.57	15.22	0.69	36.99	37.00	1.56E-04	1.51E-03	2.92E-04	5.57E-02	2.83E-04	3.10E-03
				Biomass	CH4	-	0.51	10.00	59.16	60.00	4.53E-07	9.70E-06	9.70E-06	5.74E-04	1.37E-04	3.48E-07
				Gaseous F.	CH4	-	0.23	5.00	29.58	30.00	2.33E-08	4.40E-06	4.40E-06	1.30E-04	3.11E-05	1.79E-08
				Diesel	CH4	2.34	5.10	0.88	19.98	20.00	5.11E-06	5.90E-05	9.77E-05	1.18E-03	1.22E-04	1.40E-06
				Gasoline	CO2	11'334.49	7'082.42	0.69	0.13	0.70	1.20E-02	5.19E-02	1.36E-01	6.68E-03	1.32E-01	1.74E-02
				Gaseous F.	CO2	-	33.16	5.00	0.88	5.08	1.39E-05	6.35E-04	6.35E-04	5.59E-04	4.49E-03	2.05E-05
				Diesel	CO2	2'632.59	7'373.27	0.88	0.07	0.88	2.09E-02	9.76E-02	1.41E-01	6.66E-03	1.76E-01	3.11E-02
				Gasoline	N2O	159.87	19.23	0.69	50.00	50.00	4.54E-04	2.28E-03	3.68E-04	1.14E-01	3.57E-04	1.30E-02
				Biomass	N2O	-	6.05	10.00	149.67	150.00	4.04E-04	1.16E-04	1.16E-04	1.73E-02	1.64E-03	3.03E-04
				Gaseous F.	N2O	-	0.55	5.00	79.84	80.00	0.00	0.00	0.00	0.00	0.00	0.00
				Diesel	N2O	5.96	96.85	0.88	21.98	22.00	2.23E-03	1.76E-03	1.85E-03	3.86E-02	2.31E-03	1.50E-03
1A3c			3. Transport; Railways	Biomass	CH4	-	0.00	10.00	59.16	60.00	1.77E-13	6.06E-09	6.06E-09	3.59E-07	8.57E-08	1.36E-13
				Liquid F.	CH4	0.03	0.01	0.88	29.99	30.00	7.16E-11	2.47E-07	2.44E-07	7.41E-06	3.04E-07	5.50E-11
				Liquid F.	CO2	28.69	28.22	0.88	0.07	0.88	3.06E-07	6.55E-05	5.40E-04	4.47E-06	6.74E-04	4.54E-07
				Biomass	N2O	-	0.01	10.00	149.67	150.00	1.14E-09	1.95E-07	1.95E-07	2.91E-05	2.75E-06	8.57E-10
				Liquid F.	N2O	0.43	0.41	0.69	80.00	80.00	5.25E-07	7.76E-07	7.83E-06	6.21E-05	7.59E-06	3.91E-09
1A3d			3. Transport; Domestic navigation	Biomass	CH4	-	0.00	10.00	59.16	60.00	3.32E-11	8.30E-08	8.30E-08	4.91E-06	1.17E-06	2.55E-11
				Liquid F.	CH4	1.68	0.31	0.69	30.00	30.01	4.16E-08	2.20E-05	5.88E-06	6.59E-04	5.70E-06	4.35E-07
				Liquid F.	CO2	114.27	111.70	0.69	0.08	0.69	2.92E-06	2.47E-04	2.14E-03	2.02E-05	2.07E-03	4.31E-06
				Biomass	N2O	-	0.03	10.00	149.67	150.00	7.48E-09	4.98E-07	4.98E-07	7.46E-05	7.05E-06	5.61E-09
				Liquid F.	N2O	1.16	1.21	0.69	150.00	150.00	1.61E-05	3.98E-06	2.31E-05	5.98E-04	2.24E-05	3.58E-07
1A3e			3. Transport; Other transportation	Gaseous F.	CH4	0.07	0.02	5.00	29.58	30.00	2.65E-10	6.89E-07	4.69E-07	2.04E-05	3.32E-06	4.27E-10
				Gaseous F.	CO2	31.42	27.54	5.00	0.88	5.08	9.59E-06	7.34E-06	5.27E-04	6.46E-06	3.73E-03	1.39E-05
				Gaseous F.	N2O	0.02	0.01	5.00	79.84	80.00	6.70E-10	3.40E-09	2.80E-07	2.72E-07	1.98E-06	3.98E-12
1A4a			4. Other sectors; Commercial/institutional	Biomass	CH4	9.22	4.20	10.00	28.28	30.00	7.77E-06	7.22E-05	8.03E-05	2.04E-03	1.14E-03	5.46E-06
				Gaseous F.	CH4	0.68	1.21	5.00	29.58	30.00	6.44E-07	1.19E-05	2.31E-05	3.53E-04	1.64E-04	1.51E-07
				Liquid F.	CH4	15.17	8.24	0.69	30.00	30.01	3.00E-05	9.34E-05	1.58E-04	2.80E-03	1.53E-04	7.88E-06
				Gaseous F.	CO2	920.00	1'189.23	5.00	0.88	5.08	1.79E-02	7.54E-03	2.28E-02	6.64E-03	1.61E-01	2.60E-02
				Liquid F.	CO2	3'918.47	2'294.11	0.69	0.08	0.69	1.23E-03	2.09E-02	4.39E-02	1.70E-03	4.26E-02	1.82E-03
				Biomass	N2O	3.49	9.83	10.00	79.37	80.00	3.03E-04	1.30E-04	1.88E-04	1.04E-02	2.66E-03	1.14E-04
				Gaseous F.	N2O	0.49	0.63	5.00	79.84	80.00	1.25E-06	3.99E-06	1.21E-05	3.18E-04	8.54E-05	1.09E-07
				Liquid F.	N2O	9.51	5.61	0.69	80.00	80.00	9.87E-05	5.01E-05	1.07E-04	4.01E-03	1.04E-04	1.61E-05
1A4b			4. Other sectors; Residential	Biomass	CH4	109.93	22.83	10.00	28.28	30.00	2.30E-04	1.38E-03	4.37E-04	3.91E-02	6.18E-03	1.57E-03
				Gaseous F.	CH4	0.70	1.35	5.00	29.58	30.00	8.07E-07	1.43E-05	2.59E-05	4.24E-04	1.83E-04	2.14E-07
			4. Other sectors; Residential	Liquid F.	CH4	34.83	17.14	0.69	30.00	30.01	1.30E-04	2.48E-04	3.28E-04	7.45E-03	3.18E-04	5.55E-05
				Solid F.	CH4	4.73	0.75	5.00	29.58	30.00	2.48E-07	6.38E-05	1.44E-05	1.89E-03	1.02E-04	3.58E-06
				Gaseous F.	CO2	1'450.97	2'580.46	5.00	0.88	5.08	8.42E-02	2.54E-02	4.94E-02	2.23E-02	3.49E-01	1.23E-01
				Liquid F.	CO2	10'099.07	5'015.62	0.69	0.08	0.69	5.89E-03	7.10E-02	9.60E-02	5.78E-03	9.32E-02	8.71E-03
				Solid F.	CO2	58.40	9.27	5.00	5.06	7.12	2.14E-06	7.89E-04	1.78E-04	4.00E-03	1.26E-03	1.75E-05
				Biomass	N2O	25.85	21.71	10.00	79.37	80.00	1.48E-03	1.21E-05	4.16E-04	9.59E-04	5.88E-03	3.55E-05
				Gaseous F.	N2O	0.77	1.37	5.00	79.84	80.00	5.88E-06	1.34E-05	2.62E-05	1.07E-03	1.85E-04	1.19E-06
				Liquid F.	N2O	24.53	12.21	0.69	80.00	80.00	4.68E-04	1.72E-04	2.34E-04	1.38E-02	2.27E-04	1.90E-04
				Solid F.	N2O	0.28	0.04	5.00	79.84	80.00	6.28E-09	3.80E-06	8.56E-07	3.04E-04	6.05E-06	9.23E-08

Table A – 2 (continued)

Code	Sector	IPCC Source category		Fuel	Gas	Base year emissions or removals	Year 2018 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2018	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
						kt CO2 eq	kt CO2 eq	%	%	%	-	%	%	%	%	%
1A4c	1. Energy	A. Fuel combustion activities	4. Other sectors; Agriculture / forestry / fishing	Biomass	CH4	1.97	0.36	10.00	28.28	30.00	5.64E-08	2.57E-05	6.84E-06	7.27E-04	9.67E-05	5.38E-07
				Gaseous F.	CH4	0.03	0.05	5.00	29.58	30.00	1.24E-09	4.98E-07	1.01E-06	1.47E-05	7.17E-06	2.68E-10
				Liquid F.	CH4	6.72	1.30	0.69	30.00	30.01	7.50E-07	8.62E-05	2.49E-05	2.59E-03	2.42E-05	6.69E-06
				Gaseous F.	CO2	70.06	119.12	5.00	0.88	5.08	1.79E-04	1.12E-03	2.28E-03	9.87E-04	1.61E-02	2.61E-04
				Liquid F.	CO2	742.30	468.18	0.69	0.08	0.69	5.13E-05	3.32E-03	8.96E-03	2.70E-04	8.70E-03	7.57E-05
				Biomass	N2O	0.51	1.43	10.00	79.37	80.00	6.39E-06	1.89E-05	2.73E-05	1.50E-03	3.86E-04	2.39E-06
				Gaseous F.	N2O	0.04	0.06	5.00	79.84	80.00	1.25E-08	5.94E-07	1.21E-06	4.74E-05	8.55E-06	2.32E-09
				Liquid F.	N2O	4.82	4.65	0.69	80.00	80.00	6.78E-05	9.22E-06	8.90E-05	7.37E-04	8.63E-05	5.51E-07
1A5			5. Other	Biomass	CH4	-	0.00	10.00	59.16	60.00	7.13E-14	3.85E-09	3.85E-09	2.28E-07	5.44E-08	5.48E-14
				Liquid F.	CH4	0.12	0.04	0.69	30.00	30.01	6.87E-10	1.21E-06	7.55E-07	3.64E-05	7.33E-07	1.33E-09
				Liquid F.	CO2	217.65	125.43	0.69	0.08	0.69	3.68E-06	1.20E-03	2.40E-03	9.78E-05	2.33E-03	5.44E-06
				Biomass	N2O	-	0.01	10.00	149.67	150.00	3.51E-10	1.08E-07	1.08E-07	1.62E-05	1.53E-06	2.63E-10
				Liquid F.	N2O	1.84	1.10	0.69	150.00	150.00	1.33E-05	9.41E-06	2.10E-05	1.41E-03	2.04E-05	1.99E-06
1B2		B. Fugitive emissions from fuels	2. Oil and natural gas and other emissions from energy production		CH4	336.23	190.88	5.00	29.58	30.00	1.61E-02	1.91E-03	3.65E-03	5.65E-02	2.58E-02	3.86E-03
					CO2	26.34	27.89	5.00	5.10	7.14	1.95E-05	9.81E-05	5.34E-04	5.00E-04	3.78E-03	1.45E-05
					N2O	0.03	0.00	5.00	79.84	80.00	4.22E-13	4.56E-07	7.02E-09	3.64E-05	4.96E-08	1.33E-09
1ind		Indirect emissions			CO2	43.55	5.73	12.34	12.34	17.45	4.91E-06	6.11E-04	1.10E-04	7.54E-03	1.92E-03	6.05E-05
2A1	2. Industrial processes and product use	A. Mineral industry	1. Cement production		CO2	2'580.79	1'738.40	2.00	4.00	4.47	2.97E-02	9.42E-03	3.33E-02	3.77E-02	9.42E-02	1.03E-02
2A2			2. Lime production		CO2	53.35	46.48	2.00	2.00	2.83	8.48E-06	6.94E-06	8.90E-04	1.39E-05	2.52E-03	6.34E-06
2A3			3. Glass production		CO2	15.25	7.89	2.00	3.00	3.61	3.97E-07	1.01E-04	1.51E-04	3.04E-04	4.27E-04	2.75E-07
2A4			4. Other process uses of carbonates		CO2	160.16	74.24	2.00	2.00	2.83	2.16E-05	1.23E-03	1.42E-03	2.46E-03	4.02E-03	2.22E-05
2B2		B. Chemical industry	2. Nitric acid production		N2O	65.49	2.23	2.00	7.23	7.50	1.38E-07	1.04E-03	4.28E-05	7.53E-03	1.21E-04	5.67E-05
2B5			5. Carbide production		CH4	1.74	2.77	2.00	20.00	20.10	1.52E-06	2.42E-05	5.30E-05	4.84E-04	1.50E-04	2.56E-07
			5. Carbide production		CO2	15.72	25.47	2.00	10.00	10.20	3.31E-05	2.28E-04	4.88E-04	2.28E-03	1.38E-03	7.08E-06
2B8			8. Petrochemical and carbon black production		CO2	94.08	97.05	2.00	10.00	10.20	4.81E-04	3.01E-04	1.86E-03	3.01E-03	5.26E-03	3.67E-05
2B10			10. Other (Niacin, Limestone pit)		CH4	0.09	-	-	-	-	0.00E+00	1.49E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
					CO2	17.34	19.65	2.00	60.00	60.03	6.83E-04	8.93E-05	3.76E-04	5.36E-03	1.06E-03	2.99E-05
					N2O	432.38	554.65	2.00	60.00	60.03	5.44E-01	3.46E-03	1.06E-02	2.08E-01	3.00E-02	4.41E-02
2C1		C. Metal industry	1. Iron and steel production		CO2	11.91	12.04	2.00	5.00	5.39	2.06E-06	3.34E-05	2.30E-04	1.67E-04	6.52E-04	4.53E-07
2C3			3. Aluminium production		CO2	139.26	-	5.00	20.00	20.62	-	2.30E-03	-	4.61E-02	-	2.12E-03
			3. Aluminium production		PFC	116.46	-	6.36	6.36	9.00	-	1.93E-03	-	1.23E-02	-	1.50E-04
2C4			4. Magnesium production		SF6	-	-	19.59	19.59	27.70	-	-	-	-	-	-
2C7			7. Other		CO2	1.65	1.65	2.00	20.00	20.10	5.37E-07	4.21E-06	3.15E-05	8.43E-05	8.92E-05	1.50E-08
2D		D. Non-energy products from fuels and solvent use			CO2	57.92	54.27	10.00	10.00	14.14	2.89E-04	8.06E-05	1.04E-03	8.06E-04	1.47E-02	2.17E-04
2E1		E. Electronics industry	1. Integrated circuit or semiconductor		HFC	-	0.80	35.36	35.36	50.00	7.91E-07	1.54E-05	1.54E-05	5.43E-04	7.69E-04	8.86E-07
					PFC	-	9.16	55.72	55.72	78.80	2.56E-04	1.75E-04	1.75E-04	9.77E-03	1.38E-02	2.86E-04
					SF6	-	10.36	42.83	42.83	60.58	1.93E-04	1.98E-04	1.98E-04	8.49E-03	1.20E-02	2.16E-04
2E3			3. Photovoltaics		NF3	-	0.50	35.36	35.36	50.00	3.10E-07	9.62E-06	9.62E-06	3.40E-04	4.81E-04	3.47E-07
2E5			5. Other Electronic		PFC	-	0.44	44.19	51.27	67.68	4.30E-07	8.37E-06	8.37E-06	4.29E-04	5.23E-04	4.58E-07
2F1		F. Product uses as substitutes for ODS	1. Refrigeration and air conditioning		HFC	0.02	1'410.44	10.60	10.60	14.99	2.19E-01	2.70E-02	2.70E-02	2.86E-01	4.05E-01	2.46E-01
					PFC	0.05	1.89	81.88	81.88	115.79	2.36E-05	3.53E-05	3.62E-05	2.89E-03	4.20E-03	2.60E-05
2F2			2. Foam blowing agents		HFC	-	28.30	107.32	107.32	151.77	9.05E-03	5.42E-04	5.42E-04	5.81E-02	8.22E-02	1.01E-02
2F4			4. Aerosols		HFC	-	20.50	28.97	28.97	40.98	3.46E-04	3.93E-04	3.93E-04	1.14E-02	1.61E-02	3.88E-04
2F5			5. Solvents		HFC	-	0.73	45.46	45.46	64.29	1.09E-06	1.41E-05	1.41E-05	6.39E-04	9.04E-04	1.23E-06

Table A – 2 (continued)

		IPCC Source category	Gas	Base year emissions or removals	Year 2018 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2018	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
				kt CO2 eq	kt CO2 eq	%	%	%	-	%	%	%	%	%
2G	2. Ind. Processes	G. Other product manufacture and use	CO2	6.15	36.35	10.00	10.00	14.14	1.30E-04	5.94E-04	6.96E-04	5.94E-03	9.84E-03	1.32E-04
			HFC	-	63.28	25.53	25.53	36.11	2.56E-03	1.21E-03	1.21E-03	3.09E-02	4.37E-02	2.87E-03
			N2O	106.44	31.22	1.00	79.99	80.00	3.06E-03	1.16E-03	5.98E-04	9.31E-02	8.45E-04	8.67E-03
			PFC	-	24.15	24.35	24.35	34.44	3.40E-04	4.62E-04	4.62E-04	1.13E-02	1.59E-02	3.81E-04
			SF6	137.01	146.84	32.90	32.90	46.53	2.29E-02	5.44E-04	2.81E-03	1.79E-02	1.31E-01	1.74E-02
2H		H. Other	CO2	1.04	0.32	3.00	7.07	7.68	3.03E-09	1.10E-05	6.20E-06	7.79E-05	2.63E-05	6.76E-09
2ind		Indirect emissions	CO2	333.46	90.96	80.76	80.77	114.22	5.30E-02	3.78E-03	1.74E-03	3.05E-01	1.99E-01	1.33E-01
3A	3. Agriculture	A. Enteric fermentation	CH4	3'584.87	3'296.43	6.46	19.35	20.40	2.22E+00	3.79E-03	6.31E-02	7.32E-02	5.76E-01	3.38E-01
3B		B. Manure Management	CH4	890.82	743.27	6.46	54.89	55.27	8.28E-01	5.12E-04	1.42E-02	2.81E-02	1.30E-01	1.77E-02
		B. Manure Management	N2O	193.96	135.33	23.46	70.72	74.51	4.99E-02	6.19E-04	2.59E-03	4.38E-02	8.60E-02	9.31E-03
		B. Manure Management Indirect	N2O	244.67	272.11	54.85	400.00	403.74	5.92E+00	1.16E-03	5.21E-03	4.64E-01	4.04E-01	3.79E-01
3D		D a. Direct Emissions Managed Soils	N2O	1'286.50	1'100.77	17.71	156.90	157.90	1.48E+01	2.15E-04	2.11E-02	3.37E-02	5.28E-01	2.80E-01
		D b. Indirect Emissions Managed Soils	N2O	576.72	396.84	33.74	282.53	284.54	6.26E+00	1.95E-03	7.60E-03	5.50E-01	3.63E-01	4.34E-01
3G		G. Limestone	CO2	22.25	32.84	40.00	5.00	40.31	8.60E-04	2.61E-04	6.29E-04	1.30E-03	3.56E-02	1.27E-03
3H		H. Urea application	CO2	26.66	13.54	5.00	5.00	7.07	4.50E-06	1.82E-04	2.59E-04	9.09E-04	1.83E-03	4.19E-06
5A	5. Waste	A. Solid waste disposal	CH4	769.74	302.59	21.21	21.21	30.00	4.04E-02	6.94E-03	5.79E-03	1.47E-01	1.74E-01	5.19E-02
			CO2	-	-	7.07	7.07	10.00	-	-	-	-	-	-
5B		B. Biological treatment of solid waste	CH4	11.89	24.92	30.00	30.00	42.43	5.49E-04	2.80E-04	4.77E-04	8.41E-03	2.02E-02	4.81E-04
			N2O	5.22	8.77	30.00	30.00	42.43	6.80E-05	8.17E-05	1.68E-04	2.45E-03	7.13E-03	5.68E-05
5C		C. Incineration and open burning of waste	CH4	8.89	4.98	10.00	59.16	60.00	4.38E-05	5.18E-05	9.53E-05	3.07E-03	1.35E-03	1.12E-05
			CO2	40.23	9.35	10.00	38.73	40.00	6.87E-05	4.87E-04	1.79E-04	1.89E-02	2.53E-03	3.62E-04
			N2O	16.51	31.59	10.00	38.73	40.00	7.84E-04	3.32E-04	6.05E-04	1.28E-02	8.55E-03	2.38E-04
5D		D. Wastewater treatment and discharge	CH4	130.55	188.97	32.00	36.00	48.17	4.07E-02	1.46E-03	3.62E-03	5.25E-02	1.64E-01	2.96E-02
			N2O	80.75	99.66	32.00	146.55	150.00	1.10E-01	5.72E-04	1.91E-03	8.38E-02	8.64E-02	1.45E-02
5ind		Indirect emissions	CO2	1.97	1.11	33.52	33.52	47.40	1.35E-06	1.14E-05	2.12E-05	3.82E-04	1.01E-03	1.16E-06
6	6. Other	Direct emissions	CH4	0.66	0.65	42.43	42.43	60.00	7.56E-07	1.60E-06	1.25E-05	6.78E-05	7.51E-04	5.69E-07
			CO2	10.96	12.31	28.28	28.28	40.00	1.19E-04	5.43E-05	2.36E-04	1.54E-03	9.43E-03	9.12E-05
			N2O	0.60	0.55	106.07	106.07	150.00	3.39E-06	7.43E-07	1.06E-05	7.89E-05	1.59E-03	2.54E-06
6ind		Indirect emissions	CO2	1.04	1.13	53.44	53.44	75.57	3.61E-06	4.52E-06	2.17E-05	2.41E-04	1.64E-03	2.76E-06

Table A – 2 (continued)

IPCC Source category				Gas	Base year emissions or removals	Year 2018 emissions or removals	AD uncertainty	EF uncertainty	Combined uncertainty	Contribution to variance by Category in 2018	Type A sensitivity	Type B sensitivity	Uncertainty in trend in nat. emissions introduced by EF uncertainty	Uncertainty in trend in nat. emissions introduced by AD uncertainty	Uncertainty introduced into the trend in total national emissions
					kt CO2 eq	kt CO2 eq	%	%	%	-	%	%	%	%	%
4 II	4. LULUCF	Drainage, rewetting and other management of organic and mineral soils		CH4	10.75	35.75	10.00	70.00	70.71	3.14E-03	5.07E-04	6.85E-04	3.55E-02	9.68E-03	1.35E-03
				N2O	2.95	2.93	48.80	66.90	82.81	2.89E-05	7.23E-06	5.61E-05	4.84E-04	3.87E-03	1.52E-05
4 III		N mineralization		N2O	35.06	36.45	83.50	135.00	158.74	1.64E-02	1.18E-04	6.98E-04	1.59E-02	8.24E-02	7.05E-03
4 IV		Indirect emissions		N2O	5.42	4.88	85.80	161.50	182.88	3.90E-04	3.69E-06	9.34E-05	5.96E-04	1.13E-02	1.29E-04
4 V		Biomass burning		CH4	18.82	2.51	30.00	70.00	76.16	1.79E-05	2.63E-04	4.80E-05	1.84E-02	2.04E-03	3.44E-04
				N2O	10.92	1.04	30.00	70.00	76.16	3.09E-06	1.61E-04	2.00E-05	1.13E-02	8.46E-04	1.27E-04
4A1		A. Forest land	1. Forest land remaining forest land	CO2	-1'110.44	-1'145.23	1.09	46.70	46.71	1.40E+00	3.55E-03	2.19E-02	1.66E-01	3.37E-02	2.86E-02
4A2			2. Land converted to forest land	CO2	-524.29	-525.70	1.54	46.70	46.73	2.96E-01	1.39E-03	1.01E-02	6.49E-02	2.19E-02	4.69E-03
4B1		B. Cropland	1. Cropland remaining cropland	CO2	235.22	-356.04	4.89	133.10	133.19	1.10E+00	1.07E-02	6.82E-03	1.43E+00	4.72E-02	2.03E+00
4B2			2. Land converted to cropland	CO2	32.47	31.32	5.12	144.00	144.09	9.99E-03	6.22E-05	6.00E-04	8.96E-03	4.34E-03	9.92E-05
4C1		C. Grassland	1. Grassland remaining grassland	CO2	43.98	96.29	5.23	1'224.70	1'224.71	6.83E+00	1.12E-03	1.84E-03	1.37E+00	1.36E-02	1.87E+00
4C2			2. Land converted to grassland	CO2	89.02	219.71	5.31	43.50	43.82	4.55E-02	2.73E-03	4.21E-03	1.19E-01	3.16E-02	1.51E-02
4D1		D. Wetlands	1. Wetlands remaining wetlands	CO2	67.76	65.48	90.80	72.24	116.03	2.83E-02	1.32E-04	1.25E-03	9.57E-03	1.61E-01	2.60E-02
4D2			2. Land converted to wetlands	CO2	20.75	41.36	3.95	20.60	20.97	3.69E-04	4.49E-04	7.92E-04	9.24E-03	4.42E-03	1.05E-04
4E1		E. Settlements	1. Settlements remaining settlements	CO2	-45.75	-40.94	4.41	50.00	50.19	2.07E-03	2.67E-05	7.84E-04	1.33E-03	4.89E-03	2.57E-05
4E2			2. Land converted to settlements	CO2	254.56	209.90	4.57	50.00	50.21	5.45E-02	1.94E-04	4.02E-03	9.70E-03	2.60E-02	7.68E-04
4F2		F. Other land	2. Land converted to other land	CO2	86.92	107.60	3.30	50.00	50.11	1.43E-02	6.22E-04	2.06E-03	3.11E-02	9.62E-03	1.06E-03
4G		G. Harvested wood products		CO2	-1'168.82	-78.34	11.20	54.80	55.93	9.42E-03	1.78E-02	1.50E-03	9.78E-01	2.38E-02	9.57E-01
Total including LULUCF (emissions or uncertainty)					**52'224**	**45'140**				**39.24**					**7.27**
Percentage uncertainty in total inventory:										**6.26**	**Trend uncertainty:**				**2.70**

Annex 3 Other detailed methodological descriptions for individual source or sink categories

A3.1 Sector Energy

A3.1.1 Emission from manufacturing industries and construction

The emission factors of precursors in the manufacturing industries and construction sector are given below. Further and more detailed emission factors can be found in Switzerland's Informative Inventory Report (FOEN 2020b).

Emission factors for greenhouse gases are given in 3.2.6.2.

Table A – 3 Emission factors 2018 of precursors from boiler in 1A2 Manufacturing industries and construction.

1A2 Boiler	NO_x	NMVOC	SO_2	CO
	kg/TJ			
Boiler gas oil	31	2	8	6.4
Boiler residual fuel oil	125	4	619	10
Boiler liquefied petroleum gas	19	2	0.5	8
Boiler petroleum coke	125	4	619	10
Boiler other bituminous coal	200	10	500	100
Boiler lignite	203	10	500	100
Boiler natural gas	19	2	0.5	8

A3.1.2 Civil aviation

This paragraph contains further information on the emission modelling. More complete information is provided in FOCA (2006, 2006a, 2007–2019) and on request for reviewers by FOCA.

Emission factors (1A3a)

Table A – 4 Aircraft cruise factors, used for cruise emission calculation (extract of list of 881 aircraft) GKL_ICAO = ICAO seat categories. Mass emissions are given in kilograms or grams per nautical mile (NM).

Aircraft Cruise _Factors						
Aircraft_ICAO	GKL_ICAO	Cruise_D_Source	kg_fuel_NM	kg_NOx_NM	g_VOC_NM	g_CO_NM
AA1	0	P002FOCA	0.21	0.0098	1.79	61.7
AA5	0	P002FOCA	0.21	0.0098	1.79	61.7
AC11	0	P002FOCA	0.21	0.0098	1.79	61.7
AC14	0	P002FOCA	0.21	0.0098	1.79	61.7
AC50	0	P001FOCA	0.77	0.021	4.14	364.17
AC68	0	P001FOCA	0.77	0.0075	4.14	364.17
AC6T	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC90	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC95	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AEST	0	P001FOCA	0.77	0.021	4.14	364.17
AJET	0	FOCAEDBJ014	2.92	0.0146	8.53	63
ALO2	0	FOCAHeli	1.91	0.024	0.42	2.1
ALO3	0	FOCAHeli	1.91	0.024	0.42	2.1
AN12	0	AN26*2	5.36	0.0062	143	348
AN2	0	FOCA/91/DC3	0.82	0.0002	13.7	1000
AN22	6	FOCAINV95-03.2T*2	3.16	0.042	1.74	5.8
AN24	2	AN26	2.68	0.0031	71.7	174
AN26	1	500	2.68	0.0031	71.7	174
AN72	2	FOCAINV95-03.2J	6.4	0.1	0.83	10
AR7	0	P002FOCA	0.21	0.0098	1.79	61.7
AR7A	0	P002FOCA	0.21	0.0098	1.79	61.7
AS02	0	P002FOCA	0.21	0.0098	1.79	61.7
AS16	0	P002FOCA	0.21	0.0098	1.79	61.7
AS20	0	P002FOCA	0.21	0.0098	1.79	61.7
AS24	0	P002FOCA	0.21	0.0098	1.79	61.7
AS25	0	P002FOCA	0.21	0.0098	1.79	61.7
AS26	0	P002FOCA	0.21	0.0098	1.79	61.7
AS2T	0	FOCAEDBT758	0.95	0.005	1.8	12
AS30	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS32	1	FOCAHeli*2	3.82	0.048	0.82	4.2
AS33	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS35	0	FOCAHeli	1.91	0.024	0.42	2.1
AS50	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS55	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS65	0	FOCAHeli*2	3.82	0.048	0.82	4.2
ASK1	0	P002FOCA	0.21	0.0098	1.79	61.7
ASTA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTR	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTRA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
AT42	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AT43	1	500	1.6	0.013	0	15

Activity data (1A3a)

LTO-cycle times (minutes). ICAO standard cycle times were originally designed for emissions certification, not for emissions modelling. Today, they do generally not match real world aircraft LTO operations. Swiss FOCA has therefore adjusted some of the ICAO standard cycle times for different aircraft categories. For jets, the mean time for taxi-in and taxi-out at Swiss airports has been determined 20 minutes instead of the standard 26 minutes (Aerocert 2012, FOCA 2007b, ZRH 2017).

Table A – 5 For jets, business jets, turboprops, piston engines and helicopters, the times in mode are shown and are based on ICAO, US EPA and Swiss FOCA data. “Type” is a classification variable. J = Jet, T = Turboprop, P = Piston, H = Helicopter, HP = Helicopter with Piston Engine, B = Business jet, SJ = Supersonic Jet, E = Electric Aircraft. The number in “Type” stands for the number of engines. For Jet Aircraft, the cycle times and associated thrust settings still lead to an overestimation of LTO emissions (FOCA 2007b).

LTO Cycle				
Type	Time_Take_Off	Time_Climbout	Time_Approach	Time_Taxi
1J	0.7	2.2	4	20
1T	0.5	2.5	4.5	13
1P	0.3	2.5	3	12
1H	0	3	5.5	5
2B	0.4	0.5	1.6	13
3B	0.4	0.5	1.6	13
2T	0.5	2.5	4.5	13
4T	0.5	2.5	4.5	13
2J	0.7	2.2	4	20
3J	0.7	2.2	4	20
4J	0.7	2.2	4	20
2P	0.3	2.5	3	12
3P	0.3	2.5	3	12
4P	0.3	2.5	3	12
2H	0	3	5.5	5
4SJ	1.2	2	2.3	20
3H	0	3	5.5	5
4H	0	3	5.5	5
4B	0.4	0.5	1.6	13
1HP	0	4	5.5	5
2HP	0	4	5.5	5
3HP	0	4	5.5	5
4HP	0	4	5.5	5
1B	0.4	0.5	1.6	13
1E	0.7	10	5	13
4E	0.3	10	5	13
6J	0.7	2.2	4	20

Table A – 6 Aircraft-Engine Combinations and associated codes for SWISS FOCA emissions database. (Extract from list of more than 40’000 individual aircraft)

Aircraft Engine Combinations							
Engine Name	Aircraft Name	Aircraft Registr.	No. Eng.	Code	Type	Aircr. ICAO	Source
V2527-A5	AIRBUS A320-232	ECHXA	2	J220	2J	A320	1IA003
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHXM	2	J090	2J	CRJ2	1GE034
CFM56-3C1	BOEING 737-4K5	ECHXT	2	J022	2J	B734	1CM007
TPE331-11U-611G	FAIRCHILD (SWEARIN-GEN) SA227AC METR	ECHXY	2	T310	2T	SW4	FOI
CFM56-5B4/P	AIRBUS A320-214	ECHYC	2	J067	2J	A320	3CM026
CFM56-5B4/P	AIRBUS A320-214	ECHYD	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHYG	2	J090	2J	CRJ2	1GE034
CFEC-FE738-1-1B	DASSAULT FALCON 2000	ECHYI	2	B130	2B	F2TH	FOI-Ho-neywell
GA TPE331-11U-612G		ECHZH	2	T310	2T	FA3	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHZR	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-86Q (WINGLETS)	ECHZS	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECHZU	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIAA	2	J090	2J	CRJ2	1GE034
FJ44-1A	CESSNA 525 CITATIONJET	ECIAB	2	B001	2B	C525	FOCA
CFM56-5B4/P	AIRBUS A320-214	ECIAG	2	J067	2J	A320	3CM026
V2527-A5	AIRBUS A320-232	ECIAZ	2	J220	2J	A320	1IA003
BRBR700-710A2-20	BOMBARDIER BD-700-1A10 GLOBAL EX-PRE	ECIBD	2	J854	2J	GLEX	4BR009
PT6A-60A	BEECH-CRAFT KING AIR 350 (RAYTHEON B	ECIBK	2	T738	2T	B350	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIBM	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-81Q (WINGLETS)	ECICD	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECICK	2	J067	2J	A320	3CM026

Emissions (1A3a)

The output of the FOCA emission modelling consists of tables with the following structure:

Table A – 7 Extract of the output file of FOCA emission and fuel consumption modelling (example for 2004). Emissions and fuel consumption in tonnes.

Airport	Distance	Type Traffic	Move-ments	Type	Aircraft ICAO	Engine Name	Fuel (LTO) tons	Emissions (LTO) in tons					
	Km		No.					CO_2	H_2O	SO_2	NO_x	VOC	CO
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	5673.492	17871.5	6978.395	5.673	26.04	139	359.2
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	47470.5	149532.1	58388.72	47.47	554.91	0	361.47
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	6164.2728	19417.46	7582.056	6.164	87.539	40.59	185.53
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	5668.542	17855.91	6972.307	5.669	46.937	28.13	163.44
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	4725.108	14884.09	5811.883	4.725	31.31	53.62	169.01
LSGG	112510.267	Taxi	100	2B	F2TH	CFE738-1-1B	5223.96	16455.47	6425.471	5.224	74.186	34.4	157.23
LSGG	107945.477	Taxi	96	2B	C560	JT15D-5D	3795.3216	11955.26	4668.246	3.795	16.959	271.6	287.98
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	307732.68	969357.9	378511.2	307.7	4513	29.43	274.71
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	673698.47	2122150	828649.1	673.7	7986.4	647.8	1038.2
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	225781.85	711212.8	277711.7	225.8	3311.2	21.59	201.55
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	298139.18	939138.4	366711.2	298.1	4372.3	28.52	266.14
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	193723.81	610230	238280.3	193.7	2841	18.53	172.93
LSGG	106761.289	Taxi	100	2B	F2TH	CFE738-1-1B	181011.75	570187	222644.4	181	2654.6	17.31	161.58
LSGG	103217.159	Taxi	96	2B	C560	JT15D-5D	175002.74	551258.6	215253.4	175	2566.5	16.74	156.22

A3.1.3 Road transportation

Base emission factors (1A3b)

The derivation of the emission factors for road transport is described in detail in INFRAS (2019a) and Matzer et al. (2019). The emission factors are contained in the “Handbook Emission Factors for Road Transport (HBEFA)” (version 4.1), which is available publicly as a database application (INFRAS 2019b). Some important features of the emission factor methodologies are summarised in the following paragraphs.

HBEFA differentiates emission factors by emission category, vehicle types and traffic situations.

The following **emission categories** are accounted for:

a) Hot emissions – the emissions caused by vehicles on the road with hot engines;

b) Cold start (excess) emissions – the excess emissions caused by vehicles after cold start when the engine is still cold (note that these emission can be negative in some cases, when the cold engine produces less emissions than in the hot state)

c) Evaporation emissions – evaporation of hydrocarbons (i.e. methane, NMVOC) from the fuel tank of gasoline vehicles. Three sub-processes are distinguished:

- Soak emissions: evaporation after stopping when the engine is still hot;
- Diurnal emissions: evaporation caused by the daily temperature variation;
- Running losses: evaporation during driving.

The hot emissions are generally the most relevant emission category; results show that for CO_2 the hot exhaust emissions contribute to about 97% of the total. Only 3% stem from cold start excess emissions. For CH_4, however, the picture is different. Hot exhaust emissions contribute about two third to the total, cold start emissions about one third. For N_2O, the cold start emission factors are based on the EMEP Guidebook (EMEP/EEA 2016). According to these emission factors, the share of cold start emissions amounts to roughly 9% of total emissions in the year 2018.

Regarding **vehicle types**, HBEFA distinguishes six vehicle categories at the highest aggregation level (i.e. passenger cars, light commercial vehicles, urban buses, coaches, heavy goods vehicles and motorcycles). Each vehicle category is further differentiated by technology (in turn related to fuel type), emission standard, and (optionally) size class. The following table illustrates the segmentation of passenger cars. Similar “segmentations” hold for the other vehicle categories, too.

Table A – 8 Vehicle segmentation of passenger cars for different fuel types (according to HBEFA 4.1, INFRAS 2019b).

Technology	Vehicle sub-segment
Gasoline	<ECE
	AGV82 (CH)
	ECE-15'00
	ECE-15'01/02
	ECE-15'03
	PreEuro 3WCat <1987
	PreEuro 3WCat 1987-90
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6ab
	Euro-6c
	Euro-6d-temp
	Euro-6d
Diesel	conv
	1986-1988
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-5 EA189 before software update
	Euro-5 EA189 after software update
	Euro-6ab
	Euro-6c
	Euro-6d-temp
	Euro-6d

Technology	Vehicle sub-segments
Bifuel CNG/Gasoline	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6
Bifuel LPG/Gasoline	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6
Flex-fuel E85	Euro-3
	Euro-4
	Euro-5
	Euro-6
PHEV	Euro-4
	Euro-5
	Euro-6d
	Euro-6ab
Electricity	BEV
FuelCell	FuelCell

Traffic situations are relevant for hot emissions. They are defined by a scheme (see table below) taking into account 4 parameters: area type (urban/rural areas), 10 road types, speed limits and 5 levels of service (i.e. traffic density classes). This leads to the definition of 365 different traffic situations in total. Each traffic situation implies a typical driving behaviour. The traffic situations have been defined based on driving behaviour studies in Germany and in Switzerland (see Ericsson et al. 2019, INFRAS 2015b).

Table A – 9 Traffic situation-scheme in HBEFA 4.1 (INFRAS 2019b). Every traffic situation is characterised by a typical driving pattern (i.e. a speed-time curve). Legend: Orange colour = urban, blue colour = rural, green colour = motorway.

			Speed Limit [km/h]											
Area	Road type	Levels of service	30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway-Nat.	5 levels of service												
	Semi-Motorway	5 levels of service												
	TrunkRoad/Primary-Nat.	5 levels of service												
	Distributor/Secondary	5 levels of service												
	Distributor/Secondary(sinuous)	5 levels of service												
	Local/Collector	5 levels of service												
	Local/Collector(sinuous)	5 levels of service												
	Access-residential	5 levels of service												
Urban	Motorway-Nat.	5 levels of service												
	Motorway-City	5 levels of service												
	TrunkRoad/Primary-Nat.	5 levels of service												
	TrunkRoad/Primary-City	5 levels of service												
	Distributor/Secondary	5 levels of service												
	Local/Collector	5 levels of service												
	Access-residential	5 levels of service												

Traffic situations are defined independently of vehicle categories (LDV, HDV, 2-wheelers). But for the same traffic situation, each vehicle category is assigned its own “driving pattern” which is expressed as a speed curve (i.e. speed time series).

(Hot) emission factors for these driving patterns are developed by first creating engine maps (i.e. emissions by torque and engine speed) based on measurements performed both on laboratory test benches and on the road using Portable Emission Measurement Systems (PEMS); the PHEM model (Passenger car and Heavy duty Emission model) is then used to simulate emissions for the HBEFA driving patterns by using the emission maps as input. This process is described in detail in Matzer et al. (2019).

For **cold start and evaporation emission factors**, not the driving pattern is determining but ambient conditions. These include climatic parameters (diurnal temperature and humidity profiles for all seasons) but also diurnal profiles of traffic volumes, trip length and parking time distributions. The methodology for the development of cold start emission factors is described in INFRAS (2004, 2019a). The methodology for the evaporation emission factors is adopted from EMEP/EEA (2013, 2016); its implementation in HBEFA is described in INFRAS (2019a).

Cold start excess emissions for N_2O are estimated on the basis of the Tier 3 emission factors for cold-start and hot-start urban conditions published in Tables 3-56 ff. in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA 2016). Based on these emission factors, two N_2O emission calculations are carried out for Switzerland – one hypothetical calculation assuming all starts are hot starts, and a second calculation using the actual cold start share in Switzerland. The difference between the two emission values are the cold start excess emissions. These are divided by the number of cold starts in order to obtain the cold start excess emission factors in g/start.

Activity data (1A3b)

Activity data for the emission model include (see also chp. 3.2.9.2.2.):

a) mileage (vehicle kilometres) for hot emissions and evaporation running losses.

b) the number of starts for cold start excess emissions.

c) the number of stops for evaporation soak emissions.

d) the number of vehicles for evaporation diurnal emissions.

Mileage must be differentiated by vehicle types and traffic situation in order to be able to link it to the hot emission factors differentiated by the same parameters. To do so, three steps must be carried out:

1. Vehicle turnover: The vehicle fleet is built up for each year accounting for stock changes. This vehicle turnover is modelled

a) for historical periods (ex-post) on the basis of vehicle stock and age distributions, and

b) for future periods on the basis of new registrations and by applying survival probabilities.

Trends in traffic volume per vehicle category and segment, including structural changes (size distributions, shares of diesel vehicles) are then combined to draw the continual substitution of older technologies by new ones constantly altering the fleet composition or mileage by emission concepts (Euro classes) in all vehicle categories, see also the following Figure A-1 (INFRAS 2017).

2. The total mileage is an input dataset by the Swiss Federal Statistical Office (SFSO 2019f/g).

3. Assignment of the traffic situations to the mileage for all vehicle categories: This step requires the use of a traffic model: Each road network link carries the information on modelled traffic volume and can be characterized with the parameters defining traffic situations (described above), which allows the assignment sought.

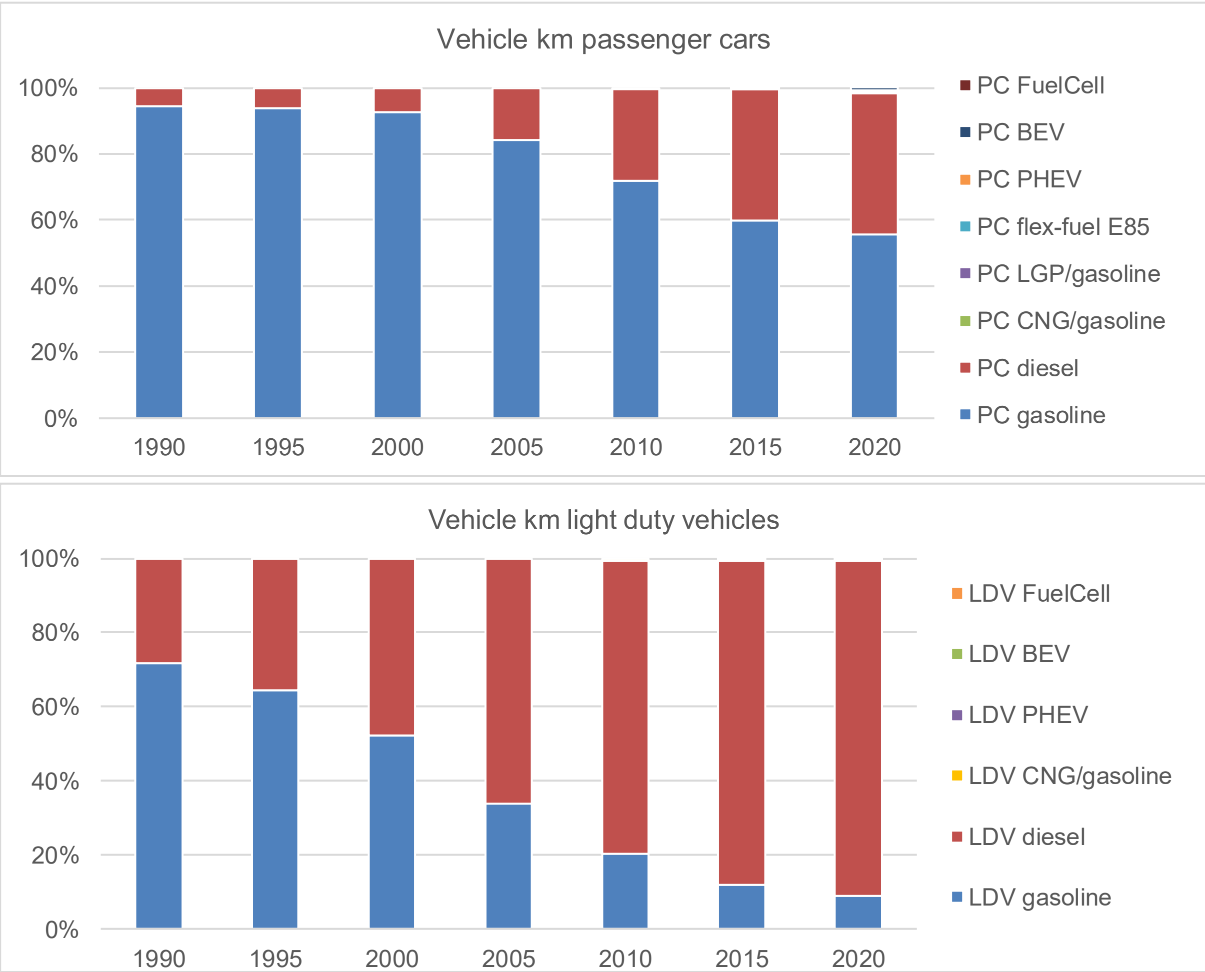


Figure A – 1 Vehicle kilometres per fleet composition for passenger cars (PC, above) and light duty vehicles (LDV, below). Data source: INFRAS (2019b).

Aggregated emission factors (1A3b)

From the base emission factors differentiated by vehicle type and traffic situations, aggregated emissions can be derived by using the activity data described above – i.e. taking into account the fleet composition, which varies from year to year, and the distribution of vehicle kilometres across traffic situations (temporally dynamic as well, derived from traffic models – see section on activity data below).

Average emission factors by vehicle and emission category for Switzerland are shown in the next table.

Table A – 10 Mean emission factors of passenger cars (PC), light duty vehicles (LDV), heavy duty vehicles (HDV), coaches, urban buses (Bus) and Motorcycles (MC) in grams per kilometre (from HBEFA 4.1). Cold start excess emissions are given in g/start.

Pollutant	Year	PC	LDV	HDV	Coach	Bus	MC	PC	LDV
		Hot emission factors gram per vehicle kilometre						Cold start emissions gram per start	
CH_4	1990	0.030	0.048	0.034	0.028	0.060	0.184	0.675	0.725
CH_4	1995	0.016	0.035	0.028	0.026	0.053	0.127	0.422	0.496
CH_4	2000	0.011	0.026	0.018	0.022	0.040	0.152	0.282	0.288
CH_4	2005	0.009	0.014	0.012	0.016	0.021	0.146	0.186	0.149
CH_4	2010	0.006	0.006	0.005	0.009	0.015	0.138	0.124	0.074
CH_4	2015	0.005	0.004	0.004	0.004	0.010	0.102	0.075	0.037
CO	1990	6.6	23.2	3.7	3.3	6.7	11.6	41.2	60.8
CO	1995	2.9	17.7	3.3	3.1	6.3	11.5	29.4	46.9
CO	2000	1.5	12.6	2.4	2.7	5.1	10.7	22.0	31.3
CO	2005	1.1	6.5	2.0	2.4	3.5	9.2	15.7	17.5
CO	2010	0.7	2.9	1.9	2.3	1.8	7.2	10.6	9.1
CO	2015	0.5	1.2	1.5	1.8	1.3	4.9	6.8	4.9
CO_2 (fossil)	1990	222	287	782	932	1'192	115	106	137
CO_2 (fossil)	1995	227	285	815	932	1'219	130	99	127
CO_2 (fossil)	2000	230	282	821	913	1'228	116	97	120
CO_2 (fossil)	2005	220	268	858	889	1'230	124	100	110
CO_2 (fossil)	2010	208	254	842	850	1'182	117	102	101
CO_2 (fossil)	2015	188	248	813	751	1'132	123	89	94
VOC	1990	0.82	1.41	1.42	1.16	2.50	3.04	7.15	6.84
VOC	1995	0.34	0.88	1.15	1.09	2.21	2.34	5.75	5.59
VOC	2000	0.15	0.46	0.75	0.93	1.66	2.42	4.68	4.14
VOC	2005	0.08	0.18	0.45	0.67	0.89	1.62	3.33	2.50
VOC	2010	0.04	0.07	0.19	0.36	0.27	1.13	2.27	1.34
VOC	2015	0.02	0.03	0.14	0.17	0.11	0.72	1.39	0.69
N_2O	1990	0.0093	0.0052	0.0079	0.0084	0.0120	0.0016	0.0203	0.0023
N_2O	1995	0.0125	0.0068	0.0085	0.0084	0.0120	0.0018	0.0410	0.0269
N_2O	2000	0.0110	0.0085	0.0089	0.0083	0.0112	0.0018	0.0526	0.0573
N_2O	2005	0.0050	0.0072	0.0073	0.0069	0.0085	0.0019	0.0009	0.0777
N_2O	2010	0.0034	0.0056	0.0297	0.0137	0.0171	0.0019	0.0084	0.0765
N_2O	2015	0.0034	0.0057	0.0401	0.0247	0.0302	0.0019	0.0113	0.0631
NMVOC	1990	0.79	1.36	1.38	1.13	2.44	2.85	6.48	6.11
NMVOC	1995	0.33	0.85	1.13	1.06	2.16	2.22	5.33	5.10
NMVOC	2000	0.14	0.43	0.73	0.91	1.62	2.26	4.40	3.86
NMVOC	2005	0.07	0.17	0.44	0.66	0.87	1.47	3.14	2.35
NMVOC	2010	0.03	0.06	0.18	0.36	0.26	0.99	2.15	1.27
NMVOC	2015	0.01	0.02	0.13	0.16	0.10	0.62	1.32	0.66
NO_x	1990	0.98	2.38	11.75	13.97	19.14	0.14	0.56	0.03
NO_x	1995	0.58	1.89	11.19	13.17	18.57	0.18	1.20	0.53
NO_x	2000	0.45	1.48	9.87	11.88	16.93	0.17	1.20	0.57
NO_x	2005	0.42	1.32	8.23	9.96	13.90	0.18	0.75	0.24
NO_x	2010	0.42	1.46	5.45	7.63	9.79	0.20	0.39	0.02
NO_x	2015	0.44	1.45	3.57	4.85	6.61	0.17	0.29	-0.06
SO_2	1990	0.038	0.106	0.694	0.828	1.059	0.015	0.017	0.042
SO_2	1995	0.030	0.046	0.176	0.202	0.264	0.017	0.013	0.020
SO_2	2000	0.022	0.038	0.142	0.158	0.212	0.010	0.009	0.015
SO_2	2005	0.001	0.002	0.005	0.006	0.008	0.001	0.001	0.001
SO_2	2010	0.001	0.002	0.005	0.005	0.007	0.001	0.001	0.001
SO_2	2015	0.001	0.002	0.005	0.005	0.007	0.001	0.000	0.001

Modelling total emissions (1A3b)

In order to calculate total emissions, the activity data is multiplied with the respective emission factors resulting in total emissions.

These results correspond to territorial emissions; they do not yet contain the emissions from fuel tourism and statistical differences. Emissions from fuel tourism and statistical differences are calculated by assigning the fuel consumption to categories 1A3bi, 1A3bii, and 1A3biii (as described in chp. 3.2.9.2.2), and using mean emission factors averaged over all vehicle categories.

A3.1.4 Non-road vehicles: supplementary activity data

The following table shows some aggregated information on stock numbers and annual operation hours of non-road vehicles. Detailed information is available in the report FOEN (2015j) and most disaggregated information is available by query from the online non-road database INFRAS (2015a):
https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html

Table A – 11 Overview over stock and operating hours of non-road vehicles (FOEN 2015j): Upper table: Number of vehicles; middle table Specific operating hours per year; lower table: Total operating hours per year (in million hours)

Category	1980	1990	2000	2010	2020	2030
	number of vehicles					
Construction machinery	63'364	58'816	52'729	57'102	60'384	62'726
Industrial machinery	26'714	43'244	70'671	69'786	69'757	70'083
Agricultural machinery	292'773	324'567	337'869	318'876	309'825	305'235
Forestry machinery	11'815	13'844	13'055	11'857	10'831	10'170
Garden-care / hobby appliances	1'198'841	1'539'624	1'944'373	2'322'737	2'464'323	2'499'627
Navigation machinery	94'866	103'383	93'912	95'055	97'522	99'104
Railway machinery	529	1'300	1'255	697	640	640
Military machinery	13'092	13'373	14'272	13'083	12'853	12'856
Total	**1'701'994**	**2'098'151**	**2'528'136**	**2'889'193**	**3'026'135**	**3'060'441**

Category	1980	1990	2000	2010	2020	2030
	Specific operating hours per year					
Construction machinery	247	322	406	417	424	429
Industrial machinery	666	670	684	680	675	671
Agricultural machinery	136	119	112	103	99	95
Forestry machinery	203	199	203	193	188	182
Garden-care / hobby appliances	12	17	20	64	77	81
Navigation machinery	39	38	38	36	35	35
Railway machinery	877	613	617	783	719	719
Military machinery	64	64	63	73	74	74

Category	1980	1990	2000	2010	2020	2030
	million operating hours per year					
Construction machinery	15.7	19.0	21.4	23.8	25.6	26.9
Industrial machinery	17.8	29.0	48.4	47.5	47.1	47.0
Agricultural machinery	39.9	38.8	37.7	33.0	30.6	29.0
Forestry machinery	2.4	2.8	2.6	2.3	2.0	1.9
Garden-care / hobby appliances	14.6	25.7	39.3	149.7	190.8	201.3
Navigation machinery	3.7	3.9	3.5	3.4	3.4	3.4
Railway machinery	0.5	0.8	0.8	0.5	0.5	0.5
Military machinery	0.8	0.9	0.9	0.9	0.9	0.9
Total	**95**	**121**	**155**	**261**	**301**	**311**

A3.1.5 Sulphur dioxide (SO_2)

Table A – 12 shows sulphur contents and SO_2 emission factors per fuel type. Explanations:

- For liquid and solid fuels the SO_2 emission factors are determined by the sulphur content. The upper table depicts the maximum values as defined in the Federal Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985).
- The middle table contains the effective sulphur contents. They are based on measurements: Summary and annual reports of Avenergy Suisse (formerly Erdöl-Vereinigung EV), reports by the Federal Customs Administration (FCA) since 2000, as well as their measurement project 'Schwerpunktaktion Brenn und Treibstoffe'. For diesel oil and gasoline, the measurement project 'Tankstellensurvey', arranged by the FOEN, is a central data source.
- The lower table shows the emission factors in kg/TJ. They are calculated from the effective sulphur content S, the net calorific value NCV and the quotient of the molar masses of S and SO_2.
- $EF_{SO_2} = \frac{M_{SO_2}}{M_S} * \frac{S}{NCV} = 2\frac{S}{NCV}$
- Gas oil: starting from 1990 and for each fifth subsequent year up to and including 2015 the values for the SO_2 emission factors are based on five-year averages (eg. the value for 1995 is based on an average of the years 1993–1997). 1990 is the exception: for this year, the value is based on an average of the three years 1990–1992. The values for all other years are linear interpolations between the years 2015 and 2025 (value 2025: 2 g/GJ). Furthermore, 2006 saw the introduction to the market of low-sulphur eco-grade gas oil with a maximum legal sulphur limit of 50 ppm. From this year onwards, FCA measurements include both standard Euro- and eco-grade gas oil. For each year, the two grades are weighted by the respective total annual fuel consumption. Additionally, as of 2018 heating gas is also classified as gas oil.
- (Bituminous) coal: The legal limit of sulphur content depends on the size of the heat capacity of the combustion system. The value of 1% sulphur content (350 kg SO_2/TJ; see Table A – 12) holds for heat capacity below 1 MW (see OAPC Annex 3, §513 (Swiss Confederation 1985)). For larger capacities, the value is 3% (OAPC Annex 5, §2, Swiss Confederation 1985). For industrial combustion plants, the limit for the exhaust emissions actually sets the corresponding maximum sulphur content to 1.4% (500 kg SO_2/TJ).
- Residual fuel oil: OAPC Annex 5, §11, lit.2 sets 2.8% for the legal limit (denoted as class B in the upper table). Simultaneously, OAPC dispenses from emission control measurements if residual fuel oil of class A is used with sulphur content of maximum 1% (see OAPC Annex 3, §421, lit.2, Swiss Confederation 1985), which holds for most combustion plants. The emission factors are based on five-year averages in the case of 1995, 2000 and 2015. 1990 is based on an average of the years 1990–1992 because no non-interpolated data is available for 1988 and 1989. Similarly, because the emission factors of the years 2006–2008 are not available, the average of 2005 is based on the years 2003–2005 and that of 2010 on 2009–2012. The values for all other years are linear interpolations between the years 2015 and 2035 (value 2035: 500 g/GJ).
- Natural gas: OAPC Annex 5, §42 sets 190 ppm as the legal limit for natural gas.

Table A – 12 Sulphur content (legal limits and effective) and SO_2 emission factors. Legal limits that did not change in a specific year are printed in grey color.

Year	**Maximum legal limit of sulphur content**						
	Diesel oil	Gasoline	Gas oil (Euro)	Natural gas	Res. fuel oil	Res. fuel oil	Coal
	ppm	ppm	ppm	ppm	Class A, %	Class B, %	%
1990	1400	200	2000	190	1.0	2.8	1-3
1991	1300	200	2000	190	1.0	2.8	1-3
1992	1200	200	2000	190	1.0	2.8	1-3
1993	1000	200	2000	190	1.0	2.8	1-3
1994	500	200	2000	190	1.0	2.8	1-3
2000	350	150	2000	190	1.0	2.8	1-3
2005	50	50	2000	190	1.0	2.8	1-3
2008	50	50	1000	190	1.0	2.8	1-3
2009	10	50	1000	190	1.0	2.8	1-3
2010-2018	10	10	1000	190	1.0	2.8	1-3

Year	**Effective sulphur content**				
	Diesel oil	Gasoline	Gas oil (Euro)	Gas oil (Oeko)	Res. fuel oil
	ppm	ppm	ppm	ppm	%
1990	1400	200	1600	NO	0.97
1991	1300	200	1300	NO	0.89
1992	1200	200	1200	NO	0.86
1993	1000	200	1000	NO	0.87
1994	434	200	1350	NO	0.77
1995	341	200	1170	NO	0.78
1996	372	200	1160	NO	0.78
1997	353	200	1250	NO	0.70
1998	402	200	926	NO	0.83
1999	443	200	650	NO	0.62
2000	272	142	680	NO	0.66
2001	250	121	830	NO	0.82
2002	235	101	798	NO	0.82
2003	200	81	700	NO	0.79
2004	10	8.0	700	NO	0.76
2005	10	8.0	800	NO	0.78
2006	10	8.0	740	NO	0.74
2007	10	8.0	680	NO	0.71
2008	10	8.0	620	NO	0.67
2009	7.6	5.3	549	NO	0.92
2010	6.7	4.7	519	NO	0.88
2011	6.6	5.0	417	NO	0.90
2012	7.0	5.3	503	NO	0.91
2013	7.1	4.8	224	NO	0.90
2014	6.8	4.8	516	14	1.11
2015	7.7	4.5	516	14	1.93
2016	7.0	4.6	246	10	1.92
2017	7.7	5.2	248	19	0.98
2018	7.2	4.4	486	5	0.91

Year	**SO_2 emission factor used for Switzerland's emission inventory**								
	Diesel oil (average in 1A3b)	Gasoline (average in 1A3b)	Gas oil (boilers and engines in 1A1a, 1A2, 1A4) *	Natural gas (boilers and engines in 1A1, 1A2, 1A4, 1A3e)	Natural gas (for 1A3b only)	Res. fuel oil (boilers in 1A1a, 1A2) *	Lignite (boilers in 1A2g)	Bituminous coal (boilers in 1A4b)	Kerosene (average)
	kg/TJ								
1990	65	9.4	64			440			23.2
1991	61	9.4	*62*			*428*			23.2
1992	56	9.4	*61*			*416*			23.2
1993	47	9.4	*59*			*404*			23.3
1994	20	9.4	*58*			*392*			23.3
1995	16	9.4	56			380			23.3
1996	17	9.4	*52*			*376*			23.3
1997	16	9.4	*48*			*372*	NO		23.3
1998	19	9.4	*45*			*368*			23.2
1999	21	9.4	*41*			*364*			23.2
2000	13	6.7	37			360			23.2
2001	12	5.7	*36*			*364*			23.2
2002	11	4.8	*35*			*368*			23.2
2003	9.3	3.8	*35*			*372*			23.2
2004	0.47	0.38	*34*	0.5	NE	*376*		350	23.2
2005	0.47	0.38	33			380			23.2
2006	0.47	0.38	*31*			*392*			23.1
2007	0.47	0.38	*30*			*404*			23.2
2008	0.47	0.38	*28*			*416*			23.2
2009	0.47	0.38	*27*			*428*			23.2
2010	0.47	0.38	25			440			23.2
2011	0.47	0.38	*22*			*480*	500		23.2
2012	0.47	0.38	*19*			*520*			23.2
2013	0.47	0.38	*17*			*560*			23.1
2014	0.47	0.38	*14*			*600*			23.1
2015	0.47	0.38	11			640			23.1
2016	0.47	0.38	*10*			*633*			23.1
2017	0.47	0.38	*9.2*			*626*			23.1
2018	0.47	0.38	*8.3*			*619*			23.2

** blue cells = interpolation*

A3.2 Industrial processes and product use (illustrative example of mobile air conditioning)

The use of HFCs as substitutes of ODSs in 2F1 refrigeration and air conditioning is the main factor for the increase of HFC emissions from 1990 to 2015. Refrigerants contained in installed equipment lead to a considerable stock with annual losses depending from equipment type between 0.5% to 20% (see Table 4-48). Emissions are calculated for the production, operation, service and disposal of equipment. The following illustrative example shows the calculations for the example of mobile air conditioning (HFC-134a use as refrigerant). The example is calculated bottom up, based on vehicle statistics and information on air conditioning equipment. There is no production of air conditioning equipment for cars in Switzerland, equipment is imported already charged.

Table A – 13 Applied model parameters and assumption for mobile air conditioning of cars

Characteristic values			
Initial charge in kg HFC per unit AC	1994	1	kg
	2002	1	kg
	2014	1	kg
	Extrapolation of other years		
Lifetime		15	years
Production			
Import of precharged equipment		100	%
Operation			
Annual losses		8.5	%
Recharge of losses (7.2% of 8.5%)		85	%
Additional service losses over lifetime		10	%
Disposal			
Export rate		31-72	%
Share with total loss of refrigerant		40	%
Disposal loss of professional recovery		15	%

Since 1991 HFC-134a has been used to replace ODS in the mobile air conditioning sector leading to a considerable stock of about 2’151 t of HFC-134a in registered cars at present. A phase-out of HFC-134a is excpected in the near future due to regulations in the European Union and their implementation in Switzerland. AC-refrigerants exceeding a GWP of 150 are not allowed for new car models since 2011. Since 2017, no new cars with AC-refrigerant exceeding a GWP of 150 are allowed. Due to safety concerns with alternative use of HFO-1234yf (GWP 4), there has been a delay in the replacement of HFC-134a.

Interviews were carried out 2014, 2017 and 2018 with garages in Switzerland to follow the development of HFC-134a replacement. The first interviews held in 2014 showed that only few of the imported brands switched to HFO-1234yf (GWP 4). In 2014, garages confirmed a minor portion below 5% of equipment with HFO-1234yf. In 2017 feedback of garages on the sold vehicles of the former year varied widely depending on the models sold and origin of cars. In interviews carried out in 2018, garages confirmed complete phase-out of HFC-134a in new vehicles sold in 2017 (excluding sold vehicles from former years in stock and second-hand vehicles). Most of them switched to HFO-1234yf, few models apply CO_2 (R744). A complete replacement of HFC-134a was assumed for all new vehicles models sold in 2018.

For the new registered vehicles a remaining share of vehicles with HFC-134a of 10% was assumed due to sold older models and imported second-hand vehicles.

Table A – 14 Bottom up calculations to identify number of air conditioning equipment and amount of HFC-134a

Year	New registered vehicles	Vehicles in use	Disposed vehicles	New equipment: number of air conditioning units with HFC-134a in new registered cars			Equipment stock: Number of air conditioning units with HFC-134a in use		Equipment disposal	Initial equipment charge
	Statistics	Statistics	Calculated	Portion of vehicles with AC [%]	HFC-134a as refrigerant [%]	AC units with HFC-134 [units]	Portion of vehicles with HFC-134a [%]	AC units with HFC-134 [units]	Units AC with HFC-134a [units]	Filled in amount [kg HFC/ unit]
1989	335'094	2'895'842		5	0	0	0	0	0	0.85
1990	327'456	2'985'399	237'899	6	0	0	0	0	0	0.84
1991	314'824	3'057'800	242'423	7	10	2'204	0	2'204	0	0.83
1992	296'009	3'091'230	262'579	9	30	7'992	0	10'196	0	0.83
1993	262'814	3'109'524	244'520	14	66	24'284	1	34'480	0	0.82
1994	270'009	3'165'043	214'490	19	90	46'172	3	80'652	0	0.81
1995	272'897	3'229'169	208'771	24	100	65'495	5	146'147	0	0.78
1996	269'529	3'268'073	230'625	38	100	102'421	8	248'568	0	0.77
1997	272'441	3'323'421	217'093	52	100	141'669	12	390'237	0	0.76
1998	297'336	3'383'275	237'482	68	100	202'188	18	592'426	0	0.75
1999	317'985	3'467'275	233'985	75	100	238'489	24	830'914	0	0.73
2000	315'398	3'545'247	237'426	77	100	242'856	30	1'073'771	0	0.72
2001	317'126	3'629'713	232'660	85	100	269'557	37	1'343'328	0	0.71
2002	295'109	3'704'822	220'000	87	100	256'745	43	1'600'073	0	0.70
2003	271'541	3'754'000	222'363	89	100	241'671	49	1'841'744	0	0.69
2004	269'211	3'811'351	211'860	91	100	244'982	55	2'086'726	0	0.68
2005	259'426	3'863'807	206'970	92	100	238'672	60	2'325'398	0	0.66
2006	269'421	3'899'917	233'311	96	100	258'644	66	2'581'839	2'204	0.65
2007	284'674	3'955'787	228'804	96	100	273'287	72	2'847'133	7'992	0.64
2008	288'525	4'030'965	213'347	96	100	276'984	77	3'099'833	24'284	0.63
2009	266'018	4'051'569	245'414	96	100	255'377	82	3'309'039	46'172	0.61
2010	294'239	4'119'370	226'438	96	100	282'469	86	3'526'013	65'495	0.60
2011	327'896	4'209'300	237'966	96	100	314'780	90	3'738'372	102'421	0.59
2012	328'139	4'254'725	282'714	96	100	315'013	92	3'911'717	141'669	0.58
2013	310'154	4'320'885	243'994	96	92	273'928	92	3'983'456	202'188	0.56
2014	304'083	4'384'490	240'478	96	85	248'132	91	3'993'099	238'489	0.55
2015	327'143	4'458'069	253'564	96	77	241'510	90	3'991'753	242'856	0.55
2016	319'331	4'524'029	253'371	96	69	211'525	87	3'933'720	269'557	0.55
2017	315'032	4'570'823	268'238	96	30	90'729	82	3'767'705	256'745	0.55
2018	300'887	4'602'688	271'541	97	10	29'186	77	3'555'219	241'671	0.55

Table A – 15 Results and structure of emission calculations of HFC-134a from mobile air conditioning of cars for the inventories 1990 to 2018.

HFC-134a	Activity			Emissions				Recharge	Disposal
	Input with vehicles	Stock	Retiring vehicles (incl. Export)	Production	Stock incl. Recharge	Disposal	Total	import in bulk	recovered for disposal
	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]
1990	0	0	0	NO	0	0	0	0	0
1991	2	2	0	NO	0	0	0	0	0
1992	7	8	0	NO	1	0	1	0	0
1993	20	28	0	NO	3	0	3	1	0
1994	37	65	0	NO	6	0	6	2	0
1995	51	115	0	NO	11	0	11	5	0
1996	79	193	0	NO	18	0	18	9	0
1997	107	297	0	NO	27	0	27	15	0
1998	151	444	0	NO	41	0	41	23	0
1999	175	612	0	NO	56	0	56	35	0
2000	175	779	0	NO	71	0	71	48	0
2001	191	960	0	NO	88	0	88	61	0
2002	180	1'126	0	NO	103	0	103	75	0
2003	166	1'277	0	NO	117	0	117	88	0
2004	165	1'425	0	NO	131	0	131	100	0
2005	158	1'563	0	NO	143	0	143	111	0
2006	168	1'709	1	NO	157	0	157	122	1
2007	174	1'856	4	NO	170	1	171	133	2
2008	173	1'992	12	NO	183	3	186	145	6
2009	156	2'096	25	NO	192	8	200	155	13
2010	169	2'206	31	NO	202	9	211	163	16
2011	185	2'311	50	NO	212	14	226	172	26
2012	181	2'379	81	NO	218	18	236	180	41
2013	155	2'412	90	NO	221	24	245	185	46
2014	136	2'418	96	NO	222	26	248	188	49
2015	133	2'416	102	NO	221	26	248	188	52
2016	117	2'388	111	NO	219	28	247	188	57
2017	50	2'287	118	NO	210	30	240	186	60
2018	16	2'151	120	NO	197	31	228	178	61

A3.3 Agriculture

Additional data for estimating CH_4 emission from 3A Enteric fermentation

Table A – 16 Data for estimating enteric fermentation emission factors for cattle (Table according to outline in IPCC 1997c, p 4.31–4.33).

Type	Age [a]	Weight [a] kg	Weight Gain [a] kg*day^{-1}	Feeding Situation / Further Specification [a]	Milk [b] kg*day^{-1}	Work hrs*day^{-1}	Pregnant [a] %	Digestibility of Feed % [d]	Y_m [d] %	Em. Factor kg*head^{-1}*year^{-1} [e]
Mature Dairy Cattle	NA	650	0		16.1-23.2 [c]	0	305 days of lactation	72	6.90	117.3 - 137.6
Other Mature Cattle	NA	650	0		8.2	0		60	6.50	106.8
Fattening Calves	0-98 days	124	1.43	Rations of unskimmed milk and supplementary milk feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day.	0	0	0	65	0.00	0.0
Pre-Weaned Calves	0-300 days	195	0.88	"Natura beef" production, milk from mother cow and additional feed.	0	0	0	65	4.13	16.3
Breeding Calves	0-105 days	85	0.67	Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total).	0	0	0	65	4.12	30.0
Breeding Cattle (4-12 months)	4-12 month	210	0.80	Premature race (Milk-race)	0	0	0	60	6.50	
Breeding Cattle (> 1 year)	12-28/30 month	450	0.80	Premature race (Milk-race)	0	0	0	60	6.50	61.2
Fattening Calves (0-4 months)	0-132 days	115	0.83	Diet based on milk or milk-powder and feed concentrate, hay and/or silage	0	0	0	65	5.72	43.2
Fattening Cattle (4-12 months)	4-12 month	361	1.37	Feeding recommendations for fattening steers, concentrate based	0	0	0	60	6.50	

[a] Data source: RAP 1999 and calculations according to Soliva 2006.

[b] Milk production in kg/day is calculated by dividing the average annual milk production per head by 305 days (lactation period).

[c] data source: Swiss farmers union (MISTA 2015).

[d] data source: IPCC 2006 and Zeitz et al. 2012.

[e] For better comparability emission factors of young cattle were converted to kg*head^{-1}*year^{-1} although the time span of most of the individual categories is less than 365 days.

Table A – 17 Gross energy intake of Swiss livestock.

Gross Energy Intake	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	MJ/head/day																												
Cattle																													
Mature Dairy Cattle	259.3	261.6	261.9	265.0	264.7	267.4	266.4	270.4	274.2	277.4	280.1	281.8	284.5	287.7	291.5	291.6	292.2	295.2	297.2	299.8	300.7	301.4	301.2	299.8	302.5	303.6	303.1	301.9	304.0
Other Mature Cattle	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)	103.3	103.4	103.6	103.3	103.7	103.9	103.6	104.1	103.1	101.4	103.6	102.5	102.3	102.0	101.6	101.0	101.1	100.9	101.0	100.3	99.8	99.9	100.2	100.1	99.9	99.7	99.2	99.0	98.6
Fattening Calves	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1
Pre-Weaned Calves	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1
Breeding Calves	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Breeding Cattle (4-12 months)	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1
Breeding Cattle (> 1 year)	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6
Fattening Calves (0-4 months)	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9
Fattening Cattle (4-12 months)	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3
Sheep	21.2	21.7	22.2	22.4	23.8	24.0	22.0	22.1	21.5	22.9	22.4	22.9	22.8	22.7	23.3	22.8	22.6	22.2	22.0	22.7	22.6	22.6	22.5	22.4	22.6	22.5	22.9	22.9	22.9
Swine	25.7	26.2	26.2	26.0	25.1	26.5	26.6	27.4	25.9	25.4	25.1	24.6	24.4	24.4	24.8	24.5	23.9	24.2	24.6	24.9	24.7	24.6	24.4	25.1	25.1	25.4	25.8	25.8	26.5
Buffalo (weighted average)	NA	NA	134.7	138.2	137.5	136.6	137.0	136.5	137.0	130.6	146.9	137.5	140.8	137.2	140.0	140.6	138.9	130.4	129.1	134.8	136.9	139.8	135.9	136.0	134.6	134.5	134.4	133.1	162.8
Bisons < 3 years	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0	91.0
Bisons > 3 years	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1
Camels (weighted average)	NA	NA	NA	NA	NA	NA	37.9	37.9	37.9	34.6	34.8	32.2	33.0	34.0	32.8	31.7	31.7	31.7	31.6	31.5	31.0	31.4	31.6	31.9	31.8	31.6	31.2	31.2	31.0
Llamas < 2 years	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8
Llamas > 2 years	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Alpacas < 2 years	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Alpacas > 2 years	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
Deer (weighted average)	50.5	51.6	53.6	54.5	55.0	55.3	59.7	55.4	54.8	55.5	56.4	55.8	56.7	55.2	55.6	55.4	55.8	55.9	56.5	56.8	56.5	56.7	57.0	58.1	58.0	58.0	58.5	58.8	59.3
Fallow Deer [1]	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5
Red Deer [1]	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1	101.1
Goats	25.0	24.6	25.0	25.4	25.5	27.9	25.3	25.6	26.9	25.8	25.7	26.0	25.2	25.4	25.2	25.4	25.3	25.0	25.0	25.3	25.1	25.6	25.6	25.6	25.0	25.5	25.1	24.9	24.9
Horses (weighted average)	107.3	107.3	107.3	107.3	107.1	106.9	107.1	107.3	107.3	107.2	107.4	107.5	107.6	107.6	107.6	107.7	107.7	107.7	107.7	107.8	107.9	107.9	107.9	108.0	108.1	108.3	108.4	108.4	108.5
Horses <3 years	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Horses >3 years	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0
Mules and Asses (weighted average)	39.2	39.2	39.2	39.2	39.5	39.7	39.7	39.8	39.6	39.8	39.5	39.6	39.6	39.6	39.5	39.4	39.5	39.3	39.2	40.0	40.2	39.9	39.9	39.6	39.6	39.6	39.6	39.5	38.6
Mules	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0
Asses	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9
Poultry [2]	1.2	1.2	1.2	1.2	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.1
Rabbits	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)	95.6	95.6	95.6	95.6	96.1	83.4	43.2	40.1	38.6	38.6	37.7	36.5	35.7	34.6	34.6	33.3	33.2	32.9	31.7	34.3	36.9	37.2	37.9	38.2	38.5	37.2	38.3	38.7	38.8
Sheep Non-Agr.	21.2	21.7	22.2	22.4	23.8	24.0	22.0	22.1	21.5	22.9	22.4	22.9	22.8	22.7	23.3	22.8	22.6	22.2	22.0	22.7	22.6	22.6	22.5	22.4	22.6	22.5	22.9	22.9	22.9
Goats Non-Agr.	25.0	24.6	25.0	25.4	25.5	27.9	25.3	25.6	26.9	25.8	25.7	26.0	25.2	25.4	25.2	25.4	25.3	25.0	25.0	25.3	25.1	25.6	25.6	25.6	25.0	25.5	25.1	24.9	24.9
Horses <3 years Non-Agr.	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Horses >3 years Non-Agr.	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0
Mules Non-Agr.	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0	86.0
Asses Non-Agr.	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.9

1) Deer: Gross energy intake per animal place (mother with offspring)

2) Poultry data is not Gross Energy intake (GE) but Metabolizable Energy intake (ME)

Table A – 18 Livestock population. For some categories the numbers of the total population is not equal to the sum of the numbers of the subcategories because the latter refer to animal places instead of head. See also ART/SHL 2012.

Population Size	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	1000 head																												
Cattle	1855.2	1828.9	1782.6	1745.1	1755.4	1748.3	1747.1	1672.9	1640.9	1608.7	1588.0	1611.4	1593.7	1570.2	1544.5	1554.7	1566.9	1571.8	1604.3	1597.5	1591.2	1577.4	1564.6	1557.5	1562.8	1554.3	1555.4	1544.6	1543.3
Mature Dairy Cattle	783.1	780.5	763.5	744.5	749.7	739.6	736.0	711.6	701.3	683.5	669.4	669.4	657.9	638.3	621.0	620.7	618.1	614.8	628.5	599.4	589.0	589.2	591.2	586.6	587.4	583.3	575.8	569.2	564.2
Other Mature Cattle	12.0	14.0	17.0	18.0	20.0	23.0	28.0	32.0	36.0	41.2	44.9	50.6	58.1	65.1	70.0	78.5	87.3	93.5	98.4	108.4	111.3	110.7	114.4	116.9	118.0	117.9	120.8	123.4	125.5
Growing Cattle	1060.1	1034.4	1002.1	982.6	985.7	985.6	983.0	929.3	903.5	884.0	873.7	891.3	877.7	866.7	853.6	855.5	861.5	863.4	877.4	889.7	890.9	877.5	859.0	854.0	857.4	853.1	858.8	852.0	853.7
Fattening Calves	112.3	111.4	109.5	111.1	101.4	101.7	112.0	106.0	108.1	116.4	103.3	114.7	114.4	113.9	111.3	105.6	101.2	100.5	95.0	107.3	113.5	111.1	103.1	101.9	102.5	102.6	107.0	107.6	111.0
Pre-Weaned Calves	9.6	11.2	13.6	14.4	16.0	18.4	22.4	25.6	28.8	33.2	35.7	40.4	46.9	52.3	56.6	62.5	67.3	72.2	76.1	83.9	86.3	85.8	88.4	90.3	91.1	91.1	93.5	95.5	97.1
Breeding Cattle 1st Year	346.4	336.7	324.0	308.2	306.2	294.7	286.1	260.1	253.5	218.7	236.0	238.1	229.5	219.8	214.7	222.0	223.3	223.3	232.4	224.5	221.6	215.7	210.4	207.7	209.5	210.2	211.3	209.3	207.8
Breeding Cattle 2nd Year	253.3	251.9	250.5	238.7	237.2	238.6	243.0	232.9	217.4	187.5	221.9	219.3	219.1	212.7	205.4	204.7	210.2	210.5	212.7	215.9	214.9	212.7	210.7	209.5	210.4	209.0	209.2	207.5	207.3
Breeding Cattle 3rd Year	150.7	148.4	146.7	142.3	141.3	139.4	139.9	139.3	132.7	117.9	129.8	130.4	126.0	124.0	120.9	113.3	110.1	109.1	109.6	111.7	110.8	108.9	106.3	103.0	101.3	98.5	97.1	97.8	94.4
Fattening Cattle	187.8	174.8	157.8	168.0	183.5	192.9	179.6	165.4	163.1	210.2	147.1	148.5	141.7	144.1	144.7	147.5	149.3	148.0	151.6	146.5	143.8	143.2	140.0	141.5	142.7	141.7	140.8	134.3	136.1
Sheep	395.2	409.4	414.7	424.0	405.4	386.7	418.6	420.4	422.3	423.5	420.7	420.0	429.5	444.8	440.5	446.4	447.5	443.6	446.2	431.9	434.1	424.0	417.3	409.5	402.8	395.3	396.8	398.3	403.0
Fattening Sheep	190.6	200.8	201.0	211.1	201.2	191.4	207.6	208.0	208.7	221.7	216.6	216.6	219.9	228.6	227.5	229.4	230.6	230.0	229.4	227.3	228.2	221.8	219.3	216.2	209.5	204.0	205.0	206.9	208.2
Milksheep	4.3	4.0	3.8	3.5	3.3	3.0	2.8	3.1	4.4	5.8	6.7	7.0	7.2	8.0	8.1	8.9	9.5	10.2	10.7	11.7	12.4	12.4	12.8	13.3	13.7	13.6	12.9	13.7	14.5
Swine	1965.5	1899.3	1888.6	1893.0	1780.0	1739.0	1542.6	1521.5	1602.8	1660.1	1669.8	1740.9	1731.6	1691.5	1685.7	1744.4	1797.2	1747.9	1671.0	1690.9	1750.5	1726.2	1678.2	1614.5	1630.9	1604.6	1553.5	1544.1	1497.7
Piglets	299.4	282.5	290.8	299.6	287.2	274.8	240.9	252.2	261.8	281.0	296.6	318.8	326.6	322.8	327.8	337.6	366.5	344.8	336.1	338.4	350.9	352.7	344.7	333.3	339.2	330.0	314.4	313.7	305.7
Fattening Pig over 25 kg	1203.1	1166.3	1155.7	1144.2	1066.8	1061.3	942.0	906.1	953.3	941.2	922.4	955.7	942.7	914.3	901.5	931.7	948.5	941.7	894.2	913.1	949.6	934.7	909.7	877.9	892.4	886.1	862.2	857.6	830.0
Dry Sows	129.3	126.0	124.9	125.3	117.1	108.9	98.8	104.3	110.9	101.2	104.8	108.0	108.6	105.3	107.9	112.7	115.2	105.7	105.4	104.7	106.1	103.4	97.4	95.8	94.2	93.3	90.9	88.9	84.7
Nursing Sows	37.4	36.8	36.8	37.3	35.1	33.0	30.2	29.9	31.4	35.0	36.7	37.5	36.5	35.8	35.3	36.0	36.5	34.9	32.6	33.1	33.5	32.3	31.0	29.4	29.4	29.4	28.7	27.9	27.3
Boars	8.4	8.1	8.0	8.2	7.7	7.1	6.3	6.4	6.4	6.2	6.2	6.1	5.8	5.3	5.2	5.1	4.9	4.2	4.0	3.8	3.7	3.3	3.0	3.2	2.9	2.7	2.6	2.7	2.6
Buffalo	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5
Bisons < 3 years	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
Bisons > 3 years	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4
Camels	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.4	1.0	1.0	1.6	1.6	1.7	2.2	3.1	3.3	3.9	4.4	4.7	6.1	6.0	5.8	5.9	6.1	6.4	6.5	6.6	6.7
Llamas < 2 years	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Llamas > 2 years	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.5	0.5	0.7	0.7	0.9	1.0	1.1	1.3	1.5	1.8	1.9	2.1	2.2	2.3	2.4	2.3	2.4	2.3	2.3	2.3
Alpacas < 2 years	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.7	0.8	0.8	0.7	0.9	0.9	0.8	0.9
Alpacas > 2 years	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.5	0.5	0.4	0.6	1.2	1.1	1.2	1.3	1.4	2.3	2.3	2.0	2.1	2.4	2.6	2.6	2.8	2.8
Deer	0.2	0.4	0.7	0.9	1.2	1.4	1.9	1.9	2.2	2.6	2.8	2.9	3.1	3.2	3.5	3.8	4.2	4.4	4.8	5.1	5.5	5.7	5.7	5.7	5.7	6.0	6.0	6.0	6.4
Fallow Deer	0.2	0.4	0.6	0.8	1.1	1.3	1.6	1.8	2.0	2.4	2.5	2.6	2.7	2.9	3.2	3.5	3.7	4.0	4.3	4.4	4.9	5.0	5.0	4.8	4.9	5.1	5.1	5.0	5.3
Red Deer	0.0	0.0	0.0	0.1	0.1	0.1	0.4	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.1
Goats	68.3	65.2	58.2	56.7	54.9	53.2	56.8	58.0	60.1	61.6	62.5	63.0	66.0	67.4	70.6	74.0	76.3	79.1	81.4	81.2	82.8	83.0	84.7	84.5	84.7	83.7	84.9	87.6	91.0
Goat Places	44.8	43.1	38.4	37.3	35.9	34.6	37.1	37.7	39.8	40.8	41.4	42.1	43.0	44.9	46.2	48.5	50.5	51.9	53.4	54.3	54.7	55.9	57.4	57.4	57.9	56.1	56.9	58.7	60.9
Horses	28.2	30.2	32.3	34.5	37.9	41.4	43.0	45.8	46.3	48.5	50.3	50.1	51.2	52.7	53.7	55.1	56.4	57.7	59.0	60.2	62.1	57.2	58.0	57.2	57.2	55.5	55.7	55.5	55.3
Horses <3 years	6.1	6.5	7.0	7.4	9.2	11.0	10.7	10.0	10.0	11.0	10.1	9.7	9.5	9.4	9.4	9.4	9.5	9.6	9.6	9.0	8.7	8.3	8.0	7.1	6.5	4.7	4.3	4.1	3.6
Horses >3 years	22.1	23.7	25.4	27.1	28.7	30.4	32.3	35.8	36.3	37.5	40.2	40.4	41.7	43.3	44.3	45.8	46.9	48.1	49.4	51.1	53.4	49.0	50.1	50.2	50.7	50.8	51.4	51.4	51.7
Mules and Asses	5.9	6.3	6.7	7.2	7.4	7.6	8.5	9.4	9.9	11.3	11.8	12.5	13.2	14.1	14.8	16.0	16.5	17.2	17.8	19.2	20.4	19.0	20.1	19.6	19.6	19.7	20.2	20.7	26.8
Mules	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1.0	0.8	0.9	0.7	0.7	0.7	0.7	0.7	0.4
Asses	5.7	6.1	6.6	7.0	7.1	7.3	8.1	9.0	9.6	10.9	11.4	12.0	12.8	13.6	14.4	15.5	15.9	16.7	17.3	18.4	19.4	18.2	19.3	18.9	18.9	19.0	19.5	20.0	26.5
Poultry [1)]	7310.4	6887.4	7139.7	7022.2	6691.9	6656.3	6467.9	6626.5	6870.5	6957.1	7159.8	7124.1	7370.4	7556.3	8103.3	8910.6	8107.4	9303.1	9813.1	10098.9	10628.6	10903.9	11409.2	11844.3	12445.5	12540.6	13179.6	13398.8	13944.4
Growers	718.9	664.2	709.6	719.2	716.8	714.4	732.1	732.9	793.5	760.9	831.7	745.3	753.9	809.0	853.1	867.7	888.4	901.8	919.0	966.7	925.5	969.7	1075.6	1054.5	1195.6	1033.0	959.3	1084.0	1078.4
Layers	3083.0	2645.4	2535.8	2517.6	2317.9	2118.2	2226.0	2277.5	2270.1	2222.8	2150.3	2069.5	2154.1	2117.2	2088.8	2188.5	2147.3	2197.7	2254.9	2318.3	2438.1	2437.0	2520.6	2588.6	2665.1	2821.9	3055.9	3173.5	3371.3
Broilers	3392.1	3439.2	3733.6	3602.5	3472.3	3636.6	3320.6	3416.0	3633.2	3797.0	3984.5	4177.8	4330.0	4487.4	5013.4	5710.6	4918.4	6077.0	6570.7	6745.7	7183.8	7410.4	7736.6	8125.7	8505.9	8613.8	9063.7	9048.5	9390.4
Turkey	94.7	117.4	140.1	162.8	166.5	170.2	173.8	184.4	157.8	154.6	172.6	123.0	123.9	133.8	138.8	132.3	137.1	112.5	53.8	52.4	58.1	57.8	51.2	55.1	57.2	49.3	70.9	77.1	84.4
Other Poultry	21.8	21.2	20.6	20.0	18.4	16.9	15.3	15.8	15.9	21.9	20.7	8.6	8.5	8.8	9.3	11.5	16.1	14.2	14.7	15.9	23.2	29.0	25.1	20.4	21.7	22.6	29.8	15.7	19.8
Rabbits	60.9	56.8	52.7	48.7	44.6	40.5	36.5	37.4	32.8	31.3	27.9	25.1	33.4	31.1	20.5	25.4	24.5	27.2	24.9	27.8	35.0	34.3	27.9	27.5	27.0	25.3	24.7	21.9	21.8
Livestock NCAC	27.9	26.6	25.3	23.9	24.0	29.6	82.1	94.9	93.8	95.6	93.8	94.8	91.7	91.8	86.1	85.7	82.4	79.8	85.5	90.0	91.4	99.2	111.7	107.3	105.6	112.4	106.3	103.5	104.5
Total Sheep	0.0	0.0	0.0	0.0	0.0	0.0	53.4	66.9	67.1	67.3	66.9	69.3	66.7	68.7	63.4	62.4	60.3	58.8	63.4	65.5	62.5	65.0	73.5	69.5	67.9	73.8	68.7	66.5	64.6
Fattening Sheep	0.0	0.0	0.0	0.0	0.0	0.0	26.7	33.3	33.1	34.8	34.0	34.9	33.5	34.8	32.1	31.4	30.1	30.0	33.1	34.6	33.2	36.5	43.4	40.7	39.7	42.2	39.1	37.8	36.8
Milksheep	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.6	0.8	0.9	0.9	0.9	0.9	0.9	0.7	0.6	0.5	0.6	0.6	0.7	0.6	0.4	0.5	0.4	0.3	0.4	0.3	0.3
Total Goats	0.0	0.0	0.0	0.0	0.0	5.7	5.5	5.2	5.4	7.6	7.4	7.7	8.5	7.9	8.9	10.8	9.9	9.1	10.6	9.7	10.1	13.6	13.6	13.6	13.4	14.8	13.6	12.9	14.0
Goat Places	0.0	0.0	0.0	0.0	0.0	4.0	3.7	3.3	3.5	5.3	4.9	5.2	5.6	5.2	5.9	7.3	6.5	5.8	6.9	6.2	6.3	9.4	9.5	9.5	9.4	10.0	9.1	8.6	9.5
Horses <3 years Non-Agr.	5.0	4.7	4.5	4.3	4.9	5.4	4.8	4.1	3.8	3.8	3.2	2.8	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.7	2.0	2.2	2.5	2.2	2.0	1.5	1.4	1.3	1.1
Horses >3 years Non-Agr.	18.1	17.3	16.4	15.5	15.2	14.8	14.6	14.8	13.8	13.0	12.6	11.5	10.7	9.9	8.9	8.1	7.8	7.6	7.4	9.6	12.1	13.2	15.8	15.8	16.0	16.0	16.2	16.2	16.3
Mules Non-Agr.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1
Asses Non-Agr.	4.7	4.5	4.2	4.0	3.8	3.6	3.7	3.7	3.6	3.8	3.6	3.4	3.3	3.1	2.9	2.7	2.7	2.6	2.6	3.4	4.4	4.9	6.1	6.0	6.0	6.0	6.2	6.3	8.4

1) Other Poultry: Geese, Ducks, Ostriches, Quails

Additional data for estimating CH_4 and N_2O emission from 3B Manure management

Table A – 19 Data for estimating manure management CH_4 emission factors (Table according to outline in IPCC 1997c, Tables B-1 to B-7).

Type	Weight kg [a]	Digestibility of Feed % [b]	Energy Intake $MJ*day^{-1}$	Feed Intake $kg*day^{-1}$	% Ash Dry Basis [b]	VS $kg*head^{-1}*day^{-1}$	B_0 $m^3\ CH_4*kgVS^{-1}$ [b]
Mature Dairy Cattle	650	72	259 - 304	15.34 [c]	8.8 - 9.1	4.08 - 4.82	0.24
Other Mature Cattle	650	60	251	13.70 [c]	8	5.50	0.18
Fattening Calves	124	65	47	2.02 [a]	8	0.92	0.18
Pre-Weaned Calves	195	65	60	2.99 [a]	8	0.74	0.18
Breeding Calves	85	65	44	2.19 [a]	8	0.54	0.18
Breeding Cattle (4-12 months)	210	60	90	4.88 [a]	8	1.98	0.18
Breeding Cattle (> 1 year)	450	60	144	7.78 [a]	8	3.15	0.18
Fattening Calves (0-4 months)	115	65	57	3.00 [a]	8	0.97	0.18
Fattening Cattle (4-12 months)	361	60	126	6.84 [a]	8	2.77	0.18
Sheep	NA	60	21 - 24	1.08-1.24 [c]	8	0.40 [b]	0.19
Swine	NA	75	24 - 27	NA	2	0.31 [b#]	0.45
Buffalo	NA	55	129 - 163	7.00-8.82 [c]	8	3.98	0.10
Camels	NA	60 [d]	31 - 38	1.68-2.05 [c]	8	0.68	0.26
Deer	NA	60	51 - 60	2.74-3.24 [c]	8	1.30	0.19
Goats	NA	60	25 - 28	1.34-1.40 [c]	8	0.30 [b]	0.18
Horses	NA	70	107 - 108	7.73-7.89 [c]	4	1.90	0.33
Mules and Asses	NA	70	39 - 40	2.87-2.93 [c]	4	0.94 [b]	0.33
Poultry	NA	NA	1 - 1.4 [e]	NA	NA	0.01 [b#]	0.37 [#]
Rabbits	NA	NA	1.2	NA	NA	0.10 [b]	0.32
Livestock NCAC	NA	NA	NA	NA	NA	0.68	0.27

[a] RAP 1999

[b] IPCC 1997c and IPCC 2006

[c] Richner et al. 2017

[d] Llamas and alpacas: same value as for sheep

[e] metabolizable energy (ME)

[#] weighted average

Table A – 20 Manure management system distribution for volatile solids (VS) in Switzerland.

MS Distribution for VS	1990					1995					2002					2007					2010					2015				
	%					%					%					%					%					%				
	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	63.7	27.6	8.3	0.4	0.0	65.7	24.4	9.5	0.4	0.0	65.3	16.2	18.0	0.5	0.0	67.5	13.5	17.7	1.3	0.0	67.1	14.2	16.9	1.8	0.0	69.9	10.7	15.9	3.4	0.0
Other Mature Cattle	41.2	32.1	26.3	0.4	0.0	39.3	34.1	26.2	0.4	0.0	39.8	20.6	39.1	0.5	0.0	49.7	20.1	29.0	1.3	0.0	48.0	17.8	32.4	1.8	0.0	51.0	14.1	31.5	3.4	0.0
Growing Cattle (weighted average)	32.9	45.2	15.9	0.4	5.6	33.8	44.3	15.9	0.4	5.6	27.4	38.9	27.3	0.5	5.9	27.9	40.4	25.2	1.3	5.3	28.4	40.3	23.6	1.8	5.9	31.4	36.9	23.2	3.4	5.1
Fattening Calves	*6.0*	*0.0*	*0.0*	*0.4*	*93.5*	*6.0*	*0.0*	*0.0*	*0.4*	*93.6*	*7.8*	*0.0*	*0.3*	*0.5*	*91.4*	*9.5*	*0.0*	*0.2*	*1.3*	*89.1*	*8.3*	*0.0*	*0.2*	*1.8*	*89.7*	*12.2*	*0.0*	*1.7*	*3.4*	*82.7*
Pre-Weaned Calves	*28.1*	*45.1*	*26.3*	*0.4*	*0.0*	*24.4*	*49.0*	*26.2*	*0.4*	*0.0*	*22.8*	*39.5*	*37.3*	*0.5*	*0.0*	*29.6*	*39.0*	*30.1*	*1.3*	*0.0*	*35.4*	*41.9*	*20.9*	*1.8*	*0.0*	*33.0*	*31.5*	*32.0*	*3.4*	*0.0*
Breeding Cattle 1st Year	*18.4*	*67.1*	*14.1*	*0.4*	*0.0*	*19.7*	*65.7*	*14.2*	*0.4*	*0.0*	*17.1*	*55.4*	*27.0*	*0.5*	*0.0*	*19.7*	*55.8*	*23.3*	*1.3*	*0.0*	*22.0*	*54.7*	*21.5*	*1.8*	*0.0*	*23.6*	*52.0*	*20.9*	*3.4*	*0.0*
Breeding Cattle 2nd Year	*28.9*	*45.3*	*25.4*	*0.4*	*0.0*	*30.9*	*43.1*	*25.6*	*0.4*	*0.0*	*23.4*	*37.7*	*38.4*	*0.5*	*0.0*	*23.3*	*38.9*	*36.5*	*1.3*	*0.0*	*25.6*	*38.3*	*34.3*	*1.8*	*0.0*	*26.6*	*35.2*	*34.8*	*3.4*	*0.0*
Breeding Cattle 3rd Year	*33.0*	*46.5*	*20.0*	*0.4*	*0.0*	*34.1*	*45.2*	*20.3*	*0.4*	*0.0*	*27.3*	*37.5*	*34.8*	*0.5*	*0.0*	*28.6*	*38.4*	*31.8*	*1.3*	*0.0*	*30.2*	*37.3*	*30.6*	*1.8*	*0.0*	*35.6*	*35.4*	*25.6*	*3.4*	*0.0*
Fattening Cattle	*65.3*	*26.1*	*0.0*	*0.4*	*8.1*	*59.7*	*31.7*	*0.0*	*0.4*	*8.3*	*55.1*	*37.4*	*2.2*	*0.5*	*4.8*	*49.8*	*40.4*	*4.3*	*1.3*	*4.2*	*44.3*	*45.0*	*4.0*	*1.8*	*4.9*	*50.6*	*37.0*	*4.9*	*3.4*	*4.1*
Sheep (weighted average)	0.0	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	33.2	0.0	66.8	0.0	0.0	39.3	0.0	60.7	0.0	0.0	33.7	0.0	66.3	0.0	0.0	37.0	0.0	63.0
Fattening Sheep	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Milksheep	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*26.1*	*0.0*	*73.9*	*0.0*	*0.0*	*24.1*	*0.0*	*75.9*	*0.0*	*0.0*	*22.8*	*0.0*	*77.2*	*0.0*	*0.0*	*40.9*	*0.0*	*59.1*
Swine (weighted average)	98.9	0.0	0.0	1.1	0.0	99.0	0.0	0.0	1.0	0.0	98.2	0.4	0.1	1.3	0.0	95.0	0.2	1.2	3.7	0.0	94.0	0.5	0.1	5.3	0.0	89.3	0.0	0.0	10.7	0.0
Piglets	*98.9*	*0.0*	*0.0*	*1.1*	*0.0*	*99.0*	*0.0*	*0.0*	*1.0*	*0.0*	*97.8*	*0.8*	*0.0*	*1.3*	*0.0*	*95.3*	*0.7*	*0.4*	*3.7*	*0.0*	*92.4*	*2.3*	*0.0*	*5.3*	*0.0*	*89.3*	*0.0*	*0.0*	*10.7*	*0.0*
Fattening Pig over 25 kg	*98.9*	*0.0*	*0.0*	*1.1*	*0.0*	*99.0*	*0.0*	*0.0*	*1.0*	*0.0*	*98.2*	*0.3*	*0.2*	*1.3*	*0.0*	*94.8*	*0.0*	*1.5*	*3.7*	*0.0*	*94.5*	*0.0*	*0.1*	*5.3*	*0.0*	*89.3*	*0.0*	*0.0*	*10.7*	*0.0*
Dry Sows	*98.9*	*0.0*	*0.0*	*1.1*	*0.0*	*99.0*	*0.0*	*0.0*	*1.0*	*0.0*	*98.6*	*0.0*	*0.1*	*1.3*	*0.0*	*95.2*	*0.1*	*1.0*	*3.7*	*0.0*	*94.5*	*0.0*	*0.2*	*5.3*	*0.0*	*89.3*	*0.0*	*0.1*	*10.7*	*0.0*
Nursing Sows	*98.9*	*0.0*	*0.0*	*1.1*	*0.0*	*99.0*	*0.0*	*0.0*	*1.0*	*0.0*	*98.0*	*0.7*	*0.0*	*1.3*	*0.0*	*95.4*	*0.5*	*0.3*	*3.7*	*0.0*	*94.5*	*0.2*	*0.0*	*5.3*	*0.0*	*89.3*	*0.0*	*0.0*	*10.7*	*0.0*
Boars	*98.9*	*0.0*	*0.0*	*1.1*	*0.0*	*99.0*	*0.0*	*0.0*	*1.0*	*0.0*	*97.9*	*0.5*	*0.2*	*1.3*	*0.0*	*95.2*	*0.0*	*1.2*	*3.7*	*0.0*	*92.8*	*1.2*	*0.6*	*5.3*	*0.0*	*89.1*	*0.0*	*0.3*	*10.7*	*0.0*
Buffalo (weighted average)	NA	NA	NA	NA	NA	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	44.8	20.4	34.8	0.0	0.0
Bisons < 3 years	*45.6*	*29.0*	*25.4*	*0.0*	*0.0*	*47.5*	*26.8*	*25.6*	*0.0*	*0.0*	*38.2*	*23.5*	*38.4*	*0.0*	*0.0*	*42.4*	*21.1*	*36.5*	*0.0*	*0.0*	*44.5*	*21.2*	*34.3*	*0.0*	*0.0*	*44.8*	*20.4*	*34.8*	*0.0*	*0.0*
Bisons > 3 years	*45.6*	*29.0*	*25.4*	*0.0*	*0.0*	*47.5*	*26.8*	*25.6*	*0.0*	*0.0*	*38.2*	*23.5*	*38.4*	*0.0*	*0.0*	*42.4*	*21.1*	*36.5*	*0.0*	*0.0*	*44.5*	*21.2*	*34.3*	*0.0*	*0.0*	*44.8*	*20.4*	*34.8*	*0.0*	*0.0*
Camels (weighted average)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	33.5	0.0	66.5	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Llamas < 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Llamas > 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Alpacas < 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Alpacas > 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Deer (weighted average)	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Fallow Deer	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Red Deer	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Goats	0.0	0.0	13.6	0.0	86.4	0.0	0.0	13.6	0.0	86.4	0.0	0.0	12.2	0.0	87.8	0.0	0.0	7.1	0.0	92.9	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4
Goat Places	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*12.2*	*0.0*	*87.8*	*0.0*	*0.0*	*7.1*	*0.0*	*92.9*	*0.0*	*0.0*	*10.0*	*0.0*	*90.0*	*0.0*	*0.0*	*11.6*	*0.0*	*88.4*
Horses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.1	23.9	0.0	0.0	0.0	78.7	21.3	0.0	0.0	0.0	74.4	25.6	0.0	0.0	0.0	78.7	21.3	0.0	0.0
Horses <3 years	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*61.8*	*38.2*	*0.0*	*0.0*	*0.0*	*61.7*	*38.3*	*0.0*	*0.0*	*0.0*	*66.4*	*33.6*	*0.0*	*0.0*	*0.0*	*66.1*	*33.9*	*0.0*	*0.0*
Horses >3 years	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*81.9*	*18.1*	*0.0*	*0.0*	*0.0*	*75.6*	*24.4*	*0.0*	*0.0*	*0.0*	*79.8*	*20.2*	*0.0*	*0.0*
Mules and Asses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	77.6	22.4	0.0	0.0
Mules	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Asses	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Poultry (weighted average)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.5	0.0	99.5	0.0	0.0	2.7	0.0	97.3	0.0	0.0	3.5	0.0	96.5	0.0	0.0	2.5	0.0	97.5	0.0	0.0	2.7	0.0	97.3
Growers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*0.2*	*0.0*	*99.8*	*0.0*	*0.0*	*1.5*	*0.0*	*98.5*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*
Layers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*5.1*	*0.0*	*94.9*	*0.0*	*0.0*	*7.3*	*0.0*	*92.7*	*0.0*	*0.0*	*6.1*	*0.0*	*93.9*	*0.0*	*0.0*	*6.9*	*0.0*	*93.1*
Broilers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*0.3*	*0.0*	*99.7*	*0.0*	*0.0*	*0.2*	*0.0*	*99.8*
Turkey	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*1.9*	*0.0*	*98.1*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*
Other Poultry [a]	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*2.5*	*0.0*	*97.5*
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	89.5	7.1	0.0	3.4	0.0	37.3	27.7	0.0	35.0	0.0	33.8	30.1	0.0	36.2	0.0	39.5	28.1	0.0	32.4	0.0	42.1	27.0	0.0	30.9
Fattening Sheep Non-Agr.	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Milksheep Non-Agr.	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*26.1*	*0.0*	*73.9*	*0.0*	*0.0*	*24.1*	*0.0*	*75.9*	*0.0*	*0.0*	*22.8*	*0.0*	*77.2*	*0.0*	*0.0*	*40.9*	*0.0*	*59.1*
Total Goats Non-Agr.	*NA*	*NA*	*NA*	*NA*	*NA*	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*12.2*	*0.0*	*87.8*	*0.0*	*0.0*	*7.1*	*0.0*	*92.9*	*0.0*	*0.0*	*10.0*	*0.0*	*90.0*	*0.0*	*0.0*	*11.6*	*0.0*	*88.4*
Horses <3 years Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*61.8*	*38.2*	*0.0*	*0.0*	*0.0*	*61.7*	*38.3*	*0.0*	*0.0*	*0.0*	*66.4*	*33.6*	*0.0*	*0.0*	*0.0*	*66.1*	*33.9*	*0.0*	*0.0*
Horses >3 years Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*81.9*	*18.1*	*0.0*	*0.0*	*0.0*	*75.6*	*24.4*	*0.0*	*0.0*	*0.0*	*79.8*	*20.2*	*0.0*	*0.0*
Mules Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Asses Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

Table A – 21 Manure management system distribution for nitrogen in Switzerland.

MS Distribution for nitrogen	1990					1995					2002					2007					2010					2015				
	%					%					%					%					%					%				
	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid manure	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	63.6	27.6	8.3	0.5	0.0	65.6	24.5	9.5	0.4	0.0	65.2	16.3	18.0	0.5	0.0	67.2	13.7	17.7	1.4	0.0	66.6	14.5	16.9	2.1	0.0	69.0	11.2	15.9	3.9	0.0
Other Mature Cattle	41.1	32.2	26.3	0.5	0.0	39.2	34.2	26.2	0.4	0.0	39.7	20.7	39.1	0.5	0.0	49.3	20.3	29.0	1.4	0.0	47.5	18.0	32.4	2.1	0.0	50.1	14.5	31.5	3.9	0.0
Growing Cattle (weighted average)	47.4	31.8	15.7	0.5	4.5	48.4	30.9	15.8	0.4	4.5	42.1	25.5	27.3	0.5	4.6	45.3	24.0	24.7	1.4	4.7	44.4	25.0	22.7	2.1	5.8	46.3	22.2	22.4	3.9	5.3
Fattening Calves	*14.5*	*0.0*	*0.0*	*0.5*	*85.1*	*14.9*	*0.0*	*0.0*	*0.4*	*84.7*	*21.5*	*0.0*	*0.3*	*0.5*	*77.6*	*21.6*	*0.0*	*0.2*	*1.4*	*76.8*	*16.4*	*0.0*	*0.2*	*2.1*	*81.3*	*22.8*	*0.0*	*1.7*	*3.9*	*71.7*
Pre-Weaned Calves	*41.1*	*32.2*	*26.3*	*0.5*	*0.0*	*39.2*	*34.2*	*26.2*	*0.4*	*0.0*	*41.2*	*21.0*	*37.3*	*0.5*	*0.0*	*49.8*	*18.7*	*30.1*	*1.4*	*0.0*	*44.2*	*32.9*	*20.9*	*2.1*	*0.0*	*34.5*	*29.7*	*32.0*	*3.9*	*0.0*
Breeding Cattle 1st Year	*36.8*	*48.6*	*14.1*	*0.5*	*0.0*	*37.9*	*47.5*	*14.2*	*0.4*	*0.0*	*33.6*	*38.8*	*27.0*	*0.5*	*0.0*	*40.7*	*34.6*	*23.3*	*1.4*	*0.0*	*42.9*	*33.5*	*21.5*	*2.1*	*0.0*	*43.7*	*31.5*	*20.9*	*3.9*	*0.0*
Breeding Cattle 2nd Year	*45.2*	*29.0*	*25.4*	*0.5*	*0.0*	*47.2*	*26.8*	*25.6*	*0.4*	*0.0*	*37.7*	*23.4*	*38.4*	*0.5*	*0.0*	*41.2*	*20.9*	*36.5*	*1.4*	*0.0*	*42.8*	*20.9*	*34.3*	*2.1*	*0.0*	*41.4*	*19.9*	*34.8*	*3.9*	*0.0*
Breeding Cattle 3rd Year	*50.4*	*29.1*	*20.0*	*0.5*	*0.0*	*51.3*	*28.0*	*20.3*	*0.4*	*0.0*	*42.1*	*22.5*	*34.8*	*0.5*	*0.0*	*45.4*	*21.4*	*31.8*	*1.4*	*0.0*	*45.8*	*21.6*	*30.6*	*2.1*	*0.0*	*53.0*	*17.6*	*25.6*	*3.9*	*0.0*
Fattening Cattle	*70.0*	*24.1*	*0.0*	*0.5*	*5.5*	*66.3*	*27.7*	*0.0*	*0.4*	*5.6*	*67.3*	*26.8*	*2.2*	*0.5*	*3.2*	*62.1*	*29.0*	*4.3*	*1.4*	*3.2*	*57.2*	*32.9*	*4.0*	*2.1*	*3.9*	*62.0*	*26.0*	*4.9*	*3.9*	*3.3*
Sheep (weighted average)	0.0	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	33.2	0.0	66.8	0.0	0.0	39.3	0.0	60.7	0.0	0.0	33.7	0.0	66.3	0.0	0.0	37.0	0.0	63.0
Fattening Sheep	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Milksheep	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*26.1*	*0.0*	*73.9*	*0.0*	*0.0*	*24.1*	*0.0*	*75.9*	*0.0*	*0.0*	*22.8*	*0.0*	*77.2*	*0.0*	*0.0*	*40.9*	*0.0*	*59.1*
Swine (weighted average)	98.8	0.0	0.0	1.2	0.0	98.8	0.0	0.0	1.2	0.0	97.6	0.3	0.1	1.9	0.0	92.8	0.1	1.3	5.8	0.0	91.3	0.2	0.1	8.3	0.0	82.5	0.0	0.0	17.4	0.0
Piglets	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*97.2*	*0.8*	*0.0*	*1.9*	*0.0*	*93.2*	*0.7*	*0.4*	*5.8*	*0.0*	*89.4*	*2.3*	*0.0*	*8.3*	*0.0*	*82.6*	*0.0*	*0.0*	*17.4*	*0.0*
Fattening Pig over 25 kg	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*97.6*	*0.3*	*0.2*	*1.9*	*0.0*	*92.7*	*0.0*	*1.5*	*5.8*	*0.0*	*91.5*	*0.0*	*0.1*	*8.3*	*0.0*	*82.5*	*0.0*	*0.0*	*17.4*	*0.0*
Dry Sows	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.0*	*0.0*	*0.1*	*1.9*	*0.0*	*93.1*	*0.1*	*1.0*	*5.8*	*0.0*	*91.5*	*0.0*	*0.2*	*8.3*	*0.0*	*82.5*	*0.0*	*0.1*	*17.4*	*0.0*
Nursing Sows	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*97.4*	*0.7*	*0.0*	*1.9*	*0.0*	*93.3*	*0.5*	*0.3*	*5.8*	*0.0*	*91.5*	*0.2*	*0.0*	*8.3*	*0.0*	*82.5*	*0.0*	*0.0*	*17.4*	*0.0*
Boars	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*1.2*	*0.0*	*97.3*	*0.5*	*0.2*	*1.9*	*0.0*	*93.1*	*0.0*	*1.2*	*5.8*	*0.0*	*89.8*	*1.2*	*0.6*	*8.3*	*0.0*	*82.3*	*0.0*	*0.3*	*17.4*	*0.0*
Buffalo (weighted average)	NA	NA	NA	NA	NA	47.5	26.8	25.6	0.0	0.0	38.2	23.5	38.4	0.0	0.0	42.4	21.1	36.5	0.0	0.0	44.5	21.2	34.3	0.0	0.0	44.8	20.4	34.8	0.0	0.0
Bisons < 3 years	*45.6*	*29.0*	*25.4*	*0.0*	*0.0*	*47.5*	*26.8*	*25.6*	*0.0*	*0.0*	*38.2*	*23.5*	*38.4*	*0.0*	*0.0*	*42.4*	*21.1*	*36.5*	*0.0*	*0.0*	*44.5*	*21.2*	*34.3*	*0.0*	*0.0*	*44.8*	*20.4*	*34.8*	*0.0*	*0.0*
Bisons > 3 years	*45.6*	*29.0*	*25.4*	*0.0*	*0.0*	*47.5*	*26.8*	*25.6*	*0.0*	*0.0*	*38.2*	*23.5*	*38.4*	*0.0*	*0.0*	*42.4*	*21.1*	*36.5*	*0.0*	*0.0*	*44.5*	*21.2*	*34.3*	*0.0*	*0.0*	*44.8*	*20.4*	*34.8*	*0.0*	*0.0*
Camels (weighted average)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	33.5	0.0	66.5	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Llamas < 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Llamas > 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Alpacas < 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Alpacas > 2 years	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Deer (weighted average)	0.0	0.0	30.7	0.0	69.3	0.0	0.0	30.7	0.0	69.3	0.0	0.0	33.5	0.0	66.5	0.0	0.0	40.2	0.0	59.8	0.0	0.0	34.5	0.0	65.5	0.0	0.0	36.7	0.0	63.3
Fallow Deer	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Red Deer	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Goats	0.0	0.0	13.6	0.0	86.4	0.0	0.0	13.6	0.0	86.4	0.0	0.0	12.2	0.0	87.8	0.0	0.0	7.1	0.0	92.9	0.0	0.0	10.0	0.0	90.0	0.0	0.0	11.6	0.0	88.4
Goat Places	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*12.2*	*0.0*	*87.8*	*0.0*	*0.0*	*7.1*	*0.0*	*92.9*	*0.0*	*0.0*	*10.0*	*0.0*	*90.0*	*0.0*	*0.0*	*11.6*	*0.0*	*88.4*
Horses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.1	23.9	0.0	0.0	0.0	78.7	21.3	0.0	0.0	0.0	74.4	25.6	0.0	0.0	0.0	78.7	21.3	0.0	0.0
Horses <3 years	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*61.8*	*38.2*	*0.0*	*0.0*	*0.0*	*61.7*	*38.3*	*0.0*	*0.0*	*0.0*	*66.4*	*33.6*	*0.0*	*0.0*	*0.0*	*66.1*	*33.9*	*0.0*	*0.0*
Horses >3 years	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*81.9*	*18.1*	*0.0*	*0.0*	*0.0*	*75.6*	*24.4*	*0.0*	*0.0*	*0.0*	*79.8*	*20.2*	*0.0*	*0.0*
Mules and Asses (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	93.2	6.8	0.0	0.0	0.0	76.9	23.1	0.0	0.0	0.0	75.2	24.8	0.0	0.0	0.0	79.3	20.7	0.0	0.0	0.0	77.6	22.4	0.0	0.0
Mules	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Asses	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Poultry (weighted average)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.5	0.0	99.5	0.0	0.0	2.6	0.0	97.4	0.0	0.0	3.4	0.0	96.6	0.0	0.0	2.4	0.0	97.6	0.0	0.0	2.9	0.0	97.1
Growers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*0.2*	*0.0*	*99.8*	*0.0*	*0.0*	*1.5*	*0.0*	*98.5*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*
Layers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*5.1*	*0.0*	*94.9*	*0.0*	*0.0*	*7.3*	*0.0*	*92.7*	*0.0*	*0.0*	*6.1*	*0.0*	*93.9*	*0.0*	*0.0*	*6.9*	*0.0*	*93.1*
Broilers	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*	*0.0*	*0.0*	*0.6*	*0.0*	*99.4*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*0.3*	*0.0*	*99.7*	*0.0*	*0.0*	*0.2*	*0.0*	*99.8*
Turkey	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.4*	*0.0*	*99.6*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*1.9*	*0.0*	*98.1*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*
Other Poultry [a]	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*100.0*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*3.1*	*0.0*	*96.9*	*0.0*	*0.0*	*1.2*	*0.0*	*98.8*	*0.0*	*0.0*	*2.5*	*0.0*	*97.5*
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	93.2	6.8	0.0	0.0	0.0	89.5	7.1	0.0	3.4	0.0	37.3	27.7	0.0	35.0	0.0	33.8	30.1	0.0	36.2	0.0	39.5	28.1	0.0	32.4	0.0	42.1	27.0	0.0	30.9
Fattening Sheep Non-Agr.	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*30.7*	*0.0*	*69.3*	*0.0*	*0.0*	*33.5*	*0.0*	*66.5*	*0.0*	*0.0*	*40.2*	*0.0*	*59.8*	*0.0*	*0.0*	*34.5*	*0.0*	*65.5*	*0.0*	*0.0*	*36.7*	*0.0*	*63.3*
Milksheep Non-Agr.	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*11.4*	*0.0*	*88.6*	*0.0*	*0.0*	*26.1*	*0.0*	*73.9*	*0.0*	*0.0*	*24.1*	*0.0*	*75.9*	*0.0*	*0.0*	*22.8*	*0.0*	*77.2*	*0.0*	*0.0*	*40.9*	*0.0*	*59.1*
Total Goats Non-Agr.	*NA*	*NA*	*NA*	*NA*	*NA*	*0.0*	*0.0*	*13.6*	*0.0*	*86.4*	*0.0*	*0.0*	*12.2*	*0.0*	*87.8*	*0.0*	*0.0*	*7.1*	*0.0*	*92.9*	*0.0*	*0.0*	*10.0*	*0.0*	*90.0*	*0.0*	*0.0*	*11.6*	*0.0*	*88.4*
Horses <3 years Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*61.8*	*38.2*	*0.0*	*0.0*	*0.0*	*61.7*	*38.3*	*0.0*	*0.0*	*0.0*	*66.4*	*33.6*	*0.0*	*0.0*	*0.0*	*66.1*	*33.9*	*0.0*	*0.0*
Horses >3 years Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*81.9*	*18.1*	*0.0*	*0.0*	*0.0*	*75.6*	*24.4*	*0.0*	*0.0*	*0.0*	*79.8*	*20.2*	*0.0*	*0.0*
Mules Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*
Asses Non-Agr.	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*93.2*	*6.8*	*0.0*	*0.0*	*0.0*	*76.9*	*23.1*	*0.0*	*0.0*	*0.0*	*75.2*	*24.8*	*0.0*	*0.0*	*0.0*	*79.3*	*20.7*	*0.0*	*0.0*	*0.0*	*77.6*	*22.4*	*0.0*	*0.0*

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

Table A – 22 Nitrogen excretion of livestock in Switzerland.

Nitrogen Excretion	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	kg N/head or place/year																												
Mature Dairy Cattle	100.4	100.7	100.9	101.1	101.3	101.5	102.0	102.5	103.0	103.4	103.9	104.4	104.8	105.9	106.9	108.0	109.1	110.1	110.3	110.4	110.5	110.7	111.0	111.2	111.4	111.6	111.6	111.6	111.6
Other Mature Cattle	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)	33.0	33.0	33.0	33.0	33.1	33.1	33.0	33.2	32.9	32.4	33.1	32.7	32.6	32.7	32.7	32.6	32.7	32.7	32.9	32.8	32.7	32.8	33.0	33.1	33.1	33.1	33.0	32.9	32.8
Fattening Calves	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.4	13.8	14.2	14.6	15.0	15.3	15.7	16.0	16.4	16.8	17.2	17.6	18.0	18.0	18.0	18.0
Pre-Weaned Calves	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Breeding Cattle 1st Year	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Breeding Cattle 2nd Year	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Breeding Cattle 3rd Year	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
Fattening Cattle	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.4	33.8	34.2	34.6	35.0	35.3	35.7	36.0	36.4	36.8	37.2	37.6	38.0	38.0	38.0	38.0
Sheep (weighted average)	7.5	7.6	7.5	7.6	7.6	7.6	7.6	7.6	7.6	8.1	8.0	8.1	8.0	8.1	8.1	8.1	8.2	8.2	8.2	8.4	8.5	8.4	8.5	8.6	8.5	8.4	8.4	8.5	8.5
Fattening Sheep	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Milksheep	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Swine (weighted average)	14.3	14.3	14.3	14.1	14.0	14.0	13.7	13.1	12.7	11.8	11.3	10.8	10.4	10.2	10.0	9.9	9.7	9.5	9.6	9.7	9.7	9.6	9.5	9.4	9.4	9.4	9.4	9.4	9.3
Piglets	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.5	4.5	4.5	4.4	4.4	4.4	4.2	4.0	3.8	3.6	3.5	3.5	3.5	3.5
Fattening Pig over 25 kg	18.2	18.1	18.0	18.0	17.9	17.8	17.2	16.6	16.1	15.5	14.9	14.3	13.7	13.4	13.2	12.9	12.6	12.3	12.4	12.5	12.6	12.4	12.2	12.0	11.8	11.6	11.6	11.6	11.6
Dry Sows	22.6	22.6	22.6	22.6	22.6	22.6	22.1	21.7	21.2	20.8	20.3	19.9	19.4	19.5	19.6	19.7	19.7	19.8	19.9	20.0	20.1	21.0	22.0	23.0	24.0	25.0	25.0	25.0	25.0
Nursing Sows	49.3	49.3	49.3	49.3	49.3	49.3	47.6	46.0	44.3	42.7	41.1	39.4	37.8	38.4	38.9	39.5	40.1	40.7	40.0	39.2	38.5	39.0	39.6	40.1	40.6	41.2	41.2	41.2	41.2
Boars	18.9	18.9	18.9	18.9	18.9	18.9	18.3	17.8	17.2	16.6	16.1	15.5	14.9	15.0	15.1	15.2	15.3	15.4	15.7	15.9	16.2	16.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Buffalo (weighted average)	NA	NA	36.5	37.8	37.5	37.2	37.3	37.1	37.3	34.9	41.1	37.5	38.8	37.4	38.5	38.7	38.0	34.9	34.4	36.5	37.3	38.4	36.9	36.9	36.4	36.4	36.4	35.9	47.1
Bisons < 3 years	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Bisons > 3 years	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Camels (weighted average)	NA	NA	NA	NA	NA	NA	15.3	15.3	15.3	14.0	14.1	13.0	13.3	13.7	13.3	12.8	12.8	12.8	12.8	12.8	12.6	12.7	12.8	12.9	12.8	12.7	12.6	12.6	12.5
Llamas < 2 years	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Llamas > 2 years	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Alpacas < 2 years	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Alpacas > 2 years	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Deer (weighted average)	20.0	20.4	21.2	21.6	21.8	21.9	23.6	21.9	21.7	22.0	22.3	22.1	22.4	21.8	22.0	21.9	22.1	22.1	22.4	22.5	22.4	22.4	22.5	23.0	23.0	23.0	23.1	23.3	23.4
Fallow Deer	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Red Deer	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Goats	11.2	11.2	11.2	11.2	11.1	11.1	11.1	11.1	11.2	11.3	11.3	11.4	11.1	11.3	11.1	11.1	11.3	11.2	11.2	11.4	11.2	11.4	11.5	11.6	11.6	11.4	11.4	11.4	11.4
Goat Places	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Horses (weighted average)	43.6	43.6	43.6	43.6	43.5	43.5	43.5	43.6	43.6	43.5	43.6	43.6	43.6	43.6	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.8	43.8	43.8	43.8	43.9	43.9
Horses <3 years	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
Horses >3 years	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Mules and Asses (weighted average)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Mules	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Asses	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Growers	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Layers	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Broilers	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Turkey	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Other Poultry [a]	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Rabbits	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)	38.8	38.8	38.8	38.8	39.0	34.0	16.8	15.3	14.8	14.9	14.5	13.8	13.5	13.1	13.0	12.6	12.5	12.6	12.3	13.2	14.3	14.9	15.4	15.6	15.7	14.9	15.3	15.4	15.5
Fattening Sheep Non-Agr.	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Milksheep Non-Agr.	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Total Goats Non-Agr.	NA	NA	NA	NA	NA	12.0	11.2	11.0	11.1	11.8	11.2	11.4	11.2	11.1	11.2	11.6	11.2	10.9	11.1	10.8	10.7	11.8	11.9	11.9	12.0	11.5	11.4	11.4	11.5
Horses <3 years Non-Agr.	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
Horses >3 years Non-Agr.	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Mules Non-Agr.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Asses Non-Agr.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0

[a] Other Poultry: Geese, Ducks, Ostriches, Quails

Additional data for estimating N_2O emissions from 3D Agricultural soils

Table A – 23 Additional data for estimating N_2O emission from crop residues.

2018		Total crop production t DM	Nitrogen incorporated with crop residues $F_{(CR)}$ t N	N_2O emissions from crop residues t N_2O
1. Cereals	Wheat	403'005	1'688	26.53
	Barley	153'806	784	12.32
	Maize	114'609	1'079	16.95
	Oats	7'018	44	0.68
	Rye	8'595	36	0.57
	Other:			
	Triticale	40'241	197	3.10
	Spelt	18'527	170	2.66
	Mix of Fodder Cereals	952	5	0.08
	Mix of Bread Cereals	156	1	0.01
	Millet	147	4	0.06
2. Pulse	Dry Beans	2'222	88	1.39
	Peas (Eiweisserbsen)	10'607	312	4.90
	Soybeans	3'179	131	2.06
	Leguminous Vegetables	2'842	296	4.66
	Lupines	413	16	0.26
3. Tuber and Root	Potatoes	95'837	350	5.50
	Other:			
	Fodder Beet	6'400	46	0.72
	Sugar Beet	277'962	1'984	31.17
5. Other	Fruit	66'046	617	9.69
	Grass	5'748'021'536	26'313	413.49
	Green Corn	121'932	116	1.82
	Non-Leguminous Vegetables	56'576	669	10.51
	Rape	69'730	1'195	18.78
	Renewable Energy Crops	801	14	0.22
	Silage Corn	717'244	423	6.64
	Sunflowers	14'036	297	4.67
	Tobacco	991	26	0.41
	Berries	2'752	48	0.76
	Vine	28'148	493	7.74
	Oil Squash	6	0	0.00
	Oil Hemp	23	1	0.02
	Oil Flax	306	3	0.04
	Hops	29	0	0.00
	Medicinal Plants and Herbs	387	32	0.50
Total Non-leguminous		2'206'262	10'319	162.16
Total Leguminous		19'263	844	13.26
Total excluding grass		2'225'525	11'163	175.42
Total including grass		5'750'247'060	37'476	588.92

Table A – 24 Additional data for estimating N_2O emission from crop residues (fractions).

2018		Residue/ Crop ratio kg/kg	Dry matter fraction of residue kg/kg	Nitrogen content of residues kg/kg
1. Cereals	Wheat	1.15	0.85	0.0037
	Barley	1.00	0.85	0.0051
	Maize	1.10	0.85	0.0086
	Oats	1.27	0.85	0.0049
	Rye	1.17	0.85	0.0036
	Other :			
	Triticale	1.25	0.85	0.0039
	Spelt	1.56	0.85	0.0059
	Mix of Fodder Cereals	1.00	0.85	0.0051
	Mix of Bread Cereals	1.15	0.85	0.0037
	Millet	1.29	0.85	0.0196
2. Pulse	Dry Beans	1.13	0.85	0.0353
	Peas (Eiweisserbsen)	1.25	0.85	0.0235
	Soybeans	1.00	0.85	0.0412
	Other:	0.00	0.00	0.0000
	Leguminous Vegetables	3.87	0.16	0.0328
	Lupines	1.00	0.85	0.0412
3. Tuber and Root	Potatoes	0.47	0.13	0.0127
	Other :			
	Fodder Beet	0.37	0.15	0.0233
	Sugar Beet	0.53	0.15	0.0220
5. Other	Fruit	NA	0.17	0.0040
	Grass	0.24	NA	0.0204
	Green Corn	0.05	0.32	0.0190
	Non-Leguminous Vegetables	0.46	0.13	0.0230
	Rape	2.57	0.85	0.0071
	Renewable Energy Crops	2.57	0.85	0.0071
	Silage Corn	0.05	0.32	0.0118
	Sunflowers	2.00	0.60	0.0150
	Tobacco	1.18	NA	0.0221
	Berries	NA	0.20	0.0060
	Vine	NA	0.20	0.0060
	Oil Squash	0.46	0.13	0.0230
	Oil Hemp	4.62	0.85	0.0106
	Oil Flax	1.25	0.85	0.0071
	Hops	NA	1.00	NA
	Medicinal Plants and Herbs	2.50	NA	0.0330

Table A – 25 NH_3 and NO_x emission factors for 3Db Indirect N_2O emissions from managed soils.

Emission Factors Volatilisation	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
	%														
NH_3 from application of animal manure N ($Frac_{GASMT}$)	24.18	24.19	24.16	24.12	24.19	24.18	23.90	23.57	23.23	22.84	22.52	22.19	21.81	21.99	22.18
Mature Dairy Cattle	26.69	26.71	26.73	26.75	26.76	26.78	26.52	26.25	25.98	25.69	25.40	25.10	24.78	24.96	25.13
Other Mature Cattle	24.16	24.06	23.97	23.87	23.78	23.68	23.35	22.99	22.61	22.20	21.76	21.29	20.78	21.44	22.07
Growing Cattle (weighted average)	24.47	24.46	24.45	24.47	24.52	24.54	24.16	23.82	23.40	22.93	22.60	22.10	21.62	22.03	22.42
Sheep (weighted average)	3.73	3.86	3.99	4.12	4.26	4.39	4.34	4.28	4.23	4.17	4.11	4.05	3.99	4.38	4.78
Swine (weighted average)	21.52	21.42	21.32	21.22	21.12	21.02	20.83	20.61	20.38	20.11	19.82	19.49	19.11	19.36	19.62
Buffalo (weighted average)	NA	NA	25.24	25.29	25.33	25.38	25.11	24.81	24.49	24.16	23.79	23.40	22.99	23.34	23.70
Camels (weighted average)	NA	NA	NA	NA	NA	NA	4.33	4.29	4.24	4.19	4.14	4.09	4.04	4.44	4.85
Deer (weighted average)	3.72	3.85	3.99	4.12	4.25	4.38	4.33	4.29	4.24	4.19	4.14	4.09	4.04	4.44	4.85
Goats	3.83	3.97	4.10	4.24	4.37	4.51	4.39	4.27	4.15	4.03	3.91	3.79	3.68	4.86	5.99
Horses (weighted average)	3.75	3.88	4.01	4.15	4.28	4.41	4.29	4.16	4.01	3.86	3.70	3.53	3.34	3.55	3.75
Mules and Asses (weighted average)	3.75	3.88	4.01	4.15	4.28	4.41	4.25	4.09	3.91	3.72	3.52	3.31	3.08	3.36	3.63
Poultry (weighted average)	13.04	13.53	14.02	14.50	14.99	15.46	15.14	14.81	14.48	14.15	13.80	13.48	13.17	12.87	12.55
Rabbits	9.66	9.66	9.66	9.66	9.66	9.66	9.59	9.52	9.44	9.37	9.29	9.22	9.14	9.12	9.09
Livestock NCAC (weighted average)	3.75	3.88	4.01	4.15	4.28	4.42	4.30	4.19	4.08	3.97	3.84	3.73	3.60	3.99	4.40
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.65	4.66	4.67	4.68	4.69	4.69	4.72	4.74	4.76	4.78	4.78	4.78	4.79	4.83	4.86
Mature Dairy Cattle	4.67	4.67	4.66	4.66	4.66	4.65	4.65	4.64	4.64	4.64	4.64	4.63	4.63	4.63	4.62
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	NA	NA	NA	NA	NA	NA	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Buffalo (weighted average)	NA	NA	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Camels (weighted average)	NA	NA	NA	NA	NA	NA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Deer (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Goats	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Horses (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Mules and Asses (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Poultry (weighted average)	NA	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00
Rabbits	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Livestock NCAC (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	6.19	5.61	5.63	5.85	6.04	6.05	6.04	5.80	5.37	5.39	5.42	4.98	4.99	4.67	4.82
Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.59	2.44	2.62	2.51	2.44	2.66	2.58	2.62
Recycling Fertilisers (weighted average)	17.60	18.12	18.63	19.17	19.60	19.97	19.78	19.70	19.61	19.21	18.81	17.67	15.96	15.06	14.20
Sewage Sludge	20.00	20.81	21.60	22.39	23.17	23.94	24.25	24.61	25.02	25.50	26.07	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	29.55	29.10	28.09	27.08
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Emission Factors Volatilisation	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	%													
NH_3 from application of animal manure N ($Frac_{GASMT}$)	22.36	22.63	22.81	22.30	21.68	21.08	20.88	20.64	20.43	20.21	20.00	19.97	19.95	19.91
Mature Dairy Cattle	25.30	25.47	25.63	25.00	24.38	23.76	23.44	23.12	22.80	22.49	22.18	22.18	22.18	22.18
Other Mature Cattle	22.65	23.20	23.72	23.31	22.88	22.45	22.28	22.11	21.94	21.77	21.60	21.60	21.60	21.60
Growing Cattle (weighted average)	22.80	23.19	23.57	23.02	22.47	21.92	21.73	21.57	21.38	21.19	21.01	21.01	21.01	21.00
Sheep (weighted average)	5.19	5.61	6.04	5.86	5.69	5.54	5.40	5.26	5.12	4.96	4.81	4.81	4.81	4.80
Swine (weighted average)	19.89	20.16	20.48	19.85	19.25	18.66	18.53	18.40	18.27	18.14	18.00	17.99	18.00	18.00
Buffalo (weighted average)	24.05	24.40	24.75	24.07	23.40	22.75	22.50	22.24	21.99	21.73	21.48	21.48	21.48	21.48
Camels (weighted average)	5.28	5.72	6.18	5.94	5.71	5.50	5.39	5.27	5.16	5.04	4.92	4.92	4.92	4.92
Deer (weighted average)	5.28	5.72	6.18	5.94	5.71	5.50	5.39	5.27	5.16	5.04	4.92	4.92	4.92	4.92
Goats	7.06	8.09	9.07	7.72	6.31	4.82	5.02	5.23	5.44	5.65	5.86	5.86	5.86	5.86
Horses (weighted average)	3.96	4.16	4.35	4.50	4.65	4.81	4.87	4.95	5.02	5.10	5.18	5.19	5.19	5.20
Mules and Asses (weighted average)	3.90	4.18	4.46	5.35	6.20	7.00	6.52	6.03	5.53	5.01	4.48	4.48	4.48	4.48
Poultry (weighted average)	12.24	12.07	11.68	12.33	13.09	13.85	13.82	13.78	13.75	13.71	13.68	13.68	13.69	13.69
Rabbits	9.06	9.03	9.00	9.07	9.14	9.21	9.21	9.21	9.21	9.21	9.21	9.21	9.21	9.21
Livestock NCAC (weighted average)	4.89	5.28	5.65	5.59	5.33	5.19	5.17	5.16	5.14	5.13	5.13	5.13	5.13	5.13
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.91	4.93	4.97	4.92	4.88	4.84	4.85	4.86	4.87	4.88	4.90	4.92	4.94	4.96
Mature Dairy Cattle	4.61	4.61	4.60	4.60	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Buffalo (weighted average)	4.57	4.56	4.56	4.56	4.56	4.57	4.57	4.56	4.56	4.56	4.56	4.56	4.56	4.56
Camels (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Deer (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Goats	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Horses (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Mules and Asses (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Poultry (weighted average)	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00	42.00
Rabbits	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Livestock NCAC (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	4.67	4.46	4.84	4.70	4.59	4.72	4.82	4.86	5.08	5.26	5.65	5.54	5.65	5.72
Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	2.76	2.65	2.74	2.94	3.12	3.07	2.99	3.11	3.12	3.04	3.37	2.82	3.05	3.08
Recycling Fertilisers (weighted average)	13.52	12.96	12.06	10.85	9.46	9.78	10.18	10.76	11.10	11.34	11.59	11.85	11.98	12.12
Sewage Sludge	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	26.06	25.05	24.04	23.03	22.01	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Table A – 26 Overview of N pools and flows for calculating 3Db Indirect N_2O emission from managed soils.

Nitrogen pools and flows		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
		1990-2004														
		t N/yr														
	Animals manure N applied to soils	114'921	113'137	110'800	108'587	107'596	106'384	102'239	97'187	94'586	91'182	87'900	86'604	83'621	82'665	81'975
	Commercial fertiliser	75'085	75'390	75'318	70'487	66'846	67'018	64'629	56'402	56'433	58'641	57'969	61'422	59'352	56'512	56'740
Deposition	Sum volatised N (NH_3 and NO_x)	34'173	33'345	32'751	32'008	31'748	31'469	30'104	27'931	26'814	25'835	24'875	24'312	23'291	22'883	22'965
	NH_3 emissions from commercial fertilisers	4'644	4'229	4'243	4'120	4'037	4'058	3'907	3'271	3'032	3'158	3'142	3'057	2'963	2'640	2'735
	NH_3 emissions from applied animal manure	27'785	27'367	26'767	26'189	26'024	25'722	24'438	22'905	21'973	20'829	19'795	19'214	18'234	18'178	18'181
	NH_3 emissions from pasture, range and paddock	625	637	642	639	652	659	754	816	878	918	1'019	1'100	1'173	1'167	1'155
	NO_x emissions from commercial fertilisers	413	415	414	388	368	369	355	310	310	323	319	338	326	311	312
	NO_x emissions from applied animal manure	632	622	609	597	592	585	562	535	520	501	483	476	460	455	451
	NO_x emissions from PR&P	74	75	76	75	76	77	88	95	101	106	117	127	135	133	131
Leaching and run-off	Sum leaching and run-off	51'114	49'742	49'272	51'336	49'733	50'001	45'469	43'520	43'598	41'477	46'143	44'360	42'150	38'840	38'572
	Leaching and run-off from commercial fertilisers	15'474	15'536	15'522	14'526	13'776	13'811	13'200	11'415	11'317	11'652	11'411	11'978	11'464	10'811	10'751
	Leaching and run-off from applied animal manure	23'683	23'316	22'834	22'378	22'174	21'924	20'881	19'670	18'969	18'118	17'303	16'888	16'152	15'815	15'532
	Leaching and run-off from pasture, range and paddock	2'767	2'816	2'832	2'813	2'866	2'892	3'263	3'483	3'700	3'818	4'196	4'488	4'729	4'627	4'502
	Leaching and run-off from crop residues	8'052	7'949	7'959	7'910	7'742	7'751	7'987	7'829	7'889	7'536	7'778	7'393	7'504	7'115	7'441
	Leaching and run-off from mineralisation of SOM	1'139	125	126	3'709	3'176	3'623	138	1'123	1'722	353	5'454	3'613	2'301	471	346

Nitrogen pools and flows		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
		2004-2018														
		t N/yr														
	Animals manure N applied to soils	83'526	84'382	85'122	86'661	85'739	86'088	85'811	85'894	85'411	85'937	85'516	85'093	84'543	84'257	
	Commercial fertiliser	55'425	54'519	56'947	53'680	50'701	58'698	52'479	51'521	50'380	56'484	51'043	54'166	57'430	53'850	
Deposition	Sum volatised N (NH_3 and NO_x)	23'336	23'609	24'287	23'946	22'953	22'979	22'451	22'238	21'992	22'357	21'967	21'992	22'122	21'849	
	NH_3 emissions from commercial fertilisers	2'591	2'432	2'755	2'522	2'325	2'772	2'527	2'504	2'560	2'970	2'886	3'001	3'244	3'080	
	NH_3 emissions from applied animal manure	18'677	19'093	19'419	19'323	18'586	18'151	17'917	17'729	17'446	17'367	17'104	16'997	16'869	16'777	
	NH_3 emissions from pasture, range and paddock	1'173	1'187	1'199	1'195	1'160	1'131	1'119	1'122	1'114	1'111	1'102	1'105	1'105	1'109	
	NO_x emissions from commercial fertilisers	305	300	313	295	279	323	289	283	277	311	281	298	316	296	
	NO_x emissions from applied animal manure	459	464	468	477	472	473	472	472	470	473	470	468	465	463	
	NO_x emissions from PR&P	131	132	133	134	131	128	127	127	126	125	124	123	123	123	
Leaching and run-off	Sum leaching and run-off	41'107	37'490	39'727	37'262	36'640	37'812	37'087	39'763	36'486	39'052	37'459	38'053	39'332	35'994	
	Leaching and run-off from commercial fertilisers	10'399	10'128	10'446	9'737	9'122	10'450	9'335	9'164	8'960	10'051	9'078	9'628	10'161	9'494	
	Leaching and run-off from applied animal manure	15'671	15'676	15'656	15'780	15'453	15'357	15'308	15'323	15'237	15'330	15'255	15'180	15'082	15'031	
	Leaching and run-off from pasture, range and paddock	4'485	4'475	4'436	4'423	4'284	4'164	4'117	4'120	4'079	4'062	4'013	4'003	3'994	3'990	
	Leaching and run-off from crop residues	7'254	6'976	7'035	6'906	6'912	6'619	6'800	6'697	6'437	7'065	6'629	6'556	6'774	6'686	
	Leaching and run-off from mineralisation of SOM	3'298	234	2'154	416	868	1'221	1'526	4'460	1'774	2'543	2'484	2'685	3'321	793	

Annex 4 National energy balance and reference approach

A4.1 Swiss energy balance: energy flows

The diagram shows a summary of the Swiss energy flow 2018 as published by the Swiss Federal Office of Energy (SFOE 2019). Diagram languages are German and French. The energy balance is also provided in tabular form in Table A – 27.

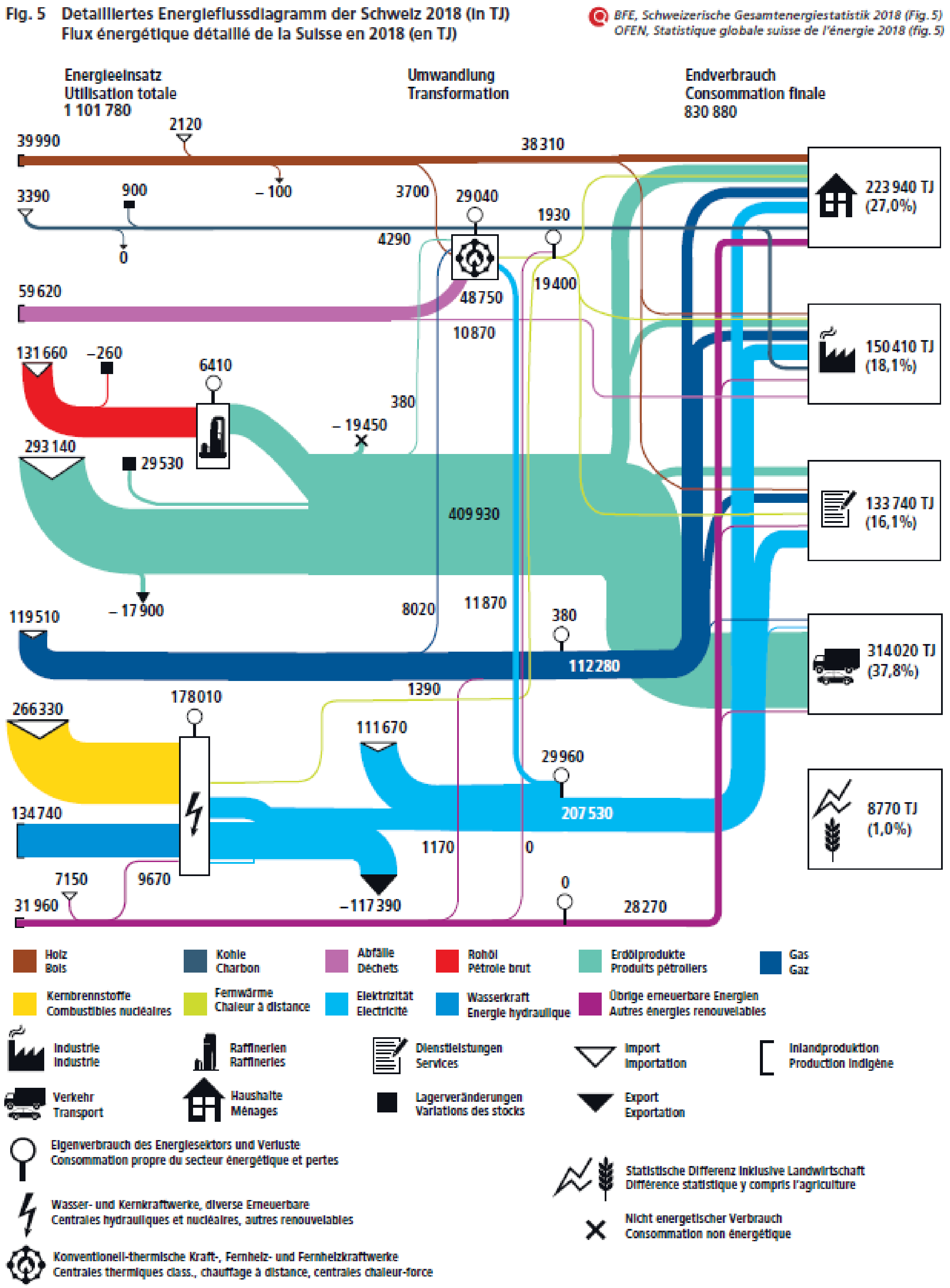


Figure A – 2 Energy flow in Switzerland 2018 in TJ (SFOE 2019)

Table A – 27 Switzerland's energy balance 2018 (SFOE 2019) in TJ[13].

Tab. 4 Energiebilanz der Schweiz für das Jahr 2018 (in TJ)
Bilan énergétique de la Suisse pour 2018 (en TJ)

		Holzenergie	Kohle	Müll und Industrie-abfälle	Rohöl	Erdöl-produkte	Gas	Wasserkraft	Kernbrenn-stoffe	Übrige erneuerbare Energien	Elektrizität	Fernwärme	Total	
		Energie du bois	Charbon	Ord. mén. et déchets ind.	Pétrole brut	Produits pétroliers	Gaz	Energie hydraulique	Combustibles nucléaires	Autres énergies renouvelables	Electricité	Chaleur à distance		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Inlandproduktion	(a)	39 990	–	59 620	–	–	–	134 740	–	31 960	–	–	266 310	Production indigène
+ Import	(b)	2 120	3 390		131 660	293 140	119 510		266 330	7 150	111 670	–	934 970	+ Importation
+ Export	(c)	−100	–	–	–	−17 900	–	–	–	–	−117 390	–	−135 390	+ Exportation
+ Lagerveränderung¹	(d)	–	900	–	−260	29 530	–	–	–	–	–	–	30 170	+ Variation de stock¹
= Bruttoverbrauch	(e)	42 010	4 290	59 620	131 400	304 770	119 510	134 740	266 330	39 110	−5 720	0	1 096 060	= Consommation brute
+ Energieumwandlung:													0	+ Transformation d'énergie
· Wasserkraftwerke	(f)	–	–	–	–	–	–	−134 740	–	–	134 740	–	0	· Centrales hydrauliques
· Kernkraftwerke	(g)	–	–	–	–	–	–	–	−266 330	–	87 890	1 390	−177 050	· Centrales nucléaires
· konventionell-thermische Kraft-, Fernheiz- und Fernheizkraft-werke	(h)	−2 130		−48 750	–	−380	−8 020	–	–	–	10 830	19 940	−28 510	· Centrales thermiques class., chauffage à distance, centrales chaleur-force
· Gaswerke	(i)	–	–	–	–	–	–	–	–	–	–	–	0	· Usines à gaz
· Raffinerien	(j)	–	–	–	−131 400	131 400	–	–	–	–	–	–	0	· Raffineries
· Diverse Erneuerbare	(k)	−1 570	–	–	–	–	1 170	–	–	−10 840	9 750	0	−1 490	· Renouvelables div.
+ Eigenverbrauch des Energie-sektors, Netzverluste, Verbrauch der Speicherungen	(l)	–	–	–	–	−6 410	−380	–	–	–	−29 960	−1 930	−38 680	+ Consommation propre du secteur énergétique, pertes de réseau, pompage d'accumulation
+ Nichtenergetischer Verbrauch	(m)	–	–	–	–	−19 450	–	–	–	–	–	–	−19 450	+ Consommation non énergétique
= Endverbrauch	(n)	38 310	4 290	10 870	0	409 930	112 280	0	0	28 270	207 530	19 400	830 880	= Consommation finale
Haushalte	(o)	18 300	100	–	–	67 980	46 070	–	–	15 250	68 710	7 530	223 940	Ménages
Industrie	(p)	10 950	4 190	10 870	–	14 250	39 230	–	–	1 690	62 320	6 910	150 410	Industrie
Dienstleistungen	(q)	8 240	0	–	–	30 670	24 580	–	–	3 390	61 900	4 960	133 740	Services
Verkehr	(r)	–	–	–	–	294 300	1 080	–	–	7 520	11 120	0	314 020	Transport
Statistische Differenz inkl. Landwirtschaft	(s)	820	0	–	–	2 730	1 320	–	–	420	3 480	0	8 770	Différence statistique, y compris l'agriculture

¹ + Lagerabnahme
− Lagerzunahme

¹ + diminution de stock
− augmentation de stock

BFE, Schweizerische Gesamtenergiestatistik 2018 (Tab. 4)
OFEN, Statistique globale suisse de l'énergie 2018 (tabl. 4)

[13] Liechtenstein's consumption of liquid fuels is included in the numbers (see chapter below on Final Swiss energy consumption).

A4.2 Differences between IEA data and the reference approach

Reviewers have repeatedly asked for explanations of the apparent differences between the energy data held by the International Energy Agency (IEA) and the data reported in the Reference Approach. In order to clarify the pertaining issues, the reasons for the major differences are given below. Data for the year 2010 are used to illustrate the description, however, a recent comparison with data for 2016 produced similar results.

General remarks

The net calorific values used by IEA differ from those used in the GHG inventory. In order to avoid differences caused by the conversion with different NCV, the comparison between IEA and the Reference Approach is made in kt.

Stock changes as reported by IEA are only including primary stocks (IEA 2005), while the reporting in the Reference Approach includes secondary and tertiary stocks. This results in a particularly large difference for gas oil, as retailers and end-consumers hold considerable amounts of heating fuel on stock. The IEA subsumes secondary and tertiary stock changes under statistical differences.

All data regarding liquid fuel consumption reported by the IEA includes fuel consumption in Liechtenstein (geographical coverage in IEA 2012). For reporting purposes under the UNFCCC, consumption of Liechtenstein is subtracted.

Data sources used for the comparison shown in Table A – 28 below are:

- Switzerland's greenhouse gas inventory 1990–2011, submission of 15. April 2013, CRF Table1.A(b), (FOEN 2013).
- Energy statistics of OECD countries (2012 Edition), (IEA 2012).

Liquid fuels

The total amount of liquid fuel consumption as reported in the greenhouse gas inventory is 11'052 kt. There is a difference of 13 kt (0.1%) between CRF and IEA. This difference is primarily caused by the different methodology used for aviation bunkers (see below).

Crude oil

Crude oil in the reference approach contains additives, while IEA lists them separately (data in italics in Table A – 28. The difference between CRF and IEA is smaller than 0.1% if the sum of additives, refinery feedstocks and crude oil is considered.

Gasoline

The comparison is made for motor gasoline only. Aviation gasoline is included under aviation fuels. Gasoline reported by IEA includes gasoline used in Liechtenstein (LIE), which is subtracted for reporting under the UNFCCC. The difference between CRF and IEA is approximately 0.1%, if the consumption of LIE is taken into account.

Aviation fuels

The different aviation fuels are aggregated in the greenhouse gas inventory. For comparison of IEA and reference approach, all aviation fuels are summed up. The difference between IEA and reference approach if considering the apparent final consumption is 12 kt (approximately 1% of imports). This difference is largely due to a different methodology used to estimate international bunker. Aviation bunkers have to be reported monthly to the IEA. As the tier 3 approach used for the greenhouse gas inventory is not available on a monthly basis, the international bunker fuel estimate of IEA consists of the total consumption at the two international airports in Zurich and Geneva, while all remaining fuel use is considered domestic. The reporting in the national greenhouse gas inventory is based on a much more detailed approach, where information on single flights is taken into account. Due to the different approach, the numbers are somewhat different. However, the order of magnitude is the same, and the information in the inventory is based on a higher-tier method and presumably more accurate.

Diesel and gas oil

The IEA numbers include diesel and gas oil used in Liechtenstein. Furthermore, stock changes are reported differently in the CRF and by the IEA. Secondary and tertiary stock changes are subsumed under statistical differences by the IEA, while they are included in the stock change reported in the reference approach. If the statistical differences are taken into account, the difference in the apparent consumption is less than 0.1%.

Residual fuel oil

Data agree between IEA and UNFCCC. It seems as if there is a rounding error in the imported amounts, leading to an apparent difference of 1 kt. According to the foreign trade statistics, 33'693 t of residual fuel oil had been imported in 2010.

Bitumen

Bitumen is a main feedstock in the greenhouse gas inventory. Data between IEA and the reference approach compare well. Again, small differences are likely due to the use of rounded values, leading to apparent differences of the order of 1-2 kt.

Petroleum coke

There are considerable differences (26 kt) in the reported numbers for petroleum coke import. The reason for this apparent difference is that for IEA, all petroleum coke is reported together. In the greenhouse gas inventory submitted in 2013, however, only the petroleum coke used as a fuel was reported under petroleum coke, while calcined petroleum coke was reported together with “other oil” as feedstocks. This is largely a consequence of the treatment of fuels and feedstocks in the Swiss overall energy statistics (SFOE 2012).

Lubricants

There are small differences between IEA and the reference approach, as the data reported to the IEA comprises a slightly different set of customs tariff headings for lubricants to the one used for the Swiss overall energy statistics. The substances not reported under lubricants in the reference approach are reported under other oil.

Liquefied petroleum gas (LPG)

The reporting of liquefied petroleum gas in the greenhouse gas inventory includes white spirit and lamp oil. As for petroleum coke, IEA numbers include fuels that are used as feedstocks, while in the reference approach, only liquefied petroleum gas, white spirit and lamp oil used as fuels are reported under liquefied petroleum gas. The difference in apparent consumption between IEA and the reference approach is 3 kt (0.03% of total liquid fuel consumption).

Other oil products

In the greenhouse gas inventory, all other oil products are reported together, while IEA has a finer degree of disaggregation. As already mentioned above, the share of petroleum coke that is used as a feedstock is reported under other oil in the greenhouse gas inventory. Therefore, the difference between IEA and the reference approach corresponds largely to the difference in apparent consumption of petroleum coke.

Solid fuels

Solid fuels play only a minor role in Switzerland (246 kt) and are reported in good agreement.

Gaseous fuels

In the greenhouse gas inventory, the amount of gas reported under 1B2b Fugitive emissions is subtracted from the total gas import as reported by IEA, as this gas is not used for energy purposes. Taking this into account the difference is of the order of 2 TJ.

Table A – 28 Comparison of the IEA energy statistic with the Reference Approach for the year 2010. Numbers in italics are fuels that are reported in a finer disaggregation in the IEA energy statistic than in the Reference Approach. Numbers in bold aggregate the data to the level of disaggregation used in the Reference Approach.

CRF vs. IEA (2010)	**Import**		**Export**		**Bunker**		**Stock change**		**Stat.diff.**	**LIE**	**Consumption**	
Gg	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**
Crude oil	*4'488*	*4'546*					*0*	*1*	*0*		*4'488*	*4'547*
Refinery feedstocks	*3*						*1*		*2*		*6*	
Additives/blending components	*51*						*-1*		*2*		*52*	
											4'546	**4'547**
Motor gasoline	1'850	1'838					-9	-6	4	15	**1'830**	**1'832**
Aviation gasoline	*7*						*-2*		*-1*		*4*	
Kerosene type jet fuel	*1'354*	*1'362*			*-1'367*	*-1'352*		*2*	*6*		*-7*	*12*
Other Kerosene	*3*										*3*	
											0	**12**
Gas/diesel oil	3'510	3'485	-21	-39	-10	-11	38	1'072	1'020	27	**4'510**	**4'507**
Fuel oil	33	34	-323	-316			-17	-17	7		**-300**	**-299**
Liquefied petroleum gases (LPG)	*50*	*54*	*-24*	*-25*						*0.1*	*26*	*29*
White spirit & SBP	*7*								*-1*		*6*	
											32	**29**
Bitumen	317	318	-2	-2							**315**	**317**
Lubricants	86	72	-38	-16					7		**55**	**56**
Petroleum coke	73	47									**73**	**47**
Naphtha	*1*						*5*		*-1*		*5*	
Paraffin waxes	*1*										*1*	
Non-specified oil products / other oil	*4*	*63*	-	*-23*			-	*-6*			*4*	*33*
											10	**33**
Liquid fuels											**11'039**	**11'052**
Anthracite	*7*										*7*	
Other bituminous coal	*123*	*152*					*36*	*32*			*159*	*184*
Lignite	*66*	*62*					*-4*				*62*	*62*
Coke oven coke	*18*										*18*	
Solid fuels											**246**	**246**
Natural gas (TJ, NCV)	126'014	125'627									126'014	125'627
Fugitive emissions (TJ, NCV)		389										389
Gaseous fuels											**126'014**	**126'016**

Additional information regarding reporting of waste-derived fuels

During the in-country review in 2016, the ERT identified that the apparent consumption of non-biomass fraction of waste in the CRF Table1.A(b) was systematically smaller than the consumption reported to IEA. The difference stems from the assumptions made with regard to the fossil and renewable fractions. The SFOE, which is responsible for reporting to the IEA, allocates total wastes to 50% fossil and 50% renewable. For the greenhouse gas inventory, a more sophisticated method based on a detailed analysis of waste composition and measurements in the flue gas of waste incineration plants is used to estimate fossil and renewable fractions (see chp. 3.2.5.2.1).

Annex 5 Additional information on verification activities

A5.1 Independent verification of the Swiss National Inventory for F-gases

Introduction

Since 2000, the Swiss Federal Laboratories for Materials Science and Technology (Empa) performs continuous measurements of halogenated greenhouse gases at the high-Alpine site of Jungfraujoch (3580 m asl). These measurements are used for estimating emissions of fluorinated greenhouse gases (HFCs, SF_6) from Switzerland and neighbouring countries. The information can be used for an independent assessment of Swiss inventory data of these greenhouse gases. The independent emission estimate is not used directly for deriving data for the inventory. Data is used, however, to identify either consistency in support of the inventory or discrepancies, which could lead to a reassessment for identifying sources for disagreement and options for improvements.

For the independent assessment of fluorinated greenhouse gas emissions from Switzerland the so-called tracer-ratio method is applied, where Swiss pollution events of HFC and SF_6, arriving at Jungfraujoch, are scaled to concurrent pollution events of carbon monoxide (CO) and then multiplied by the Swiss CO emission inventory (see Figure A – 3 for a graphical illustration of the method). Similar approaches are also used for the independent verification of greenhouse gas emissions in the United Kingdom (UK MetOffice – using atmospheric observations from Mace Head (Ireland) combined with atmospheric transport models) and in Australia (CSIRO – using the tracer-ratio method with measurements from Cape Grim, Tasmania).

Method description

For estimates of annual Swiss HFCs and SF_6 emissions, only observations at the high-Alpine station Jungfraujoch are taken, which reflect air masses that are predominantly influenced by emissions from Switzerland. The number of events which can be used each year depends on the meteorological conditions and lies between 7-15 days per year (mostly in the summer). The process to select these periods is shown in Figure A – 3 and is shortly described here. First, the footprints from the COSMO-model are screened for periods when the Jungfraujoch site is under the influence of air masses which were within the Swiss boundary layer for the last 48 hours. Second, for these periods, mixing ratios of HFCs and SF_6 are compared with those of CO. Periods which show a concurrent increase are selected for the independent assessment of Swiss emissions, as this is taken as an indication of thorough mixing of Swiss emissions during the transport to Jungfraujoch. Third, the emissions are calculated for each case/day using the formula given in Figure A – 3. The resulting emissions are only used for the annual emission estimate if they are within three standard deviations of the average (Grubbs test). This criterion is met by approximately 90% of the selected data. Finally, annual emissions are estimated as the median of these individual cases. These annual estimates are merged to a 3-year annual average centered over a 3-year period (e.g. the estimate for the 2015 emissions is calculated by using data from 2014–2016). Since 2009, the uncertainty of the estimates for HFCs has been assessed by using the range of the 25%-75% percentiles of the estimates from single pollution events. For estimates between 2001–2008 the average of the 2009–2011 uncertainties has been taken. For SF_6, with comparably low emissions and a higher degree of uncertainty, a overall uncertainty of 50% is estimated, based on the long-term average of the 25%-75% percentiles. An additional systematic error could occur if the Swiss emissions of CO are over/underestimated by the inventory. This would linearly impact the emissions of the fluorinated greenhouse gases. Uncertainities may vary from year to year due to the limited amount of data for performing the analysis. Therefore, even subsequent years of lower or higher uncertainty do not signify a change towards lower or higher uncertainty but are just a result of this.

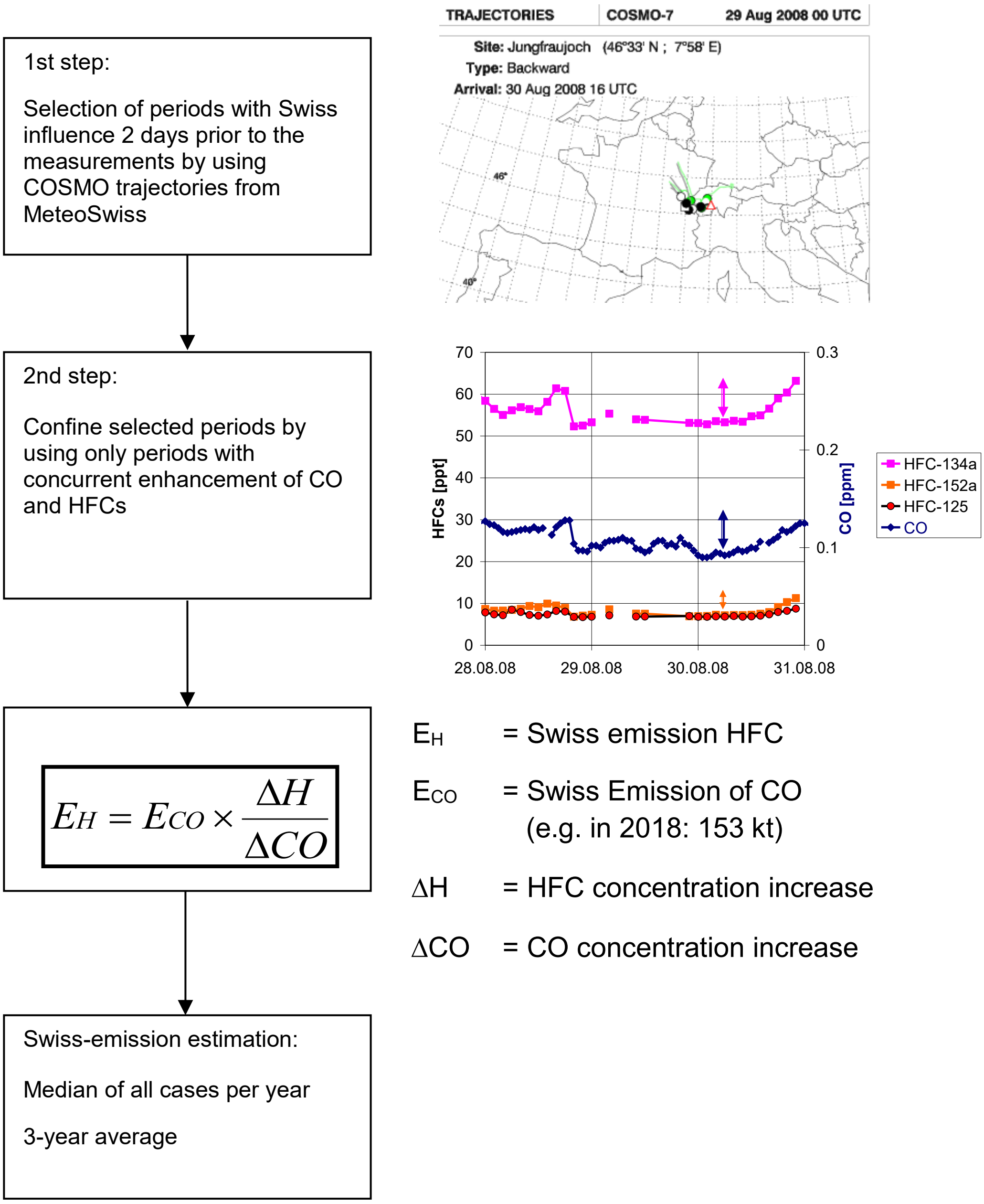


Figure A – 3 Description of the procedure to estimate annual emissions of HFCs from Switzerland by using continuous measurements of HFCs at Jungfraujoch (Switzerland).

Results and discussion

In the following, Swiss emissions of five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and of SF_6 are estimated based on data from Jungfraujoch and are compared to the emission estimate of the Swiss greenhouse gas inventory. Further emission estimates of other fluorinated greenhouse gases will be added in future National Inventory Reports (NIR) upon availability.

HFC-134a

HFC-134a is the most important anthropogenic HFC. One of its main sources is the diffuse emission from its usage as cooling agent in mobile air conditioners (MACs). Further relevant applications are the usage as propellant, as tracer gas in research and in cooling mixtures in the industrial and commercial refrigeration as well as in stationary air conditioners and heat pumps. The stock of HFC-134a in MACs and the related emissions have been steadily increasing until 2016. In most recent years numbers are declining due to the replacement of HFC-134a in this application. After 2007 both the emission estimate from Jungfraujoch and the inventory showed a stabilization of the emissions. This could be related to the decreasing HFCs used in propellants and to optimizations in the industrial and commercial refrigeration. In the inventory increasing tendencies are found again from 2008 until around 2012, whereas the measurement-based estimate shows no clear trend. Overall, the agreement between the two methods was excellent from 2001 – 2006; while a discrepancy of ca. 40% is observed since 2012 (Figure A – 4). Interestingly, also emission estimates for HFC-134a for the United Kingdom of Great Britain and Northern Ireland show a similar discrepancy in the comparison between measurement-based emission estimates (comparable to those performed here) and the UK inventory (Brown et al. 2019).

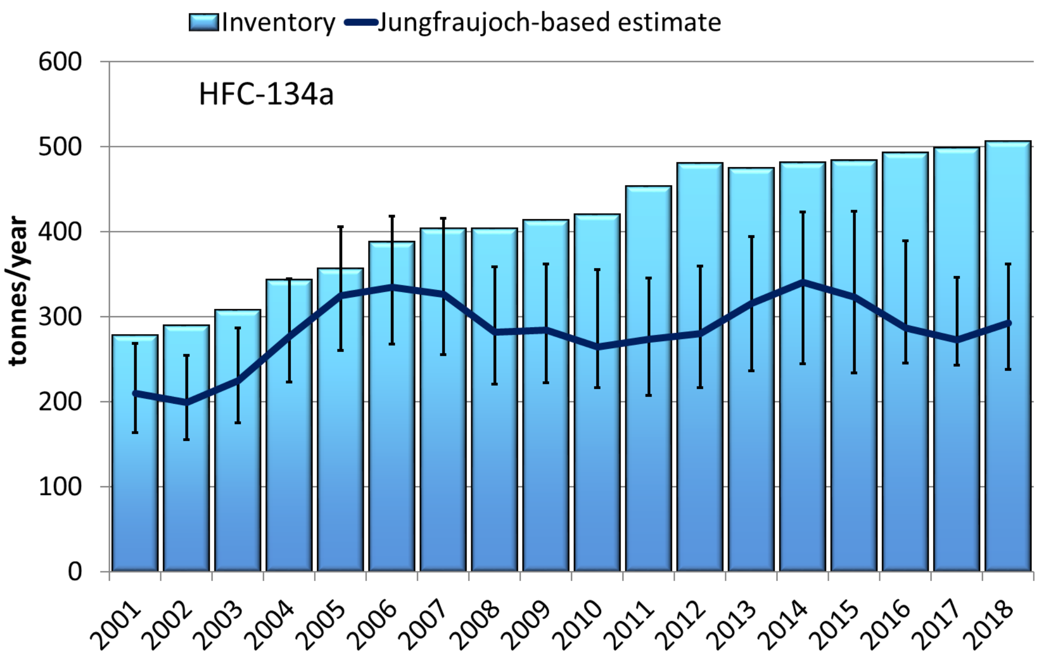


Figure A – 4 Comparison of HFC-134a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-125

HFC-125 is mainly used in cooling mixtures in air conditioners and commercial refrigeration equipment. Estimated emissions from Jungfraujoch measurement data tend to be slightly but consistently lower than in the inventory (Figure A – 5). Emission estimates from Jungfraujoch show a decrease of emissions since 2017. A turnaround and sinking emissions are also expected starting with 2019 in Swiss inventories, due to regulations of GWP for refrigeration applications and the related elimination of HFC-125 containing blends. Potentially the timing between the two approaches is different due to differences in the real-world usage of HFC-125 and the model approach in the inventory.

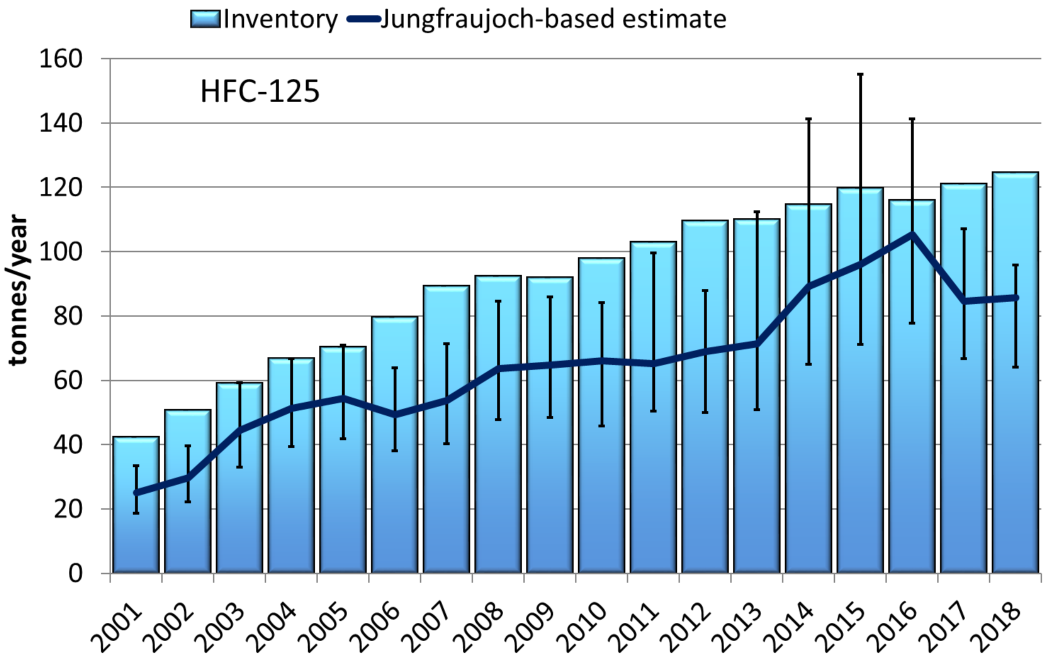


Figure A – 5 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-152a

HFC-152a is mainly used as a blowing agent in open-cell polyurethane (PU) foams, in closed cell PU sprays and closed-cell extruded polystyrene (XPS) foams. In open cell foams, 100% of emissions are related to the blowing process. In closed cell foams, part of the blowing agent remains in the product and emissions occur over its lifetime, with a rate depending on the cell- and molecular-structure of the blowing agent. Unlike for other blowing agents, experts assume that within the first year of the lifetime of the foam 95–100% of HFC-152a is emitted. The emissions of the first year are commonly allocated to the country of production (according to UNFCCC good practice guidance). These assumptions and allocation are also applied for the model used in the Swiss inventory for estimating HFC-152a emissions under the source category 2F2 (Foam Blowing).

HFC-152a emissions from foams in the inventory are mainly related to the production and consumption of PU spray. Most of other foam products are imported, and consequently these emissions are allocated to the country of origin. The reported decrease in the inventory since 2003 reflects the replacement of HFC-152a in PU spray.

Up to the year 2002, estimated emissions from Jungfraujoch measurement data are lower than reported in the inventory and from then onwards they are higher. This can be explained by the UNFCCC practice to allocate HFC-152a emissions of the first year to the country of production of foams (which is except for PU spray mainly outside Switzerland). However, in reality a fraction of these first-year emissions occur during the usage of the products (e.g. for insulation) in Switzerland and are, therefore, reflected in the measurements but, by definition, not in the inventory[14]. Emissions estimated from Jungfraujoch show a consistent decrease related to the partial phase-out of HFC-152a from the foam-blowing applications (Figure A – 6).

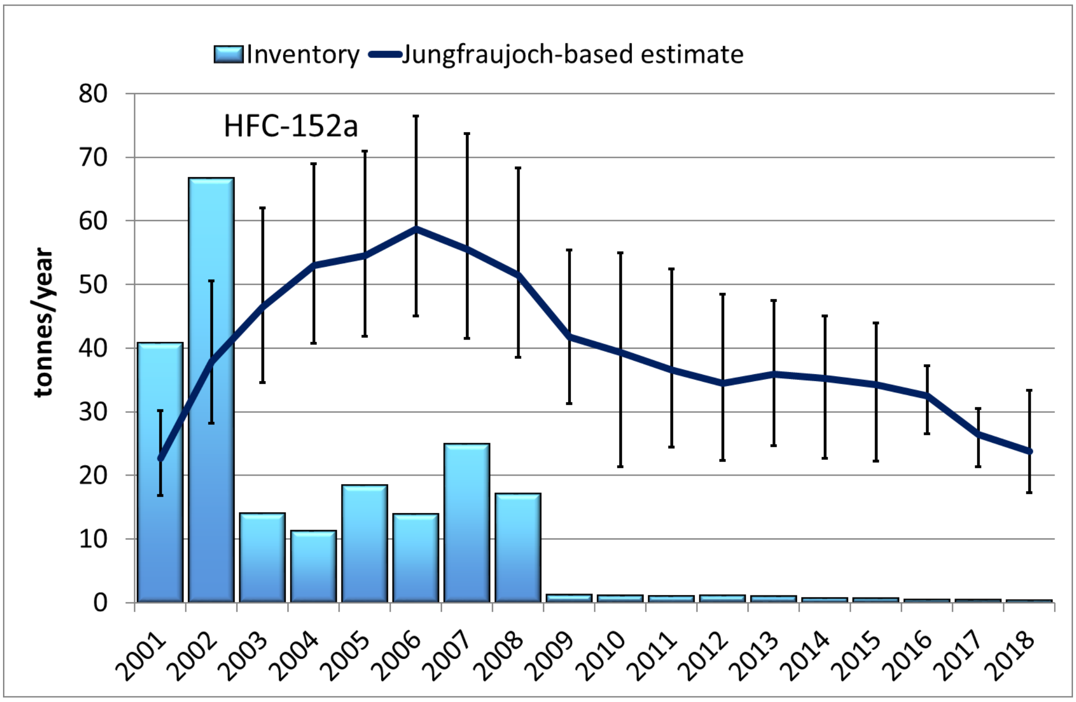


Figure A – 6 Comparison of HFC-152a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-143a and HFC-32

HFC-143a (Figure A – 7) and HFC-32 (Figure A – 8) are mainly used in cooling agent mixtures in commercial refrigeration and stationary air conditioners (together with HFC-134a and/or HFC-125). Until 2013, HFC-143a emissions estimated from Jungfraujoch measurement data were slightly lower than those from the inventory. From 2014- 2016, there was a very good agreement between the two methods and a slight decrease in emissions in most recent years, which is seen by both methods. Since 2017 a downward trend is seen by both methods, with a more pronounced tendency by the measurement-based method. A similar trend can also be seen in measurement-based estimated HFC-125 emissions (see Figure A – 5). A further decline is expected in the near future because of regulations of GWP for refrigeration applications and the related elimination of HFC-143a containing blends.

[14] Nonetheless, it is important to apply the UNFCCC approach in the inventory as otherwise double counting may occur when allocating the total emissions to the country of origin and the country of product use.

The measurement-based estimates of HFC-32 are consistently lower (by about 40%) than the data from the inventory. In contrast to HFC-125 and HFC-143a, emissions of HFC-32 do not decrease in most recent years. This could be due to the fact that HFC-32 has a lower GWP than the other two compounds and is therefore preferably used in new air-conditioner applications. Until 2016 both methods showed a continuous increase in emissions. Since 2017, however, the measurement-based method estimates a stabilization, whereas the inventory-based method sees a slower increase of emissions.

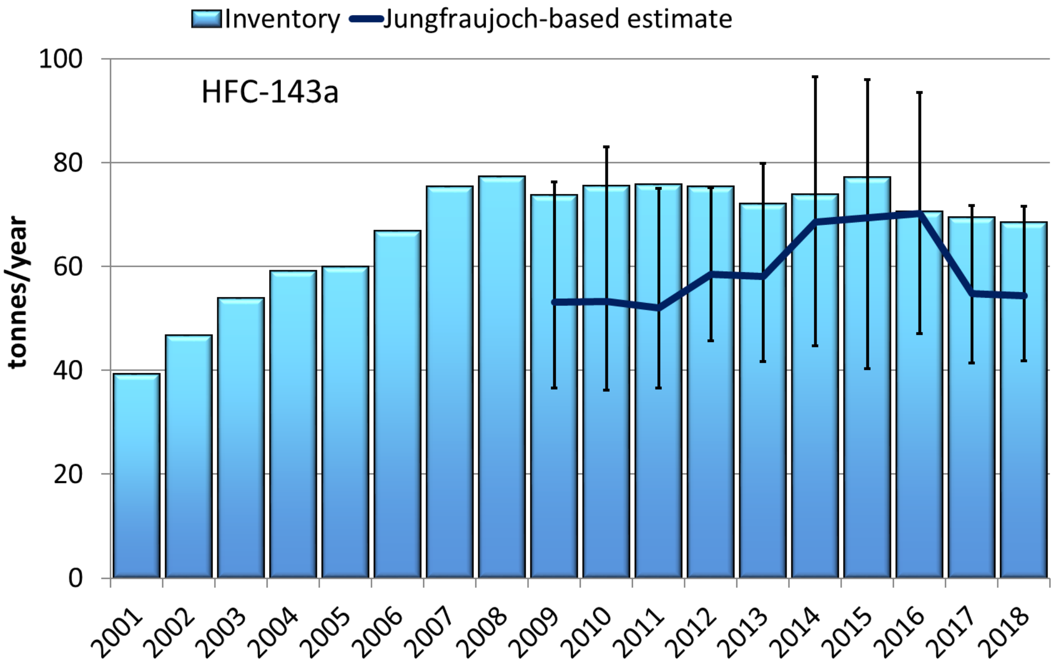


Figure A – 7 Comparison of HFC-143a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

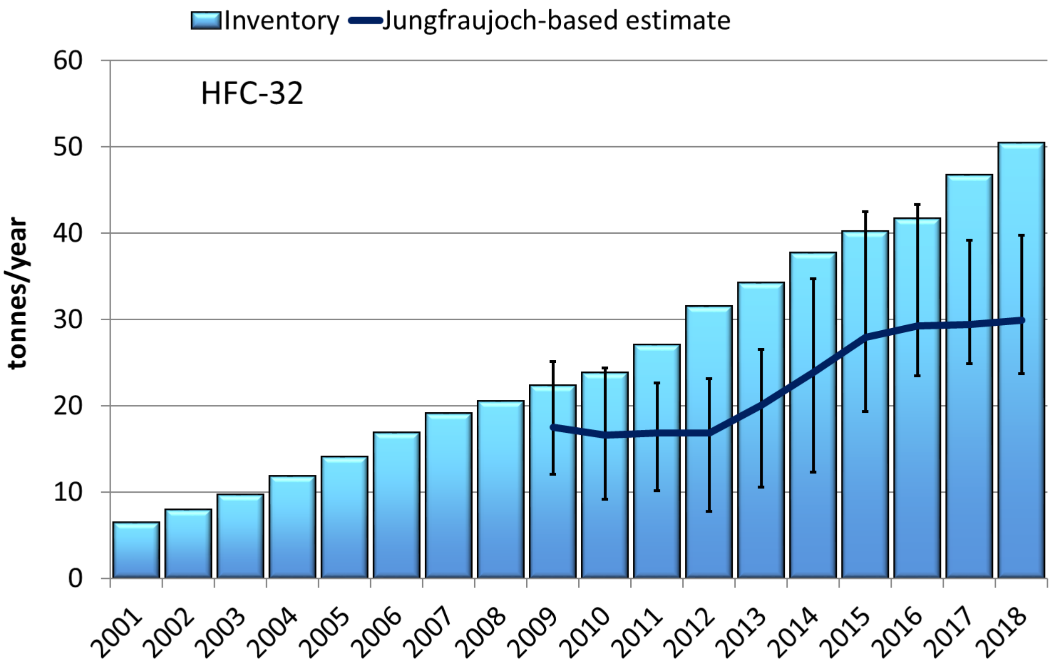


Figure A – 8 Comparison of HFC-32 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

Sulphur hexafluoride (SF_6)

Until 2010, emissions of SF_6 in Switzerland were mainly due to its use as an insulator of electrical equipment, as for example in gas insulated switchgears and in gas circuit breakers. Since then, emissions from decommissioning of insulating windows are dominant. Additional minor emissions arise from magnesium smelters, industrial particle accelerators and various other applications. Emission estimates for both methods show a remarkable similarity in the trend, except for the early comparison period of 2001–2003, when slightly higher emissions were estimated from the measurement-based method. This could be due to the mass balance approach based on industry data, which has been introduced since 2003. Increasing SF_6 emissions were estimated between 2010 and 2015 and could be the result of the increased disposal of insulating windows (all SF_6 released) during this period. Since then, the inventory-based emissions are decreasing, which is in very good agreement with the measurement-based method (Figure A – 9).

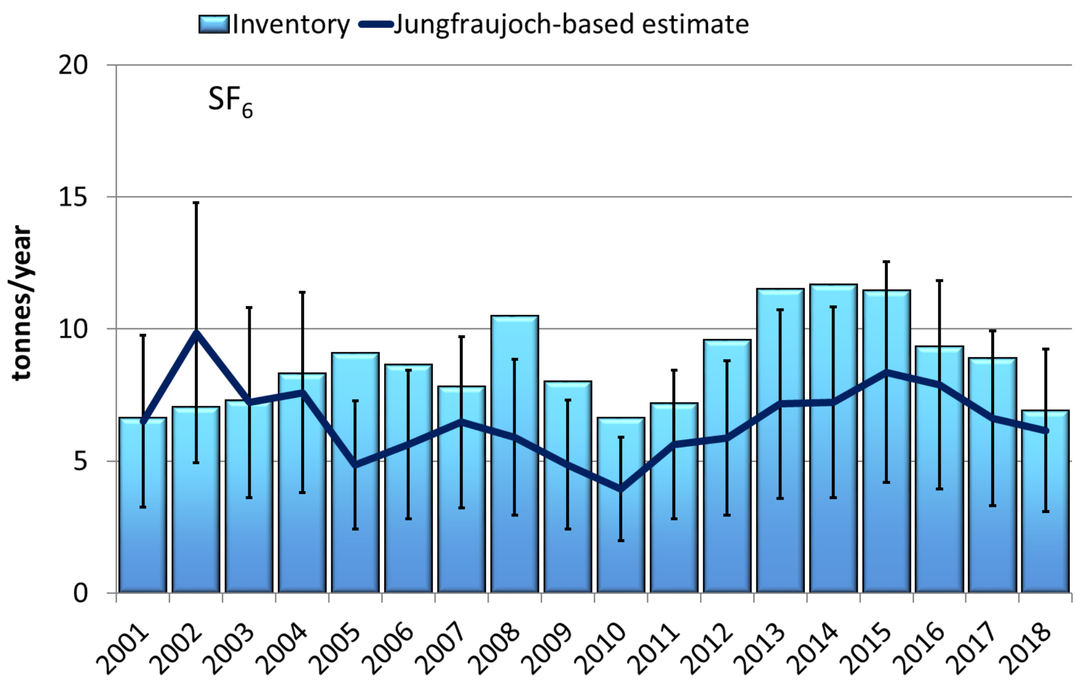


Figure A – 9 Comparison of SF_6 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

A5.2 Independent verification of methane and nitrous oxide emissions by inverse modelling

Introduction

In 2013 the Swiss Federal Laboratories for Material Science and Technology (Empa), ETH Zurich and the University of Bern established a greenhouse gas (GHG) observing network in Switzerland as part of the CarboCount-CH SNF-Sinergia project (www.carbocount.ch). The network consisted of four sites that continuously measure the atmospheric concentration of carbon dioxide (CO_2) and methane (CH_4). The sites were chosen to cover most of the densely populated and agriculturally used Swiss Plateau (see Figure A – 10). Atmospheric transport simulations confirm that the measurements at these sites are sensitive to emissions from a large part of Switzerland (Oney et al. 2015). The aim of CarboCount-CH was to better understand and quantify the anthropogenic emissions and biosphere-atmosphere exchange of the abovementioned GHGs by inverse modelling. Currently (March 2020), 3 of the 4 sites

(Beromünster, Lägern-Hochwacht, Gimmiz) are still operational, whereas the measurements at Früebüel were closed down in 2016. Additional GHG measurements were carried out in the summer of 2017 in north-eastern Switzerland (Gäbris, GBR, Appenzell) as part of a FOEN-funded validation study to analyse the sensitivity of inverse modelling results to additional measurements in an area poorly covered by the network. Further continuous GHG observations with sensitivity to emissions over Switzerland are available from the high altitude site Jungfraujoch (Empa) and Schauinsland (Germany, UBA, mountain top). High precision measurements of N_2O commenced in March 2017 at the tall tower site Beromünster and additional N_2O observations are available from Jungfraujoch and Schauinsland.

Here, the results of inverse modelling to validate total Swiss CH_4 and N_2O emissions are reported. A previous analysis for CH_4 had been carried out for the measurement period March 2013 to February 2014, the first year with data available from all four CarboCount-CH sites, which showed good agreement between the NIR reporting and the top-down inverse modelling (Henne et al. 2016). That study also raised further questions regarding the spatial and temporal distribution of the emissions and the sensitivity to boundary conditions (i.e., CH_4 baseline concentrations) required for the regional inversion. Additional sensitivity tests concerning the use of additional measurements in north-eastern Switzerland and the use of baseline concentrations from global scale models were reported in the previous NIR (FOEN 2018). Here, results for CH_4 are given for the period 2013 to 2019, whereas for N_2O inverse modelling results are given for 2017 onwards.

Methods

The inversion approach applied here was described in detail in Henne et al. (2016). It is based on source sensitivities that were calculated for each of the mentioned measurement sites with the Lagrangian atmospheric transport model FLEXPART. Source sensitivities give the sensitivity of an atmospheric concentration observation to the emissions released at a distant source and as such can be given as concentration units divided by a mass flux (e.g. ppb kg^{-1} s). FLEXPART was driven with high resolution meteorological input data from the numerical weather prediction model COSMO (7 km by 7 km horizontal resolution) provided by the Swiss national weather service (MeteoSwiss). For each site, 3-hourly source sensitivities were calculated by running the model in time-inverted mode, releasing in each 3-hour time interval 50’000 air parcels and following them 4 days backward in time.

When convoluting source sensitivities with gridded surface emission fluxes, atmospheric concentrations at the location of the observations can be obtained. These simulated concentrations can be compared with the measurements, and through “inverse modelling” an optimized (*a posteriori*) emission distribution can be estimated that minimizes the differences between simulated and observed concentrations while also considering the uncertainties of the initial (*a priori*) emission distribution. In addition to the emission distribution, the applied inversion system also optimizes a baseline concentration for each site, which is required to subtract the non-regional contribution from the total observed concentration. Additional tests including this baseline concentration from global-scale CH_4 models are discussed at the end of this annex.

In contrast to the previously reported approach (Henne et al. 2016), which contained a large number of sensitivity inversions to investigate the structural uncertainty of the inversion system, only a reduced set of sensitivity inversions was used here, varying some key aspects of the transport model and the inversion system (particle release height, absolute *a priori* emissions, and seasonality).

As *a priori* emissions for Switzerland, the MAIOLICA CH_4 inventory was used (Hiller et al. 2014), which disaggregates the emissions reported by the Swiss National Inventory Report (NIR) onto a regular spatial grid. For emissions outside of Switzerland the European TNO/MACC-2 inventory was employed (Kuenen et al. 2014). The total anthropogenic emissions of the MAIOLICA inventory was 176 kt yr^{-1}, which corresponds to the Swiss CH_4 emissions in 2012 as reported by the NIR in 2014 (FOEN 2014). The MAIOLICA inventory also includes a small contribution from natural sources of 3 kt yr^{-1} (<2%). For the application to more recent years the Swiss national total emissions were scaled to those included in the NIR in 2016 (FOEN 2016).

The same inversion technique as for CH_4 was also applied to N_2O for the period March 2017 to December 2019. In addition to the grid-resolved inversion used for CH_4, an additional sector-based inversion system was set-up for N_2O, allowing for the distinction between emissions from different source sectors, but at a reduced spatial resolution (Henne et al. 2019). *A priori* emissions for the N_2O inversion were developed with a spatial resolution of 500 m by 500 m and for 26 emission sectors based on EMIS/NIR total national emission estimates and an evaluation of indirect emissions from (semi-)natural ecosystems (Bühlmann et al. 2015).

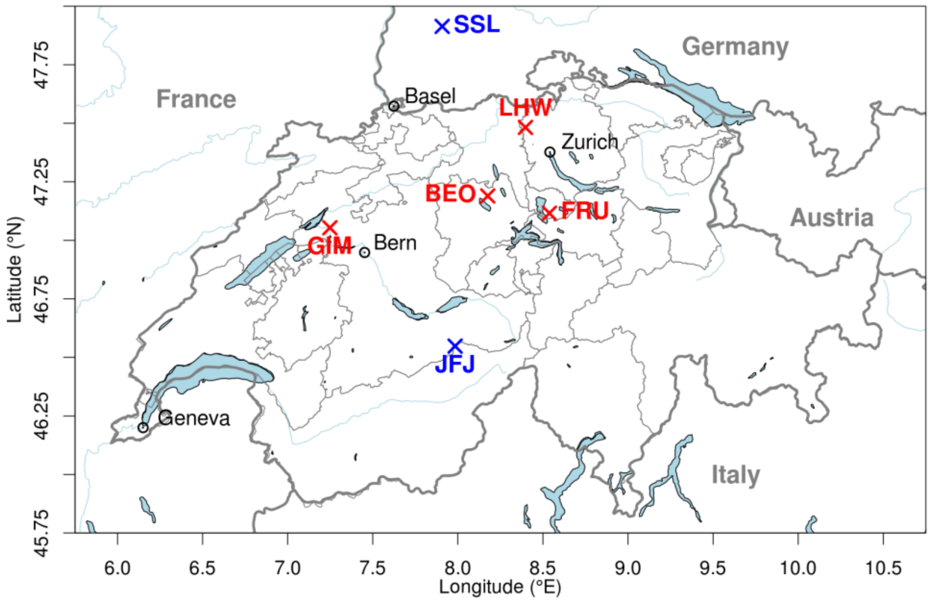


Figure A – 10: Map of Switzerland illustrating the location of CarboCount-CH sites (red), supplementary sites (blue), cantonal and national borders (grey) as well as major cities (black). The sites are: Beromünster (tall tower, BEO), Lägern Hochwacht (mountain top, tower, LHW), Gimmiz (flat, tower, GIM), Früehbüehl (mountain, near surface, FRU), Schauinsland (mountain top, SSL), and Jungfraujoch (high Alpine, JFJ).

Methane emissions

The inversion results are presented in the following in terms of national total emissions and spatial distribution. The inversion system was not set-up to optimize emissions by category separately, but to estimate the spatial distribution of total emissions. Nevertheless, through the spatial and temporal information the results can provide qualitative insights into the contribution from specific source categories that dominate in a given region or period. Further details and discussion on the inversion performance and results can be found in Henne et al. (2017).

The overall mean inverse estimate of total Swiss CH_4 emissions for the period 2013 to 2018 was 203±16 kt yr^{-1} (1-σ confidence interval around the mean). This number represents the average and standard deviation over the reference and all sensitivity inversions for all years. It is in very close agreement with the NIR values (incl. emissions from LULUCF) reported in this submission (2020) for the same period of 198 kt yr^{-1} (CRF Table10s3) with a 1-σ uncertainty range of ±18 kt yr^{-1} for the reporting year 2018. Since inverse modelling estimates integrate all fluxes (sources and sinks) between the land surface and the atmosphere, they need to be compard to inventory emissions including those from LULUCF.

For the period 2013 to 2018, the NIR suggests a CH_4 emission (incl. LULUCF) reduction of 6.7 kt (from 201 to 195 kt yr^{-1} between 2013 and 2018), whereas the inversion estimates showed large inter-annual variability (standard deviation of 14 kt yr^{-1} for individual years) with considerable downward tendencies in the last years (2018, 2019) (Figure A – 11). This variability may mostly reflect the uncertainty of the inverse modelling system itself rather than a real temporal variability in the emissions. Due to this variability it is currently not possible to determine or validate the reported tendency. Additional years of observations and inverse modelling are required for this purpose.

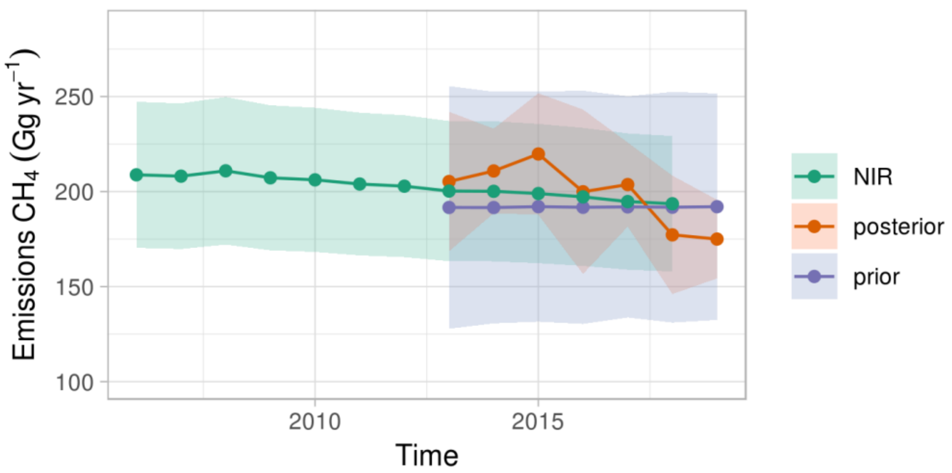


Figure A – 11: Time series of total Swiss CH_4 emissions as reported in the latest NIR (green), used as *a priori* information in the inverse modelling (purple), and as estimated by the inverse modelling (*a posteriori*, orange). The uncertainty ribbons give the 95% confidence (2σ) level of each estimate.

In Figure A – 12 the spatial distribution of the *a priori* emissions is shown, whereas the absolute differences between *a posteriori* minus *a priori* emissions for individual years are shown in Figure A – 13. An irregular inversion grid was used that exhibits high spatial resolution close to the observations and gets coarser with distance to these. In the *a priori* emissions the dominating role of agricultural emissions in the rural areas of the Cantons Lucerne and Thurgau/Appenzell is clearly seen. In contrast, the densely populated areas of Zurich, Basel and Geneva do not show up as emission hot-spots, consistent with the small contribution of emissions from natural gas distribution and wastewater treatment reported in the NIR.

The *a posteriori* results for the seven analysed years (2013 to 2019) in terms of annual totals and spatial distribution were rather similar providing evidence for the robustness of the method. The *a posteriori* emissions were smaller than *a priori* emissions in the agricultural areas of Canton Lucerne, but were increased in the north-eastern part of Switzerland

(Cantons Appenzell and Saint Gallen). Smaller differences were seen in other parts of the country.

Previously, an alternative sensitivity inversion was performed that used *a priori* emissions from the EDGAR inventory (v4.2 FT2010, EC JRC 2009). In EDGAR, the Swiss country total amounts to 228 kt yr^{-1}, mostly due to about 25 kt yr^{-1} larger emissions from the natural gas distribution network (IPCC category 1B2: fugitive emissions from oil and gas). *A posteriori* emissions in this sensitivity inversion were very similar to those of the reference inversion, which in turn required large reductions from the *a priori* distribution especially in densely populated areas. From this Henne et al. (2016) concluded that the natural gas emissions as given in the NIR (8 kt yr^{-1}) are in much better agreement with the atmospheric observations than the emissions in the EDGAR inventory (32 kt yr^{-1}).

When allowing the inversion to derive seasonal mean instead of annual mean emissions, a clear seasonal cycle with reduced winter time and increased spring to summer emissions was detected for all years (Figure A – 14). This is in line with the temperature-dependent seasonality expected from manure handling and storage (fewer emissions at lower temperatures) and the productivity-dependent seasonality of milk cows (spring maximum in productivity and calving date). However, considerable variability in the seasonality was observed for different years, sometimes showing a secondary summer minimum (2018) and in other years a summer maximum (2019). In how far these variations could be traced to climate variability needs yet to be analysed.

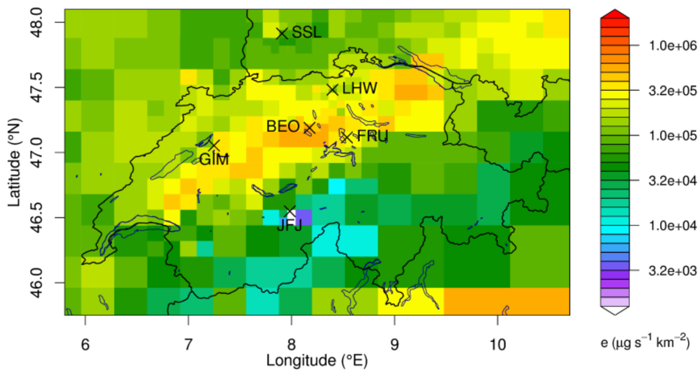


Figure A – 12: Spatial distribution of *a priori* emissions. Within Switzerland the distribution follows that derived by Hiller et al. (2014), scaled to the bottom-up estimates of the NIR (2016), outside Switzerland the bottom-up inventory of TNO/MACC (Kuenen et al. 2014) was used.

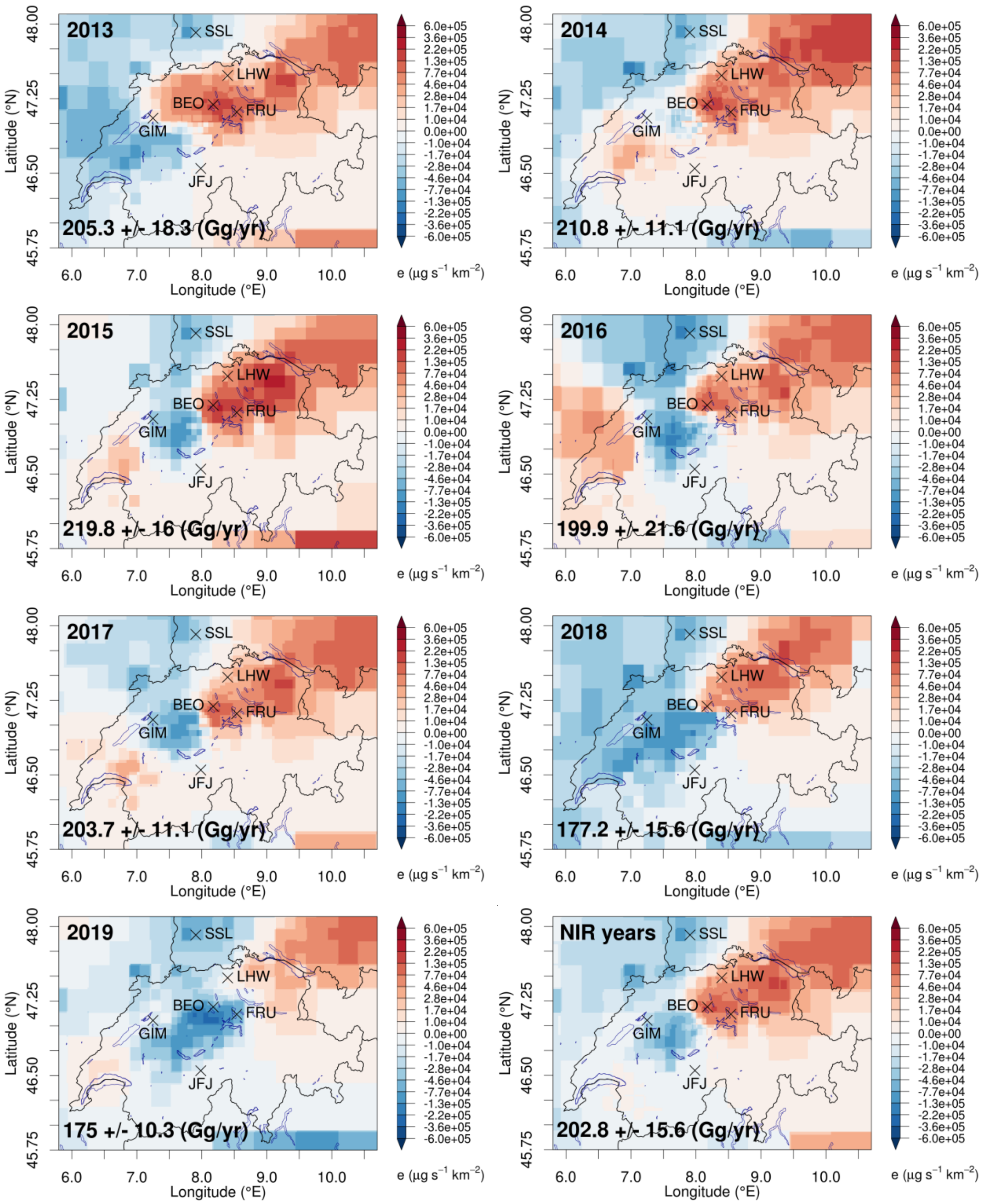


Figure A – 13: Absolute difference between *a posteriori* and *a priori* mean annual emissions (each being the mean over 8 sensitivity runs). The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1σ level) for the given year. NIR years refers to the years covered by the latest NIR (2013 to 2018) and gives the according mean estimates and uncertainties.

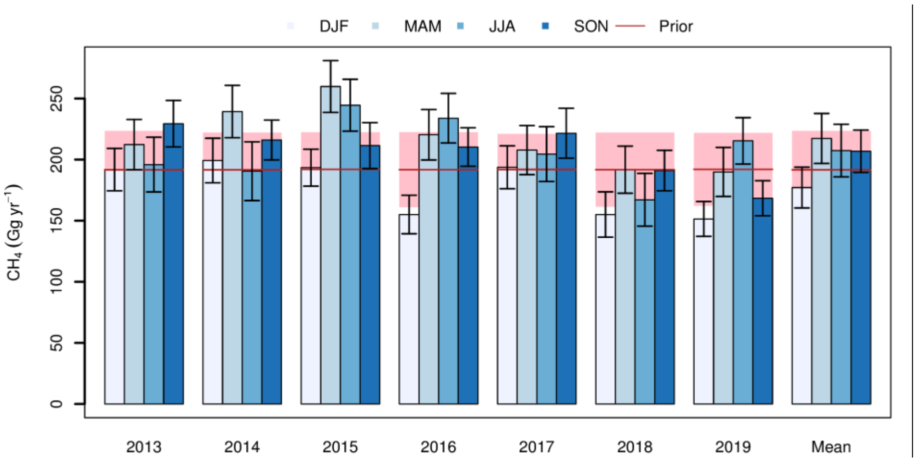
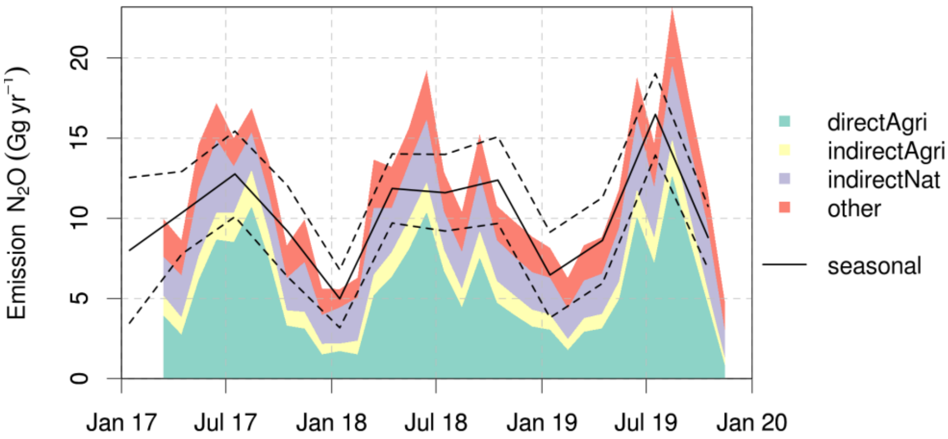


Figure A – 14: Seasonality of Swiss CH_4 emissions. *A priori* values and their uncertainties are given as red lines and red shaded areas. *A posteriori* emissions are given as blue bars and uncertainty bars for different seasons (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 1-σ confidence intervals.

Nitrous oxide emissions

With the N_2O observations established at the Beromünster tall tower site in 2017, it was possible to estimate Swiss N_2O emissions by inverse methods at the country scale for the period March 2017 to November 2019 (Henne et al. 2019). The best estimate of annual N_2O emissions for the years 2017 and 2018 was 11.4±1.8 Gg yr^{-1} and 10.8±1.1 Gg yr^{-1}, respectively. This compares to 10.5±2.1 Gg yr^{-1} and 9.8±1.9 Gg yr^{-1} given in this NIR (incl. emissions from LULUCF; 1- σ confidence level). Due to the large uncertainties connected to these numbers, the inverse estimates are not significantly different from the NIR. The relative uncertainty of the inverse modelling estimate (14%) was smaller than that of the NIR estimate (20%). The relatively large uncertainty range of the inverse method was calculated from the spread of 14 sensitivity inversions (



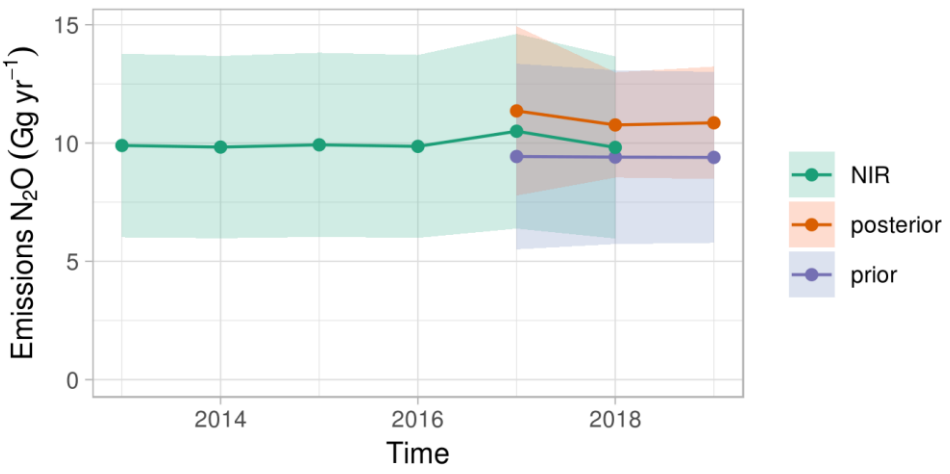


Figure A – 15). These sensitivity tests comprised the application of two different inversion approaches: one focussing on the spatial distribution (grid inversion), the other on the temporal evolution and emissions by sector (sector inversion). The largest contributors to the *a posteriori* spread were the definition and uncertainty of a baseline of the atmospheric concentrations required by the model approach and systematic differences between grid and sector inversions.

Most of the larger emissions estimates of the inversion model as compared with the *a priori* estimates were assigned to direct emissions from agricultural soils (central and eastern Swiss Plateau) and to a smaller degree to indirect emissions from (semi-)natural ecosystems (southern Switzerland) and agricultural soils (northern Switzerland) (Figure A – 16). The general increase from agricultural lands and (semi)natural ecosystems may partly be explained by solely natural N_2O emissions, which were not taken into account in the applied *a priori* inventory, since they are not part of the NIR (only indirect emissions from (semi)natural ecosystems were considered). Lower than *a priori* emissions were assigned to other types of anthropogenic emission sectors such as transport, heating, industry and wastewater treatment. However, the changes in these smaller sectors were associated with larger uncertainties and considerable negative covariance towards the major emission sectors. Hence, it cannot be concluded that they are significant. However, some further support for this result is provided by the grid inversion, which also estimated that emissions in urban areas are potentially overestimated in the NIR. The latest NIR reports considerably larger N_2O emissions from industry (2B10 Niacin production) than the previous report. Considering these in the *a priori* further increased national total emission as estimated by the inverse calculations, however, assigning the increases to the same sectors as before (soils), at the same time revising emissions from industry downward. The newly documented industrial emissions occur in an area that is not well covered by the observational network and, hence, cannot easily be constrained.

All inversions suggested a pronounced seasonality in the emissions with a mean amplitude over all inversions of around ±40% of the annual total (

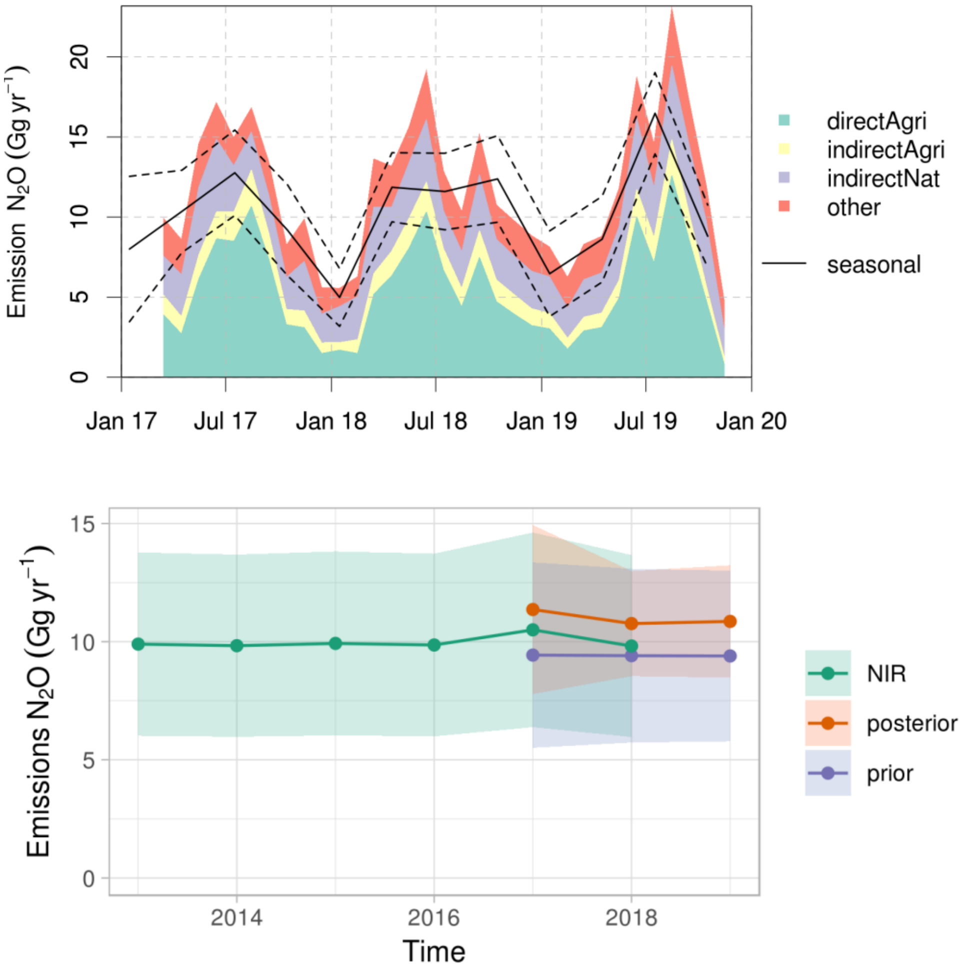


Figure A – 15). Largest emissions were estimated in summer, smallest in winter. However, there was considerable spread in the seasonal amplitude as well, with the tendency of inversions with smaller annual total emissions to predict smaller summertime emissions and correspondingly smaller seasonal amplitudes. Seasonality was dominated by emissions from soils. The month-to-month variability in soil emissions was clearly linked to two environmental controls, soil temperature and soil water filled pore space, explaining 86% of the observed variability.

The tendency to larger than reported N_2O emissions obtained here for Switzerland compares well with other recent inverse estimates of N_2O emissions in Europe. Some of these studies also highlight a similarly pronounced seasonality (Ganesan et al. 2015, Brown et al. 2019).

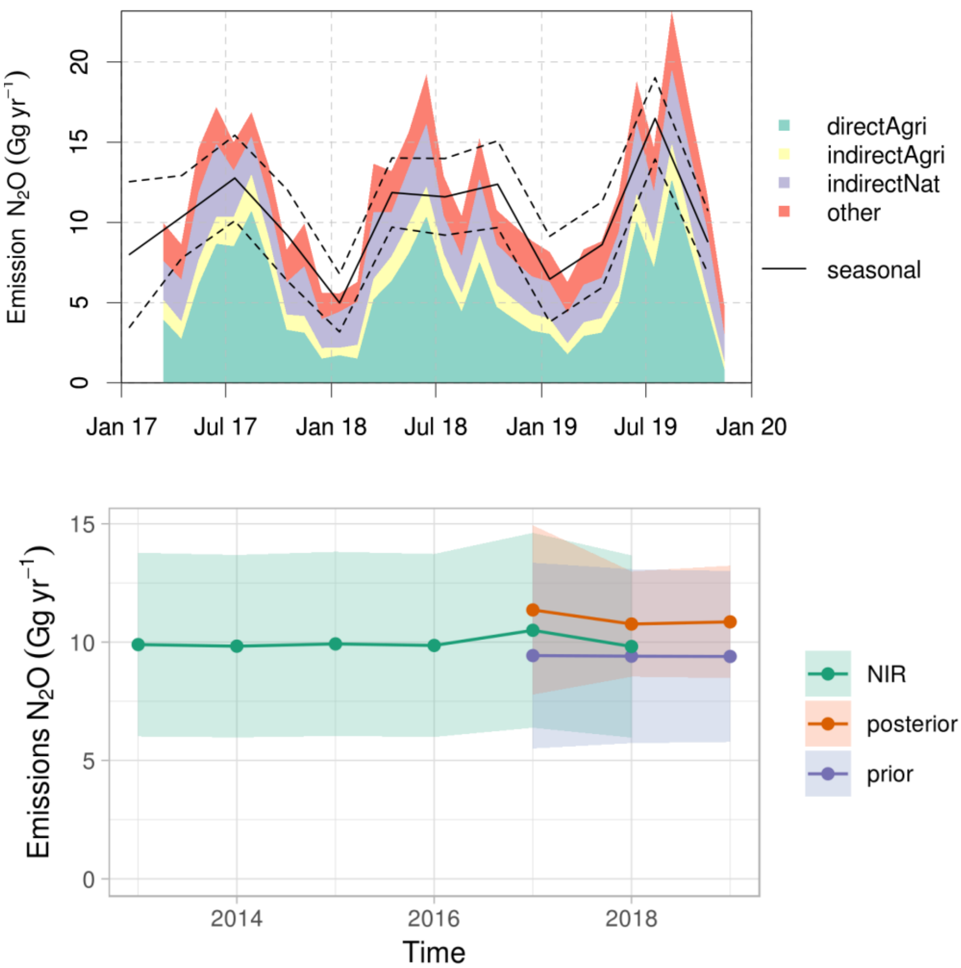


Figure A – 15: Time series of inversely estimated and NIR reported Swiss N_2O emissions. (top) Monthly mean over all sector inversions are given by solid areas for the main emission sectors, whereas the mean and uncertainty of all seasonal inversions (grid and sector) are given by the black lines. (bottom) NIR reported and inversely estimated annual values and their uncertainties are given by lines, symbols and uncertainty ribbons. All uncertainty indicators refer to 2σ levels.

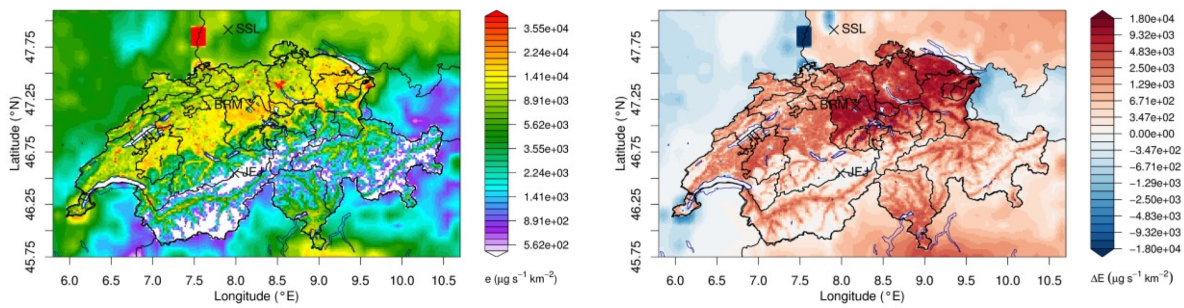


Figure A – 16: (Left) mean *a priori* and (right) *a posteriori* minus *a priori* emission distribution over all sensitivity inversions (sector inversion only) for the period 2017 March to 2019 November.

Annex 6 Information on the CRF reporter

The CRF reporter still seems to generate errors in the numerical output of some reporting tables. A non-exhaustive list of issues and errors identified so far is provided in Table A – 29. In some instances where numbers are not identical in the reporting tables (CRF) and in the NIR, a remark was added in the NIR. This aspect should be taken into consideration when comparing information in the NIR with the reporting tables.

Table A – 29: Identified errors in the output of some reporting tables (CRF).

Reporting table CRF	**Problem**	**Solution**
Table1A(d)	The column "Reported under ..." should include the NFR code in the Text.	Actually, there is no possibility to change it, because a drop-down-menu determines the text.
Table2(I)s1-s2	In all empty cells should be written „NO", but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new nod and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we passed on it.
Table2(II)	In all empty cells should be written „NO", but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new nod and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we indicate in the documentation box: „2.B.9, 2.C, 2.E, 2.F.1-2.F6, 2.G: "NO" for all empty cells".
Table2(II)B-Hs1	In Line 49 of the reporting table the emissions are indicated as kt CO2 eq instead of t.	Problem in the CRF web application.
Table3.B(a)s2	NFR codes 3B4g and 3B4hi: cells I55 and L103 are still empty despite of correctly imported values.	Problem in the CRF web application.
Table3.B(b)	The IEF for "indirect emissions from atmospheric deposition" (cell R37): Wrong molecular weight. The IEF is displayed in kg N_2O per kg N handled instead of kg N_2O-N per kg N handled.	Problem in the CRF web application.
Table3s1; Table3.As1; Table3.As2; Table3.B(a)s1; Table3.B(a)s2; Table3.B(b)	All cells for "Cattle, Option A" should be filled with "IE" but this Option A cannot be selected together with Option B.	Problem in the CRF web application. Solved with comment in documentation boxes of tables Table3.As1, Table3.B(a)s1, Table3.B(b)
Table4	N_2O from 4(IV) (indirect emissions) are included in the total sum in Table 4 without being displayed in any subcategory in Table 4. The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application. The total is not equal to the sum of the subcategories.
Table4	There are several empty cells in the CH_4 and N_2O columns, where numbers and/or notation keys are not inserted.	Problem in the CRF web application.
Table4(V)	"Values" and "IEF" in lines 8 to 10 are missing.	Problem in the CRF web application.
Summary3s1	Empty cells in "Method applied" and	Inaccuracy in the CRF web

Summary3s2	“Emission factor” for several sectors and gases: There should be indicated “NO” instead of empty cells.	application. „NO“ is not imported and there is no possibility to change it, because „NO“ or „NA“ are not in the drop-down menu.
Summary3s1 Summary3s2	Some method and emission factor information are not imported into the web application.	Problem in the CRF web application.
Table8s4	PFC emissions from 2G2 are also displayed under 2G4.	Problem in the CRF web application.
Table10s1	For CO_2 eq in sector 4 LULUCF, the total is not equal to the sum of the displayed CO_2 eq emissions in the categories 4A+4B+4C+4D+4E+4F (rows 40 to 47) but includes also indirect N_2O from 4(IV) in CO_2 eq. The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application.
Table10s2	Empty cell for CO2 captured in the year 2005	Problem in the CRF web application.
Table10s4	For N_2O in sector 4 LULUCF, the total is not equal to the sum of the displayed N_2O emissions in the categories 4A+4B+4C+4D+4E+4F (rows 39 to 46) but includes also indirect N_2O from 4(IV). The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application.
4(KP-I)B.1	Description of category and sub-category is shown twice under „identification code“ and „subdivision“. This is not wrong but not necessary.	Problem in the CRF web application.
All	Documentation box entries are not consistent. Sometimes all entries are in a single cell, sometimes there are several lines with entries, some of them empty.	Inaccuracy in the CRF web application.

References

Abegg, M. 2017: Drained organic soils in forests. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. http://www.climatereporting.ch

Aerocert 2012: Work Package 2 Report: Review of current aircraft operating procedures and their consequences for noise in the community relative to certification procedures. Caves, R., Department of Civil and Building Engineering - Loughborough University, https://www.forschungsinformationssystem.de/servlet/is/33250/ [18.03.2020]

Agrammon 2010: The Swiss ammonia model, Federal Office for the Environment FOEN. Internet version in German, French and English: http://www.agrammon.ch/documents-to-download, Technical description for download (updated periodically): https://www.agrammon.ch/model-documentation/technical-description/ [17.02.2020]

Agricura 2018: Geschäftsbericht 2017/2018. Agricura, Bern [confidential/internal].

Agroscope 2014a: Lime application in Swiss Agriculture. Internal documentation by Bretscher, D., Agroscope Reckenholz-Tänikon Research Station, Zürich [confidential/internal].

Agroscope 2014b: Futtermitteldatenbank. Agroscope, Institut für Nutztierwissenschaften (INT). Posieux, Schweiz. http://www.feedbase.ch [queries from database].

Agroscope 2014c: Fütterungstool zur Ermittlung des Energie- und Stickstoffumsatzes von Milchkühen in der Schweiz. Agroscope, Institut für Nutztierwissenschaften (INT). Posieux, Schweiz. http://www.feedbase.ch [queries from database].

Agroscope 2019a: Agricultural CH_4 and N_2O emissions in Switzerland: QA/QC. Internal documentation (with continual update) by Bretscher, D. Agroscope Research Station; Zürich, Switzerland [confidential/internal].

Agroscope 2020: Treibhausgasinventar Sektor Landwirtschaft, Tabellen zur Berechnung der Treibhausgasemissionen der schweizerischen Landwirtschaft. Internes Dokument. [GHG inventory, sector Agriculture. Spreadsheets to calculate the GHG emissions of Switzerland's agriculture. Internal document]. Agroscope Research Station, Zürich [confidential/internal].

Alberti, G., Peressotti, A., Piussi, P., Zerbi, G. 2008: Forest ecosystem carbon accumulation during a secondary succession in the Eastern Prealps of Italy. Forestry 81: 1–11. http://dx.doi.org/10.1093/forestry/cpm026 [08.04.2019]

Alcan 2002: Written communication from Kurt Buxmann (ALCAN) to Carbotech, 30.1.2002 [confidential/internal].

Alcan 2003: Written communication from François Veuthey (ALCAN) to Carbotech [confidential/internal].

Amon, B., Amon, T., Boxberger, J., Alt, C. 2001: Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutrient Cycling in Agroecosystems 60 (1–3): 103–113. http://dx.doi.org/10.1023/A:1012649028772 [28.03.2019]

ARE 2002: Fahrleistungen der Schweizer Fahrzeuge. Ergebnisse der periodischen Erhebung Fahrleistungen (PEFA) 2000. Federal Office for Spatial Development, Bern. http://www.climatereporting.ch

ARE 2016: Perspektiven des Schweizerischen Personen- und Güterverkehrs bis 2040 - Technischer Bericht. https://www.are.admin.ch/are/de/home/medien-und-publikationen/publikationen/verkehr/verkehrsperspektiven–2040-technischer-bericht.html [04.02.2020]

ARE 2019: Externe Kosten und Nutzen des Verkehrs in der Schweiz – Strassen-, Schienen-, Luft- und Schiffsverkehr 2016. Swiss Federal Office for Spatial Development, Bern. https://bit.ly/38tTM41 [10.02.2020]

ARE/FOEN 2007: Le paysage sous pression, suite 3. [Landschaft unter Druck, 3. Fortschreibung]. Federal Office for Spatial Development, Bern and Federal Office for the Environment, Bern. https://www.are.admin.ch/are/de/home/raumentwicklung-und-raumplanung/grundlagen-und-daten/raumbeobachtung/landschaft-unter-druck.html [18.03.2020]

ARE/SFSO 2005: Mobilität in der Schweiz. Ergebnisse des Mikrozensus 2005 zum Verkehrsverhalten. [La mobilité en Suisse. Résultats du microrecensement 2005 sur le comportement de la population en matière de transports]. Federal Office for Spatial Development, Bern and Swiss Federal Statistical Office, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken/publikationen.assetdetail.344011.html [05.02.2020]

ARE/SFSO 2012: Mobilität in der Schweiz. Ergebnisse des Mikrozensus Mobilität und Verkehr 2010. [La mobilité en Suisse. Résultats du microrecensement mobilité et transports 2010]. Federal Office for Spatial Development, Bern and Swiss Federal Statistical Office, Neuchâtel.2012 http://www.portal-stat.admin.ch/mz10/files/fr/00.xml [05.02.2020]

ARE/SFSO 2017: Verkehrsverhalten der Bevölkerung – Ergebnisse des Mikrozensus Mobilität und Verkehr 2015. Federal Office for Spatial Development, Bern and Swiss Federal Statistical Office, Neuchâtel. 2017. https://www.bfs.admin.ch/bfsstatic/dam/assets/1840477/master [25.03.2020]

ART 2008a: Uncertainty in agricultural CH_4 and N_2O emissions of Switzerland. Internal documentation by Bretscher, D. and Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich. http://www.climatereporting.ch

ART 2009b: Emission factor drained peatlands Switzerland – A brief analysis of recent studies and comparison to EF used in the Swiss GHG Inventory. Internal documentation by Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich. http://www.climatereporting.ch

ART 2011a: Summary of the available published data on root biomass and root carbon in Swiss grasslands. Internal documentation by Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich. http://www.climatereporting.ch

ART 2011b: First estimate on CO_2 emission factor of organic soils under unproductive wetland. Internal documentation by Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich. http://www.climatereporting.ch

ART/SHL 2012: Categorization of livestock animals in Switzerland. D. Bretscher and T. Kupper. Agroscope Research Station Zürich (ART), Schweizerische Hochschule für Landwirtschaft Zollikofen (SHL). March 2012. http://www.climatereporting.ch

AWEL 2009: Qualitätsentwicklung konventionell ausgetragener Schlacke. Zurich, April 2009. https://t1p.de/AWEL2009 [10.02.2020]

Bader, M.K., Leuzinger, S., Keel, S.G., Siegwolf, T.W., Hagedorn, F., Schleppi, P., Körner, C. 2013: Central European hardwood trees in a high-CO_2 future: synthesis of an 8-year forest canopy CO_2 enrichment project. Journal of Ecology 101 (6): 1509–1519. http://dx.doi.org/10.1111/1365-2745.12149 [18.03.2020]

Bamberger, I., Stieger, J., Buchmann, N., Eugster, W. 2014: Spatial variability of methane: Attributing atmospheric concentrations to emissions. Environmental Pollution 190: 65–74. https://www.sciencedirect.com/science/article/pii/S0269749114001195 [18.03.2020]

Bolinder, M.A., Janzen, H H., Gregorich, E.G., Angers, D.A., VandenBygaart, A.J. 2007: An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. Agriculture, Ecosystems & Environment 118: 29-42. https://doi.org/10.1016/j.agee.2006.05.013 [19.02.2020]

Brändli, U.-B. (Red.) 2010: Schweizerisches Landesforstinventar. Ergebnisse der dritten Aufnahme 2004–2006. [Results of the third Swiss national forest inventory 2004–2006]. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf. Bundesamt für Umwelt, Bern, 312 S. http://www.lfi.ch/publikationen/publ/lfi3-fr.php [18.03.2020]

Brändli, U.-B. 2014: Mehr Laubbäume und weniger Fichtenholz im Mittelland. Medienmitteilung 06.11.2014, Birmensdorf. https://web.archive.org/web/20161206065031/http://www.wsl.ch/medien/news/landesforstinventar_2014/index_DE [18.03.2020]

Brändli, U.-B., Hägeli, M. 2019: Swiss NFI at a Glance. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Springer International Publishing, Cham, pp 3-35. doi:10.1007/978-3-030-19293-8_1 [18.03.2020]

Brändli, U.-B., Abegg, M., Allgaier Leuch, B. (Red.) 2020: Schweizerisches Landesforstinventar. Ergebnisse der vierten Erhebung 2009–2017. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft. Bern, Bundesamt für Umwelt. In preparation [confidential/internal].

Brassel, P., Brändli, U.-B. 1999: Schweizerisches Landesforstinventar. Ergebnisse der Zweitaufnahme 1993–1995. [Results of the second Swiss national forest inventory 1993–1995]. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf. Bundesamt für Umwelt, Wald und Landschaft, Bern. Haupt, Bern, Stuttgart, Wien [available in German, French and Italian]. http://www.lfi.ch/publikationen/publ/lfi2-en.php [18.03.2020]

Braun, S., Flückiger, W. 2012: Bodenversauerung in den Flächen des Interkantonalen Walddauerbeobachtungsprogramms. Schweizerische Zeitschrift für Forstwessen 163: 374–382. http://dx.doi.org/10.3188/szf.2012.0374 [18.03.2020]http://www.iap.ch/publikationen/szf163_braun_versauerung.pdf

Braun, S., Thomas, V.F., Quiring, R., Flückiger, W. 2010: Does nitrogen deposition increase forest production? The role of phosphorus. Environmental Pollution 158: 2043–2052. http://dx.doi.org/10.1016/j.envpol.2009.11.030 [18.03.2020]

Brown, P., Broomfield, M., Cardenas, L., Choudrie, S., Kilroy, E., Jones, L., MacCarthy, J., Passant, N., et al., 2018: UK Greenhouse Gas Inventory 1990 to 2016: Annual Report for submission under the Framework Convention on Climate Change, Department for Business, Energy & Industrial Strategy, 860, 2018. http://naei.beis.gov.uk/reports/reports?report_id=954 [18.03.2020]

Brown, P., Broomfield, M., Cardenas, L., Choudrie, S., Jones, L., Karagianni, E., Passant, N., Thistlethwaite, G., Thomson, A., Turtle, L., Wakeling, D. 2019: UK Greenhouse Gas Inventory 1990 to 2017: Annual Report for submission under the Framework Convention on Climate Change, Department for Business, Energy & Industrial Strategy, 2019. https://unfccc.int/documents/194909 [25.03.2020]

Bühler and Kupper 2018: Agricultural emissions of NMVOC and PM. Literature review and selection of emission factors, HAFL Zollikofen, Bern. https://www.aramis.admin.ch/Default.aspx?DocumentID=49767&Load=true [10.03.2020]

Bühlmann, T. 2014: Durch Stickstoffdeposition induzierte Emissionen von Stickoxiden und Lachgas aus (semi-)natürlichen Ökosystemen. Analyse der schweizerischen Situation mit Vorschlägen zur Umsetzung im Schweizerischen Emissionsinventar (EMIS). Bundesamt für Umwelt (BAFU), Juli 2014. Bern; Schweiz [confidential/internal].

Bühlmann, T., Hiltbrunner, E., Körner, Ch., Rihm, B., Achermann, B. 2015: Induction of indirect N_2O and NO emissions by atmospheric nitrogen deposition in (semi-)natural ecosystems in Switzerland. Atmospheric Environment 103: 94–101. http://dx.doi.org/10.1016/j.atmosenv.2014.12.037 [18.03.2020]

BUS 1978: Stand der kommunalen Abfallbeseitigung in der Schweiz. Mengen 1970–1977. Bern, 1. Januar 1978, Nr. 408.78, Eidg. Amt für Umweltschutz. http://www.climatereporting.ch

BUS 1984: Abfallerhebung, Schriftenreihe Umweltschutz, Nr. 27, 1984 (ergänzt 1987). http://www.climatereporting.ch

BUS 1986: Leitbild für die Schweizerische Abfallwirtschaft. [Lignes directrices pour la gestion des déchets en Suisse]. Schriftenreihe Umweltschutz Nr. 51. Bundesamt für Umweltschutz BUS. [Les cahiers de l'environnement No 51. Office fédéral de la protection de l’ environnement], Bern. http://www.climatereporting.ch

BUS 1988: Luftreinhaltung beim Verbrennen von Spitalabfällen. Max Suter in: Umweltschutz in der Schweiz, Bulletin des Bundesamts für Umweltschutz, 1/88, 14-18, Bern. http://www.climatereporting.ch

Carbotech 2019: Swiss Greenhouse Gas Inventory 2017: PFCs, HFCs, NF_3 and SF_6 Emissions. Confidential report no. 251.18. For internal use on behalf of the Federal Office for the Environment, Bern. Carbotech, Basel [confidential/internal].

Carbotech 2019a: CO_2 aus VOC-Verbrennung Confidential report no. 129.15. For internal use on behalf of the Federal Office for the Environment, Bern. Carbotech Basel [confidential/internal].

Carbotech 2020: Swiss Greenhouse Gas Inventory 2018: PFCs, HFCs, NF_3 and SF_6 Emissions. Confidential report no. 251.18. For internal use on behalf of the Federal Office for the Environment, Bern. Carbotech, Basel [confidential/internal].

Cemsuisse 2010a: Bestimmung der Emissionsfaktoren an Mischproben, Interner Bericht von Wessling im Auftrag von cemsuisse, 2010 [confidential/internal].

Cemsuisse 2018: Bestimmung der Emissionsfaktoren von Altöl, Kunststoffen, Lösungsmitteln und imprägniertem Sägemehl an Mischproben für das Jahr 2017. Wessling im Auftrag von Cemsuisse, 2018 [confidential/internal].

CH2018 2018: CH2018 – Climate Scenarios for Switzerland, Technical Report, National Centre for Climate Services, Zurich, 271 pp, ISBN: 978-3-9525031-4-0. https://www.nccs.admin.ch/nccs/en/home/data-and-media-library/data/ch2018---climate-scenarios-for-switzerland.html, Dataset doi: 10.18751/Climate/Scenarios/CH2018/1.0 CH2018 web atlas: https://www.nccs.admin.ch/nccs/en/home/data-and-media-library/data/ch2018-web-atlas%20.html [18.03.2020]

Chadwick, D.R. 2005: Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmos. Environ. 39(4): 787-799. https://doi.org/10.1016/j.atmosenv.2004.10.012 [18.03.2020]

Coleman, K. and Jenkinson, D.S 1999, ROTHC-26.3 - A model for the turnover of carbon in soil. Model description and windows users guide. November 1999 issue (modified August 2008), Rothamsted Research, Harpenden https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc [18.03.2020]

Coleman, K., Jenkinson, D.S., Crocker, G.J., Grace, P.R., Klír, J., Körschens, M., Poulton, P.R., Richter, D.D., 1997. Simulating trends in soil organic carbon in long-term experiments using RothC-26.3. Geoderma 81, 29-44. https://www.sciencedirect.com/science/article/pii/S0016706197000797 [18.03.2020]

Consaba 2016: Erhebung Verwertung Deponiegas über Fackelanlagen in der Schweiz 1990 bis 2014. Consaba GmbH (A. Bauen) im Auftrag des Bundesamtes für Umwelt (BAFU), Bern, Schlussbericht, 23.09.2016. http://www.climatereporting.ch

CRC Handbook of Chemistry and Physics 2004: Chemical Rubber Company. CRC Handbook of Chemistry and Physics: A Ready-reference Book of Chemical and Physical Data. D. R. Lide: 84th edition 2003–2004.

Crutzen, P.J., Aselmann, I., Seiler, W. 1986: Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. Tellus 38B(3–4): 271–284. http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0889.1986.tb00193.x/full [18.03.2020]

CSD 2013: Swiss Greenhouse Gas Inventory Submission 2012. National Review of Sector Industrial Processes. On behalf of the Federal Office for the Environment, Bern. Basel. http://www.climatereporting.ch

CSI 2011: Cement Sustainability Initiative (CSI), The Cement CO_2 and Energy Protocol, CO_2 and Energy Accounting and Reporting Standard for the Cement Industry, May 2011, Version 3.0, World Business Council for Sustainable Development (WBCSD). http://www.cement-co2-protocol.org/en/Content/Resources/Downloads/WBCSD_CO2_Protocol_En.pdf [18.02.2020]

Davidson, E.A., Janssens, I.A. 2006: Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440: 165–173. http://dx.doi.org/10.1038/nature04514 [18.03.2020]

DDPS 2014a: List of military non-road machinery (stocks, engine-power, annual operating hours). E-Mail C. Stucki (Federal Department of Defence, Civil Protection and Sport) to B. Notter (INFRAS) 27.05.2014 [confidential/internal].

DDPS 2018b: Consumption of aviation fuel and jet kerosene of Swiss military aircraft for the year 2018 per type of aircraft. Didier Castella (Federal Department of Defence, Civil Protection and Sport) to Anouk-Aimée Bass (FOEN, Bern), 08.01.2018 [confidential/internal].

DDPS 2019: Consumption of aviation fuel and jet kerosene of Swiss military aircraft 1990–2018. Marina Vkovski (Federal Department of Defence, Civil Protection and Sport) to Anouk-Aimée Bass (FOEN, Bern), 19.06.2019 [confidential/internal].

de Keizer, C., Ramirez, A., van der Sluijs, J. 2007: Uncertainty Ranges and Correlations Assumed in Tier 2 Studies of Several European Countries. In: Proceedings of the 2nd International Workshop on Uncertainties in Greenhouse Gas Inventories, 27–28 September 2007, Laxenburg, Austria: 35–39. http://www.ibspan.waw.pl/ghg2007/GHG-total.pdf [18.03.2020]

Didion, M. 2014: Impacts of forest management on carbon stock changes in litter and soil in Swiss forests. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M. 2017: Domestic review of the calculation of the harvested wood products pool in Switzerland, 11 September 2017. Markus Didion, Forest Resources and Management, Swiss Federal Institute for Forest, Snow and Landscape Research WSL. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M. 2019: Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss NIR 2020 (1990–2018). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M., Thürig, E 2013: Revision der CC13 (Harmonizing activity data from the Swiss land use statistics (AREA) with the Kyoto Protocol guidelines). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M., Thürig, E. 2017: Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss GHGI 2018 (1990–2016). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M., Zell, J. 2019: Model of Carbon Cycling in Dead Organic Matter and Soil (Yasso07). In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 281-284. doi:10.1007/978-3-030-19293-8_18

Didion, M., Kaufmann, E., Thürig, E. 2012: Estimation of carbon stocks and stock changes in soil, LFH layer and deadwood in Swiss forests with Yasso07. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Didion, M., Frey, B., Rogiers, N., Thürig, E. 2014a: Validating tree litter decomposition in the Yasso07 carbon model. Ecological Modelling 291: 58–68. http://dx.doi.org/10.1016/j.ecolmodel.2014.07.028 [18.03.2020]

Didion et al. 2019: Didion, M., Herold, A., Thürig, E. 2019. Whole tree biomass and carbon stock. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 243-248. doi:10.1007/978-3-030-19293-8_14

Düggelin, C., Abegg, M. 2011: Modelle zur Biomasse- und Holzvolumenschätzung im Schweizer Gebüschwald. Schweizerische Zeitschrift für Forstwesen 162 (2): 32–40. http://dx.doi.org/10.3188/szf.2011.0032 [18.03.2020]

Dunger, K., Petersson, S.H., Barreiro, S., Ciencialo, E., Coli, A., Hylen, G., Kusar, G., Oehmichen, K., Tomppo, E., Tuomainen, T., Ståhl, G. et al. 2012: Harmonizing Greenhouse Gas Reporting from European Forests: Case Examples and Implications for European Union Level Reporting. Forest Science 58: 248-256. doi:10.5849/forsci.10-06

EAFV (Eidg. Anstalt für das forstliche Versuchswesen)/BFL (Bundesamt für Forstwesen und Landschaftsschutz) (eds.) 1988: Schweizerisches Landesforstinventar. Ergebnisse der Erstaufnahme 1982–1986. [Results of the first Swiss national forest inventory 1982–1986]. Ber. Eidgenöss. Forsch.anst. Wald Schnee Landsch. 305. http://www.lfi.ch/publikationen/publ/lfi1-en/php [18.03.2020]

EAWAG 2018: Review of “Source category 5D – Wastewater treatment and discharge” in Switzerland, Prepared by Manuel Luck, Wenzel Gruber, Adriano Joss from eawag, Dübendorf, Switzerland. Commissioned by the Federal Office for the Environment (FOEN) – Division: Climate; Section: Climate Reporting and Adaptation, 23.08.2018. http://www.climatereporting.ch

EC 2004: Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC. Official Journal of the European Union. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004L0042&qid=1455622565462&from=EN [18.03.2020]

European Commission Joint Research Centre (EC JRC)/Netherlands Environmental Assessment Agency (PBL) 2009: Emission Database for Global Atmospheric Research (EDGAR), release version 4.0 [queries from database].

Eckmeier, E., Egli, M., Schmidt, MWI, Schlumpf, N., Nötzli, M., Minikus-Stary, N., Hagedorn, F. 2010: Preservation of fire-derived carbon compounds and sorptive stabilisation promote the accumulation of organic matter in black soils of the Southern Alps. Geoderma 159:147-155. doi:http://dx.doi.org/10.1016/j.geoderma.2010.07.006

Ecoplan, 2009: Volkswirtschaftliche Auswirkungen der Schweizer Post-Kyoto-Politik. Ecoplan, Bern (mandated by the Swiss Federal Office for the Environment, Bern). https://bit.ly/2L2ydgz [10.02.20209]

EMEP/EEA 2002: EMEP/CORINAIR Emission Inventory Guidebook. European Environment Agency. 3rd edition October 2002 update. http://www.eea.europa.eu/publications/EMEPCORINAIR3/page002.html [20.02.2020]

EMEP/EEA 2013: Air Pollutant Emission Inventory Guidebook 2013, European Environment Agency. http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 [18.03.2020]

EMEP/EEA 2016: Air pollutant emission inventory guidebook – 2016. European Environment Agency. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016 [18.03.2020]

EMEP/EEA 2019: EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. European Environment Agency. https://www.eea.europa.eu/ds_resolveuid/e0473b3047bf435b95cf245894a9b197 [18.03.2020]

EMIS 2020/(NFR-Code): Comments to EMIS (Swiss Emission Information System) database. Internal documents. Federal Office for the Environment, Bern [confidential/internal]

EMPA 1999: Written communication from Dr. H.W. Jäckle (EMPA, Dübendorf) to Andreas Liechti (FOEN, Bern), 09.03.1999. http://www.climatereporting.ch

EPA 1992: Emission factors for automobile body incineration. EPA - 1992 - AP-42 - Vol. I - CH 2.6. October 1992. https://www3.epa.gov/ttn/chief/ap42/ch02/final/c02s06.pdf [20.02.2020]

EPA 2010: Exhaust and Crankcase Emission Factors for Nonroad Engine Modelling – Compression Ignition. EPA-420-R-10-018/NR-009d. Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency. July 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi/P10005BI.PDF?Dockey=P10005BI.PDF [18.02.2020]

Ericsson, E., Nolinder, E., Persson, A., Steven, H. 2019: Work programme 2016–2018 for HBEFA Version 4.1. Report oft he work carried out for work package 2. https://www.hbefa.net/e/documents/Ericsson_Steven_2019_HBEFA41_Development_WP2_final.pdf [27.02.2020]

ERM 2016: Bauabfälle in der Schweiz – Tiefbau. Aktualisierung 2015. Schlussbericht. Energie- und Ressourcen-Management GmbH, Freienbach, Mai 2016. https://www.bafu.admin.ch/dam/bafu/de/dokumente/abfall/externe-studien-berichte/studie_bauabfaelle_tiefbau_2015.pdf [20.02.2020]

Estermann, B. L., Wettstein, H.-R., Sutter, F., Kreuzer, M. 2001: Nutrient and energy conversion of grass-fed dairy and suckler beef cattle kept indoors and on high altitude pasture. Animal Research 50(6): 477–493. http://dx.doi.org/10.1051/animres:2001109 [18.03.2020]

Etzold, S., Ruehr, N.K., Zweifel, R., Dobbertin, M., Zingg, A., Pluess, P., Häsler, R., Eugster, W. Buchmann, N. 2011: The Carbon Balance of Two Contrasting Mountain Forest Ecosystems in Switzerland: Similar Annual Trends, but Seasonal Differences. Ecosystems 14: 1289–1309. http://dx.doi.org/10.1007/s10021-011-9481-3 [18.03.2020]

EV 2014: Jahresbericht 2013. Erdöl-Vereinigung, Zürich. https://www.avenergy.ch/images/pdf/1621_ev_jb13_d.pdf [20.03.2020]

EV2015a: Tanktourismus und Eurokurs. Mario Keller, MK Consulting GmbH im Auftrag der Erdöl-Vereinigung. Bern, 18. Dez. 2015. https://www.erdoel.ch/images/pdf/Studie_Tanktourismus_d.pdf [27.02.2020]

EV 2016: Jahresbericht 2015. Erdöl-Vereinigung, Zürich. https://www.avenergy.ch/images/pdf/ev_jb_2015_de.pdf [20.03.2020]

EV 2019: Jahresbericht 2018. Erdöl-Vereinigung, Zürich. https://www.avenergy.ch/images/pdf/93090_EV_JB_2018_DE_WEB.pdf [04.02.2020]

FAL/RAC 2001: Grundlagen für die Düngung im Acker- und Futterbau 2001. [Principles of fertilization in crop and feed production]. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau/Eidgenössische Forschungsanstalt für Pflanzenbau, Agrarforschung, June 2001, Zürich-Reckenholz, Nyon. http://www.climatereporting.ch [available in German and French]

Falloon, P., Smith, P. 2003: Accounting for changes in soil carbon under the Kyoto protocol: need for improved long-term data sets to reduce uncertainty in model projections. Soil Use and Management 19(3): 265–269. http://dx.doi.org/10.1079/SUM2003201 [18.03.2020]

Falloon, P., Jones, C.D., Ades, M,. Paul, K. 2011: Direct soil moisture controls of future global soil carbon changes: An important source of uncertainty. Global Biogeochemical Cycles 25: 1:14.

FCA 2015c: Import- und Exportstatistik Swiss-Impex. Tarifnummer 87 Automobile etc. (tarif no. 87 motorised vehicles) https://www.swiss-impex.admin.ch [18.02.2020]

FCA 2019: Mineralölsteuer. Versteuerte Mengen 2018. Federal Customs Administration (FCA). https://www.ezv.admin.ch/dam/ezv/de/dokumente/abgaben/A%20MML/Min%C3%B6St/t21.pdf.download.pdf/T%202.1%202018%20per%20Q4%20m%20Kommentar.pdf [05.02.2020]

FCA 2019a: Import- und Exportstatistik Swiss-Impex. Tarifnummer 3102 – Mischungen von Ammoniumnitrat und Calciumcarbonat oder anderen nichtdüngenden anorganischen Stoffen https://www.swiss-impex.admin.ch [11.09.2019]

FEDPOL 2018: Bundesamt für Polizei fedpol, Statistik Pyrotechnikumsatz in der Schweiz. https://www.fedpol.admin.ch/fedpol/de/home/sicherheit/sprengstoff_pyrotechnik/pyrotechnische-gegenstaende/statistik.html [18.03.2020]

FEDRO 2014: Extract 2AA of MOFIS database (reference date 30.09.2013) of the Federal Roads Office (FEDRO) containing vehicle stock numbers. E-mail from A. Lehmann (FEDRO) to P. Wüthrich, INFRAS on 14.11.2014 [hardcopy].

Felber, R., Münger, A., Neftel, A., Ammann, C. 2015: Eddy covariance methane flux measurements over a grazed pasture: effect of cows as moving point sources. Biogeosciences, 12 (12): 3925-3940. https://www.biogeosciences.net/12/3925/2015/ [18.03.2020]

Fellner et al. 2007: A New Method to Determine the ratio of Electricity Production from Fossil and Biogenic Sources in Waste-to-Energy Plants. Environ. Sci. Technol. 2007, 41, 2579–2586. http://dx.doi.org/10.1021/es0617587 [18.03.2020]

Fernández, C., Espinós, F.J., López, M.C., García-Diego, F.J., Cervera, C. 2013: Representation of a mathematical model to predict methane output in dairy goats. Computers and Electronics in Agriculture 91(0): 1–9. http://dx.doi.org/10.1016/j.compag.2012.11.013 [18.03.2020]

Fial 2013: Die Schweizer Nahrungsmittel-Industrie im Jahr 2012. http://www.fial.ch/wp-content/uploads/2017/03/fial_Statistik-2012_de.pdf [10.02.2020]

Flisch, R., Sinaj, S., Charles, R., Richner, W. 2009: Grundlagen für die Düngung im Acker- und Futterbau 2009. Forschungsanstalt Agroscope Changins-Wädenswil ACW und Agroscope Reckenholz-Tänikon ART, Agrarforschung 16 (2). http://www.agrarforschungschweiz.ch/archiv_11de.php?jahr=2009&band=16&heft=02 [09.04.2019]

FM Global 2010: Environmental impact of automatic fire sprinklers. Research technical report. By Wieczorek, C.J., Ditch, B., Bill, R.G., 2010, FM Global Research Division. https://iccsafe.org/gr/Documents/AdoptionToolkit/FM-Global-EnvironmenmtalImpactAutomaticFireSprinklers.pdf [20.02.2020]

FOCA 1991: Crossair confidential data 1991. Federal Office of Civil Aviation, Bern [confidential/internal].

FOCA 1991a: L'aviation civile Suisse en 1990. Federal Office of Civil Aviation, Bern. http://www.climatereporting.ch

FOCA 2004: Unternehmensstatistik der Schweizerischen Helikopterunternehmungen. Federal Office of Civil Aviation, Bern. http://www.climatereporting.ch

FOCA 2006: GHG emissions of Swiss civil aircraft in 1990 and 2004: data, proceeding and description of the calculations. Written communication from Theo Rindlisbacher and Paul Stulz (FOCA, Bern) to Andreas Liechti (FOEN, Bern), 20./22.02.2006. http://www.climatereporting.ch

FOCA 2006a: GHG emissions of Swiss civil aircraft in 1990, 1995, 2000, 2002, 2004 and 2005: data, proceeding and description of the calculations. Written communication from Theo Rindlisbacher (FOCA, Bern) to Paul Filliger (FOEN, Bern), 17.11.2006. http://www.climatereporting.ch

FOCA 2007: GHG emissions of Swiss civil aircraft in 2006. Written communication from Theo Rindlisbacher (FOCA, Bern) to Beat Müller (FOEN, Bern), 03.12.2007. http://www.climatereporting.ch

FOCA 2007a: Aircraft Piston Engine Emissions. Summary Report. Federal Office of Civil Aviation. Report Ref. 0/3/33/33-05-003 ECERT. Bern. http://www.climatereporting.ch

FOCA 2007b: Validation of ADAECAM (Advanced Aircraft Emission Calculation Method). Report on fuel calculation. Federal Office of Civil Aviation. Report Ref. 0/3/33/33-05-007.021. Bern, 10.08.2007. http://www.climatereporting.ch

FOCA 2008: GHG emissions of Swiss civil aircraft in 2007. Written communication from Theo Rindlisbacher (FOCA, Bern) to Beat Müller (FOEN, Bern), 01.12.2008. http://www.climatereporting.ch

FOCA 2009: GHG emissions of Swiss civil aircraft in 2008. Written communication from Theo Rindlisbacher (FOCA, Bern) to Beat Müller (FOEN, Bern), 04.11.2009. http://www.climatereporting.ch

FOCA 2009a: Guidance on the determination of helicopter emissions. Federal Office of Civil Aviation. Report Ref. 0/3/33/33-05-020. Edition 1. Bern. March 2009. http://www.climatereporting.ch

FOCA 2010: GHG emissions of Swiss civil aircraft in 2009. Written communication from Theo Rindlisbacher (FOCA, Bern) to Sophie Hoehn (FOEN, Bern), 18.11.2010. http://www.climatereporting.ch

FOCA 2011: GHG emissions of Swiss civil aircraft in 2010. Written communication from Theo Rindlisbacher (FOCA, Bern) to Sopie Hoehn (FOEN, Bern), 09.11.2011. http://www.climatereporting.ch

FOCA 2012: GHG emissions of Swiss civil aircraft in 2011. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 07.09.2012. http://www.climatereporting.ch

FOCA 2013: GHG emissions of Swiss civil aircraft in 2012. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 07.11.2013. http://www.climatereporting.ch

FOCA 2014: GHG emissions of Swiss civil aircraft in 2013 and corrections for the year 2011. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 30.10.2014 [confidential/internal].

FOCA 2015: GHG emissions of Swiss civil aircraft in 2014. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 29.10.2015 [confidential/internal].

FOCA 2015a: Guidance on the Determination of Helicopter Emissions. Federal Office of Civil Aviation. Reference: COO.2207.111.2.2015750. Edition 2. Bern. December 2015**.** https://www.bazl.admin.ch/bazl/en/home/specialists/regulations-and-guidelines/environment/pollutant-emissions/aircraft-engine-emissions/guidance-on-the-determination-of-helicopter-emissions.html [29.01.2020]

FOCA 2016: GHG emissions of Swiss civil aircraft in 2015. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 6.12.2016 [confidential/internal].

FOCA 2016a: Swiss Civil Aviation Emissions Inventory 2015. Federal Office of Civil Aviation FOCA. Reference: FOCA/047.1-00017/00002. 29.11.2016 [confidential/internal].

FOCA 2017: GHG emissions of Swiss civil aircraft in 2016. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 24.11.2017 [confidential/internal].

FOCA 2018: GHG emissions of Swiss civil aircraft in 2017. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 12.07.2018 [confidential/internal].

FOCA 2019: GHG emissions of Swiss civil aircraft in 2018. Written communication from Theo Rindlisbacher (FOCA, Bern) to Anouk-Aimée Bass (FOEN, Bern), 25.06.2019 [confidential/internal].

FOEN 2006h: Switzerland's Initial Report under Article 7, paragraph 4 of the Kyoto Protocol. Federal Office for the Environment, Bern. Including the Update following the UNFCCC review (FCCC/IRR/2007/CHE). http://www.climatereporting.ch

FOEN 2008: Switzerland's Greenhouse Gas Inventory 1990–2006, National Inventory Report and CRF-tables 2008. Submission of 15 April 2008 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2008h: Wood Resource Policy: Strategy, Objectives and Action Plan for the Resource Wood. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2010d: Deforestations in Switzerland as reported under the Kyoto Protocol Art. 3.3. Forest Division, Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2010h: Afforestations in Switzerland as reported under the Kyoto Protocol Art. 3.3. Forest Division, Federal Office for the Environment, Bern.http://www.bafu.admin.ch/ghginv-ref http://www.climatereporting.ch

FOEN, 2010k: Synthesebericht zur Volkswirtschaftlichen Beurteilung der Schweizer Klimapolitik nach 2012. Swiss Federal Office for the Environment, Bern. http://goo.gl/Fxzcrj [10.02.2020]

FOEN 2011: Switzerland's Greenhouse Gas Inventory 1990–2009: National Inventory Report, CRF-tables, Kyoto Protocol LULUCF tables 2008–2009, SEF and SIAR tables from the National Registry. Submission of 15 April 2011 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2011l: Switzerland's Submission on Reference Levels as an accounting approach for Forest Management under the Kyoto Protocol. Submission of 28 February 2011 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/awgkp_switzerland_2011.pdf [18.03.2020]

FOEN 2012: Switzerland's Greenhouse Gas Inventory 1990–2010: National Inventory Report, CRF-tables, Kyoto Protocol LULUCF tables 2008–2010, SEF and SIAR tables from the National Registry. Submission of 13 April 2012 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2012b: Adaptation to climate change in Switzerland. Goals, challenges and fields of action. First part of the Federal Council's strategy. Adopted on 2 March 2012. Federal Office for the Environment. Bern. https://www.bafu.admin.ch/ud-1055-e [18.03.2020]. Available in English, French, German, Italian.

FOEN 2012i: Jahrbuch Wald und Holz 2012. Umwelt-Zustand Nr. 1224, Bern. https://www.bafu.admin.ch/dam/bafu/de/dokumente/wald-holz/uz-umwelt-zustand/jahrbuch_wald_undholz2012.pdf.download.pdf/jahrbuch_wald_undholz2012.pdf [German and French], [18.03.2020]

FOEN 2013: Switzerland's Greenhouse Gas Inventory 1990–2011: National Inventory Report, CRF-tables, Kyoto Protocol LULUCF tables 2008–2010, SEF and SIAR tables from the National Registry. Submission of April 2013 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2013l: Forest Policy 2020, Visions, objectives and measures for the sustainable management of forests in Switzerland. Federal Office for the Environment, Bern. https://www.bafu.admin.ch/ud-1067-e [18.03.2020]

FOEN 2014: Switzerland's Greenhouse Gas Inventory 1990–2012: National Inventory Report, CRF-tables, Kyoto Protocol LULUCF tables 2008–2012, SEF and SIAR tables from the National Registry. Submission of 15 April 2014 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2014f: Illustration of unproductive forests in Switzerland. Internal report by the Swiss Federal Office for the Environment. http://www.climatereporting.ch

FOEN 2014l: Kohlenstoffgehalt Abfall auf Basis des Heizwerts – Berechnungsgrundlage, FOEN, Bern. 31.10.2014 [confidential/internal].

FOEN 2014n: Standardmethode für Kompensationsprojekte des Typs „Landwirtschaftliche Biogasanlagen“. Version für informelle Konsultation, 1.5.2014. Federal Office for the Environment, Geschäftsstelle Kompensation, Bern [confidential/internal].

FOEN 2014o: Erhebung der Kehrichtzusammensetzung 2012. Federal Office for the Environment, Bern.
http://www.news.admin.ch/NSBSubscriber/message/attachments/33597.pdf
http://www.news.admin.ch/NSBSubscriber/message/attachments/33601.pdf [10.02.2020]

FOEN 2014p: Von Arx U.: Feuerwerkskörper. Umweltauswirkungen und Sicherheitsaspekte. Umwelt-Wissen Nr.1423. Federal Office for the Environment, Bern. https://www.bafu.admin.ch/uw-1423-d [18.03.2020]

FOEN 2015: Switzerland’s Greenhouse Gas Inventory 1990–2013: National Inventory Report, CRF-tables. Submission of 15 April 2015 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2015g: Zusammenstellung der Feedstocks basierend auf GEST-, EV- und bottom-up Industrie-Daten, BAFU, internal documentation (confidential, Excelfile), Federal Office for the Environment, Bern [confidential/internal].

FOEN 2015j: Non-road energy consumption and pollutant emissions. Study for the period from 1980 to 2050 (Original in German: Energieverbrauch und Schadstoffemissionen des Nonroad-Sektors. Studie für die Jahre 1980–2050. Schlussbericht). INFRAS. Ed. by the Federal Office for the Environment. https://www.bafu.admin.ch/uw-1519-e [29.01.2020]

FOEN 2015n: Biological Treatment of Solid Waste (5B) – Revision 2015 (internal documentation) [confidential/internal].

FOEN 2015p: Ergebnisse der Nationalen Bodenbeobachtung (NABO) 1985–2009. Zustand und Veränderungen der anorganischen Schadstoffe und Bodenbegleitparameter. Umwelt-Zustand Nr. 1507. Federal Office for the Environment, Bern. http://www.bafu.admin.ch/uz-1507-f [French] https://www.bafu.admin.ch/uz-1507-d [German] [18.03.2020]

FOEN 2015q: Forest Report 2015: Condition and Use of Swiss Forests. Umwelt-Zustand Nr. 1512. Federal Office for the Environment, Bern.
https://www.bafu.admin.ch/bafu/en/home/topics/forest/publications-studies/publications/forest-report-2015.html [English] [09.04.2019]

FOEN 2016: Switzerland’s Greenhouse Gas Inventory 1990–2014: National Inventory Report, CRF-tables. Submission of 15 April 2016 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2016c: Switzerland’s Second Initial Report under the Kyoto Protocol. Report to facilitate the calculation of the assigned amount pursuant to Article 3, paragraphs 7bis, 8 and 8bis, of the Kyoto Protocol for the second commitment period 2013–2020.
http://www.climatereporting.chhttp://www.climatereporting.ch/

FOEN 2016d: Switzerland's Second Initial Report under the Kyoto Protocol. Update following the in-country review by an expert review team coordinated by the UNFCCC secretariat. http://www.climatereporting.ch

FOEN 2016l: Hitze und Trockenheit im Sommer 2015. Federal Office for the Environment. UZ-1629-D http://www.bafu.admin.ch/uz-1629-d [German] http://www.bafu.admin.ch/uz-1629-f [French] [18.03.2020]

FOEN 2016m: Mandaliev P., Schleiss K. 2016: Kompostier- und Vergärungsanlagen. Erhebung in der Schweiz und in Liechtenstein. Bundesamt für Umwelt, Bern. Umwelt-Zustand Nr. 1602, Bern. www.bafu.admin.ch/uz-1602-d [German and French] [20.02.2020]

FOEN 2017d: Jahrbuch Wald und Holz 2017. Umwelt-Zustand Nr. 1718 [Annuaire La forêt et le bois 2017. Etat de l'environnement no 1718]. Federal Office for the Environment, Bern. http://www.bafu.admin.ch/uz-1718-d [German] http://www.bafu.admin.ch/uz-1718-f [French] [18.03.2020]

FOEN 2017g: UNFCCC FOD spreadsheet model Switzerland for estimating methane emissions from landfill sites. [confidential/internal]

FOEN 2017j: Wood Resource Policy. Strategy, Objectives and Wood Action Plan. Swiss Federal Office for the Environment, Bern / Swiss Federal Office of Energy, Bern / Swiss State Secretariat for Economic Affairs, Bern. UD-1102-E. http://www.bafu.admin.ch/ud-1102-e [18.03.2020]

FOEN 2017k: Köllner P., Gross C., Lerch J., Nauser M. 2017: Klimabedingte Risiken und Chancen. Eine schweizweite Synthese. Bundesamt für Umwelt, Bern. Umwelt-Wissen Nr. 1706: 148 S. http://www.bafu.admin.ch/uw-1706-d (German), http://www.bafu.admin.ch/uw-1706-f (French), http://www.bafu.admin.ch/uw-1706-i (Italian) [18.03.2020]

FOEN 2017l: Adressliste der Schweizer Kläranlagen mit Angaben zur Ausbaugrösse. Swiss Federal Office of Energy, Bern. https://www.bafu.admin.ch/dam/bafu/de/dokumente/wasser/fachinfo-daten/ARA_Liste_August2017_Version_Internet_.pdf.download.pdf/ARA_Liste_August2017_Version_Internet_.pdf [18.03.2020]

FOEN 2018: Switzerland's Greenhouse Gas Inventory 1990–2016: National Inventory Report, CRF-tables. Submission of April 2018 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2018d: Switzerland's Seventh National Communication and Third Biennial Report under the UNFCCC, Fourth National Communication under the Kyoto Protocol to the UNFCCC. 1 January 2018 http://www.climatereporting.ch

FOEN 2018g: Biodiversity Monitoring Switzerland. Website in English including indicator system, monitoring results etc. [queries from database] https://www.biodiversitymonitoring.ch/en/home.html [18.03.2020]

FOEN 2019: Switzerland's Greenhouse Gas Inventory 1990–2017: National Inventory Report, CRF-tables. Submission of April 2019 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. http://www.climatereporting.ch

FOEN 2019g: Manual: Calculation of technical corrections of Swiss FMRL for NIR submission 2019. Including 1 Excel data file. Internal document. Federal Office for the Environment, Bern [confidential/internal].

FOEN 2019h: Abfallstatistiken des Jahres 2018 sowie Zeitreihen. Diverse Dateien. Federal Office for the Environment, Bern https://www.bafu.admin.ch/bafu/de/home/themen/abfall/zustand/daten/abfallstatistiken-2018.html [20.02.2020]

FOEN 2019i: CO_2-Emissionsfaktor Erdgas, Zeitreihe 1990–2018 für das Treibhausgasinventar der Schweiz, internal documentation, Federal Office for the Environment, Bern [confidential/internal]

FOEN 2019j: Hitze und Trockenheit im Sommer 2018, UZ-1909-D. [La canicule et la sécheresse de l'été 2018. French: UZ-1909-F] Federal Office for the Environment, Bern. https://www.bafu.admin.ch/uz-1909-d [German] https://www.bafu.admin.ch/uz-1909-f [French] [12.02.2020]

FOEN 2020a: Qualitätsmanagement Treibhausgasinventar – Handbuch. Bundesamt für Umwelt (BAFU), Bern [German for: Quality management system Greenhouse Gas Inventory – Manual. Federal Office for the Environment (FOEN), Bern [confidential/internal].

FOEN 2020b: Switzerland's Informative Inventory Report 2020 (IIR), Submission under the UNECE Convention on Long-range Transboundary Air Pollution, Submission of March 2020 to the United Nations ECE Secretariat. Federal Office for the Environment, Bern. https://www.bafu.admin.ch/dam/bafu/en/dokumente/luft/fachinfo-daten/Switzerlands-Informative-Inventory-Report-2019.pdf [25.03.2020]

FOEN 2020c: Handbuch Berechnung der Kohlenstoffvorräte und ihre Änderungen im Wald für die Submission 2020 [Manual: Calculation of carbon stock changes for Forest Land]. Including 1 Excel data file. Internal document. Federal Office for the Environment, Bern [confidential/internal].

FOEN 2020e: Harvested wood products (HWP) in the Swiss National Inventory Report 2020 (GHG inventory 1990–2018). Description of time series, modelling methodology and results used for accounting HWP under the Kyoto Protocol. Federal Office for the Environment, Bern. www.climatereporting.ch

FOEN 2020f: Jahrbuch Wald und Holz 2019. Umwelt-Zustand Nr. 1914 [Annuaire La forêt et le bois 2019. Etat de l'environnement no 1914]. Federal Office for the Environment, Bern. https://www.bafu.admin.ch/uz-1914-d [German] https://www.bafu.admin.ch/uz-1914-f [French] [27.02.2020]

FOEN 2020k: Emissions Trading Scheme (ETS); Appendix G, Guidance document on activity specific monitoring methods, Federal Office for the Environment, Bern. https://www.bafu.admin.ch/uv-1317-d [German] https://www.bafu.admin.ch/uv-1317-f [French] [18.02.2020]

FOEN/SFOE/VBSA 2019: Einheitliche Heizwert- und Energiekennzahlenberechnung der Schweizer KVA nach europäischem Standardverfahren. Resultate 2018. Bern. 30. April 2019. https://www.bfe.admin.ch/bfe/de/home/news-und-medien/publikationen.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvOTY5OQ==.html [10.02.2020]

Franko, U., Kolbe, H., Thiel, E., Ließ, E. 2011: Multi-site validation of a soil organic matter model for arable fields based on generally available input data. Geoderma, 166 (1): 119-134. https://doi.org/10.1016/j.geoderma.2011.07.019 [26.02.2020]

Frischknecht, R., Hofstetter, P., Knoepfel, I., Ménard, M. 1996: Ökoinventare von Energiesystemen. Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. BEW 1996, Kapitel IV, Abschnitt 9.7.1. www.esu-services.ch/fileadmin/download/frischknecht-1996-oekoinventare.pdf [18.02.2020]

Ganesan, A. L., Manning, A. J., Grant, A., Young, D., Oram, D. E., Sturges, W. T., Moncrieff, J. B., and O'Doherty, S., 2015: Quantifying methane and nitrous oxide emissions from the UK and Ireland using a national-scale monitoring network, Atmos. Chem. Phys., 15, 6393-6406, doi: 10.5194/acp-15-6393-2015. https://www.atmos-chem-phys.net/15/6393/2015/acp-15-6393-2015.html [18.03.2020]

Gehrig-Fasel, J., Guisan, A., Zimmermann, N.E. 2007: Treeline shifts in the Swiss Alps: climate change or land abandonment? Journal of Vegetation Science 18: 571–582. http://dx.doi.org/10.1111/j.1654-1103.2007.tb02571.x [18.03.2020]

Genossenschaft Ökostrom Schweiz 2014: Projekte zur Emissionsverminderung im Inland – Methanemissionsreduktion bei landwirtschaftlichen Biogasanlagen in der Schweiz (Bündel I) – Monitoringberichte zu Handen BAFU für die Jahre 2010, 2011 und 2012. Frauenfeld, Schweiz [confidential/internal].

GES Biogas GmbH 2014: Projekte zur Emissionsverminderung im Inland – Methanemissionsreduktion bei landwirtschaftlichen Biogasanlagen in der Schweiz (Bündel II) – Monitoringberichte zu Handen BAFU für die Jahre 2011 und 2012. Zürich, Schweiz [confidential/internal].

Ginzler, C. 2014: Crown cover and basal area in unproductive forest: special analysis of plots covered by aerial photographs and terrestrial NFI. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern [confidential/internal].

Giuliani, S. 2019: Energiebedarfswerte der Nutztiere für die Periode 2015–2017. Written communication from Silvano Giuliani (SBV, Swiss Farmers Union) to Daniel Bretscher (Agroscope, Reckenholz), 12.08.2019 [confidential/internal].

Grassi, G., Blujdea, V. 2011: Pools to be reported under KP-LULUCF. Harmonized guidance and decision tree on the application of “not a source" principle. Joint Research Centre, Ispra. Presentation at “JRC technical workshop on LULUCF issues under the Kyoto Procotol", 21 November 2011. http://slideplayer.com/slide/743707/ [18.03.2020]

Gschwantner, T. 2006: Zuwachsänderungen nach den Daten der Österreichischen Waldinventur und ihre klimatischen Ursachen. [Growth changes according to the data of the Austrian National Forest Inventory and their climatic causes]. BFW-Berichte 133, Wien, Bundesamt für Wald [hardcopy].

Guidi, C., Vesterdal, L., Gianelle, D., Rodeghiero, M. 2014: Changes in soil organic carbon and nitrogen following forest expansion on grassland in the Southern Alps. Forest Ecology and Management 328: 103–116. http://dx.doi.org/10.1016/j.foreco.2014.05.025 [18.03.2020]

Hackl, A., Mauschitz, G. 2003: Emissionen aus Anlagen der Österreichischen Zementindustrie IV. Jahresreihe 2000–2002. Weitra/Wien. http://www.climatereporting.ch

Hadorn, R., Wenk, C. 1996: Effect of different sources of dietary fibre on nutrient and energy utilization in broilers. 2. Energy and N-balance as well as whole body composition. Archiv für Geflügelkunde 60: 22–29 [hardcopy].

Hagedorn, F., Martin, M., Rixen, C., Rusch, S., Bebi, P., Zürcher, A., Siegwolf, R.T.W., Wipf, W., Escape, C., Roy, J., Hättenschwiler, S. 2010: Short-term responses of ecosystem carbon fluxes to experimental soil warming at the Swiss alpine treeline. Biogeochemistry: 97: 7–19. http://dx.doi.org/10.1007/s10533-009-9297-9 [18.03.2020]

Hagedorn, F., Moeri, A., Walthert, L., Zimmermann, S. 2010: Kohlenstoff in Schweizer Waldböden - bei Klimaerwärmung eine potenzielle CO2-Quelle | Soil organic carbon in Swiss forest soils - a potential CO2 source in a warming climate. Schweizerische Zeitschrift für Forstwesen 161:530-535. doi:10.3188/szf.2010.0530

Henne, S., Brunner, D., Steinbacher, M., Emmenegger, L. 2015: Verifikation des Schweizer Methan-Emissionsinventars. Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA), Abteilung Luftfremdstoffe/Umwelttechnik. Dübendorf; Schweiz. http://www.climatereporting.ch

Henne, S., Brunner, D., Oney, B., Leuenberger, M., Eugster, W., Bamberger, I., Meinhardt, F., Steinbacher, M., Emmenegger, L. 2016: Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling. Atmos. Chem. Phys., 16, 3683–3710, 2016. http://dx.doi.org/10.5194/acp-16-3683-2016 [18.03.2020]

Henne, S., Brunner, D., Emmenegger, L. 2017: Quantifizierung der Schweizer Methanemissionen mittels atmosphärischer Messungen und inverser Modellierung. Abschlussbericht. Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA), Abteilung Luftfremdstoffe/Umwelttechnik. Dübendorf; Schweiz. http://www.climatereporting.ch

Henne, S., Mohn, J., Brunner, D., Emmenegger L. 2019: Quantification of Swiss Nitrous Oxide Emissions Through Atmospheric Observations and Inverse Modelling. Final Report 2019-02-21. Laboratory for Air Pollution / Environmental Technology, Empa, 8600 Dübendorf, Switzerland. Project on behalf of Federal Office for the Environment (FOEN). http://www.climatereporting.ch

Herold, A., Zell, J., Rohner, B., Didion, M., Thürig, E., Rösler, E. 2019: State and Change of Forest Resources. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 205-230. doi:10.1007/978-3-030-19293-8_12 https://link.springer.com/chapter/10.1007%2F978-3-030-19293-8_12 [25.03.2020]

Hiller, R.V., Bretscher, D., DelSontro, T., Diem, T., Eugster, W., Henneberger, R., Hobi, S., Hodson, E., Imer, D., Kreuzer, M., Künzle, T., Merbold, L., Niklaus, P.A., Rihm, B., Schellenberger, A., Schroth, M.H., Schubert, C.J., Sigrist, H., Stieger, J., Buchmann, N., Brunner, D. 2014: Anthropogenic and natural methane fluxes in Switzerland synthesized within a spatially explicit inventory. Biogeosciences 11: 1941–1959. http://dx.doi.org/10.5194/bg-11-1941-2014 [18.03.2020]

Hiller, R.V., Neininger, B., Brunner, D., Gerbig, Ch., Bretscher, D., Künzle, T. 2014a: Airborne CH_4 flux measurements for validation of emissions from an agriculturally dominated area in Switzerland. Journal of Geophysical Research. 119(8): 4874–4887. http://onlinelibrary.wiley.com/doi/10.1002/2013JD020918/full [09.04.2019]

Hindrichsen, I.K., Wettstein, H.-R., Machmüller, A., Bach Knudsen, K.E., Madsen, J., Kreuzer, M. 2006: Methane emission, nutrient degradation and nitrogen turnover in dairy cows and their slurry at different milk production scenarios with and without concentrate supplementation. Agricultural Ecosystems and Environment 113: 150–161. http://dx.doi.org/10.1016/j.agee.2005.09.004 [18.03.2020]

Hofer P., Altwegg, J. 2008: Holznutzungs-Potenziale im Schweizer Wald – auf Basis LFI3. Bundesamt für Umwelt, Bern. 38 p. https://www.bafu.admin.ch/dam/bafu/de/dokumente/wald-holz/fachinfo-daten/holznutzungspotenzialeimschweizerwald-aufbasislfi3.pdf [18.03.2020]

Hofer P., Altwegg, J., Schoop, A., Hässig, J., Ruegg, R. 2011: Holznutzungspotenziale im Schweizer Wald. Auswertung von Nutzungsszenarien und Waldwachstumsentwicklung. Bundesamt für Umwelt, Bern. Umwelt-Wisser Nr. 1116: 80 p. www.bafu.admin.ch/uw-1116-d [18.03.2020]

Högberg, P., Fan, H., Quist, M., Binkley, D., Tamm, C.O. 2006: Tree growth and soil acidification in response to 30 years of experimental nitrogen loading on boreal forest. Global Change Biology 12: 489–499. http://dx.doi.org/10.1111/j.1365-2486.2006.01102.x [18.03.2020]

Huber, B., Frehner M. 2012: Forschungsprojekt Grünerle. Bericht erstellt im Auftrag des Bundesamtes für Umwelt (BAFU), Bern. Abenis AG Chur und Forstingenieurbüro Monika Frehner, Sargans. http://www.climatereporting.ch

Huber, B., Frehner M. 2013: Die Verbreitung und Entwicklung der Grünerlenbestände in der Ostschweiz. Schweizerische Zeitschrift fur Forstwesen 164: 87–94. http://www.szf-jfs.org/toc/swif/164/4 [04.02.2020]

Huber, T., Thürig, E. 2014: Special analysis of stocks of living biomass in non-productive forest (CC13) on terrestrial NFI plots. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Hubschmid, S. 2014: VOC-Emissionen aus lösungsmittelhaltigen Haushaltsprodukten, Master Thesis, MAS Umwelttechnik und -management, FHNW [confidential/internal].

Hürdler, J., Prasuhn, V., Spiess, E. 2015: Abschätzung diffuser Stickstoff- und Phosphoreinträge in die Oberflächengewässer der Schweiz. MODIFFUS 3.0. – Bericht im Auftrag des Bundesamtes für Umwelt BAFU, Agroscope, Zürich, ca. 115 S. https://www.agroscope.admin.ch/dam/agroscope/de/dokumente/themen/umwelt-ressourcen/gewaesserschutz/huerdler-prasuhn-spiess-endbericht-modiffus.pdf [18.03.2020]

Hyvönen, R., Persson, T., Andersson, S., Olsson, B. Ågren, G.I., Linder, S. 2008: Impact of long-term nitrogen addition on carbon stocks in trees and soils in northern Europe. Biogeochemistry 89: 121–137. http://dx.doi.org/10.1007/s10533-007-9121-3 [18.03.2020]

IAI 2005: Aluminium for future Generations. Sustainability Update 2004. International Aluminium Institute, London. http://www.climatereporting.ch

IEA 2005: Energy statistics manual, IEA/OECD Paris. http://www.iea.org/publications/freepublications/publication/statistics_manual-1.pdf [18.03.2020]

IEA 2012: Energy statistics of OECD countries, 2012 edition, IEA/OECD Paris. http://www.oecd-ilibrary.org/energy/energy-statistics-of-oecd-countries-2012_energy_stats_oecd-2012-en [09.04.2019]

IFEU 2010: Aktualisierung des Modells TREMOD – Mobile Machinery (TRE-MOD-MM). Endbericht im Auftrag des Umweltbundesamtes. UBA Texte 28/2010. Institut für Energie- und Umweltforschung (IFEU), Heidelberg. https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/3944.pdf [18.02.2020]

IFEU/INFRAS 2009: Ermittlung der Unsicherheiten der mit den Modellen TREMOD und TREMOD-MM berechneten Luftschadstoffemissionen des landgebundenen Verkehrs in Deutschland, Endbericht. IFEU und INFRAS im Auftrag des Umweltbundesamts Dessau/Deutschland, FKZ 360 16 023. Heidelberg/Zürich/Bern. 31. Oktober 2009. http://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/3937.pdf [18.03.2020]

INFRAS 2004: Emission Factors for Passenger Cars and Light-Duty Vehicles. Handbook Emission Factors for Road Transport (HBEFA), Version 2.1. Swiss Agency for the Environment, Forests and Landscape, Bern, Umweltbundesamt, Berlin, Umweltbundesamt, Wien. http://www.hbefa.net/e/documents/HBEFA21_Dokumentation.pdf

INFRAS 2010: The Handbook Emission Factors for Road Transport (HBEFA), version 3.1 (MS AccessXP runtime application and report). INFRAS in cooperation with further editors: FOEN/Switzerland; Umweltbundesamt Dessau/Germany; Umweltbundesamt Wien/Austria; Swedish Road Administration, ADEME/France; SFT/Norway. Bern. 30.01.2010. http://www.hbefa.net/e/index.html [queries from database].

INFRAS 2011a: Bunker fuels Bodensee/Genfersee, Datenverfügbarkeit und Berechnung der Bunker Fuels. Internal document. Federal Office for the Environment. September 2011 [confidential/internal].

INFRAS 2012: Verification of Swiss implied emission factors. INFRAS, Zürich. http://www.climatereporting.ch

INFRAS 2014: Verbrennung natürlicher Wald-, Feld- und Gartenabfälle im Freien. Datengrundlagen zur Aktualisierung der Jahresleistungen. Zürich, 29. Januar 2014. [confidential/internal]

INFRAS 2015: CO_2-Emissions from Carbonate, Assessment for FOEN. Internal documentation FOEN [confidential/internal].http://www.bafu.admin.ch/ghginv-CP2-ref

INFRAS 2015a: Online database of emission factors, activity data and emissions of non-road vehicles (queries from database, corresponding report is FOEN 2015j) https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html [29.01.2020].

INFRAS 2015b: Driving behaviour, Phase II. GPS-based recording of driving behaviour. Final Report. INFRAS, Zurich. Mandated by the Swiss Federal Office for the Environment, Bern. [confidential/internal]

INFRAS 2017: Pilotstudie zum Treibstoffverbrauch und den Treibhausgasemissionen im Verkehr 1990–2050 - Szenarien für den Strassenverkehr. Schlussbericht. INFRAS, Zurich. Mandated by the Swiss Federal Office for the Environment, Bern. http://goo.gl/dgVNT2 [05.02.2020]

INFRAS 2017c: Luftschadstoffemissionen des Strassenverkehrs der Schweiz. Schlussbericht, Bern, 24. November 2017. https://www.bafu.admin.ch/dam/bafu/de/dokumente/luft/externe-studien-berichte/Bericht_Luftschadstoffemissionen_des_Strassenverkehrs_der_Schweiz_1990_2050.pdf [18.03.2020], [in German]

INFRAS 2019: Kurzdoku EMIS-Exporte Road + Non-Road 2018. B. Notter zuhanden A. Bass, BAFU. Bern. 17. Okt. 2019. [confidential/internal]

INFRAS 2019a: HBEFA 4.1 – Development Report. Notter, B., Keller, M., Althaus, H.-J., Cox, B., Knörr, W., Heidt, C., Biemann, K., Räder, D., Jamet, M. Commissioned by FOEN/Switzerland; Umweltbundesamt Dessau/Germany; Umweltbundesamt Wien/Austria; Swedish Road Administration, ADEME/France; SFT/Norway. Bern, Heidelberg. 21.08.2019. https://www.hbefa.net/e/documents/HBEFA41_Development_Report.pdf [11.02.2020]

INFRAS 2019b: The Handbook Emission Factors for Road Transport (HBEFA), version 4.1 (MS Access runtime application and report). INFRAS in cooperation with further editors: FOEN/Switzerland; Umweltbundesamt Dessau/Germany; Umweltbundesamt Wien/Austria; Swedish Road Administration, ADEME/France; SFT/Norway. Bern. http://www.hbefa.net/e/index.html (download of database [05.02.2020]).

Integer 2013: Emissions Control in Non-Road Mobile Machinery (NRMM) Markets: 2013 Edition. Integer Research Limited, London [confidential/internal].

IPCC 1997c: Greenhouse Gas Inventory Reference Manual, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Reference Manual (Volume 3). Intergovernmental Panel on Climate Change. https://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html [18.03.2020]

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html [18.03.2020]

IPCC 2014: 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (KP Supplement). Intergovernmental Panel on Climate Change. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland. http://www.ipcc-nggip.iges.or.jp/public/kpsg/index.html [18.03.2020]

IPCC 2014a: 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland. http://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html [18.03.2020]

ISPRA 2014: Italian Greenhouse Gas Inventory 1990–2012. Inventory Report and CRF-tables. Submission to the UNFCCC Secretariat 2014. Instituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Rome, Italy. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php [09.04.2019]

Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., Johnson, D. W., Minkkinen, K., Byrne, K. A. 2007: How strongly can forest management influence soil carbon sequestration? Geoderma 137: 253–268. http://dx.doi.org/10.1016/j.geoderma.2006.09.003 [18.03.2020]

Jardin Suisse 2012: Zahlen zum Schweizerischen Gartenbau. Unternehmerverband Gärtner Schweiz. http://www.climatereporting.ch

Jarvis, P.G., Linder, S. 2000: Constraints to growth of boreal forests. Nature 405: 904–905. http://dx.doi.org/10.1038/35016154 [18.03.2020]

Karhu, K., Wall, A., Vanhala, P., Liski, J., Esala, M., Regina, K. 2011: Effects of afforestation and deforestation on boreal soil carbon stocks – Comparison of measured C stocks with Yass07 model results. Geoderma 164: 33–45. http://dx.doi.org/10.1016/j.geoderma.2011.05.008 [18.03.2020]

Kaufmann, E. 2005: Personal communication from Edgar Kaufmann (WSL, Zürich) to Esther Thürig (FOEN, Bern), 12.12.2005. http://www.climatereporting.ch

Kaufmann, U. 2015: Energieverbrauch stationäre Motoren und Gasturbinen ab 1990. Excel data file for internal use on behalf of the Federal Office for the Environment, Bern. Eicher + Pauli, Liestal [confidential/internal].

Keel, S.G., Anken, T., Büchi, L. et al. 2019: Loss of soil organic carbon in Swiss long-term agricultural experiments over a wide range of management practices. Agriculture, Ecosystems and Environment 286: 106654. https://www.sciencedirect.com/science/article/pii/S0167880919302701 [04.02.2020]

Keller, A., Desaules, A., Schwab, P., Weisskopf, P., Scheid, S., Oberholzer, H.-R. 2006: Monitoring soil quality in the long term: examples from the Swiss Soil Monitoring Network. Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft, Heft 73: 5–12. http://www.climatereporting.ch

Koehlerei, 2014: Geschichte der Holzköhlerei in Romoos. http://www.koehlerei.ch [18.03.2020]

Koehli L. 2014: Landwirtschaftliche Biogasanlagen. Written communication from Lorenz Koehli (Oekostrom Schweiz) to Daniel Bretscher (Agroscope), 27.08.2014 [confidential/internal].

Krause, H.-M., Steffens, M., Bretscher, D., Schellenberger, A., Gattinger, A. 2018: Fokusstudie Treibhausgasbilanz: Treibhausgas-Emissionen aus landwirtschaftlichen Böden in der Schweiz. Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung., Nationales Forschungsprogramm 68 «Ressource Boden». Frick, Schweiz. http://www.nfp68.ch/de/projekte/fokusstudien/treibhausgasbilanz [18.03.2020]

Kuenen, J. J. P., Visschedijk, A. J. H., Jozwicka, M., and Denier van der Gon, H. A. C. 2014: TNO-MACC_II emission inventory; a multi-year (2003–2009) consistent high-resolution European emission inventory for air quality modelling, Atmos. Chem. Phys., 14, 10963–10976, http://dx.doi.org/10.5194/acp-14-10963-2014 [11.03.2020]

Külling, D. R., Dohme, F., Menzi, H., Sutter, F., Lischer, P., Kreuzer, M. 2002: Methane emissions of differently fed dairy cows and corresponding methane and nitrogen emissions from their manure during storage. Environmental Monitoring and Assessment 79 (2): 129–150. http://dx.doi.org/10.1023/A:1020248700255 [18.03.2020]

Külling D. R., Stadelmann F. X., Candinas T. 2002a: Nährstoffe und Schwermetalle im Klärschlamm 1975–1999, Agrarforschung 9(5): 200–205. http://www.agrarforschungschweiz.ch/artikel/2002_05_27.pdf [20.02.2020]

Külling, D. R., Menzi, H., Sutter, F., Lischer, P., Kreuzer, M. 2003: Ammonia, nitrous oxide and methane emissions from differently stored dairy manure derived from grass- and hay-based rations. Nutrient Cycling in Agroecosystems 65 (1): 13–22. http://dx.doi.org/10.1023/A:1021857122265 [18.03.2020]

Kupper 2014: Leaching of nitrate from manure stores. Written communication from Thomas Kupper (HAFL) to Daniel Bretscher (Agroscope, Reckenholz), 16.09.2014. [confidential/internal].

Kupper 2017: Integration of nitrous oxide (N_2O), nitrogen oxides (NO_x) and diatomic nitrogen (N_2) emissions into N-flow models for the determination of ammonia emissions. Evaluation based on a literature review. Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences. Zollikofen; Switzerland. https://www.agrammon.ch/assets/Downloads/Bericht-N2O-NO-N2-in-Emissionsmodell-incl.-app.-subm-20170303.pdf [18.03.2020]

Kupper, T., Bonjour, C., Menzi, H., Zaucker, F., Bretscher, D. 2018: Ammoniakemissionen in der Schweiz: Neuberechnung 1990–2015. Prognose bis 2030. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften. Zollikofen, Schweiz. http://www.climatereporting.ch

Kupper, T., Bühler, M., Gruber, W., Häni, C. 2018b: Methane and ammonia emissions from wastewater treatment plants. A brief literature review. Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences HAFL and Eawag. December 4, 2018. http://www.climatereporting.ch

KWF 2012: Forstmaschinenstatistik zeigt deutliche Stabilisierung des Marktes. 17. KWF-Tagung. https://www.kwf-online.de/index.php/aktuelles/presse/159-kwf-forstmaschinenstatistik-zeigt-deutliche-stabilisierung-des-marktes [18.02.2020]

Lamlom, S.H., Savidge, R.A. 2003: A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass and Bioenergy 25: 381–388. http://dx.doi.org/10.1016/S0961-9534(03)00033-3 [18.03.2020]

Lanz, A., Fischer, C., Abegg, M. 2019: Sampling Design and Estimation Procedures. In: Fischer, C., Traub, B. (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Springer International Publishing, Cham, pp 39-92. doi:10.1007/978-3-030-19293-8_2 https://link.springer.com/chapter/10.1007%2F978-3-030-19293-8_2 [25.03.2020]

Lehtonen, A., Heikkinen, J. 2016: Uncertainty of upland soil carbon sink estimate for Finland. Canadian Journal of Forest Research 46: 310-322. http://dx.doi.org/10.1139/cjfr-2015-0171 [09.04.2019]

Leifeld, J. 2018: Distribution of nitrous oxide emissions from managed organic soils under different land uses estimated by the peat C/N ratio to improve national GHG inventories. Science of the Total Environment 631-632: 23-26. https://doi.org/10.1016/j.scitotenv.2018.02.328 [18.03.2020]

Leifeld, J., Fuhrer, J. 2005: Greenhouse gas emissions from Swiss agriculture since 1990: Implications for environmental policies to mitigate global warming. Environmental Science & Policy 8: 410–417. http://dx.doi.org/10.1016/j.envsci.2005.04.001 [18.03.2020]

Leifeld, J., Bassin, S., Fuhrer, J. 2003: Carbon stocks and carbon sequestration potentials in agricultural soils in Switzerland. Schriftenreihe der FAL 44. Zürich-Reckenholz. http://www.climatereporting.ch

Leifeld, J., Bassin, S., Fuhrer, J. 2005: Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. Agriculture, Ecosystems & Environment 105 (1/2): 255–266. http://dx.doi.org/10.1016/j.agee.2004.03.006 [18.03.2020]

Leifeld, J., Zimmermann, M., Fuhrer, J. 2007: Characterization of soil carbon stocks and site-specific sequestration potentials of agricultural soils. Extended Summary. Final Report, Contract Number: 810.03.0716/2003.C.04. Agroscope Reckenholz-Tänikon Research Station ART. http://www.climatereporting.ch

Leupro 2012: Entwicklung und Prognose der Emissionsfaktoren Feuerungen für den Zeitraum 1990–2035. http://www.climatereporting.ch

LHA 2004: Letter of „Lufthygieneamt beider Basel“ to FOEN, Basel, 04.05.2004 [confidential/internal].

Mangino, J., Bartram, D., Brazy, A. 2001: Development of a methane factor to estimate emissions from animal waste lagoons. U.S.EPA's 17th Annual Emission Inventory Conference, Atlanta GA; U.S. EPA. http://www.climatereporting.ch

Martínez-Fernández, G., Abecia, L., Ramos-Morales, E., Martin-García, A.I., Molina-Alcaide, E., Yáñez-Ruiz, D.R. 2014: Effects of propyl propane thiosulfinate on nutrient utilization, ruminal fermentation, microbial population and methane emissions in goats. Animal Feed Science and Technology 191:16–25. http://dx.doi.org/10.1016/j.anifeedsci.2014.01.008 [18.03.2020]

Mathys, L., Thürig E. 2010: Baumbiomasse in der Landschaft. [Living biomass of trees in Non-Forest Land]. Final report, Sigmaplan and WSL on behalf of the Federal Office for the Environment, Bern. http://www.climatereporting.ch

Mathys, L., Gardi, O., Kükenbrink, D., Morsdorf, F. 2019: Non-forest tree biomass references. Nategra GmbH, BFH-HAFL, UZH-RSL and WSL-NFI on behalf of the Federal Office for the Environment, Bern. www.climatereporting.ch

Matzer, C., Weller, K., Dippold, M., Lipp, S., Röck, M., Rexeis, M., Hausberger, S., 2019: Update of emission factors for HBEFA 4.1. Final report. Technische Universität (TU) Graz, Austria. 12.04.2019. https://www.hbefa.net/e/documents/HBEFA41_Report_TUG_09092019.pdf [18.03.2020]

Meining, S., V.Wilpert, K., Schäffer, J., Schröter, H. 2008: Waldzustandsbericht 2008 der Forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg. Freiburg. http://www.climatereporting.ch

Menzi, H. 2014: Stickstoffausscheidung Kaninchen. Written communication from Harald Menzi (Agroscope INT) to Daniel Bretscher (Agroscope INH), 05.12.2014 [confidential/internal].

Menzi, H., Arrigo, Y., Huguenin, O., Münger, A., Schori, F., Wyss, U., Schlegel, P. 2016: Neue Ausscheidungsrichtwerte für Milchkühe. Agrarforschung Schweiz 7(10): 428-435. https://www.agrarforschungschweiz.ch/wp-content/uploads/2019/12/2016_10_2216.pdf [25.03.2020]

MeteoSwiss (Federal Office of Meteorology and Climatology) 2014: Normwerte 1981–2010: Lufttemperatur 2m. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich. http://www.meteoschweiz.admin.ch/product/input/climate-data/normwerte-pro-messgroesse/np8110/nvrep_np8110_tre200m0_d.pdf [18.03.2020]

Meteotest 2019: Treibhausgasinventar Sektor LULUCF, Tabellen zur Berechnung der Treibhausgasemissionen im Sektor LULUCF in der Schweiz inklusive Begleitdokumentation. [GHG inventory, sector LULUCF. Spreadsheets to calculate the GHG emissions of the LULUCF sector in Switzerland inclusive accompanying documents]. Meteotest AG, Bern. [confidential/internal]

Meteotest 2019a: NMVOC-Emissionen der Waldflächen in der Schweiz; Zeitreihe 1990–2016, langfristige Entwicklung, Sensitivitätsanalyse für zwei Extremtage. Meteotest AG, Bern, commissioned by the Federal Office for the Environment (FOEN). https://www.bafu.admin.ch/dam/bafu/de/dokumente/luft/externe-studien-berichte/nmvoc-emissionen-der-waldflaechen-in-der-schweiz.pdf [01.04.2020]

Meteotest 2020: Treibhausgasinventar Sektor LULUCF, Tabellen zur Berechnung der Treibhausgasemissionen im Sektor LULUCF in der Schweiz inklusive Begleitdokumentation. [GHG inventory, sector LULUCF. Spreadsheets to calculate the GHG emissions of the LULUCF sector in Switzerland inclusive accompanying documents]. Meteotest AG, Bern. [confidential/internal]

Meyer, H., Coenen, M., 2002: Pferdefütterung. Parey Buchverlag Berlin, 4. Auflage; ISBN 3-8263-3398-5 [hardcopy].

Minonzio, G., Grub, A., Fuhrer, J. 1998: Methanemissionen der schweizerischen Landwirtschaft. Schriftenreihe Umwelt Nr. 298. FOEN/BUWAL, Bern [hardcopy].

MISTA 2019: Milchstatistik der Schweiz 2018. Schweizerischer Bauernverband (SBV), TSM Treuhand GmbH, Schweizer Milchproduzenten (SMP). https://www.sbv-usp.ch/de/publikationen/milchstatistik/ [24.01.2020]

Mohn, J. 2013: Bestimmung der N_2O und CH_4 Emissionen aus Schweizer KVAs. Eidg. Materialprüfungs- und Forschungsanstalt. Schlussbericht. Im Auftrag des Bundesamts für Umwelt. http://www.climatereporting.ch

Mohn, J., Szidat, S., Fellner, J., Rechberger, H., Quartier, R., Buchmann, B., Emmenegger, L. 2008: Determination of biogenic and fossil CO_2 emitted by waste incineration based on $^{14}CO_2$ and mass balances. Bioresource Technology 99: 6471–6479 http://dx.doi.org/10.1016/j.biortech.2007.11.042 [18.03.2020]

Mohn, J., Zeyer, K., Durciova, B., Emmenegger, L., Szidat, S. 2011: Bestimmung des Anteils biogener und fossiler CO_2 Emissionen aus Schweizer KVAs. Eidg. Materialprüfungsanstalt und Forschungsanstalt. Schlussbericht. Im Auftrag des Bundesamts für Umwelt. http://www.climatereporting.ch

Moller, H.B., Sommer, S.G., Ahring, B.K. 2004: Biological degradation and greenhouse gas emissions during pre-storage of liquid animal manure. Journal of Environmental Quality 33 (1): 27–36. http://dx.doi.org/10.2134/jeq2004.0027 [18.03.2020]

Monni, S., Peltoniemi, M., Palosuo, T., Lehtonen, A., Mäkipää, R., Savolainen, I. 2007: Uncertainty of forest carbon stock changes – implications to the total uncertainty of GHG inventory of Finland. Climatic Change 81: 391–413. http://dx.doi.org/10.1007/s10584-006-9140-4 [18.03.2020]

Monteny, G.J., Bannink, A., Chadwick, D. 2006: Greenhouse gas abatement strategies for animal husbandry. Agric. Ecosyst. Environ. 112(2-3): 163-170. https://doi.org/10.1016/j.agee.2005.08.015 [18.03.2020]

Morel, I., Chassot, A., Schlegel, P., Jans, F., Kessler, J. 2015: Fütterungsempfehlungen für die Mutterkuh. Fütterungsempfehlungen für Wiederkäuer (Grünes Buch). Agroscope Posieux. Posieux; Schweiz.

Nave, L.E., Vance, E.D., Swanston, C. W., Curtis, P.S. 2010: Harvest impacts on soil carbon storage in temperate forests. Forest Ecology and Management 259: 857–866. http://dx.doi.org/10.1016/j.foreco.2009.12.009 [18.03.2020]

Nousiainen, J., Rinne, M., Huhtanen, P. 2009: A meta-analysis of feed digestion in dairy cows. 1. The effects of forage and concentrate factors on total diet digestibility. Journal of dairy science 92(10): 5019–5030. http://dx.doi.org/10.3168/jds.2008-1833 [18.03.2020]

Nowak, D., Crane, D. 2002: Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116: 381–389. http://dx.doi.org/10.1016/S0269-7491(01)00214-7 [18.03.2020]

Nussbaum, M., Papritz, A., Baltensweiler, A., Walthert, L. 2012: Organic carbon stocks of Swiss forest soils. Final report, including CD ROM. Institute of Terrestrial Ecosystems, ETH Zürich and Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. http://dx.doi.org/10.3929/ethz-a-007555133 [18.03.2020]

Nussbaum, M., Papritz, A., Baltensweiler, A., Walthert, L. 2014: Estimating soil organic carbon stocks of Swiss forest soils by robust external-drift kriging. Geoscientific Model Development 7: 1197–1210. http://dx.doi.org/10.5194/gmd-7-1197-2014 [18.03.2020]

Nussbaumer, T., Hälg, L. 2015: Emissionsfaktoren von Holzfeuerungen – Aktualisierung und Ergänzung 2014. Verenum im Auftrag des Bundesamtes für Umwelt (BAFU) inkl. Excelfile [confidential/internal].

OECD 2013: Agricultural policy monitoring and evaluation 2013: OECD countries and emerging economies. Organisation for Economic Co-operation and Development (OECD); Paris, France. http://www.oecd-ilibrary.org/agriculture-and-food/agricultural-policy-monitoring-and-evaluation-2013_agr_pol-2013-en [18.03.2020]

Oenema, O., Oudendag, D., Velthof, G.L. 2007: Nutrient losses from manure management in the European Union. Livest. Sci. 112(3): 261-272. 10.1016/j.livsci.2007.09.007 [18.03.2020]

Off-Highway Research 2005: The Market for Construction Equipment and Agricultural Tractors in Switzerland. Internal document INFRAS Bern. September 2005 [confidential/hardcopy].

Off-Highway Research 2008: The Market for Construction Equipment and Agricultural Tractors in Switzerland. Internal document FOEN. November 2008 [confidential/internal].

Off-Highway Research 2012: The Market for Construction Equipment and Agricultural Tractors in Switzerland. Internal document FOEN. April 2012 [confidential/internal].

Oney, B., Henne, S., Gruber, N., Leuenberger, M., Bamberger, I., Eugster, W., and Brunner, D. 2015: The CarboCount CH sites: characterization of a dense greenhouse gas observation network, Atmos. Chem. Phys., 15, 11147–11164. http://dx.doi.org/10.5194/acp-15-11147-2015 [18.03.2020]

OS 2019: Liechtenstein’s energy statistics 2018. Office of statistics Liechtenstein. https://www.llv.li/files/as/energiestatistik-2018.pdf [05.02.2020]

Park, K.H., Thompson, A.G., Marinier, M., Clark, K., Wagner-Riddle, C. 2006: Greenhouse gas emissions from stored liquid swine manure in a cold climate. Atmospheric Environment 40 (4): 618–627. http://dx.doi.org/10.1016/j.atmosenv.2005.09.075 [18.03.2020]

Paul, S. and Alewell, C. 2018: An assessment of CO_2 emission factors of drained organic soils in the Swiss GHG Inventory. University of Basel, Department of Environmental Sciences. June 2018. Report on behalf of the Federal Office for the Environment, Bern. www.climatereporting.ch

Paul, C., Weber, M., Mosandl, R. 2009: Kohlenstoffbindung junger Aufforstungsflächen. Literaturstudie. Karl Gayer Institut und Lehrstuhl für Waldbau der Technischen Universität München, Freising, 70 p. https://mediatum.ub.tum.de/doc/1219390/1219390.pdf [18.03.2020]

Pauli, B., Thees, O. 2009: Holz als Rohstoff und Energieträger. Dynamisches Holzmarktmodell und Zukunftsszenarien, Schlussbericht, 208 p. http://www.news.admin.ch/NSBSubscriber/message/attachments/19857.pdf [18.03.2020]

Peichl, M., Arain, M.A. 2006: Above- and belowground ecosystem biomass and carbon pools in an age-sequence of temperate pine plantation forests. Agricultural and Forest Meteorology 140: 51-63. http://dx.doi.org/10.1016/j.agrformet.2006.08.004 [18.03.2020]

Perruchoud, D., Kienast, F., Kaufmann, E., Bräker, O.U 1999: 20th Century Carbon Budget of Forest Soils in the Alps. Ecosystems 2: 320–337. http://dx.doi.org/10.1007/s100219900083 [18.03.2020]

Petersen, S.O., Lind, A.M., Sommer, S.G. 1998: Nitrogen and Organic Matter Losses during Storage of Cattle and Pig Manure. J. Agric. Sci. 130: 69-79. http://goo.gl/aHswhZ [18.03.2020]

Pezzatti, B. 2017: Uncertainty of the Swissfire database. Personal communication from Boris Pezzatti (WSL) to Nele Rogiers (FOEN), 4 December 2017 [confidential/internal].

Pezzatti, B., Bertoglatli, M., Gache, S., Reinhard, M., Conedera, M. 2019: Swissfire: technisch modernisiert und dank Archivrecherchen inhaltlich erweitert. Schweizerische Zeitschrift für Forstwesen 170 (5):234-241: https://szf-jfs.org/doi/pdf/10.3188/szf.2019.0234 [18.03.2020]

Pfab, H., Palmer, I., Buegger, F., Fiedler, S., Müller, T., Ruser, R. 2012: Influence of a nitrification inhibitor and of placed N-fertilization on N_2O fluxes from a vegetable cropped loamy soil. Agriculture, Ecosystems & Environment, 150: 91-101. https://www.sciencedirect.com/science/article/pii/S0167880912000151 [18.03.2020]

Poncet, P.-A., Guillet, A., Jallon, L., Lüth, A., Martin, R., Montavon, S., Sunier, E., Trolliet, Ch. F., Wohlfender, K. 2007: Wirtschafts-, gesellschafts- und umweltpolitische Bedeutung des Pferdes in der Schweiz. Bericht der Arbeitsgruppe Pferdebranche. Avenches, Schweiz. (ID 21285) https://t1p.de/Poncet07de [German] [18.03.2020] https://t1p.de/Poncet07fr [French] [18.03.2020]

Poncet, P.-A., Boessinger, M., Guillet, A., Klopfenstein, S., König-Bürgi, D., Lüth, A., Martin, R., Montavon, S., Obexer-Ruff, G., Rieder, S., Rubli, S., Rüegg, P., Trolliet, Ch. F. 2009: Wirtschafts-, gesellschafts- und umweltpolitische Bedeutung des Pferdes in der Schweiz – Was gibt es Neues seit 2007? Bericht der Arbeitsgruppe Pferdebranche. Avenches, Schweiz. (ID 21284). https://t1p.de/Poncet09de [German] [18.03.2020] https://t1p.de/Poncet09fr [French] [18.03.2020]

Prasuhn, V. 2016: Abklärung zum Umweltziel Landwirtschaft: Reduktion der landwirtschaftsbedingten Stickstoffeinträge in die Gewässer um 50% gegenüber 1985. Bericht im Auftrag des Bundesamtes für Umwelt (BAFU). Agroscope. Zürich; Schweiz. https://t1p.de/Prasuhn16 [09.04.2019]

Price, B., Gomez, A., Mathys, L., Gardi, O., Schellenberger, A., Ginzler, C., Thürig, E. 2017: Tree biomass in the Swiss landscape: nationwide modelling for improved accounting for forest and non-forest trees. Environmental Monitoring and Assessment, 189: 106. http://doi.org/10.1007/s10661-017-5816-7 [09.04.2019]

Prognos 2013: CO_2-Emissionen 1990–2012 von Industrie- und Dienstleistungen, Endbericht/Kurzdokumentation zuhanden Bundesamt für Umwelt, Bern. Prognos, Basel [confidential/internal].

Quantis 2014: Methanemissionen der Schweizer Gaswirtschaft. Zeitreihe 1990 bis 2012. Schlussbericht. Quantis im Auftrag des Schweizerischen Vereins des Gas- und Wasserfaches SVGW und des Bundesamts für Umwelt BAFU. http://www.climatereporting.ch

Raffinerie de Cressier 1992: Project CRISTAL – Influence sur l'environnement (incl. annexes), Raffinerie de Cressier (rapports préparé en collaboration avec Badger BV, Pays-Bas), Cressier [confidential/internal].

Ramin, M., Huhtanen, P. 2012: Development of non-linear models for predicting enteric methane production. Acta Agriculturae Scandinavica, Section A — Animal Science 62(4): 254–258. http://dx.doi.org/10.1080/09064702.2013.765908 [26.03.2020]

RAP 1999: Fütterungsempfehlungen und Nährwerttabellen für Wiederkäuer [Apports alimentaires recommandés et tables de la valeur nutritive des aliments pour les ruminants]. Landwirtschaftliche Lehrmittelzentrale, Zollikofen. Vierte Auflage [hardcopy].

Reimann 2019: Expert Review of the Swiss F–Gas Inventory, 2019, Laboratory for Air Pollution and Environmental Technology, Empa, Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland. [confidential/internal]

Richard, L. 1995: Ecologie des mégaphorbiaies subalpines à aune vert de la Vanoise et des régions environnantes (seconde partie) – Phytoécologie. Trav Sci Parc Nat Vanoise 19: 131–160.

Richner et al. 2017: Richner, W., Sinaj, S., Carlen, Ch., Flisch, R., Gilli, C., Huguenin-Elie, O., Kuster, T., Latsch, A., Mayer, J., Neuweiler, R., Spring, J.L. 2017: GRUD 2017: Grundlagen für die Düngung landwirtschaftlicher Kulturen in der Schweiz. Agroscope. Bern, Schweiz. [hardcopy]

Rigling, A., Schaffer, H.P. (Eds.) 2015: Forest Report 2015. Condition and Use of Swiss Forests. Federal Office for the Environment (FOEN), Bern, Swiss Federal Institute (WSL), Birmensdorf. 144 pages. https://www.bafu.admin.ch/uz-1512-e [English], https://www.bafu.admin.ch/uz-1512-d [German] [29.03.2019]

Ruffner, H.P. 2005: Written communication from Hans Peter Ruffner (Forschungsanstalt Wädenswil) to Jens Leifeld (ART, Reckenholz), 19.12.2005. http://www.climatereporting.ch

Rühr, N., Eugster, W. 2009: Soil respiration fluxes and carbon sequestration of two mountain forests in Switzerland. Report on behalf of the Federal Office for the Environment, Bern. http://www.climatereporting.ch

Rutherford, G.N., Bebi, P., Edwards, P.J., Zimmermann, N.E. 2008: Assessing land-use statistics to model land cover change in a mountainous landscape in the European Alps. Ecological Modelling 212(3–4): 460–471. http://dx.doi.org/10.1016/j.ecolmodel.2007.10.050 [18.03.2020]

Rytec 2010: Review of the waste sector of the national greenhouse gas inventory of Switzerland. Final report. Rytec AG, Münsingen. http://www.climatereporting.ch

Rytec 2014: Fossiler Kohlenstoffanteil im verbrannten Abfall 1992 – 2012. Errechnung einer Zeitreihe aus der Verknüpfung der Rauchgasmessung 2010/11 und der erhobenen Kehrichtzusammensetzung 1992, 2002, 2012. Rytec AG, Münsingen. http://www.climatereporting.ch

SAEFL 1992: Abfallkonzept für die Schweiz, Schriftenreihe Umwelt Nr. 173. Swiss Agency for the Environment, Forests and Landscape, Bern [hardcopy].

SAEFL 1993: NABO – Nationales Bodenbeobachtungsnetz. Messresultate 1985–1991. [NABO – Réseau d'observation des sols: période d'observation 1985–1991]. Schriftenreihe Umwelt Nr. 200. [Cahier de l'environnement No 200]. Swiss Agency for the Environment, Forests and Landscape, Bern. https://www.bafu.admin.ch/dam/bafu/de/dokumente/boden/uz-umwelt-zustand/nationales_bodenbeobachtungsnetznaboaufbauundersteergebnissemess.pdf [19.03.2020]

SAEFL 1996a: Luftschadstoff-Emissionen aus natürlichen Quellen der Schweiz. [Emissions polluantes dues aux sources naturelles en Suisse]. Schriftenreihe Umwelt Nr. 257. [Cahier de l'environnement No 257]. Swiss Agency for the Environment, Forests and Landscape, Bern. http://www.climatereporting.ch

SAEFL 2000: Handbuch Emissionsfaktoren für stationäre Quellen. Ausgabe 2000, Reihe Vollzug Umwelt. Swiss Agency for the Environment, Forests and Landscape, Bern. http://www.climatereporting.ch

SAEFL 2000a: Nationales Boden-Beobachtungsnetz – Veränderungen von Schadstoffgehalten nach 5 und 10 Jahren. [Réseau national d'observation des sols – Variations des teneurs en polluants après 5 et 10 ans de suivi]. Schriftenreihe Umwelt Nr. 320. [Cahier de l'environnement No 320]. Swiss Agency for the Environment, Forests and Landscape, Bern. https://www.bafu.admin.ch/dam/bafu/de/dokumente/boden/uz-umwelt-zustand/nationales_boden-beobachtungsnetznaboveraenderungenvonschadstoff.pdf [19.03.2020]

SAEFL 2004b: Swiss national forest programme (Swiss NFP), Environmental documentation No. 363, Swiss Agency for the Environment, Forests and Landscape, Bern. 117 pp. https://www.bafu.admin.ch/dam/bafu/en/dokumente/wald-holz/ud-umwelt-diverses/waldprogramm_schweizwap-chhandlungsprogramm2004-2015.pdf [19.03.2020]

Sagoo, E., Williams, J.R., Chambers, B.J., Boyles, L.O., Matthews, R., Chadwick, D.R. 2007: Integrated management practices to minimise losses and maximise the crop nitrogen value of broiler litter. Biosyst. Eng. 97(4): 512-519. https://www.sciencedirect.com/science/article/pii/S153751100700116X [19.03.2020]

SBV 2004: Statistiques et évaluations concernant l'agriculture et l'alimentation, 2003. [Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung 2003]. Swiss Farmers Union, Brugg [hardcopy, available in German and French].

SBV 2007a: Données mensuelles sur l'agriculture. 67.8. August 2007. [Landwirtschaftliche Monatszahlen 67.8. August 2007]. Swiss Farmers Union, Brugg. http://www.climatereporting.ch [available in German and French]

SBV 2013: Betriebsinterne Verrechnungsansätze und Inventar-Grunddaten (BIV) 2013. Schweizerischer Baumeisterverband. Verlag SBV [confidential/internal].

SBV 2017: Statistiques et évaluations concernant l'agriculture et l'alimentation, 2016. [Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, 2016]. Swiss Farmers Union, Brugg. [available in German and French, partly online, partly hardcopy] https://www.sbv-usp.ch/de/services/agristat/statistiken/ [19.03.2020]

SBV 2018: Statistiques et évaluations concernant l'agriculture et l'alimentation, 2017. [Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, 2017]. Swiss Farmers Union, Brugg. [available in German and French, partly online, partly hardcopy] https://www.sbv-usp.ch/de/services/agristat/statistiken/ [19.03.2020]

SBV 2019: Statistiques et évaluations concernant l'agriculture et l'alimentation, 2018. [Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, 2018]. Swiss Farmers Union, Brugg. [available in German and French, partly online, partly hardcopy] https://www.sbv-usp.ch/de/services/agristat/statistiken/ [19.03.2020]

Schlegel, P., Menzi, H. 2013: Schweizer Kaninchenproduktion und deren Stickstoff-, Phosphor- und Kaliumausscheidung. Agrarforschung Schweiz 4(2): 60–67. http://www.agrarforschungschweiz.ch/artikel/2013_02_1839.pdf [19.03.2020]

Schleiss, K. 2017: Erhebung Schweizer Daten zu Mengen in der Kompostierung, im Auftrag des Bundesamtes für Umwelt (BAFU), Bern, 17.11.2017. http://www.climatereporting.ch

Schmid, M., Neftel, A., Fuhrer, J. 2000: Lachgasemissionen aus der Schweizer Landwirtschaft. [Emissions de protoxyde d'azote de l'agriculture Suisse]. Schriftenreihe der FAL 33. Zürich-Reckenholz. http://www.climatereporting.ch

Schmidlin, L., Bachmann, I., Flierl, S., Schwarz, A., Roesch, A., Rieder S., von Niederhäusern R. 2013: Wirtschafts-, Gesellschafts- und Umweltpolitische Bedeutung des Pferdes in der Schweiz – Stand 2013. Agroscope Forschungsanstalt Liebefeld-Posieux ALP-Haras, Schweizerisches Nationalgestüt. Avenches, Schweiz. http://www.cofichev.ch/Htdocs/Files/v/5885.pdf/Publicationsautres/SCHMIDLINLetalBerichtPferdebranche2013AGROSCOPE20131220.pdf [19.03.2020]

Schwarz, W. 2001: Emissionen des Kältemittels R-134a aus mobilen Klimaanlagen. Jährliche Emissionsraten von bis zu sieben Jahre alten Pkw-Klimaanlagen. [Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to Seven Years Old]. Gutachten durch die Oeko-Recherche GmbH für das Umweltbundesamt (FKZ 360 09 006), Frankfurt. http://www.oekorecherche.de/sites/default/files/publikationen/vollr134a.pdf [19.03.2020]

Schwarz, W., Wartmann, S. 2005: Emissionen und Emissionsprognosen von H-FKW, FKW und SF_6 in Deutschland – Aktueller Stand und Entwicklung eines Systems zur jährlichen Ermittlung. Gutachten durch die Oeko-Recherche GmbH für das Umweltbundesamt (FKZ 202 41 356), Frankfurt. http://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/3000.pdf [19.03.2020]

SCNAT 2016: Akademien der Wissenschaften Schweiz (2016), Brennpunkt Klima Schweiz. Grundlagen, Folgen und Perspektiven. Swiss Academies Reports 11 (5), http://www.naturwissenschaften.ch/organisations/proclim/activities/brennpunkt/downloads/81637-brennpunkt-klima-schweiz [19.03.2020]

Seven2one 2014: User manual for Mesap Explorer (2014) “Leitfaden für den Anwender” [German], Seven2one, https://www.seven2one.de/ [confidential/internal].

Seven2one 2017: Uncertainty Calculation – Documentation (2017), 13 April 2017 Add-In version 171. Seven2one, https://www.seven2one.de/ [confidential/internal].

SFOE 2012: Schweizerische Gesamtenergiestatistik 2011. Statistique globale suisse de l’énergie 2011. Swiss Federal Office of Energy, Bern. In German and French. https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.html#kw-71166 [19.03.2020]

SFOE 2012a: Frage BAFU zu den Unsicherheiten der fossilen Energieträger GEST. Written message of the Swiss Federal Office of Energy (SFOE) to the Federal Office for the Environment (FOEN) [confidential/internal].

SFOE 2014c: Thermische Stromproduktion inklusive Wärmekraftkopplung (WKK) in der Schweiz. Ausgabe 2013. Swiss Federal Office of Energy, Bern. https://www.bfe.admin.ch/bfe/de/home/news-und-medien/publikationen.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvNzU4OA==.html [19.03.2020]

SFOE 2015a: Swiss renewable energy statistics. Ausgabe 2014. Swiss Federal Office of Energy, Bern. https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/sector-statistics/_jcr_content/par/tabs/items/tab/tabpar/externalcontent.external.exturl.pdf/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvODA0NC5wZGY=.pdf [18.02.2020]

SFOE 2015d: Energieverbrauch in der Industrie und im Dienstleistungssektor. Resultate 2014 (German). Swiss Federal Office of Energy, Bern. https://www.bfe.admin.ch/bfe/de/home/news-und-medien/publikationen.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvODI0Ng==.html [26.03.2020]

SFOE 2019: Schweizerische Gesamtenergiestatistik 2018. Statistique globale suisse de l’énergie 2018. Swiss Federal Office of Energy, Bern. In German and French. www.bfe.admin.ch/gesamtenergiestatistik [05.02.2020]

SFOE 2019a: Schweizerische Statistik der erneuerbaren Energien (Swiss renewable energy statistics). Ausgabe 2018. Swiss Federal Office of Energy, Bern. https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/sector-statistics.html [27.01.2020]

SFOE 2019b: Schweizerische Holzenergiestatistik. Erhebung für das Jahr 2018. Swiss Federal Office of Energy, Bern. https://t1p.de/bcvu [05.02.2020]

SFOE 2019c: Thermische Stromproduktion inklusive Wärmekraftkopplung (WKK) in der Schweiz. Ausgabe 2018. Swiss Federal Office of Energy, Bern. https://t1p.de/lzxz [10.02.2020]

SFOE 2019d: Energieverbrauch in der Industrie und im Dienstleistungssektor. Resultate 2018 (German/French). Swiss Federal Office of Energy, Bern. https://t1p.de/eir2 [05.02.2020]

SFOE 2019e: Analyse des schweizerischen Energieverbrauchs 2000 - 2018 nach Verwendungszwecken. Prognos, im Auftrag des Bundesamts für Energie. https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/analysis-of-energy-consumption-by-specific-use.html [11.02.2020] und Ex-Post-Analyse Energieverbrauch nach Verwendungszwecken 2000 – 2018 (xlsx, 254 KB), Tabellen. https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/analysis-of-energy-consumption-by-specific-use.html [11.02.2020]

SFOE 2019f: Detailtabellen zu den GEST-Daten. E-Mails P. Baumann, SFOE to R. Röthlisberger, FOEN. 10.07.2019 [confidential/internal]

SFOE/FOEN 2014: Messung von Heizwerten und CO_2-Emissionsfaktoren von Erdölprodukten 2013. Statistische Analyse der Messresultate, Bern [confidential/internal].

SFSO 2000a: Digital soil map 1:200'000 („Bodeneignungskarte", BEK). Swiss Federal Statistical Office, GEOSTAT, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/dienstleistungen/geostat/geodaten-bundesstatistik/boden-nutzung-bedeckung-eignung/abgeleitete-und-andere-daten/bodeneignungskarte-schweiz.html [queries from database].

SFSO 2002: Einblicke in die schweizerische Landwirtschaft. [Insights into Swiss Agriculture]. Swiss Federal Statistical Office, Neuchâtel. [hardcopy, available in German and French]

SFSO 2005: Swiss Land Use Statistics (Arealstatistik Schweiz). Supply of hectare-based data of the first survey (Arealstatistik 1979/85, ASCH1) and second survey (Arealstatistik 1992/97, ASCH2). Swiss Federal Statistical Office, Neuchâtel. http://www.bfs.admin.ch/bfs/portal/fr/index/infothek/erhebungen__quellen/blank/blank/arealstatistik/01.html [queries from database]

SFSO 2006a: Arealstatistik 2004/09 – Kategorienkatalog. Bodenbedeckung, Bodennutzung. Sektion Geoinformatik, Swiss Federal Statistical Office, Neuchâtel. http://www.climatereporting.ch

SFSO 2013a: Landwirtschaftliche Betriebszählung – Zusatzerhebung. Swiss Federal Statistical Office (SFSO), Neuchâtel. [internal/confidential].

SFSO 2019: Supply of provisional data of the AREA Land Use Statistics. Written communication from Michael Bühler (SFSO, Neuchâtel) to Martin Lindenmann (Sigmaplan, Bern), 15.07.2019 [confidential/internal, queries from database].

SFSO 2019a: STAT-TAB: Die interaktive Statistikdatenbank; Datenwürfel für Thema 07.2 – Landwirtschaft. Swiss Federal Statistical Office, Neuchâtel. https://www.pxweb.bfs.admin.ch/pxweb/de/ [24.01.2020]

SFSO 2019b: Background data of the Gross Nutrient Balance of the Swiss Federal Statistical Office. Swiss Federal Statistical Office, Neuchâtel. [confidential/internal, queries from database].

SFSO 2019c: Die Bevölkerung der Schweiz 2018 (Switzerland's population 2018). Swiss Federal Statistical Office. Neuchâtel. https://www.bfs.admin.ch/bfs/en/home/statistics/population/effectif-change.assetdetail.10827606.html [26.03.2020]

SFSO 2019d: Die Beschäftigungsstatistik der Schweiz 2018. (Job Statistics). Swiss Federal Statistical Office, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/aktuell/neue-veroeffentlichungen.assetdetail.7347203.html [26.03.2020]

SFSO 2019e: Distribution of road vehicles by vehicle group. Swiss Federal Statistical Office 2018 https://www.bfs.admin.ch/bfs/en/home/statistics/mobility-transport/transport-infrastructure-vehicles/vehicles/road-vehicles-stock-level-motorisation.assetdetail.8469798.html [05.02.2020]

SFSO 2019f: Fahrleistungen und Fahrzeugbewegungen im Personenverkehr. Swiss Federal Statistical Office, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken/grafiken.assetdetail.11207450.html [05.02.2020]

SFSO 2019g: Fahrleistungen und Fahrzeugbewegungen im Güterverkehr. Swiss Federal Statistical Office, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/gueterverkehr.assetdetail.10607211.html [05.02.2020]

SFSO 2019h: Bruttoinlandprodukt pro Einwohner 1990–2018. Swiss Federal Statistical Office, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/statistiken/volkswirtschaft.assetdetail.9486260.html [27.02.2020]

SGWA 2016a: G13d Richtlinie für die Einspeisung von erneuerbaren Gasen G13d, Ausgabe März 2016. Swiss Gas and Water Industry Association http://www.svgw.ch/index.php?id=215 [20.02.2020]

SGWA 2019: Erdgaseigenschaften. Calculations and written communication R. Huber (Swiss Gas and Water Industry Association) to A. Schilt (FOEN). 29.05.2019 [confidential/internal]

Sigmaplan 2010a: Deforestation under Kyoto Protocol. Documentation of implementation. Internal documentation by Mathys, L., Sigmaplan, Bern on behalf of the Federal Office for the Environment, Bern. http://www.climatereporting.ch

Sigmaplan 2012a: LULUCF and KP-LULUCF. Comparison of deforstation data. Final Report. Internal document. Sigmaplan, Bern. http://www.climatereporting.ch

Sigmaplan 2020: LULUCF, Submission April 2020. Interne Dokumentation Sigmaplan AG, Bern [Internal document]

SKW 2010: Annual reports of the Swiss Cosmetic and Detergent Association, Zurich. http://www.climatereporting.ch

Soliva, C.R. 2006: Report to the attention of IPCC about the data set and calculation method used to estimate methane formation from enteric fermentation of agricultural livestock population and manure management in Swiss agriculture. On behalf of the Federal Office for the Environment, Bern. ETH Zurich, Institute of Animal Science. http://www.climatereporting.ch

Sommer, S.G., Petersen, S.O., Sorensen, P., Poulsen, H.D., Moller, H.B. 2007: Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. Nutrient Cycling in Agroecosystems 78 (1): 27–36. http://dx.doi.org/10.1007/s10705-006-9072-4 [19.03.2020]

Spiecker, H. 1999: Growth trends in European forests, Do we have sufficient knowledge? In Karjalainen T, Spiecker H, Laroussinie, O. (Eds) 1999: Causes and consequences of accelerating tree growth in Europe. Proceedings of the international seminar held in Nancy, France 14–16. May 1998. European Forest Institute Proceedings No. 27: 157–169. https://www.efi.int/publications-bank/causes-and-consequences-accelerating-tree-growth-europe [19.03.2020]

Spiess, E. 2011: Nitrogen, phosphorus and potassium balances and cycles of Swiss agriculture from 1975 to 2008. Nutrient Cycling in Agroecosystems 91 (3): 351–365. http://dx.doi.org/10.1007/s10705-011-9466-9 [19.03.2020]

Spiess, E., Prasuhn, V. 2006: Weniger Nitrat im Grundwasser dank Ökomassnahmen. AGRARForschung 13(1): 4–9. http://www.agrarforschungschweiz.ch/artikel/2006_01_1145.pdf [19.03.2020]

Staerfl, S. M., Amelchanka, S. L., Kälber, T., Soliva, C. R., Kreuzer, M., Zeitz, J. O. 2012: Effect of feeding dried high-sugar ryegrass (‘AberMagic’) on methane and urinary nitrogen emissions of primiparous cows. Livestock Science 150(1–3): 293–301. http://dx.doi.org/10.1016/j.livsci.2012.09.019 [19.03.2020]

Stangl, R. 2004: Ingenieurbiologische Hangsicherungsmassnahmen in Wildbacheinzugsgebieten – Bestandesentwicklung und langfristige Wirksamkeit. Klagenfurt: Internationale Forschungsgesellschaft Interpraevent, Tagungspublikation Internationales Symposium Interpraevent 2004, Band 1, pp. 295–305. http://www.climatereporting.ch

Statistics Finland 2016: Greenhouse gas emissions in Finland 1990–2014. National Inventory Report under the UNFCCC and the Kyoto Protocol. Statistics Finland, Helsinki. http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/fin-2017-nir-28apr17.zip [19.03.2020]

Stehfest, E., Bouwman, L. 2006: N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74(3): 207–228. http://dx.doi.org/10.1007/s10705-006-9000-7 [19.03.2020]

Stieger, J. 2013: Methane emissions at farm and regional scales: origin, magnitude and spatio-temporal variability. PhD Thesis ETHZ, No. 21538; Zürich, Switzerland. http://www.climatereporting.ch

Stieger, J., Bamberger, I., Buchmann, N., Eugster, W. 2015: Validation of farm-scale methane emissions using nocturnal boundary layer budgets. Atmos. Chem. Phys. 15 (24): 14055–14069. http://dx.doi.org/10.5194/acp-15-14055-2015 [19.03.2020]

Stricker, B. 2012: Energiebedarfswerte der Pferde, Esel und Ponys. Written communication from Brigitte Stricker (ALP-Haras, Agroscope Liebefeld-Posieux research station) to Daniel Bretscher (ART, Reckenholz), August-October 2012. http://www.climatereporting.ch

SWI 2009: Forests continue conquest of countryside. Swissinfo.ch, published online 28.07.2009. http://www.swissinfo.ch/eng/forests-continue-conquest-of-countryside/990884 [19.03.2020]

Swiss Confederation 1983: Loi fédérale du 7 octobre 1983 sur la protection de l'environnement (Loi sur la protection de l'environnement, LPE). Status as of 01 January 2018. http://www.admin.ch/ch/f/rs/c814_01.html [official text in German, French and Italian]; Federal Act on the Protection of the Environment [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19830267/index.html [19.03.2020]

Swiss Confederation 1985: Ordonnance du 16 décembre 1985 sur la protection de l'air (OPair). Status as of 1 April 2017 http://www.admin.ch/ch/f/rs/c814_318_142_1.html [official text in German, French and Italian]; Ordinance on Air Pollution Control [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19850321/index.html [19.03.2020]

Swiss Confederation 1990: Technische Verordnung über Abfälle (TVA). In Kraft 1990–2016. https://www.admin.ch/opc/de/classified-compilation/19900325/index.html [19.03.2020]

Swiss Confederation 1991: Loi fédérale du 4 octobre 1991 sur les forêts (Loi sur les forêts, LFo). Status as of 01 January 2017. http://www.admin.ch/ch/f/rs/c921_0.html [official text in German, French and Italian]; Federal Act on Forest [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19910255/index.html [19.03.2020]

Swiss Confederation 1991a: Ordonnance du 21 janvier 1991 sur la protection des hauts-marais et des marais de transition d'importance nationale (Ordonnance sur les hauts-marais). Status as of 01.11.2017. http://www.admin.ch/ch/f/rs/c451_32.html [official text in German, French and Italian] [19.03.2020]

Swiss Confederation 1992: Ordonnance du 30 novembre 1992 sur les forêts (OFo). Status as of 01.01.2018. http://www.admin.ch/ch/f/rs/c921_01.html [official text in German, French and Italian]; Ordinance on Forest [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19920310/index.html [19.03.2020]

Swiss Confederation 1992a: Bundesstatistikgesetz vom 9. Oktober 1992. As of 1. January 2016. http://www.admin.ch/ch/d/sr/c431_01.html [official text in German, French and Italian]; Federal Statistics Act [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19920252/index.html [19.03.2020]

Swiss Confederation 1993: Verordnung über die Durchführung von statistischen Erhebungen des Bundes vom 30. Juni 1993. Status as of 1. December 2018. http://www.admin.ch/ch/d/sr/c431_012_1.html [official text in German, French and Italian] [19.03.2020]

Swiss Confederation 1994: Ordonnance du 7 septembre 1994 sur la protection des bas-marais d'importance nationale (Ordonnance sur les bas-marais). Status as of 01.01.2017. http://www.admin.ch/ch/f/rs/c451_33.html [official text in German, French and Italian] [19.03.2020]

Swiss Confederation 1997: Ordonnance du 12 novembre 1997 sur la taxe d'incitation sur les composés organiques volatils (OCOV). As at 01 January 2018. http://www.admin.ch/ch/f/rs/c814_018.html [official text in German, French and Italian]; Ordinance on the Incentive Tax on Volatile Organic Compounds [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19970460/index.html [19.03.2020]

Swiss Confederation 1998: Ordonnance du 1er juillet 1998 sur les atteintes portées aux sols (OSol) (Ordinance against deterioration of soils). Status as of 12. April 2016. http://www.admin.ch/ch/f/rs/c814_12.html [official text in German, French and Italian] [19.03.2020]

Swiss Confederation 1998a: Gewässerschutzverordnung vom 28 October 1998. Status as of 7. February 2017. http://www.admin.ch/ch/d/sr/c814_201.html [official text in German, French and Italian]; Ordinance on the Incentive Tax on Volatile Organic Compounds [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/19983281/index.html [19.03.2020]

Swiss Confederation 2003: Tierschutzgesetz (TSchG) vom 9. März 1978 (Status as of 02.12.2003) https://www.admin.ch/opc/de/classified-compilation/20022103/index.html [20.02.2020]

Swiss Confederation 2005: Ordinance of 18 May 2005 on Risk Reduction related to the Use of certain particularly dangerous Substances, Preparations and Articles (Ordinance on Chemical Risk Reduction, ORRChem). SR Number 814.81. Status as of 26.02.2018 http://www.admin.ch/ch/d/sr/814_81/index.html [official text in German, French and Italian]; Ordinance on the Reduction of Risks relating to the Use of Certain Particularly Dangerous Substances, Preparations and Articles [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/20021520/index.html [19.03.2020]

Swiss Confederation 2008: Verordnung des EVD über Ethoprogramme (Ethoprogrammverordnung), 25. Juni 2008 (Stand am 1. Oktober 2008). Der Schweiz. Bundesrat, Bern, Schweiz. http://www.admin.ch/opc/de/official-compilation/2008/3785.pdf [19.03.2020]

Swiss Confederation 2011: Bundesgesetz über die Reduktion der CO_2-Emissionen (CO_2-Gesetz). Status as of 19.02.2019. http://www.admin.ch/ch/d/sr/c641_71.html [official text in German, French and Italian]; Federal Act on the Reduction of CO_2 Emissions [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/20091310/index.html [10.02.2020]

Swiss Confederation 2012: Verordnung über die Reduktion der CO_2-Emissionen (CO_2-Verordnung). Status as of 19.02.2019. http://www.admin.ch/ch/d/sr/c641_711.html official text in German, French and Italian]; Ordinance on the Reduction of CO_2 Emissions [English translation for information purposes only]: https://www.admin.ch/opc/en/classified-compilation/20120090/index.html [19.03.2020]

Swiss Confederation 2015: Verordnung über die Vermeidung und die Entsorgung von Abfällen (Abfallverordnung, VVEA). Status as of 01.01.2019. https://www.admin.ch/opc/de/classified-compilation/20141858/ official text in German, French and Italian]. [19.03.2020]

Swiss Federal Council, 2008: Subventionsbericht des Bundesrates vom 30.05.2008. Swiss Federal Council, Bern. https://bit.ly/2XZHSdp [10.02.2020]

Swiss Safety Center 2019: Quality management system according to ISO 9001:2015. Certificate. Scope: National Inventory System and Reporting under the UNFCCC and the Kyoto Protocol. Registration Number: 13-299-113. Initial certification: 25.11.2013. Recertification: 24.09.2019. Valid until: 24.11.2022. http://www.climatereporting.ch

Theloke, J. 2005: NMVOC-Emissionen aus der Lösemittelanwendung und Möglichkeiten zu ihrer Minderung. Fortschritt-Berichte VDI Reihe 15 Nr. 252. Düsseldorf: VDI-Verlag. http://elib.uni-stuttgart.de/opus/volltexte/2005/2339 [18.02.2020]

Theloke, J. et al. 2000: Ermittlung der Lösemittelemissionen 1994 in Deutschland und Methoden zur Fortschreibung. Institut für Energiewirtschaft und Rationelle Energieanwendung (IER) der Universität Stuttgart.Forschungsbericht 295 42 628. Im Auftrag des Umweltbundesamtes. https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/2484.pdf [18.02.2020]

Thuille, A., Schulze, E.D. 2006: Carbon dynamics in successional and afforested spruce stands in Thuringia and the Alps. Global Change Biology 12: 325–342. http://dx.doi.org/10.1111/j.1365-2486.2005.01078.x [19.03.2020]

Thürig, E., Herold, A. 2013: Recalculation of emission factors in Swiss forests for the Swiss GHGI. Internal documentation of technical adjustments of data delivery and more recent data. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. http://www.climatereporting.ch

Thürig, E., Traub, B. 2015: Non-forest areas converted to forest: standing stock, gains and losses in biomass. Report commissioned by the Swiss Federal Office for the Environment, Bern. http://www.climatereporting.ch

Thürig, E., Kaufmann, E., Schmid, S., Bugmann, H. 2005a: Treibhausgas Inventar: Waldkennzahlen und jährlicher Klimaeinfluss. Internal report to FOEN. Inclusive: Excel-Datei Klimafaktoren.berechnen.xls zur Berechnung des jährlichen klimakorrigierten Zuwachses. http://www.climatereporting.ch

Thürig, E., Rösler, E., Didion, M. 2017: NFI4/2011–2015: Calculation of emission factors for living biomass in Swiss forests for the Swiss GHGI 2017. Internal documentation of data delivery and more recent data. Report commissioned by the Swiss Federal Office for the Environment, Bern. http://www.climatereporting.ch

Thürig, E., Didion, M., Rösler, E. 2019a: NFI4/2013–2017 - Calculation of emission factors for living biomass in Swiss forests prepared for the Swiss GHGI 2019 (1990–2017)7. Documentation of data delivery and more recent data. Report commissioned by the Swiss Federal Office for the Environment, Bern. http://www.climatereporting.ch

Thürig, E., Stadelmann, G., Didion, M., 2019b: Estimating carbon stock changes in living and dead biomass and soil for the technical correction of Switzerland's Forest Management Reference Level – modeling methodology and results. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Commissioned by the Federal Office for the Environment FOEN, Bern. http://www.climatereporting.ch

Tuomi, M., Thum, T., Järvinen, H., Fronzek, S., Berg, B., Harmon, M., Trofymow, J.A., Sevanto, S., Liski, J. 2009: Leaf litter decomposition – Estimates of global variability based on Yasso07 model. Ecological Modelling 220: 3362–3371. http://dx.doi.org/10.1016/j.ecolmodel.2009.05.016 [19.03.2020]

Tuomi, M., Laiho, R., Repo, A., Liski, J. 2011: Wood decomposition model for boreal forests. Ecological Modelling 222: 709–718. http://dx.doi.org/10.1016/j.ecolmodel.2010.10.025 [19.03.2020]

UBA 2005: Emissionen, Aktivitätsraten und Emissionsfaktoren von fluorierten Treibhausgasen (F-Gasen) in Deutschland für die Jahre 1995–2002. Texte: 14/05. Umwelt Bundes Amt. Berlin. https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/2902.pdf [19.03.2020]

UBA 2006: Einsatz von Sekundärbrennstoffen, Forschungsbericht 204 42 203/02, UBA-FB 000893; http://www.eefa.de/pdf/UBA-Texte_07_06.pdf [10.02.2020]

UBA 2007: Daten von H-FKW, FKW und SF6 für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention für die Berichtsjahre 2004 und 2005“ "Fluorierte Treibhausgase". Gutachten durch die Oeko-Recherche GmbH für das Umweltbundesamt (FKZ 205 41 217/01), Frankfurt. http://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/3439.pdf [19.03.2020]

UBA/Ökorecherche 2012: Entsorgung von Kältemitteln aus stationären Anlagen, Emissionsfaktor der Entsorgung, Emissionsberichterstattung von F-Gasen in der Kälte- und Klimatechnik. UBA Umweltbundesamt Berlin – 24.10.12. Öko-Recherche Büro für Umweltforschung und -beratung GmbH, W. Schwarz, Barbara Gschrey. Umweltbundesamt Berlin, 24. Oktober 2012, Ergebnisse des Forschungsvorhabens 1. Gewerbekälte und 2. Industriekälte. http://www.umweltbundesamt.de/sites/default/files/medien/419/dokumente/4_entsorgung_statanlagen1.pdf [19.03.2020]

UNFCCC 1992: United Nations Framework Convention on Climate Change, United Nations 1992, FCC/INFORMAL/84/Rev.1, http://unfccc.int/files/essential_background/convention/background/application/pdf/convention_text_with_annexes_english_for_posting.pdf [26.03.2019]

UNFCCC 1998: Kyoto Protocol to the United Nations Framework Convention on Climate Change. https://unfccc.int/resource/docs/convkp/kpeng.pdf [19.03.2020]

UNFCCC 2009: Report of the individual review of the greenhouse gas inventories of Switzerland submitted in 2007 and 2008. FCCC/ARR/2008/CHE, 29 April 2009. http://unfccc.int/resource/docs/2009/arr/che.pdf [19.03.2020]

UNFCCC 2011a: Report of the technical assessment of the forest management reference level submission of Switzerland submitted in 2011 (FCCC/TAR/2011/CHE). Published online on 21 September 2011. http://unfccc.int/resource/docs/2011/tar/che01.pdf [19.03.2020]

UNFCCC 2012: Amendment to the Kyoto Protocol pursuant to its Article 3, paragraph 9 (the Doha Amendment). Decision 1/CMP.8, FCCC/KP/CMP/2012/13/Add.1 https://unfccc.int/resource/docs/2012/cmp8/eng/13a01.pdf [19.03.2020]

UNFCCC 2013c: Approved small scale baseline and monitoring methodology AMS-III.D./Version 19.0. Methane recovery in animal manure management systems. https://cdm.unfccc.int/methodologies/SSCmethodologies/approved [19.03.2020]

UNFCCC 2014a: Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention. Decision 24/CP.19 (FCCC/CP/2013/10/Add.3) http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf [19.03.2020]

UNFCCC 2014b: Guidance for reporting information on activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol. Decision 6/CMP.9 (FCCC/KP/CMP/2013/9/Add.1) http://unfccc.int/resource/docs/2013/cmp9/eng/09a01.pdf [19.03.2020]

UNFCCC 2015: Guidelines for the technical review of information reported under the Convention related to greenhouse gas inventories, biennial reports and national communications by Parties included in Annex I to the Convention. Decision 13/CP.20 (FCCC/CP/2014/10/Add.3) http://unfccc.int/resource/docs/2014/cop20/eng/10a03.pdf [19.03.2020]

UNFCCC 2017a: Report on the review of the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol of Switzerland, FCCC/IRR/2016/CHE, 19 April 2017. http://unfccc.int/resource/docs/2017/irr/che.pdf [19.03.2020]

UNFCCC 2018: Report on the individual review of the annual submission of Switzerland submitted in 2017. FCCC/ARR/2017/CHE, 6 February 2018. http://unfccc.int/resource/docs/2018/arr/che.pdf [19.03.2020]

UNFCCC 2020: Draft Report on the individual review of the annual submission of Switzerland submitted in 2019 (FCCC/ARR/2019/CHE, received 30.12.2019) including comments by Switzerland and including responses by the Expert Review Team (Email from J. Witi to M. Bock, 26.02.2020)

USEPA 1995: Compilation of air pollutant emission factors, Chapter 10.7 Charcoal. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors [21.02.2019]

USEPA 1995a: US EPA 1995, “Emission factors for open burning of municipal refuse”. http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s05.pdf [20.02.2020]

USEPA 1995b: AP-42, Fifth Edition, Volume I, Chapter 5: Petroleum Industry. US EPA, January 1995. https://www3.epa.gov/ttn/chief/ap42/ch05/index.html [18.02.2020]

UVEK 2003: Düngen mit Klärschlamm wird verboten, UVEK Eidgenössisches Departement für Umwelt, Verkehr, Energie, Kommunikation. http://www.admin.ch/cp/d/3e816ebe_1@presse1.admin.ch.html [19.03.2020]

van Bruggen, C., Bannink, A., Groenestein, C.M., de Haan, B.J., Huijsmans, J.F.M., Luesink, H.H., van der Sluis, S.M., Velthof, G.L. 2014: Emissions into the atmosphere from agricultural activities in 2012. Calculations for ammonia, nitric oxide, nitrous oxide, methane and fine particulate matter using the NEMA model. Wageningen. WOt technical report 3 (in Dutch). Wageningen, NL: The Statutory Research Task Unit for Nature and the Environment (WOT Natuur & Milieu).

Van der Zaag, A. C., MacDonald, J. D., Evans, L., Vergé, X. P. C., Desjardins, R. L. 2013: Towards an inventory of methane emissions from manure management that is responsive to changes on Canadian farms. Environmental Research Letters 8(3): 035008. http://dx.doi.org/10.1088/1748-9326/8/3/035008 [19.03.2020]

Van Miegroet, H., Olsson, M. 2011: Ecosystem Disturbance and Soil Organic Carbon – A Review. In: Soil Carbon in Sensitive European Ecosystems. John Wiley & Sons, Ltd, Chichester: 85–117. http://dx.doi.org/10.1002/9781119970255.ch5 [19.03.2020]

Vergé, x. P. C., De Kimpe, C., Desjardins, R. L. 2007: Agricultural production, greenhouse gas emissions and mitigation potential. Agricultural and Forest Meteorology 142(2–4): 255–269. http://dx.doi.org/10.1016/j.agrformet.2006.06.011 [19.03.2020]

Vermorel, M., Martin-Rosset, W., Vernet, J. 1997: Energy utilization of twelve forages or mixed diets for maintenance by sport horses. Livestock Production Science 47(2): 157–167. http://dx.doi.org/10.1016/S0301-6226(96)01402-9 [19.03.2020]

Vesterdal, L., Ritter, E., Gundersen, P. 2002: Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management 169: 137–147. http://dx.doi.org/10.1016/S0378-1127(02)00304-3 [19.03.2020]

Vorreiter, L. 1949: Holztechnologisches Handbuch; Band I: Allgemeines, Holzkunde, Holzschutz und Holzvergütung. Verlag Georg Fromme & Co., Wien [hardcopy].

VTI 2011: Review of the LULUCF Sector of Switzerland‘s Greenhouse Gas Inventory 1990–2008. Johann Heinrich von Thünen-Institut, Braunschweig. http://www.climatereporting.ch

Walther U., Menzi, H., Ryser, J.-P., Flisch, R., Jeangros, B., Maillard, A., Siegenthaler, A., Vuilloud, P.A. 1994: Grundlagen für die Düngung im Acker- und Futterbau. Agrarforschung 1(7): 1–40 [hardcopy].

Webb, J. 2001: Estimating the Potential for Ammonia Emissions from Livestock Excreta and Manures. Environ. Pollut. 111(3): 395-406. https://doi.org/10.1016/S0269-7491(00)00090-7 [19.03.2020]

Weiske, A., Benckiser, G., Herbert, T., Ottow, J.C.B. 2001: Influence oft he nitrification inhibitor 3.4-dimethylpyrazole phosphate (DMPP) in comparison to dicyandiamide (DCD) on nitrous oxide emissions, carbon dioxide fluxes and methane oxidation during 3 years of repeated application in field experiments. Biology and Fertility of Soils 34: 109-117. https://link.springer.com/article/10.1007/s003740100386 [19.03.2020]

Werner, F. 2019: Wood densities for HWP. Written communication from Frank Werner (Environment & Development, Heiden) to Beat Rihm (Metetotest), 18.06.2019.

Widmer, A. 2006: Written communication from Albert Widmer (Forschungsanstalt Wädenswil) to Jens Leifeld (ART, Reckenholz), 20.06.2006. http://www.climatereporting.ch

Wirth, C., Schulze, E. D., Schwalbe, G., Tomczyk, I., Weber, G.-E., Weller, E. 2004: Dynamik der Kohlenstoffvorräte in den Wäldern Thüringens: Abschlussbericht zur 1. Phase des BMBF-Projektes "Modelluntersuchung zur Umsetzung des Kyoto-Protokolls". Mitteilungen der Thüringer Landesanstalt für Wald, Jagd und Fischerei 23 [hardcopy].

Wüest & Partner 2015: Bauabfälle in der Schweiz – Hochbau. Studie 2015, Schlussbericht. Wüest & Partner, Zürich, 28. September 2015 https://www.bafu.admin.ch/dam/bafu/de/dokumente/abfall/externe-studien-berichte/bauabfaelle_in_derschweiz-hochbaustudie2015.pdf [20.02.2020]

Wüst-Galley, C., 2019: Revised uncertainty associated with the surface of organic soils. Agroscope, Reckenholz. http://www.climatereporting.ch

Wüst-Galley, C., Grünig, A., Leifeld, J. 2015: Locating organic soils for the Swiss Greenhouse Gas Inventory. Agroscope Science No. 26, Zürich. http://www.climatereporting.ch

Wüst-Galley, C., Mössinger, E., Leifeld, J. 2016: Loss of the soil carbon storage function of drained forested peatlands. Mires and Peat, 18(07), 1–22. http://mires-and-peat.net/pages/volumes/map18/map1807.php [19.03.2020]

Wüst-Galley, C., Keel, S. G., Leifeld, J. 2019: A model-based carbon inventory for national greenhouse gas reporting of mineral agricultural soils. Agroscope. http://www.climatereporting.ch

Wutzler, T., Wirth, C., Schumacher, J., 2008: Generic biomass functions for common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. Canadian Journal of Forest Research 38: 1661–1675. http://dx.doi.org/10.1139/X07-194 [19.03.2020]

Zanelli, R., Egli, M., Mirabella, A., Abdelmoula, M., Plötze, M., Nötzli, M. 2006: `Black' soils in the southern Alps: clay mineral formation and transformation, X-ray amorphous Al phases and Fe forms. Clays and Clay Minerals 54: 703-720. doi:10.1346/ccmn.2006.0540606 https://pubs.geoscienceworld.org/ccm/article-abstract/54/6/703/134697 [20.03.2020]

Zeitz, J. O., Soliva, C. R., Kreuzer, M. 2012: Swiss diet types for cattle: how accurately are they reflected by the Intergovernmental Panel on Climate Change default values? Journal of Integrative Environmental Sciences, 9:sup1,199–216. http://dx.doi.org/10.1080/1943815X.2012.709253 [19.03.2020]

Zell, J., Thürig, E. 2013: Root biomass functions for for the GHG reporting under the UNFCCC and under the KP in Switzerland. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. Internal report to FOEN [confidential/internal].

Zeschmar-Lahl 2004: Schadstoffverbringung in Senken durch Abfallbehandlung. Dr. Barbara Zeschmar-Lahl, BZL Kommunikation und Projektsteuerung GmbH, Oyten. http://www.bzl.info/de/sites/default/files/SIDAF_04_BZL_end.PDF [10.02.2020]

Zimmermann, S., Hiltbrunner, D. 2012: Turnover and stabilization of soil organic matter: effect of land-use change in alpine regions. Schlussbericht [German]. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. http://www.climatereporting.ch

ZRH 2017: Taxi-Emissions at Zurich Airport, Calculation Analysis and Opportunities, Emanuel Fleuti, Silvio Maraini, Airport Zürich https://www.zurich-airport.com/~/media/flughafenzh/dokumente/das_unternehmen/laerm_politik_und_umwelt/taxi_study_zurichairport_20171207.pdf [19.03.2020]

Zumbrunnen, T., Menéndez, P., Bugmann, H., Conedera, M., Gimmi, U., Bürgi, M. 2012: Human impacts on fire occurrence: a case study of hundred years of forest fires in a dry alpine valley in Switzerland. Regional Environmental Change 12: 935–949. http://dx.doi.org/10.1007/s10113-012-0307-4 [19.03.2020]

References to EMIS database comments

Table A – 30 Assignments of NFR Codes to titles of EMIS (Swiss Emission Information System) database comments. These internal documents will be made available to reviewers on request. green cells: NEW comments for the submission at hand.

NFR Code CRF [UNECE]	EMIS Title	NFR Code CRF [UNECE]	EMIS Title
1 A	Energiemodell***	2 D 3 a [2 D 3 g]	Gummi-Verarbeitung**
1 A	Holzfeuerungen	2 D 3 a [2 D 3 g]	Klebband-Produktion
1 A 2	Sektorgliederung Industrie	2 D 3 a [2 D 3 g]	Klebstoff-Produktion
1 A 1 a	Kehrichtverbrennungsanlagen	2 D 3 a [2 D 3 g]	Lösungsmittel-Umschlag und -Lager
1 A 1 a	Sondermüllverbrennungsanlagen	2 D 3 a [2 D 3 g]	Pharmazeutische Produktion**
1 A 1 a & 5 A	Kehrichtdeponien	2 D 3 a [2 D 3 g]	Polyester-Verarbeitung
1 A 1 a & 5 B 2	Vergärung IG (industriell-gewerblich)	2 D 3 a [2 D 3 g]	Polystyrol-Verarbeitung
1 A 1 a & 5 B 2	Vergärung LW (landwirtschaftlich)	2 D 3 a [2 D 3 g]	Polyurethan-Verarbeitung
1 A 1 b	Heizkessel Raffinerien	2 D 3 a [2 D 3 g]	PVC-Verarbeitung
1 A 1 c	Holzkohle Produktion	2 D 3 a [2 D 3 g]	Gerben von Ledermaterialien
1 A 2 a & 2 C 1	Eisengiessereien Kupolöfen	2 D 3 b	Strassenbelagsarbeiten**
1 A 2 a	Stahl-Produktion Wärmeöfen**	2 D 3 c	Dachpappe**
1 A 2 b	Buntmetallgiessereien übriger Betrieb**	2 D 3 d	Urea (AdBlue) Einsatz Strassenverkehr
1 A 2 b & 2 C 3	Aluminium Produktion	2 G 3 a	Lachgasanwendung Spitäler**
1 A 2 c & 2 B 8 b [2 B 10 a]	Ethen-Produktion*	2 G 3 b	Lachgasanwendung Haushalt**
1 A 2 d & 2 A 4 d	Zellulose-Produktion Feuerung*	2 G 4 [2 D 3 a]	Pharma-Produkte im Haushalt
1 A 2 f	Kalkproduktion, Feuerung*	2 G 4 [2 D 3 a]	Reinigungs- und Lösemittel; Haushalte
1 A 2 f	Mischgut Produktion	2 G 4 [2 D 3 a]	Spraydosen Haushalte**
1 A 2 f	Zementwerke Feuerung	2 G 4 [2 D 3 h]	Verpackungsdruckereien**
1 A 2 f & 2 A 3	Glas übrige Produktion*	2 G 4 [2 D 3 h]	Druckereien uebrige**
1 A 2 f & 2 A 3	Glaswolle Produktion Rohprodukt*	2 G 4 [2 D 3 i]	Entfernung von Farben und Lacken**
1 A 2 f & 2 A 3	Hohlglas Produktion*	2 G 4 [2 D 3 i]	Entwachsung von Fahrzeugen
1 A 2 f & 2 A 4 a	Feinkeramik Produktion*	2 G 4 [2 D 3 i]	Kosmetika-Produktion**
1 A 2 f & 2 A 4 a	Ziegeleien**	2 G 4 [2 D 3 i]	Lösungsmittel-Emissionen IG nicht zugeordnet
1 A 2 f & 2 A 4 d	Steinwolle Produktion*	2 G 4 [2 D 3 i]	Öl- und Fettgewinnung
1 A 2 g iv	Faserplatten Produktion**	2 G 4 [2 D 3 i]	Papier- und Karton-Produktion**
1A2gvii, 1A3c, 1A3e, 1A4aii/bii/cii, 1A5b (without military aviation)	Non-Road	2 G 4 [2 D 3 i]	Parfum- und Aromen-Produktion**
1 A 3 a & 1 A 5	Flugverkehr	2 G 4 [2 D 3 i]	Tabakwaren Produktion**
1 A 3 b i-viii	Strassenverkehr	2 G 4 [2 D 3 i]	Textilien-Produktion
1 A 3 c	Schienenverkehr	2 G 4 [2 D 3 i]	Wissenschaftliche Laboratorien
1 A 3 e	Gastransport Kompressorstation	2 G 4 [2 G]	Korrosionsschutz im Freien
1 A 4 b i	Holzkohle-Verbrauch	2 G 4 [2 G]	Betonzusatzmittel-Anwendung
1 A 4 b i	Lagerfeuer	2 G 4 [2 G]	Coiffeursalons
1 A 4 c i	Gewächshäuser**	2 G 4 [2 G]	Fahrzeug-Unterbodenschutz**
1 A 4 c i	Grastrocknung**	2 G 4 [2 G]	Feuerwerke
1 B 2 a iii	Raffinerie, Pipeline, Crude oil import	2 G 4 [2 G]	Flaechenenteisung Flughaefen
1 B 2 a iv	Raffinerie, Leckverluste	2 G 4 [2 G]	Flugzeug-Enteisung
1 B 2 a iv	H2-Produktion*	2 G 4 [2 G]	Frostschutzmittel Automobil
1 B 2 a iv	Raffinerie, Clausanlage**	2 G 4 [2 G]	Gas-Anwendung
1 B 2 a v	Benzinumschlag Tanklager	2 G 4 [2 G]	Gesundheitswesen, übrige**
1 B 2 a v	Benzinumschlag Tankstellen	2 G 4 [2 G]	Glaswolle Imprägnierung*
1 B 2 b ii & 1 B 2 c ii	Gasproduktion und Flaring	2 G 4 [2 G]	Holzschutzmittel-Anwendung
1 B 2 b iv-vi	Netzverluste Erdgas	2 G 4 [2 G]	Klebstoff-Anwendung
1 B 2 c	Raffinerie, Abfackelung	2 G 4 [2 G]	Kosmetik-Institute
2 A 1	Zementwerke Rohmaterial	2 G 4 [2 G]	Kühlschmiermittel-Verwendung
2 A 1	Zementwerke übriger Betrieb	2 G 4 [2 G]	Medizinische Praxen**
2 A 2	Kalkproduktion, Rohmaterial*	2 G 4 [2 G]	Pflanzenschutzmittel-Verwendung
2 A 2	Kalkproduktion, übriger Betrieb*	2 G 4 [2 G]	Reinigung Gebäude IGD**
2 A 4 d	Kehrichtverbrennungsanlagen Karbonat**	2 G 4 [2 G]	Schmierstoff-Verwendung
2 A 4 d	Karbonatanwendung weitere	2 G 4 [2 G]	Spraydosen IndustrieGewerbe
2 A 5 a	Gips-Produktion übriger Betrieb**	2 G 4 [2 G]	Tabakwaren Konsum
2 A 5 a	Kieswerke	2 G 4 [2 G]	Steinwolle-Imprägnierung*
2 B 1	Ammoniak-Produktion*	2 H 1	Faserplatten Produktion**
2 B 10 [2 B 10 a]	Ammoniumnitrat-Produktion*	2 H 1	Zellulose Produktion übriger Betrieb*
2 B 10 [2 B 10 a]	Chlorgas-Produktion*	2 H 1	Spanplatten Produktion*
2 B 10 [2 B 10 a]	Essigsäure-Produktion*	2 H 2	Bierbrauereien
2 B 10 [2 B 10 a]	*Formaldehyd-Produktion*	2 H 2	Branntwein Produktion
2 B 10 [2 B 10 a]	PVC-Produktion	2 H 2	Brot Produktion
2 B 10 [2 B 10 a]	*Salzsäure-Produktion**	2 H 2	Fleischräuchereien
2 B 10 [2 B 10 a]	Schwefelsäure-Produktion*	2 H 2	Kaffeeröstereien
2 B 10	Kalksteingrube*	2 H 2	Müllereien
2 B 10	Niacin-Produktion*	2 H 2	Wein Produktion
2 B 2	Salpetersäure Produktion*	2 H 2	Zucker Produktion
2 B 5	Graphit und Siliziumkarbid Produktion*	2 H 3	Sprengen und Schiessen
2 C - 2 G	Synthetische Gase	2 I	Holzbearbeitung
2 C 1	Eisengiessereien Elektroschmelzöfen	2K, 1A1a, 2C1, 5A, 5C1, 5E & 6Ad	Emissions due to former PCB usage
2 C 1	Eisengiessereien übriger Betrieb	2 L	NH3 aus Kühlanlagen
2 C 1 & 1 A 2 a	Stahl-Produktion Elektroschmelzöfen**	3	Landwirtschaft
2 C 1	Stahl-Produktion übriger Betrieb**	3 B	Tierhaltung
2 C 1	Stahl-Produktion Walzwerke**	3 C	Reisanbau
2 C 7 a	Buntmetallgiessereien Elektroöfen**	3 D e	Landwirtschaftsflächen
2 C 7 c	Verzinkereien	4 V A 1 [11 B]	Waldbrände
2 C 7 c	Batterie-Recycling*	5 B 1	Kompostierung
2 D 1	Schmiermittel-Anwendung	5 B 2	Biogasaufbereitung (Methanverlust)
2 D 1	Schmiermittel-Verbrauch B2T	5 C 1 [5 C 1 a]	Abfallverbrennung illegal
2 D 2	Paraffinwachs-Anwendung	5 C 1 [5 C 1 b i]	Kabelabbrand
2 D 3 a [2 D 3 d]	Farben-Anwendung Bau	5 C 1 [5 C 1 b iii]	Spitalabfallverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung andere	5 C 1 [5 C 1 b iv]	Klärschlammverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung Haushalte**	5 C 1 [5 C 1 b v]	Krematorien
2 D 3 a [2 D 3 d]	Farben-Anwendung Holz	5 C 2 / 4 V A 1 (Forstwirtschaft)	Abfallverbrennung Land- und Forstwirtschaft und Private
2 D 3 a [2 D 3 d]	Farben-Anwendung Autoreparatur**	5 D 1 [5 D]	Kläranlagen kommunal (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Elektronik-Reinigung**	5 D 2 [5 D]	Kläranlagen industriell (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Metallreinigung**	5 D 1 / 5 D 2 [5 D]	Kläranlagen GHG
2 D 3 a [2 D 3 e]	Reinigung Industrie übrige**	5 E	Shredder Anlagen
2 D 3 a [2 D 3 f]	Chemische Reinigung**	6 A d	Brand- und Feuerschäden Immobilien
2 D 3 a [2 D 3 g]	Druckfarben Produktion**	6 A d	Brand- und Feuerschäden Motorfahrzeuge
2 D 3 a [2 D 3 g]	Farben-Produktion**	[11 C]	NMVOC Emissionen Wald
2 D 3 a [2 D 3 g]	Feinchemikalien-Produktion**	1, 2, 5, 6 - indirect	Indirekte Emissionen

* confidential process
** confidential EMIS comment
*** work in progress
Cursive: process not relevant for the years after 1990.
New comment for the current submission.