Emissions and natural fluxes Dataset

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D2.3 Emissions and natural fluxes Dataset

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1 Executive Summary

This document reports on progress and current status within WP2 regarding the “Emissions and natural fluxes Dataset” developed and needed in CHE WP2. The scope of WP2 “Coordinating efforts on library of simulations for emissions and atmospheric transport” is to generate a library of realistic CO_2 simulations for present-day and future emission scenarios, from the global to the regional and point-source scale. Combining these simulations outputs with satellite orbit simulations will result in a collection of synthetic satellite observations.

To be able to do the necessary (test) simulations, model teams in CHE WP2, WP3 and WP4 need emission datasets as input. This deliverable report briefly introduces the emissions data for the CHE project at 3 different scales (global, regional and local) for anthropogenic emissions of CO_2 and co-emitted species as well as biogenic fluxes of CO_2 at local to regional scale. More specifically, the partner MPG has provided the first biogenic fluxes simulation outputs performed with the VPRM model (chapter 3). The partner JRC has produced the global gridded anthropogenic CO_2 emissions (EDGAR) needed as input to WPs 2 and 3 for the nature run for year 2015 and for a climate change scenario up to year 2030 (chapter 4). The partner TNO has produced a regional (European) gridded anthropogenic emission inventory for 2015 including CO_2 and co-emitted species (chapter 5). The partner EMPA has processed a detailed emission inventory for the city of Berlin (chapter 6) into a longitude-latitude grid used for the CHE project which will be nested into a ~1 km x1 km version of a selected domain of the TNO regional inventory.

The tasks within WP2 have progressed significantly but small delays to the plan are due to some further harmonization processes of the model setups needed for the final runs. Additionally, a coarser resolution product for the biogenic fluxes is provided due to data size issues.

2 Introduction

2.1 Background

Emission quantification of anthropogenic CO_2 fluxes faces substantial challenges due to the limited precision of available satellite measurements, systematic biases introduced by incompletely accounting for the effects of aerosols and other factors on the retrieval, the limited spatial and temporal coverage and resolution of the observations, and the difficulty in separating the signals of natural CO_2 fluxes and those of anthropogenic emissions.

The overall scope of WP2 is to generate a library of realistic CO_2 simulations for present-day and future emission scenarios, the so-called "nature runs", from the global to the regional and point-source scale. These will eventually help to define the requirements and the challenges for a future CO2 space mission aiming at estimating anthropogenic CO2 emissions. A combination of the nature runs' outputs and the satellite orbit simulations, will result in a collection of synthetic satellite observations with realistic error characteristics. Within this WP, two key challenges for the detection of urban and power plant plumes will be investigated: the influence of aerosols on the CO_2 retrieval in urban plumes, and the small-scale and fluctuating nature of power plant plumes. This work package will also provide synthetic observations that will be used in WPs 1-4.

A set of high-resolution CO_2 nature runs will be conducted at the global scale with ~9 km resolution, nested European simulations at ~5 km, and nested regional simulations at ~1 km. Additional tracers, such as CO as well as tagged fossil CO_2 tracers, will be included to support the attribution to different anthropogenic and biospheric sources and sinks. The regional simulations will focus on a domain covering the city of Berlin and nearby power plants as well as, later in the project, on a second domain centred over the city of Beijing to generate simulations for a region with different challenges in terms of emission density, interferences from aerosols, and availability and quality of input data and ground-based observations.
Since CHE will address CO_2 emissions across scales, both temporally, from one hour to one year, and spatially, from kilometre and sub-kilometre resolutions at city level to 10 km or coarser at a global scale, different emission inventories will be needed at different scales. The present-day CO_2 emissions (year 2015) delivered by the EDGAR team and TNO will be accompanied by future (2030) scenarios, the latter with reduced emissions according to a scenario including a climate change policy package on emission reductions.

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverable

In this deliverable anthropogenic emissions and natural fluxes datasets for global, European and regional nature runs will be introduced and briefly described.

2.2.2 Work performed in this deliverable

MPG has provided the first biogenic fluxes simulation outputs performed with the VPRM model (chapter 3). The partner JRC has produced the global gridded anthropogenic CO_2 emissions (EDGAR) needed as input to WPs 2 and 3 for the nature run for year 2015 and for a climate change scenario up to year 2030 (chapter 4). EMPA has processed a detailed emission inventory for the city of Berlin (chapter 5) into a regular grid used for the CHE project which will be nested into a ~1 km x1 km version of a selected domain of the TNO regional inventory. The partner TNO has produced a regional (European) gridded anthropogenic emission inventory for 2015 including CO_2 and co-emitted species (chapter 6).

2.2.3 Deviations and counter measures

There was a delay of 1-2 months in the production of the emission inventories for the Berlin domain (merging of Berlin inventory with the ~1 km resolution inventory of TNO for a larger domain) as well in the production of the 2030 European inventory by TNO. A 2030 emission dataset was already produced by TNO early in 2018 but this scenario had a similar source sector breakdown as the CAMS-REGv1 emission dataset previously prepared by TNO for the CAMS project. The new regional dataset that TNO proposes for use in CHE WP2 as described in chapter 5 uses GNFR (Gridding Nomenclature for Reporting) source sector categories which has a different structure. To have the 2030 emission dataset fully compatible to the emission source categories a re-gridding was necessary, thus, the product was delayed. The delay for the high resolution was due to complications with developing a reliable ~1 km x 1 km emission grid over a relatively large domain. The amount of data to process increases substantially with spatial resolution and all proxy maps needed to be updated as inaccuracies that are acceptable at the coarser 6 x 6 km scale may cause substantial errors at ~1 km x 1 km scale. In short, this task has been more challenging than expected but all data are available before February 1, 2019 and ftp links have been provided to the CHE partners who need these data.

3 Biogenic fluxes (MPI)

The biogenic fluxes for use in the forward simulations of WP2 are derived from the VPRM model (Vegetation Photosynthesis and Respiration Model), a simple light-use-efficiency model driven by a combination of satellite reflectances from MODIS and meteorological input data. Fluxes are calculated for eight different land cover types (evergreen forest, deciduous forest, mixed forest, shrubland, trees and grasses, cropland, grassland, and other), with parameters for each land cover type determined through optimization with flux tower data from a previous year. The fractional land cover type per pixel is determined using the SYNMAP land cover product (Jung et al., 2006). The model is more fully described in Mahadevan et al. (2008).

Ratios of MODIS reflectances from different spectral bands are used to compute the indices EVI (enhanced vegetation index) and LSWI (land surface water index) at 8-day resolution. Due to noise in the signal and occasional missing pixels, these indices are loess filtered. The loess filter is a locally-weighted polynomial regression, which is used to smooth the sometimes noisy 8-day indices calculated from the MODIS reflectances. The polynomial is fitted using weighted least squares, giving more weight to points temporally close to the point whose response is being estimated and less weight to points that are further away. The meteorological drivers are 2-m temperature and downward shortwave radiation at the surface, both of which were taken from the Tier 1 simulation at 0.1° and 3-hourly resolution for this project. Because the VPRM fluxes are calculated hourly while the meteorological input is only availably 3-hourly, linear interpolation was employed.
The domain on which the VPRM fluxes are simulated is defined by the domain on which the mesoscale models will be operating. As defined in D2.1, the minimum requirements were to span the domain ranging from 11°W to 36°E, and from 36°N to 64°N. The Lambertian conic conformal projection used in the WRF-GHG simulations of MPG is the largest of these regional grids, defined with a standard longitude of 12.5°E and true latitude of 51.604°N, and 962 longitudinal gridboxes and 776 latitudinal gridboxes at 5-km resolution. As such, this was used as the maximum domain over which the VPRM fluxes were calculated.

Because the domain spans over 3800 km in the north-south direction and 4800 km in the west-east direction, it was too large to easily process in one piece with the existing software tools. As such, the domain was split into six equal-sized sub-domains for the purposes of calculating the required indices and the resultant fluxes. These sub-domains are illustrated in Figure 1, along with the minimum domain established in WP2. These domains were numbered EU1-EU6, as shown in Figure 1. The ordering of the numbering is somewhat odd, and was decided by the WRF geogrid pre-processor. All six sub-domains have the same projection information as given above, but are offset within the larger domain.

The VPRM indices and fluxes were calculated on these six sub-domains at 1-km, hourly resolution. The fluxes GPP (Gross Primary Production), RESP (ecosystem respiration) and their sum NEE (net ecosystem exchange) were saved with one file per day. At present only the first 9 days of January 2015 have been uploaded to the CHE ftp site, as this data are already using approximately 19% of the capacity of the ftp site (500 GB). These first nine days at least provide the required input for the initial test simulations for the first week of 2015.

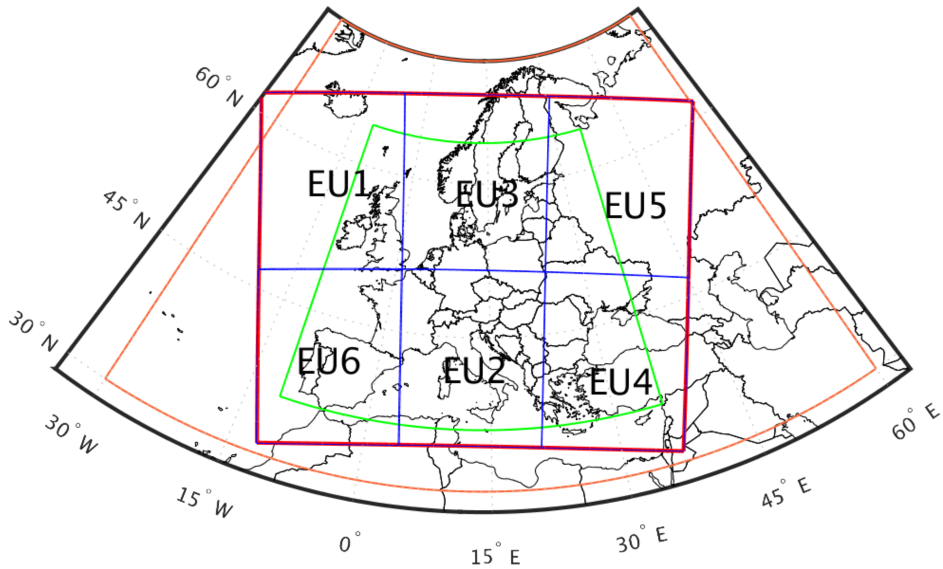

Figure 1. The minimum domain as defined in Deliverable 2.1 is shown in green, while the full WRF-GHG simulation domain is shown in red. The minimum domain is broken into six sub-domains (in blue) for VPRM pre-processing, with the unusual (model-defined) enumeration as shown in the figure above (EU1-EU6). The domain of the 0.05° latitude by 0.10° longitude grid used by TNO for the anthropogenic emissions is shown in orange.

The data file for one sub-domain for one day is approximately 1.8 GB, so one day of data is already ~10 GB. The size could be reduced by about a third by not including the redundant NEE product, which is merely the sum of GPP and RESP, but this reduction does not solve the fundamental problem of the data size. A technical solution is needed to share the full year of input.

A solution has been proposed in that the fluxes are interpolated onto the same grid as is used for the anthropogenic fluxes from TNO, namely at 0.05° latitude by 0.10° longitude. While this solution would certainly decrease the size of the data product substantially, it no longer meets the deliverable requirements described in the description of work. A further problem is that the TNO domain is larger than the VPRM domain used (as shown in orange in Figure 1), and as such will be largely filled with missing values. Nonetheless this reduced-resolution product is being provided as an additional product, which also provides potential data users with an easier to use product, in that it is on a regular latitude-longitude grid in a consistent format to the data provided by TNO. This coarser data product will eventually be shared with the public, perhaps via the ICOS Carbon Portal, once the WP2 partners have had a chance to fully test the data, likely in mid-2019.

4 EDGAR Global sector-specific CO_2 emission grid-maps for 2015 and 2030 (JRC)

Global gridded anthropogenic CO_2 emissions at 0.1 x 0.1 degree resolution are input to WPs 2 and 3 for the nature run with year 2015 (EDGARv4.3.2_FT2015) and for a climate change scenario in the year 2030 (EDGARv4.3.2_projection_2030) (A business as usual (BAU) scenario for 2030 is available upon request). These anthropogenic CO_2 emissions include all fossil CO_2 sources (fossil fuel combustion, but also from non-metallic mineral processes such as cement production, from metal (ferrous and non-ferrous) production processes, from urea production and from agricultural liming and solvents use) but exclude the large-scale biomass burning with Savannah burning, forest fires, and the sources and sinks from land-use, land-use change and forestry (LULUCF). Conform with the UNFCCC, emissions of biofuel combustion are only a memo item and reported within the latter LULUCF sector. As such they are also excluded here and no short-cycle carbon is taken up in the bottom-up inventories underneath.

4.1 EDGARv4.3.2_CO2_FT2015_grids

The EDGARv4.3.2 emission dataset of Janssens-Maenhout et al. (2017) with annual and monthly gridded emissions 1970-2012) is used in combination with the EDGARv4.3.2_FT2015 time series update 2012-2015 of Olivier et al. (2016) for the nature runs of WP 2. The detailed EDGARv4.3.2 with the full-fledged anthropogenic emission sectors (excluding large scale biomass burning and land-use, land-use change and forestry sources and sinks) provides the basis grid-map with detailed spatial information per sector for 2012 and is used with the very same spatial distribution in the update to 2015. For the update to 2015 the fast track approach of Olivier et al. (2016) with EDGARv4.3.2_FT2015 is followed with relative update from the basis in 2012 using the BP (2017) statistics for those years not covered by IEA (2016) energy statistics. The relative changes per sector, fuel type and country from 2012 to 2015 in EDGARv4.3.2_FT2015 is then applied on the EDGARv4.3.2 basis maps.

4.2 EDGARv4.3.2_CO2_2030projection_grids

The 2030 annual emissions have been calculated using the climate change scenarios developed under the FP6 project Climate Impact Research within the FP6 research project CIRCE to evaluate a change projected over a decade using the EC view point of a POLES energy scenario and assuming full implementation of the current climate change policies. These scenarios are described by Doering et al. (2010) and Russ et al. (2007) and are comparable to the IPCC AR4 Category II pathway. Again, the ratios of 2030 to 2012 in the time-series of the Climate Change scenario of CIRCE were applied per sector, fuel and country to the basis grid-maps of 2012 from EDGARv4.3.2. The spatial distribution of 2012 per sector and fuel type has been kept constant between 2012 and 2030 as no information on the future evolution of the spatial proxy was available.

4.3 Access to the data

All gridmaps can be downloaded from the EDGAR website (ftp Link upon request – contact Marilena.MUNTEAN@ec.europa.eu) in .txt with bottom left grid coordinates of the 0.1deg x0.1deg grid cells, expressing the emissions in ton CO_2 /yr/(0.1degx0.1deg) for each of the sectors:

- AGS (agricultural soils)
- CHE (chemical processes) ENE (energy generation)
- FFF (fossil fuel fires)
- IND (industrial manufacturing)
- IRO (iron & steel processes)
- NEU (non-energy use)
- NFE (non-ferrous metals production)
- NMM (non-metallic mineral processes)
- PRO (fossil fuel production)
- PRU-SOL (products use and solvents)
- RCO (energy for buildings)
- REF-TRF (refineries and transformation)
- SWD-INC (waste incineration)
- TNR_Aviation_LTO/CDS/CRS/LTO (aviation at 3 height levels: landing-takeoff / climbing-descent / cruise)
- TNR-Other (non-road transport over land)
- TNR_ship (shipping)
- TRO (road transport).

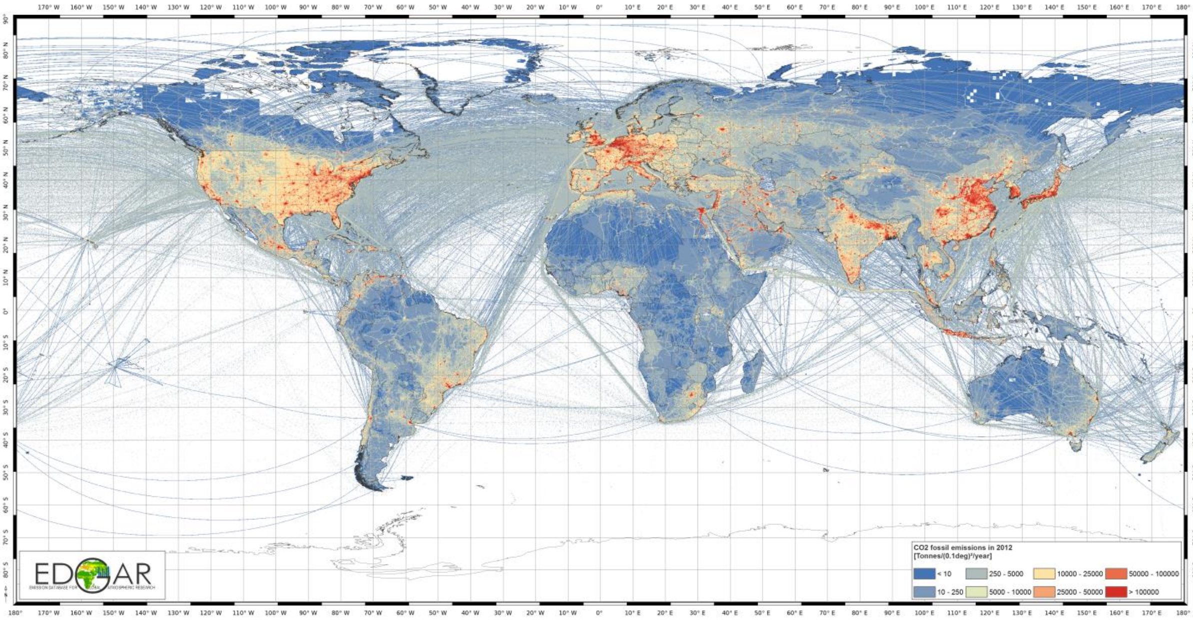

Figure 2 Global CO_2 fossil emissions in 2015 (Ton/gridcell/yr) at 0.1° x 0.1° resolution (*EDGARv4.3.2)*

5 TNO GHGco emission inventory v1.1

This chapter describes the first version of the TNO greenhouse gas and co-emitted species emission database (GHGco) at the resolution of 0.1º x 0.05º (~ 6 km x 6 km) for the year 2015. The dataset covers the entire European domain for the GHGs: CO_2 (distinguishing between fossil fuel CO_2 and biofuel CO_2), methane (CH_4) and key co-emitted species that may be used as tracers: CO (also distinguishing between fossil and biofuel) and nitrogen oxides (NO_x). This chapter describes briefly the methodology followed and presents the resulting emission inventory for the European domain.

A first version v1.0 was released in October 2018. This version will be the starting point for the modelling studies, where a specific zoom area is being defined where the work will be performed at much higher resolution (~ 1 km x 1 km). During preparation of the 1 km x 1km emissions, some errors and inconsistencies in the initial delivery were found. This has resulted in a version v1.1 where these issues are resolved, which has been released mid-December 2018.

5.1 Methodology for European anthropogenic emissions 2005-2015

The methodology that was used for developing the TNO GHG and co-emitted species regional emissions is shown in Figure 3. The development of this inventory is a shared activity with H2020 VERIFY. The methodology is a further development and refinement of the method used for the earlier TNO_MACC, MACC-II and MACC-III emission inventories (Kuenen et al., 2014). The method starts from the reported emissions by European countries to UNFCCC (United Nations Framework Convention on Climate Change, greenhouse gases) and to EMEP/CEIP (European Monitoring and Evaluation Programme/ Centre on Emission Inventories and Projections for air pollutants). The emissions have been aggregated to ~250 different combinations of sectors and fuels. Because of the different level of detail in reporting between air pollutants and greenhouse gases, in specific cases aggregation and/or disaggregation was needed to harmonize the sectors between all pollutants and countries.

The reported data have been checked for gaps, errors and inconsistencies and form the basis for the TNO_GHGco emission inventory for 2015 to be used in the H2020 CHE project. Where needed, reported data were replaced or completed using other emission data from the GAINS model. Expert judgement was used to judge the quality of each of these sources and to make choices on which source to use. Sea shipping is then added based on AIS based tracks, and inland shipping is replaced with an own TNO estimate since the reporting of shipping emissions across countries is not consistent enough. The resulting emissions are then checked in detail with regard to their absolute value and trends.

Thereafter, a consistent spatial distribution methodology is applied for Europe where each emission source gets a specific proxy assigned which defines the way emissions are to be spatially distributed over the country. For point sources information was collected on the location of power plants, large industrial installations, oil and gas production sites, airports and waste treatment locations (e.g. landfills). For area sources, proxies are collected that are thought to best represent the spatial variability of each specific emission source (Table 5). Automated scripts have been developed to calculate the spatially distributed emissions, which are subsequently aggregated to the GNFR level for the gridded output files in order to limit the total amount of data.

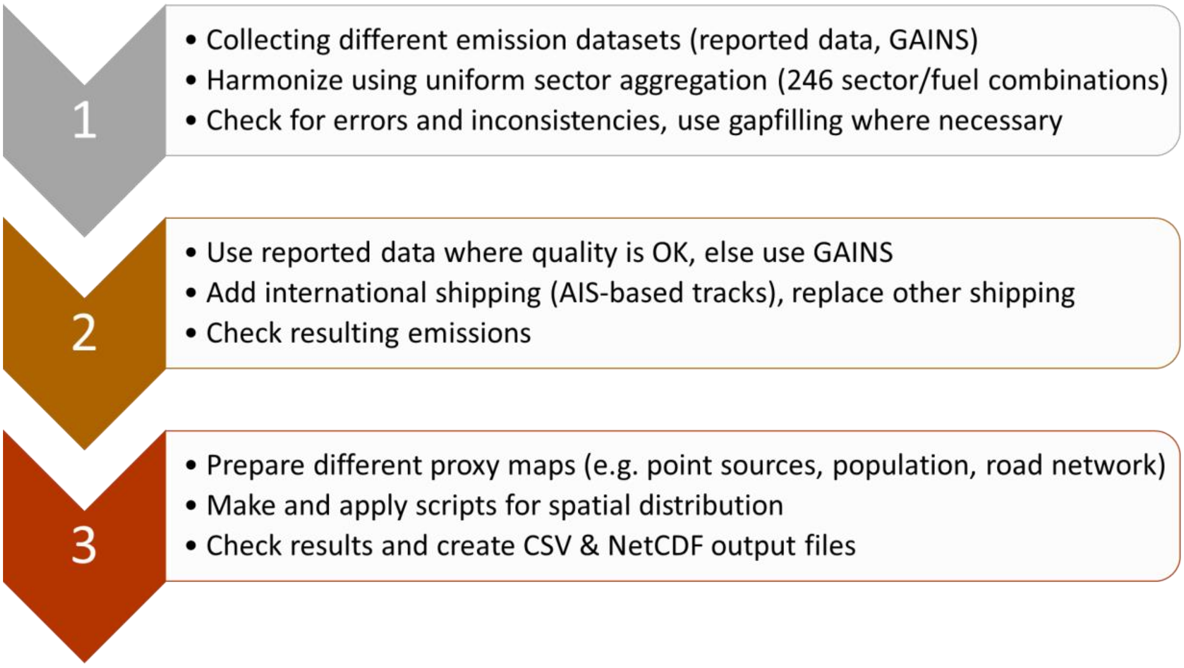

Figure 3. Methodology for developing the anthropogenic global emissions

Table 1. Proxy variables that represent spatial variability of the emission sources.

GNFR	Source	Key proxies used
A	Public power	Power plant point sources (from E-PRTR and CARMA databases), CORINE land cover industrial area
B	Industry	Industrial point sources (from E-PRTR database), CORINE land cover industrial area
C	Other stationary combustion	Population (total/rural/urban), wood use (for biomass combustion)
D	Fugitives	Point sources (coal mines, refineries), population density (for diffuse sources)
E	Solvents	Population density, CORINE land cover industrial area (for industrial solvent use)
F	Road transport	Open street map & Open transport map derived road networks
G	Shipping	AIS based shipping tracks
H	Aviation	Airport locations
I	Off road	Population density, rail network, CORINE land cover industrial area (for industrial applications)
J	Waste	Waste water treatment and large incinerators point sources, population (total/rural)
K	Agriculture livestock	Gridded livestock
L	Agriculture other	Arable land

Table 2. Characteristics of the TNO_GHGco_v1 regional European emissions

TNO_GHGco_v1.1 characteristics	
Species	CO_2_ff (fossil fuel), CO_2_bf (biofuel), CH_4, CO_ff (fossil fuel), CO_bf (biofuel), NO_x (as NO_2), NMVOC
Resolution	1/10° x 1/20° (longitude latitude, ~ 6x6 km over central Europe)
Period covered	2015 (annual emissions)
Domain	30° W – 60° E 30° N – 72°N
Sector aggregation	GNFR (A to L), with GNFR F (Road Transport) split in F1 to F4 (total 16 sectors) ***(see Table 7)***
Emission unit	kg/year/gridcell (both in CSV and NetCDF files)
Countries	42 countries + 13 sea regions ***Note:*** Emissions for other countries within the domain are added based on EDGAR v4.3.2

5.1.1 Updates and improvements compared to the earlier TNO emissions

The main features of this dataset are:

- A horizontal resolution of 0.1° x 0.05° (lon x lat) to align with other emission inventories such as EDGAR and EMEP which have a resolution of 0.1° x 0.1° (lon x lat). This means that the resolution is around 30% higher compared to earlier TNO emission inventories (such as the TNO_MACC inventories) at 0.125° x 0.0625°.
- The sector classification in the emission grids has been updated from SNAP to GNFR (See Table 7). GNFR is an aggregated version of the NFR which is used by individual country emission reporting to EMEP and European Union, therefore it has also been implemented in the TNO_GHGco emission inventory. More details on the sector classification can be found in Table 7 and http://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions/ .
- Along with the updated grid definition used, the allocation and identification of countries has been updated in accordance with the current countries and borders. Compared to the TNO_MACC emission inventories, ISO3 code YUG (consisting of Serbia and Montenegro) has been replaced by individual codes for Serbia, Montenegro and Kosovo.
- EDGAR data have been used for gapfilling for those countries that are part of the domain (see Table 2), but not part of UNECE Europe (in North Africa and the Middle East). These are based on EDGAR v4.3.2 for all substances, covering years 2000-2012. From 2012 onwards, these emissions are assumed constant since no EDGAR data were readily available at the time when this emission inventory was created.

Table 3. GNFR Sector explanation and link to SNAP nomenclature previously used in TNO-MACC emission inventories.

GNFR_Category	GNFR_Category_Name	Link to SNAP
A	A_PublicPower	SNAP 1, only power and heat plants
B	B_Industry	SNAP 1 (non-power and heat plants) + SNAP 34 (or SNAP 3+4)
C	C_OtherStationaryComb	SNAP 2
D	D_Fugitives	SNAP 5
E	E_Solvents	SNAP 6
F	F_RoadTransport	SNAP 7
G	G_Shipping	SNAP 8, only shipping (all types)
H	H_Aviation	SNAP 8, only aviation
I	I_OffRoad	SNAP 8, non-shipping and non-aviation
J	J_Waste	SNAP 9
K	K_AgriLivestock	SNAP 10, livestock only
L	L_AgriOther	SNAP 10, non-livestock only
F1	F_RoadTransport_exhaust_gasoline	SNAP 71
F2	F_RoadTransport_exhaust_diesel	SNAP 72
F3	F_RoadTransport_exhaust_LPG_gas	SNAP 73
F4	F_RoadTransport_non-exhaust	SNAP 74 + SNAP 75 [Note that SNAP 74 has only NMVOC and SNAP 75 has only PM emissions]

5.1.2 Key features of the spatial distribution

For power plants, the locations and characteristics of each large power plant in Europe have been collected from the combination of various datasets:

- E-PRTR (European Pollutant and Transfer Register, http://prtr.ec.europa.eu/)
- CARMA database (Carbon Monitoring for Action, http://carma.org/)
- Reporting of EU Member States to the Large Combustion Plants Directive
- Platts-WEPP (World Electric Power Plants database, version December 2015, https://www.platts.com/products/world-electric-power-plants-database)

These datasets have been linked together to obtain a full overview of the power plants and to identify gaps and errors, which have been corrected and gapfilled to the extent possible.

For industrial point sources, E-PRTR has been used. Absolute emissions have been obtained as described above for power plants, for selected sectors and pollutants only.

- Point sources for both power plants and industrial sources are used in an absolute instead of a relative way. In the earlier TNO_MACC inventories, the point sources were used only to distribute national total emissions for the relevant sector. In this inventory, the exact emissions from point sources are used. Remaining emissions are distributed using industrial area land cover classification from CORINE. Only in case the sum of point source emissions from E-PRTR exceeds the national total for that sector, the point source emissions within that sector are all scaled down to not exceed the national total for the respective sector.
- For population density, the default distribution for many sectors when no specific information is available, three versions of the Landscan population map (https://web.ornl.gov/sci/landscan/) for the years 2005, 2010 and 2015, respectively, have been used. Urban and rural population maps have been created from the population density map by comparing the population density in each cell (inhabitants/km^2).
- For airports, a new distribution map has been created based on Eurostat statistics on the passenger and freight flights by airport for each individual year. The main advantage of this update is that yearly specific maps can be created, reflecting the opening and closure of airports during the time series, as well as growth in air traffic in specific airports.
- For international shipping, the distribution is based on AIS data and developed by FMI using their STEAM model. The current shipping distribution is based on a consistent AIS-based map for the year 2016, which is used as the best approximation for 2015. For earlier years, scaling factors have been developed for the shipping emissions to estimate emissions for the years prior to 2015 by sea, taking into account the implementation of environmental control measures in different sea regions.

5.1.3 Emission profiles

In addition to the grid files, the following additional information is also provided:

- Temporal profiles: default time profiles are provided per GNFR sector code (consisting of a variation between months, between days of the week and hours in the day).
- Effective emission height: a default effective height is provided per GNFR sector code.

5.2 Results: the TNO_GHGco_v1 emission inventory

The emissions are provided for the year 2015 for the species listed in Table 6. As an example of the emissions Figure 4 shows distributed 2015 emissions for fossil CO_2 from diesel road transport and for biofuel CO_2 from small combustion installations in 2015.

The total anthropogenic emissions by species and per country are given in Table 8 for the year 2015.

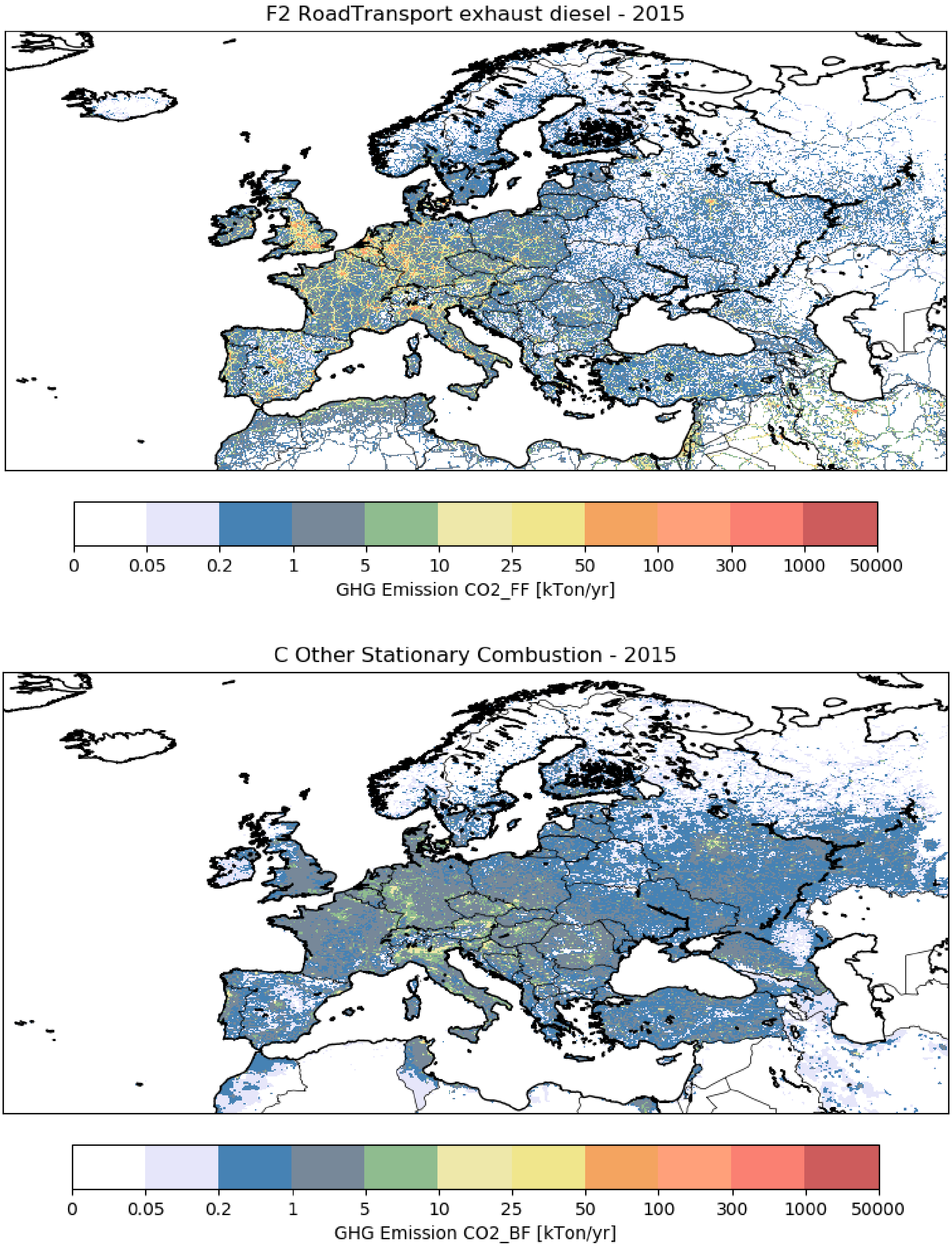

Figure 4. Examples of distributed emissions in TNO_GHGco_v1.1 emission inventory in 2015; fossil CO2 from diesel road transport (top) and biofuel CO2 from other stationary combustion (bottom) (unit: Gg/year/gridcell).

Table 4. Total emissions per country and sea region for the year 2015 (Gg/yr) as included in the TNO_GHGco_v1.1 emission inventory

Country		CO2_ff	CO2_bf	CO_ff	CO_bf	NOX	CH4	NMVOC
EU15 plus Norway/Switzerland	AUT	66 722	23 399	317	248	138	263	113
	BEL	101 417	12 269	298	103	187	324	92
	CHE	38 572	4 971	149	37	60	204	78
	DEU	791 558	102 145	2 217	473	1 071	2 241	822
	DNK	35 086	15 779	218	106	81	279	73
	ESP	269 328	36 974	671	892	742	1 548	547
	FIN	43 923	38 686	159	143	120	196	71
	FRA	343 866	58 995	1 633	1 217	807	2 398	614
	GBR	414 196	36 006	1 395	214	878	2 113	726
	GRC	81 072	6 261	798	200	196	406	183
	IRL	38 110	2 025	93	21	73	531	62
	ITA	353 471	45 182	859	1 467	665	1 735	826
	LUX	5 371	421	10	6	12	25	8
	NLD	164 866	12 847	486	84	211	763	139
	NOR	42 347	4 493	276	104	114	202	145
	PRT	51 521	12 581	92	192	158	437	180
	SWE	40 456	29 323	272	160	110	196	134
New Member States	BGR	48 227	6 583	130	205	123	293	94
	CYP	6 852	148	13	1	15	35	7
	CZE	103 790	16 944	322	210	165	557	144
	EST	15 843	4 093	52	83	29	43	19
	HRV	17 860	6 612	82	156	49	140	57
	HUN	46 751	12 692	190	276	109	307	122
	LTU	13 141	6 125	40	113	46	138	54
	LVA	7 214	6 399	36	105	32	77	36
	MLT	1 694	27	2	1	3	7	2
	POL	310 313	35 750	1 793	643	669	1 887	535
	ROU	78 747	21 553	227	699	215	1 184	277
	SVK	33 861	7 604	165	69	79	175	83
	SVN	13 598	2 984	39	72	34	82	26
Non-EU countries	ALB	5 047	1 243	25	54	16	101	26
	BIH	15 680	3 812	34	195	31	119	55
	BLR	57 698	10 993	250	222	156	608	174
	ISL	2 899	-	118	0	9	22	5
	KOS	6 609	1 368	53	69	25	56	25
	MDA	6 176	1 789	39	78	15	86	30
	MKD	9 447	1 763	24	80	28	48	24
	MNE	1 928	669	22	32	7	20	12
	RUS	978 822	108 603	5 531	4 066	2 090	16 173	2 299
	SRB	45 370	5 704	208	281	88	204	102
	TUR	386 360	36 660	1 589	1 429	926	1 894	644
	UKR	294 834	27 334	2 308	1 077	642	3 137	500
Sea regions	ATL*	34 709	-	56	-	797	-	6
	BAS	16 079	-	22	-	342	-	3
	BLS	7 099	-	11	-	149	-	1
	MED	54 851	-	83	-	1 237	-	10
	NOS**	31 224	-	48	-	643	-	6
	OTH***	1 599	-	2	-	32	-	0

*ATL includes also Barentz Sea (BAR), Greenland Sea (GRS), Norwegian Sea (NWS)

**NOS includes English Channel (ENC)

***OTH (Other sea regions) includes Caspian Sea (CAS), Kara Sea (KAR), Persian Gulf (PSG)

5.2.1 Illustration of sector importance

Figure 5 shows the contribution of the different sectors (GNFR categories) for each species included. It shows that for different species, different sources are responsible.

For CO_2, for both fossil and biofuels power plants (A), industry (B) and small combustion (C) are the main responsible sectors. For fossil fuel CO_2, road transport accounts for ~25% while for biofuels this is only around 5%. The largest contributor to European CO_2 emissions from biofuel combustion is small combustion (C) with a contribution around 40%.

For CO, fossil fuel emissions are dominated by industry (B) and road transport exhaust emissions using gasoline (F1), with smaller contributions from small combustion (C) and the off-road sector (I). CO emissions from biofuel combustion however are dominated by small combustion (C) with an additional contribution from non-livestock agriculture (L), which represents the burning of agricultural wastes.

As for the other species, CH_4 is dominated by agriculture (K and L) and waste (J), together representing 80% of the emissions. For NMVOC, the use of solvents (E) is the dominating source while for NO_x road transport using diesel (F2) is the most important source, with other important contributions from power plants (A) and industry (B).

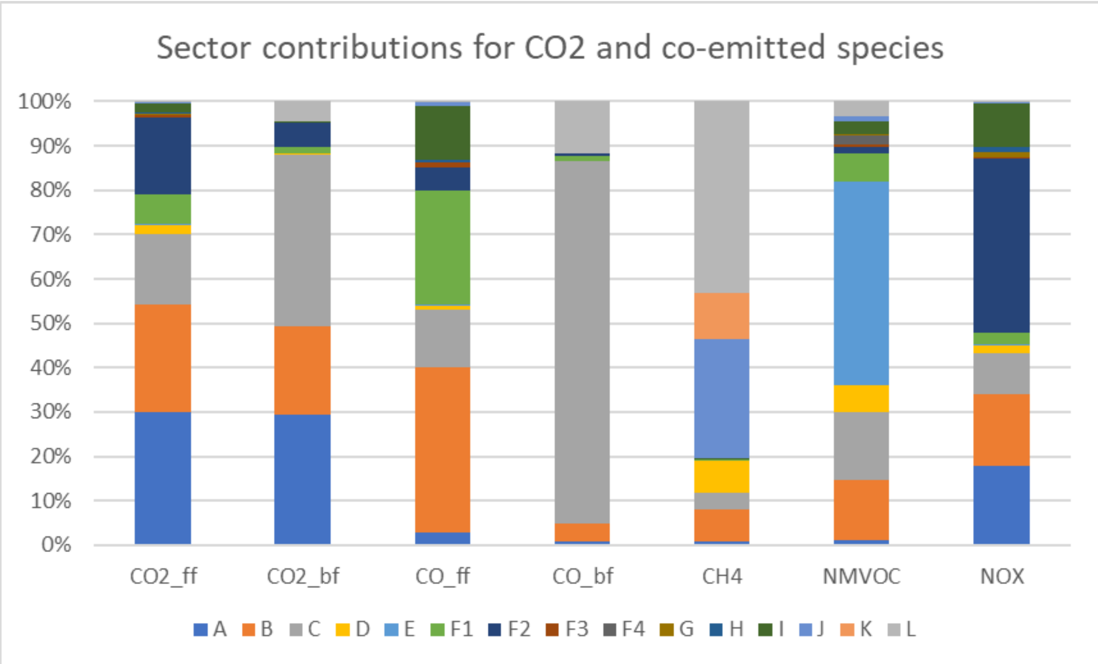

Figure 5. Contribution of the different sectors (GNFR categories) for each species.

5.3 Evaluation and follow-up

This new dataset is a major step since the release of the TNO-MACC-III data and includes a number of additional recent years as well as an improved resolution and a number of methodological improvements, as explained above. At this moment, the product is being evaluated partly in combination with European modelling teams among others in the CHE and VERIFY projects. This evaluation has already led to a version v1.1 being prepared, which was released in mid-December. This updated dataset contains a number of bug fixes and correction of errors that were identified when the teams performing the simulations started working with them.

In addition, a high resolution version of the emission inventory (at 1/60° x 1/120° resolution, roughly equivalent to 1 km x 1 km) has been prepared for a specific zoom region in Europe as envisaged in the CHE project. This high resolution version is almost ready, a couple of final issues are currently being addressed and the dataset is expected to be released in early January.

5.4 Access to the data

An ftp link will be provided to the model teams in CHE WP2 to download the data. At a later stage we will upload the data on the CHE website.

5.5 Regional CO_2 emissions for 2030

To be able to generate a library of realistic CO_2 simulations including possible future concentrations two emission scenarios are used to produce two different gridded emission data sets for 2030 at the same high resolution of 0.05 x 0.1 degree longitude latitude (~6x6 km) for the EU28. The scenarios include a business-as-usual (BAU) and a climate change (CC) scenario. The approach for the projection year 2030 is the same as for the EDGARv4.3.2_CO2_2030projection_grids (see section 4.2). The projections provide a range of the possible future emissions by 2030 that can be used for sensitivity tests. The 2030 annual emissions have been calculated using the climate change scenarios developed under the FP6 project Climate Impact Research within the FP6 research project CIRCE to evaluate a change projected over a decade using the EC view point of a POLES energy scenario and assuming full implementation of the current climate change policies. These scenarios are described by Doering et al. (2010) and Russ et al. (2007) and are comparable to the IPCC AR4 Category II pathway. The 2030 projections use the year 2015 from the TNO_GHGco_v1.1 emission inventory as the base year. The ratios of 2030 to 2015 in the time-series of the BAU and CC scenario of CIRCE per sector, fuel and country are applied to the base year grid maps of 2015. A more detailed description of the approach is available from Denier van der Gon et al. (2017) but the CHE 2030 datasets described here are based on the base year 2015 and follow the GNFR source sector classification as show in

Table 3. In the CC scenario, the fossil CO_2 emission in the EU28 is 17% lower than in the BAU scenario (Fig. 6). Although the CO_2 biofuel share is increasing in the CC scenario in absolute terms the biofuel use in the CC scenario is not larger than in the BAU scenario. Note that these scenarios are not necessarily realistic, especially since the CIRCE project scenarios were developed about 10 years ago. They do however cover a range that might be realistic for the near future. Figure 6 shows the development over time starting from the known reported emissions for the year 2000-2015 and projections up to 2050 for both scenarios. For the future years, only 2030 emissions are delivered in gridded form.

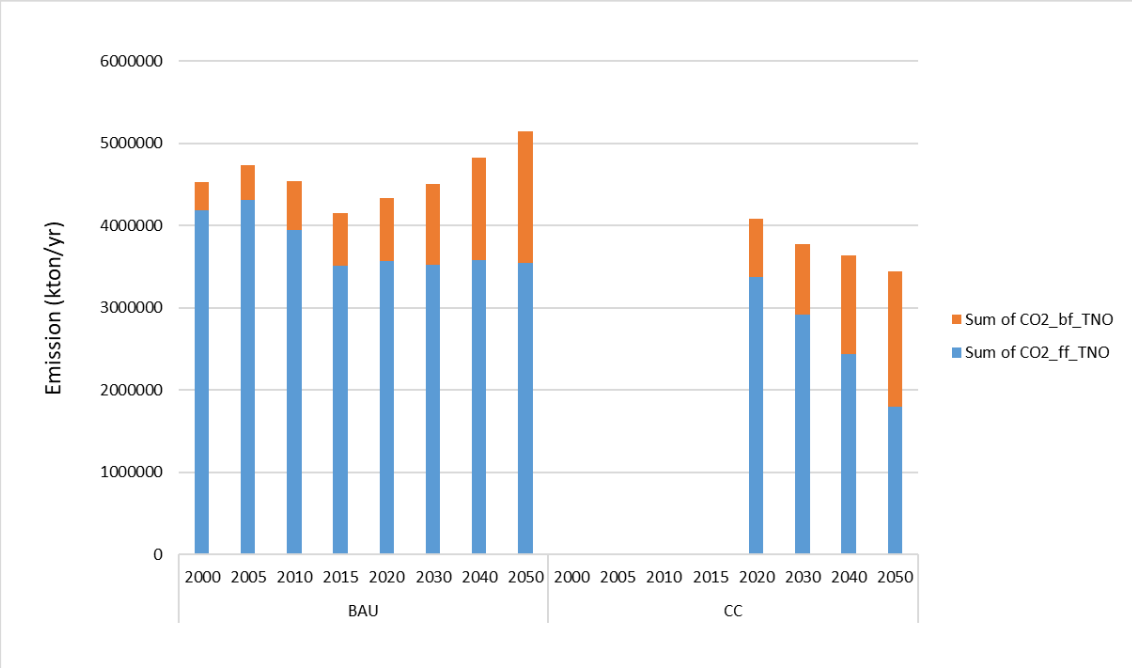

Figure 6. Fossil fuel and biofuel CO_2 emissions under the BAU and CC scenarios.

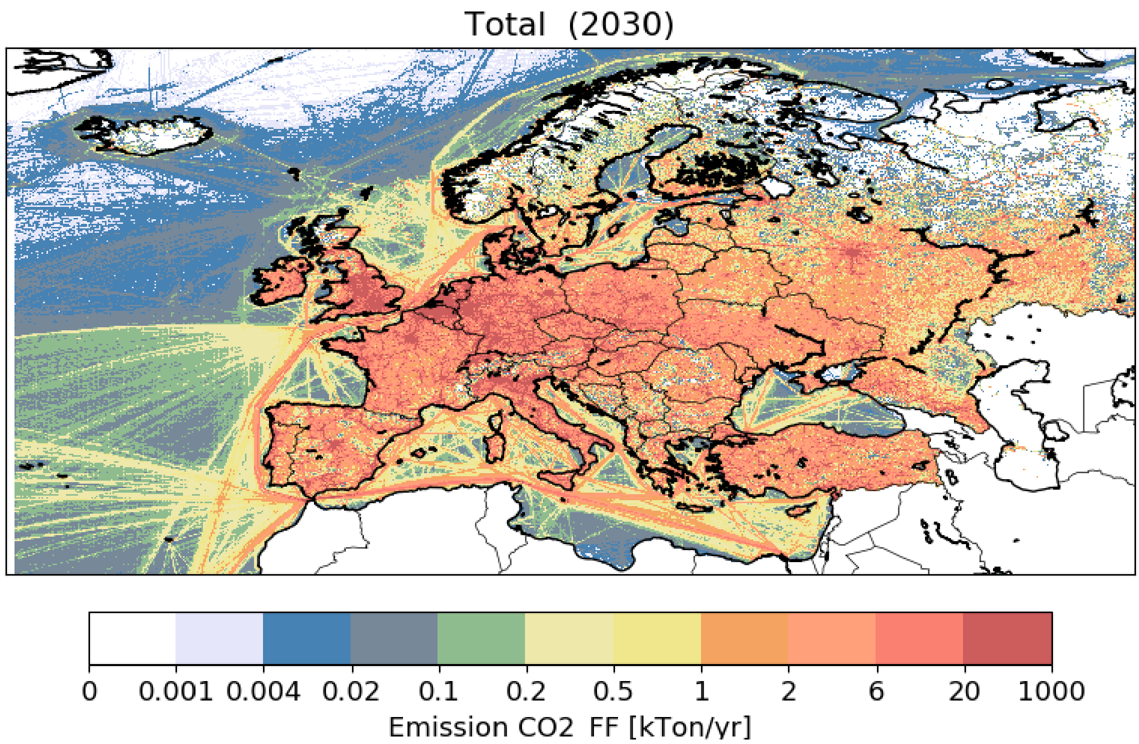

Figure 7 Emissions of CO_2 in 2030 following the climate change scenario projection using the TNO_GHGco_v1.1 emission inventory for 2015 as baseline (Gg/year/gridcell)

6 Emission inventory for the city of Berlin (EMPA)

For the city of Berlin, a very detailed inventory with line, point and area sources for a large number of air pollutants and greenhouse gases was obtained from the “Senatsverwaltung für Stadtentwicklung und Umwelt” for the year 2012 (Senatsverwaltung für Stadtentwicklung und Umwelt, Juni 2016), except for traffic emissions, which were compiled for the year 2015 (Figure 8). The inventory also includes LTO (landing and take-off cycle) aircraft emissions at the two airports of Berlin, one of which being outside the city limits. This inventory was already used in the ESA project SMARTCARB (Kuhlmann and Brunner, 2017) for emissions of CO_2, CO and NOx.

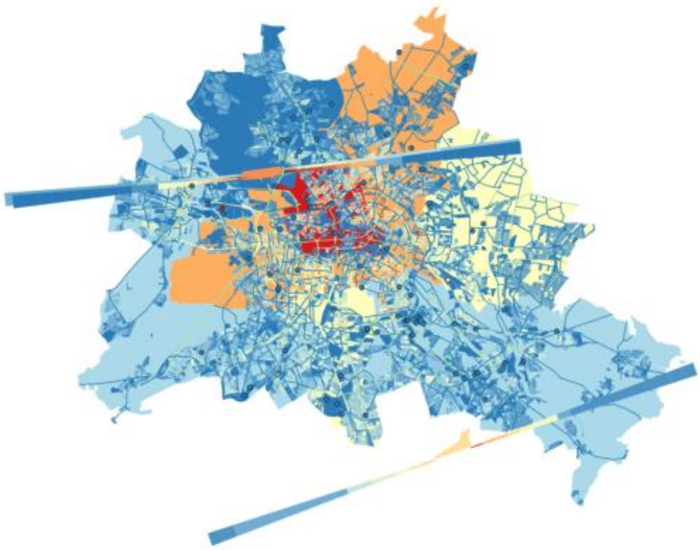

Figure 8.Sketch of CO_2 emission in the Berlin inventory showing point, line and area sources from different emission categories.

The emissions for Berlin were provided as shape files, a geospatial vector data format, and were processed to a regular grid for the CHE project. The vector data, originally provided on a Soldner Berlin projection, were first projected to geographical latitude/longitude coordinates and then rasterized by computing for each cell of the output grid the intersecting length and area of the line and area sources, respectively, thus preserving the total emissions.

The output grid is defined as follows (lower left corner of grid cell):

startlon = 13.06667°

startlat = 52.325°

dlon = 1/60°

dlat = 1/120°

ie (nx) = 44

je (ny) = 44

This grid has the same resolution and the grid cells match the ones from the high-resolution TNO_GHGco inventory. The data are provided with a netCDF format. A mask delimiting the city of Berlin is also provided to facilitate the merging with the TNO_GHGco inventory.

Emissions from large point sources ("genehmigungspflichtige Anlagen") are provided in a separate file at their exact location as a csv file format. The Berlin inventory distinguishes between a large number of emission sectors based on a different source sector nomenclature than the TNO_GHGco or EDGAR inventory. They have been aggregated into the G-NFR14 codes used also in the TNO_GHGco inventory (see also

Table 3). The inventory provided to the CHE project includes emissions of CO_2, CH_4, CO, N_2O, NMVOC, NOx, PM10, PM2.5, SO_2 and NH_3.

TNO has made a ~1 x1 km inventory for a part of Europe for CHE WP4 under Task 4.1 (High-resolution scenarios of CO_2 and CO emissions). This high-resolution inventory will be described in CHE Deliverable D4.2 *Database of high-resolution scenarios of CO_2 and CO emissions*. The Berlin inventory in its converted projection and source sector classification is nested in the high resolution (~1 x 1 km) domain of the TNO_GHGco inventory (Figure 9) to have one consistent dataset as input for model runs. The data will be made available on the ftp server of TNO and the CHE project.

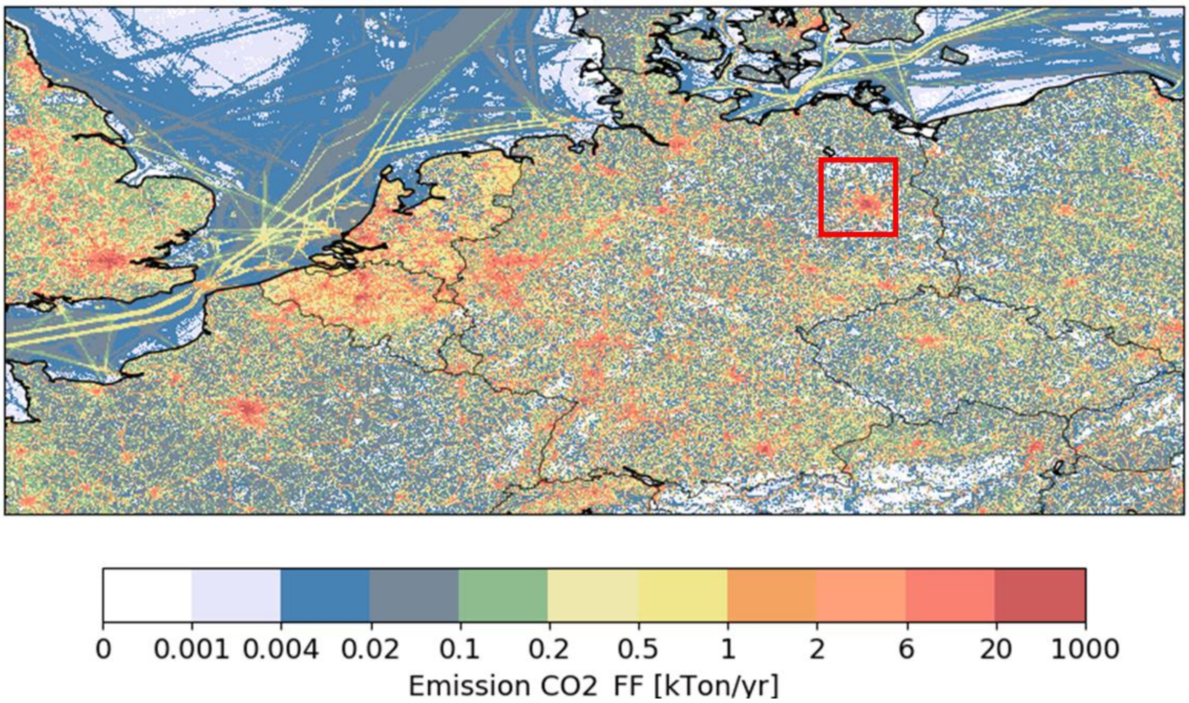

Figure 9 Domain of the TNO high resolution inventory at ~1 x 1km as prepared for CHE WP4. The Berlin inventory (Figure 8) from the Senate Berlin is nested at the same resolution inside the red box.

Table 5. Emissions from point sources (genehmigungspflichtige Anlagen)

GNFR14 category	CH_4	CO	CO_2	N_2O	NH_3	NMVOC	NO_X	PM10	PM2.5	SO_2
A PublicPower	287.772	1.424.481	7.200.002.650	250.923	14.738	49.568	5.356.926	81.146	44.559	2.133.534
B Industry	12.032	301.530	675.728.072	11.525	858	206.764	1.439.469	60.384	33.278	238.028
Sum (kg/a)	**299.804**	**1.726.011**	**7.875.730.722**	**262.448**	**15.596**	**256.332**	**6.796.395**	**141.530**	**77.837**	**2.371.562**

Table 6. Emissions from area sources

GNFR14 category	CH_4	CO	CO_2	N_2O	NH_3	NMVOC	NO_X	PM10	PM2.5	SO_2
A PublicPower	0	0	0	0	0	0	0	0	0	0
B Industry	3.916	1.393.230	139.419.376	5.904	0	148.999	1.097.105	766.468	97.206	708
C Other Stationary Comb	452.152	11.257.107	5.797.250.048	44.241	0	403.372	1.994.183	241.006	227.844	589.518
D Fugitives	2.284.749	0	0	0	0	782.289	0	0	0	0
E Solvents	0	0	0	0	0	15.966.164	0	438.907	438.907	0
F Road Transport	218.313	19.432.676	2.670.477.824	46.737	202.366	3.541.115	7.077.507	626.039	319.642	12.818
G Shipping	1.752	210.015	17.690.030	197	400	68.917	253.466	9.553	9.553	90
H Aviation	7.891	632.136	227.622.496	7.190	0	133.181	1.213.934	12.723	12.723	16.541
I OffRoad	8.353	1.833.107	45.599.144	1.741	94	136.569	324.559	284.506	38.046	250
J Waste	142.388	0	0	141.154	79.203	0	0	0	0	0
K Agri Livestock	73.453	0	0	908	27.178	0	190	327	198	0
L AgriOthers	0	0	0	131.919	299.475	0	159.608	4.097	158	0
Sum (kg/a)	**3.192.967**	**34.758.271**	**8.898.058.918**	**379.991**	**608.716**	**21.180.606**	**12.120.552**	**2.383.626**	**1.144.277**	**619.925**

Table 7. Emissions from major (Hauptnetz) and minor (Nebennetz) roads

Emissions (kg/a)	CH_4	CO	CO_2	N_2O	NH_3	NMVOC	NO_X	PM10	PM2.5	SO_2
Hauptnetz (kg/a)	155.362	13.788.177	2.222.135.552	37.210	190.039	2.474.451	5.816.988	546.156	266.964	10.668
Nebennetz (kg/a)	62.951	5.644.457	448.343.040	9.527	12.328	1.066.663	1.260.519	79.883	52.678	2.150
Hauptnetz / Sum (%)	71,2	71,0	83,2	79,6	93,9	69,9	82,2	87,2	83,5	83,2
Sum (kg/a)	**218.313**	**19.432.634**	**2.670.478.592**	**46.737**	**202.367**	**3.541.114**	**7.077.507**	**626.039**	**319.642**	**12.818**

Table 8. Sum of point and area sources (kg/yr)

GNFR14 category	CH_4	CO	CO_2	N_2O	NH_3	NMVOC	NO_X	PM10	PM2.5	SO_2
A PublicPower	287772	1424481	7200002650	250923	14738	49568	5356926	81146	44559	2133534
B Industry	15948	1694760	815147448	17429	858	355763	2536574	826852	130484	238736
C Other Stationary Comb	452152	11257107	5797250048	44241	0	403372	1994183	241006	227844	589518
D Fugitives	2284749	0	0	0	0	782289	0	0	0	0
E Solvents	0	0	0	0	0	15966164	0	438907	438907	0
F Road Transport	218313	19432676	2670477824	46737	202366	3541115	7077507	626039	319642	12818
G Shipping	1752	210015	17690030	197	400	68917	253466	9553	9553	90
H Aviation	7891	632136	227622496	7190	0	133181	1213934	12723	12723	16541
I OffRoad	8353	1833107	45599144	1741	94	136569	324559	284506	38046	250
J Waste	142388	0	0	141154	79203	0	0	0	0	0
K Agri Livestock	73453	0	0	908	27178	0	190	327	198	0
L AgriOthers	0	0	0	131919	299475	0	159608	4097	158	0
Sum (kg/a)	3492771	36484282	16773789640	642439	624312	21436938	18916947	2525156	1222114	2991487

7 Conclusion

Significant progress has been performed towards creating a library of realistic CO_2 simulations data set that will represent present-day and future emission scenarios. So far the necessary first global CO_2 simulations delivered in D2.2 have been provided as input for further steps. The partners involved in the European-scale simulation have configured the models for the European domain collecting the input data and the first test runs were conducted. The emission inventories for the global CO_2 emissions and the European CO_2 and co-emitted species have been prepared and provided to the teams performing the simulations. The necessary input data for the Berlin domain simulations were collected, and will be initiated as soon as the European simulations are completed. The product delivered here will facilitate the collection of realistic synthetic satellite observations. In addition, the comparison of simulations at different resolutions will provide an assessment of the proportion of the spatial variability of CO_2 that is missed at a given resolution.

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9 Acronyms

MODIS	*Moderate Resolution Imaging Spectroradiometer*
VPRM	*Vegetation Photosynthesis and Respiration Model*
CAMS	*Copernicus Atmosphere Monitoring Service*
GNFR	*Gridding Nomenclature for Reporting*
SYNMAP	*Synergetic Land Cover Product*
EVI	*Enhanced Vegetation Index*
LSWI	*Land Surface Water Index*
WRF	*Weather Research and Forecasting*
GPP	Gross Primary Production
RESP	*Ecosystem Respiration*
NEE	*Net Ecosystem Exchange*
ICOS	*Integrated Carbon Observation System*
LULUCF	*Land-use Change and Forestry*
IEA	*International Energy Agency*
ESA	*European Space Agency*
MACC	*Monitoring Atmospheric Composition & Climate*
EMEP	*European Monitoring and Evaluation Programme*
CEIP	*Centre on Emission Inventories and Projections*
GAINS	*Greenhouse Gas and Air Pollution Interactions and Synergies*
EEA	*European Environmental Agency*
UNECE	*United Nations Economic Commission for Europe*
UNFCCC	*United Nations Framework Convention on Climate Change*
E-PRTR	*European Pollutant and Transfer Register*
CARMA	*Carbon Monitoring for Action*
WEPP	*World Electric Power Plants*
CORINE	*EEA land cover database*

Document History

Version	Author(s)	Date	Changes
0.1	TNO	24/12/2018	
0.2	TNO	10/01/2019	Small corrections, lay-out update ECMWF
1.0	TNO	29/01/2019	Reviews processed, order of chapters changed, added TNO 2030 grid descriptions

Internal Review History

Internal Reviewers	Date	Comments
Marko Scholze (ULUND)	09/01/2019	Approved with comments
Andrew Manning (UEA)	18/01/2019	Approved with comments

Estimated Effort Contribution per Partner

Partner	Effort
TNO	9
MPG	2
JRC	1
EMPA	0.7
Total	**12.7**