AGEC-LCI tutorial

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Contents

Preface

AGEC-LCI: AGricultural Emissions Calculator for life cycle inventory

AGEC-LCI is a VBA tool that generates inventory reports of direct field emissions resulting from the application of soil amendments, fertilizers and metal-based fungicides in agriculture. This tool aims to facilitate the modelling of the foreground process of agricultural systems and to avoid the potential inconsistent linking between life cycle inventory (LCI) and life cycle impact assessment (LCIA) phases.

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Do not hesitate to contact Ivan if you need help on adding regions, crops or other agricultural inputs unavailable in the tool's database.

Download the AGEC-LCI tool

Please follow this link to download the AGEC-LCI tool.

Participation at SETAC Europe SciCon virtual meeting

This work will be presented at the SETAC Europe 30$^{\text{th}}$ Annual Meeting *"Open Science for Enhanced Global Environmental Protection"* according to the following details:

Track: 5. Life Cycle Assessment and Foot-Printing

Session: Quantifying life cycle emissions and environmental impacts of agricultural practices related to pesticides and fertilisers

Presentation Title: AGEC-LCI: an open access tool for calculating emissions from fertilizers and metal-based fungicides applications

Presentation Type: Platform

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Tool's information

Chapter 1

Introduction

AGEC-LCI is a VBA application hosted in Microsoft Excel that computes emissions generated from the application of soil amendments, fertilizers and metal-based fungicides in agriculture (Figure 1.1).

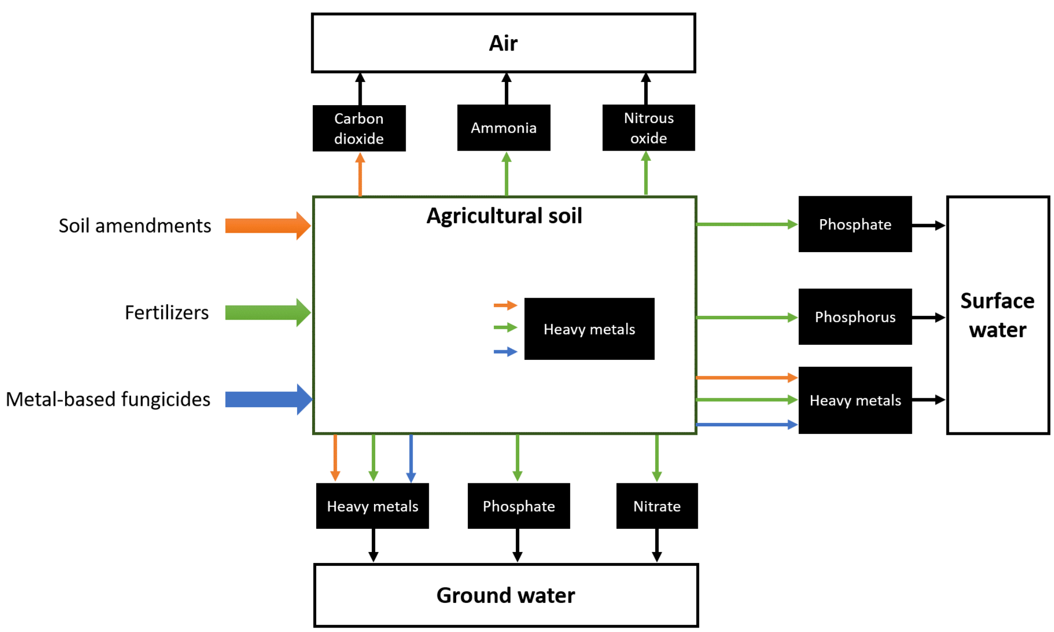
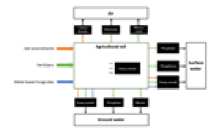


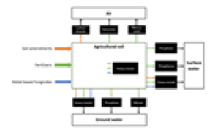
Figure 1.1: Emissions Computed by AGEC-LCI

A state of the art analysis of the models for computing direct field emission from fertilizers, pesticides and soil amendments was carried out. Acknowledging that agricultural emissions are site- and time dependent, a parsimonious approach was considered for the selection of the models (Table 1.1). See

Section 4 for more details on the selected models.

Table 1.1: Selected models for calculating agricultural emissions and comparison with LCI databases

Emission	agri footprint (Durlinger et al., 2017)	ecoinvent v3 (Nemecek and Schnetzer, 2011)	AGRIBAL-YSE ® (Koch and Salou, 2015)	WFLDB (Nemecek et al., 2014)	 AGEC-LCI
Ammonia (NH_3)	IPCC (2006)	Agrammon (Tier 3 methodology for Switzerland)	EMEP Tier 2 (EEA 2009)	EMEP Tier 2 (EEA 2013)	EMEP Tier 2 (EEA 2009 & EEA 2013)
Nitrous oxide (N_2O)	IPCC (2006)	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC (2006) crops: Tier 1 animals: Tier 2	”IPCC (2006) crops: Tier 1$^{(a)}$
Nitrate (NO_3^-)	IPCC (2006)	Europe: SALCA-Nitrate (Richner et al. 2014), Other countries: SQCB (Faist et al, 2009)	Annual French crops: COMIFER 2001 adjusted (Tailleur et al. 2012),Permanent crops: SQCB (Faist et al, 2009)	Europe: SALCA-Nitrate (Richner et al. 2014), Other countries: SQCB (Faist et al, 2009)	SQCB (Faist et al, 2009)
Phosphorus (P,PO_4^{3-})	(Struijs, Beusen, Zwart, & Huijbregts, 2011)	SALCA-P (Prasuhn, 2006)	SALCA-P (Prasuhn, 2006)	SALCA-P (Prasuhn, 2006)	SALCA-P (Prasuhn, 2006)

Emission	agri footprint (Durlinger et al., 2017)	ecoinvent v3 (Nemecek and Schnetzer, 2011)	AGRIBALYSE ® (Koch and Salou, 2015)	WFLDB (Nemecek et al., 2014)	 AGEC-LCI
Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	(Mels et al., 2008, Romkens & Rietra, 2008, Nemecek & Schnetzer, 2012)	SALCA method (Freiermuth, 2006)	SALCA method (Freiermuth, 2006)	SALCA method (Freiermuth, 2006)	SALCA method (Freiermuth, 2006)
Methane (CH_4)	Dutch National Inventory Reports	IPCC (2006) Tier 2	IPCC (2006) Tier 2	IPCC (2006) Tier 2	-
Synthetic pesticides	100 % of the substance emitted to agricultural soil	100 % of the substance emitted to agricultural soil	100 % of the substance emitted to agricultural soil	100 % of the substance emitted to soil[(b)]	-

(a): The AGEC-LCI tool does not compute enteric emissions of livestock.

(b): Rule followed in the first and second release of the WFLDB. The third release will follow the rules defined in Glasgow workshops (Nemecek et al., 2014).

Chapter 2

Instructions for use

Step 1

Unzip the compressed folder AGEC-LCI_v1_0.zip, then open the file AGEC-LCI_v1_0.xlsm (Figure 2.1).

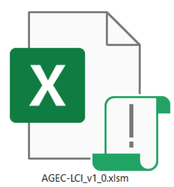


Figure 2.1: AGEC-LCI is stored in a macro-enabbled workbook

Step 2

Click on the Launch AGEC-LCI user interface button at the top of README-RUN worksheet of AGEC-LCI_v1_0.xlsm (Figure 2.2).

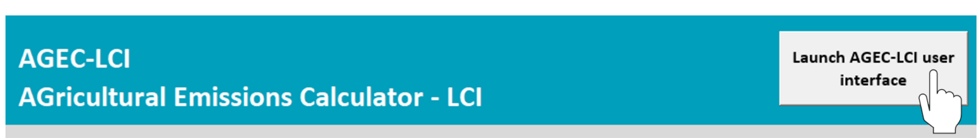


Figure 2.2: Launch AGEC-LCI user interface

Step 3

The AGEC-LCI user interface will be displayed (Figure 2.3).

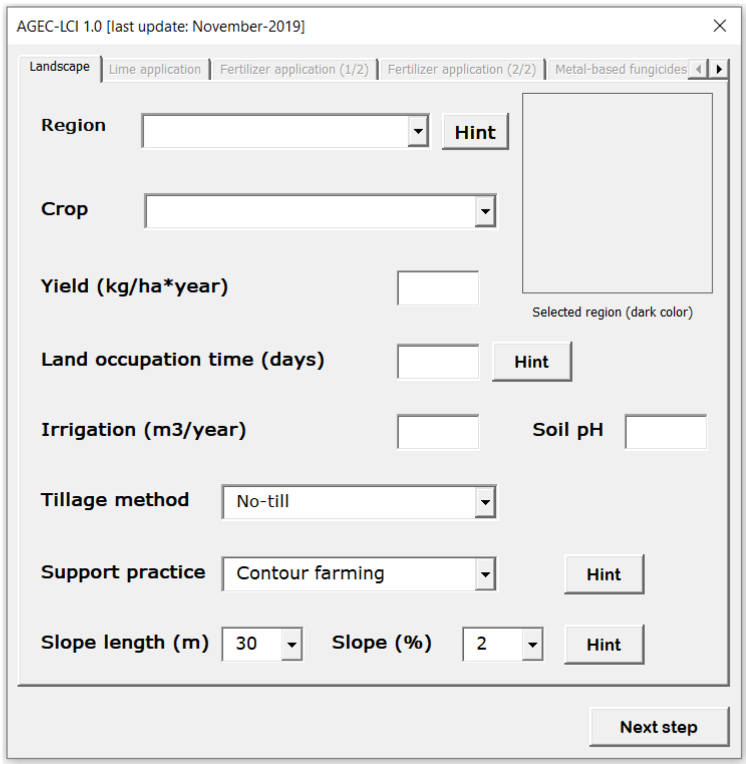


Figure 2.3: AGEC-LCI user interface

AGEC-LCI allows the user to select inputs from a database composed of 25 crops, 42 fertilizers, 6 metal-based fungicides and the pedo-climatic characteristics of 5 French regions according to data from AGRIBALYSE (Koch and Salou, 2015). Furthermore, the user is allowed to add crops, regions and other inputs not available in the accompanying database.

Step 4

You will be asked to give a short name for your current project. It is advised to give a short and meaningful name, because it will be part of the name of the reports and the process generated (Figure 2.4). Click OK to finish the computations.

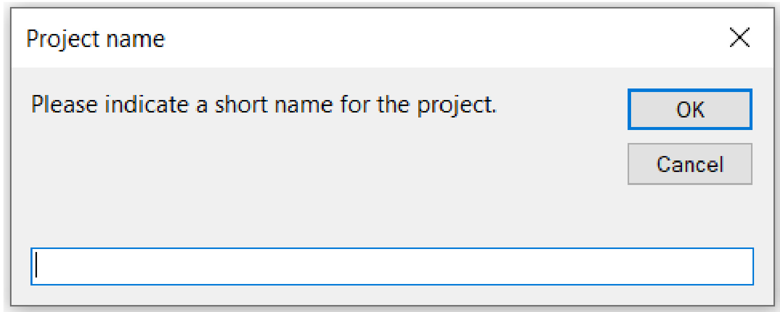


Figure 2.4: Name your current project

Step 5

Three reports will be generated and stored under the Results folder accompanying this tool (Figure 2.5). The Results folder will be automatically open at the end of the computation.

- **Report_Project_Name_YYYY-MM-DD.xlsx**: Contains the user's inputs and the calculated emissions. The aim of this report is to keep track of the inputs that need to be entered by the LCA practitioner into a LCA software.
- **Report_olca_Project_Name_YYYY-MM-DD.xlsx**: Reports the calculated emissions in an Excel file compatible with openLCA. The importation of this report was tested with openLCA 1.9.0, and the procedure is described in Section 3.1.
- **Report_SimaPro_Project_Name_YYYY-MM-DD.csv**: Reports the calculated emissions in a csv file compatible with SimaPro. The importation of this csv file was tested with SimaPro 8.5.2.2, it is not guaranteed that it will work in previous versions the software. The procedure for importing this file is described in Section 3.2.

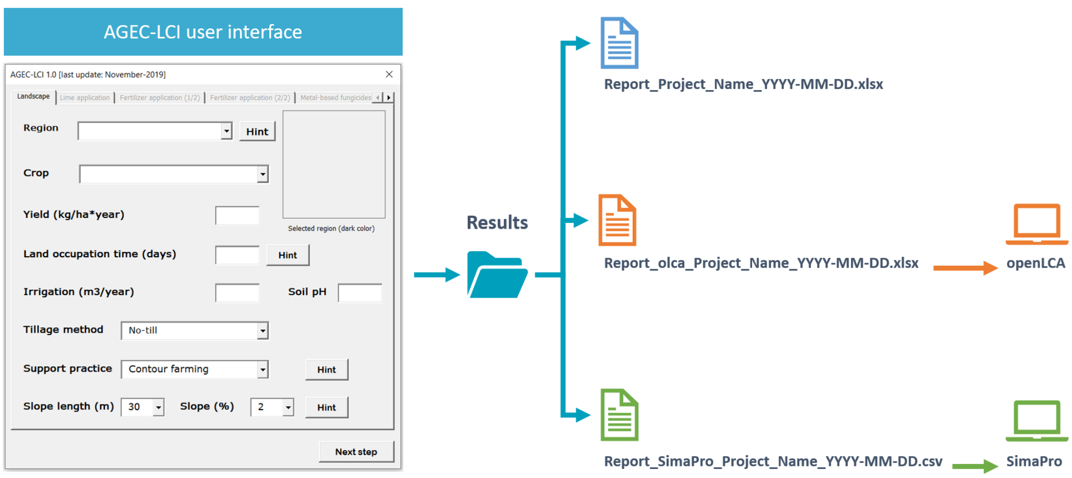


Figure 2.5: Files generated by AGEC-LCI

Chapter 3

Importing AGEC-LCI reports into LCA software

AGEC-LCI generates reports that can be directly imported into LCA software such as openLCA and SimaPro, which greatly reduces the time required for computing the impact of emissions resulting from soil amendments, fertilizers and metal-based fungicides.

3.1 openLCA

1. Activate your working database
2. Under *File*, select import.
3. Select the *Excel* file format and click on Next (Figure 3.1).
4. Find the *AGEC-LCI report in Excel format* you would like to import. The name of the AGEC-LCI report compatible with openLCA follows the pattern "Report_olca_Project_Name_YYYY-MM-DD.xlsx". Of course, you can rename this file prior to its importation into openLCA.
5. Select the file to be imported and click on finish (Figure 3.2).
6. After the importation, a child category AGEC-LCI will be created under Processes and Flows from the navigation panel (Figure 3.3).

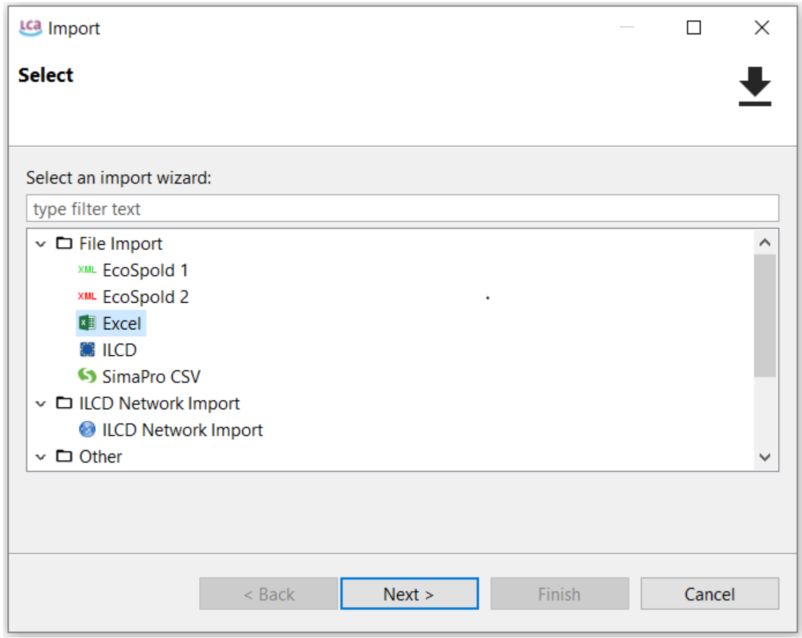


Figure 3.1: Importing an Excel file into openLCA

3.2 SimaPro

1. Open your project
2. Under *File*, select import.
3. Click on Add.
4. Select the csv file for importing (Figure 3.4).
5. Click OK to launch the importation.
6. After the importation, a child category AGEC will be created under Processes/Use/Others (Figure 3.5).

Notes:

- The default name of the flow generated by AGEC-LCI is *Agricultural emissions, AGEC*.
- The default name of the process is composed by concatenation of the strings *"Agricultural emissions, AGEC-LCI-"* and *"Your Project Name"*, which you entered at step 3 of the instructions for use.

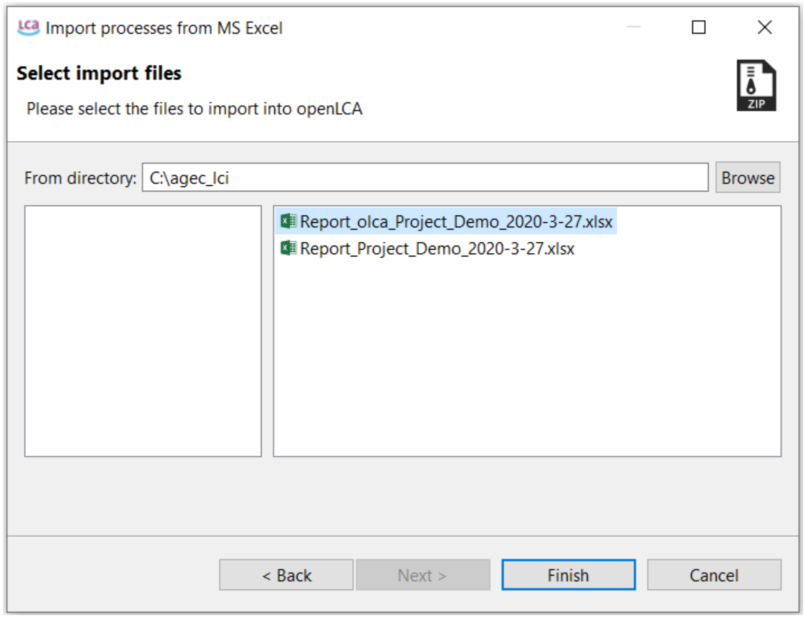


Figure 3.2: Selecting the file to be imported

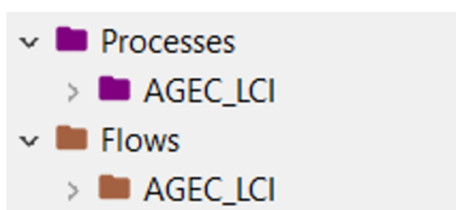


Figure 3.3: Child categories added to Processes and Flows

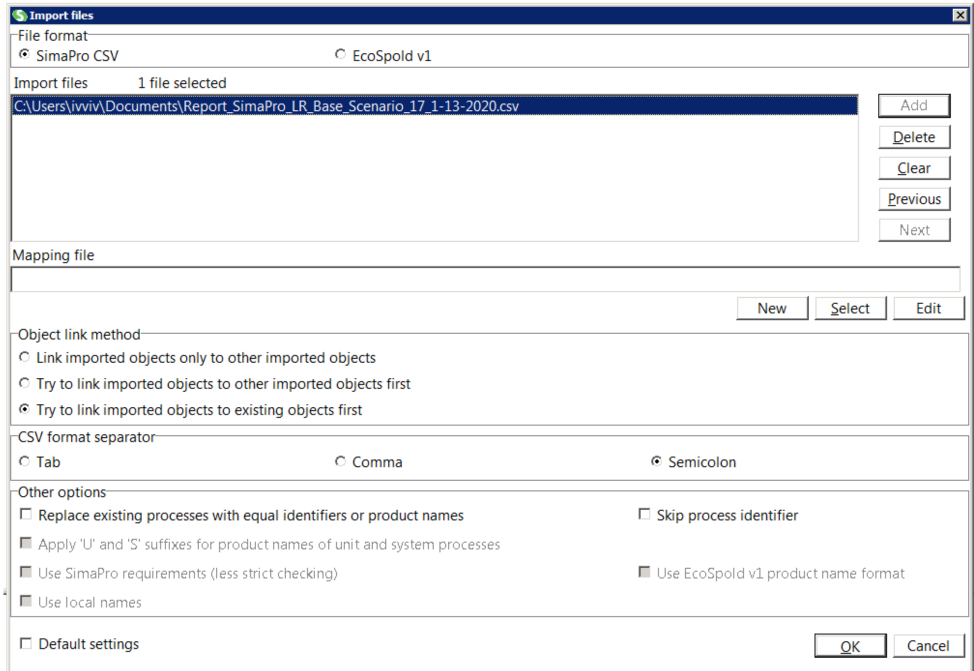


Figure 3.4: Importing a csv file into SimaPro

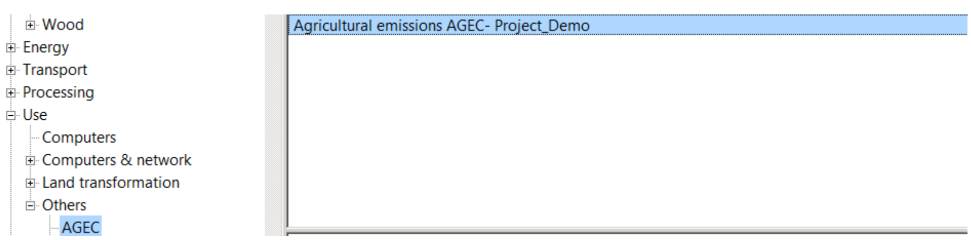


Figure 3.5: Child category added after importation

Chapter 4

Selected methods

4.1 Soil loss

In line with the AGRIBALYSE® methodology (Koch and Salou, 2015), soil loss was estimated by applying the USDA RUSLE equation.

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \cdot f$$

Where:

- A: computed spatial and temporal average soil loss per unit area [$\mathrm{t \cdot ha^{-1} \cdot yr^{-1}}$]
- R: rainfall-runoff erosivity factor
- K: soil erodibility factor
- L: slope length factor
- S: slope steepness factor
- C: cover-management factor
- P: support practice factor
- f: acre to hectare conversion factor (equal to 2.47)

The AGRIBALYSE ® program computed R and K parameters according to six principal regions of France: central, north, north-east, west, south and south-west. Furthermore, climate and soil profiles were defined for each region (Koch and Salou, 2015).

4.2 Emissions of ammonia (NH_3) to the air

In keeping with the AGRIBALYSE® methodology (Koch and Salou, 2015), emissions of NH_3 from organic fertilizers were calculated by applying the EMEP-EEA (2009) Tier 2. While the emissions of NH_3 resulting from the application of mineral fertilizers were calculated according to the EMEP-EEA (2013) Tier 2, which is in line with the World Food LCA Database (WFLDB) (Nemecek et al., 2014). This allowed to consider the effect of both temperature and soil pH in the computation of NH_3 emissions.

The NH_3 emissions were calculated according to the following equation:

$$NH_3 = \frac{17}{14} \cdot \sum_{m=1}^{M} (EF_a \cdot p + EF_b \cdot (1-p)) \cdot N$$

Where:

- *NH_3*: ammonia emissions after mineral fertilizer application [kg NH_3]
- *m*: fertilizer type (M: number of fertilizer types)
- *EF_a*: emission factor on soils with pH 7 [kg NH_3-N/Kg N]
- *EF_b*: emission factor on soils with pH > 7 [kg NH_3-N/Kg N]
- *p*: fraction of soils with pH 7 [%/100]
- *N*: fertilizer application [kg N]
- *17/14* is the conversion factor from N to NH_3.

The above equation was simplified by considering that only one value of pH is reported for a given plot, which implies assuming that the pH is homogeneous in the studied agricultural field. In the equation below, i can take the values EF_a or EF_b, whether the pH is below or above 7.

$$NH_3 = \frac{17}{14} \cdot \sum_{m=1}^{M} EF_i \cdot N$$

4.3 Emissions of nitrogen oxides (NOx,NO,NO_2) to the air

Nitrogen oxides result principally from the nitrification process. In line with the AGRIBALYSE® methodology (Koch and Salou, 2015) and the WFLDB (Nemecek et al., 2014), the EMEP-EEA (2009) Tier 1 was applied to calculate nitric oxide emission generated from the application of organic and mineral fertilizers. Regardless of the type of fertilizer (i.e., organic or mineral) the same emission factor is used:

- **Emission factor for NOx-N**: 0.012 kg NOx-N/kg N applied

Prior to the computation of NO emissions, N volatized as NH_3 was substracted from the amount of N applied.

In ecoinvent, nitrogen oxide emissions are calculated with respect to NO_2. In consequence, a conversion factor of 46/14 was applied to the calculated emissions in terms of N.

4.4 Nitrate (NO_3^-) leaching to ground water

Faist Emmenegger et al. (2009) employed a simple regression model from Willigen (2000) to calculate nitrate leaching to groundwater in the context of the *Sustainability Quick Check for Biofuels Project*. The main limitation of the SQCB-NO_3 model is that it does not account for soil hydrological and biochemical processes. In consequence, the output of this model must be considered as an estimate of nitrate leaching. Nevertheless, the SQCB-NO_3 model has been applied in AGRIBALYSE® (Koch and Salou, 2015), WFLDB (Nemecek et al., 2014) and ecoinvent (Nemecek and Schnetzer, 2011) to calculate nitrate leaching in non-European agricultural fields.

The SQCB-NO3 model was selected over the SALCA-nitrate model because the former was used by AGRIBALYSE ® to calculate nitrate leaching in vineyard fields, which is a research interest of the authors. Furthermore, this model allows to consistently compute nitrate emissions for other crops, and it facilitates updating the VBA application.

Nitrate emissions were calculated according to the following regression model (Faist Emmenegger et al., 2009):

$$N = 21.37 + \frac{P}{c \cdot L}\left[0.0037 \cdot S + 0.0000601 \cdot N_{org} - 0.00362 \cdot U\right]$$

Where:

- N: quantity of nitrogen leached [kg N · ha^{-1} · year^{-1}]
- P: precipitation and watering, in mm per year
- c: soil clay content, in basis 100
- L: rooting depth, in meters
- S: nitrogen supply, including crop residues [kg N · ha^{-1}]

- N_{org}: quantity ot nitrogen in the soil organic matter [kg N · ha^{-1}]
- U: nitrogen uptake [kg N · ha^{-1}]

A conversion factor of 62/14 was applied to the calculated emissions of nitrate in terms of N.

4.5 Emissions of nitrous oxide (N_2O) to air

Nitrous oxide (N_2O) results from nitrification and denitrification processes. The global warming potential (GWP) of N_2O for a time horizon of 100 years is 310 times the GWP of CO_2 (IPCC, 2006).

N_2O emissions were calculated according to the following equation (IPCC, 2006):

$$N_2O = \frac{44}{28} \cdot \left(0.01 \cdot \left(N_{tot} + N_{cr} + \frac{14}{17} \cdot NH_3 + \frac{14}{46} \cdot NOx\right) + 0.0075 \cdot \frac{14}{62} \cdot NO_3\right)$$

Where:

- N_2O: emissions of nitrous oxide [kg N_2O · ha^{-1}]
- N_{tot}: total nitrogen in mineral and organic fertilizer [kg N · ha^{-1}]
- N_{cr}: nitrogen contained in the crop residues [kg N · ha^{-1}]
- NH_3: losses of nitrogen in the form of ammonia [kg NH_3 · ha^{-1}]
- NOx: losses of nitrogen in the form of nitrogen oxides [kg NO_2 · ha^{-1}]
- NO_3: losses of nitrogen in the form of nitrate [kg NO_3 · ha^{-1}]

4.6 Carbon dioxide (CO_2) from liming and urea application

The aim of applying lime in agricultural soils is to decrease soil acidity and to improve plant development. The addition of carbonates by means of limestone or dolomite entails the dissolution of carbonate limes and the release of bicarbonate ($2HCO_3^-$). Subsequently, the bicarbonate is transformed into CO_2 and water (IPCC, 2006).

In agreement with the AGRIBALYSE® methodology (Koch and Salou, 2015), the WFLDB (Nemecek et al., 2014), and ecoinvent (Nemecek and Schnetzer, 2011), carbon dioxide emissions generated from the application of lime and urea were calculated according to IPCC (2006) Tier 1. The calculated emissions are based on a worst-case approach because it is considered that the total amount of carbon is released in the form of CO_2.

CO_2 emissions from lime application:

$$CO_2 - C_{Emission} = M_{limestone} \cdot EF_{limestone} + M_{dolomite} \cdot EF_{dolomite}$$

Where:

- CO_2-$C_{Emissions}$: C emissions from lime application, tonnes C · yr^{-1}
- M: annual amount of calcic limestone or dolomite, tonnes · yr^{-1}
- EF: emission factor, tonne of C · (tonne of limestone or dolomite)$^{-1}$

Table 4.1: EF-Emission factor (kg of C · kg of product^{-1})

Product	EF
Limestone	0.12
Dolomite	0.13
Urea	1.57

Finally, a factor of 44/12 is applied to transform the emissions in terms of carbon into emissions based on carbon dioxide.

$$CO_2 = \frac{44}{12} \cdot CO_2 - C_{Emission}$$

4.7 Phosphorus emissions

In agreement with the AGRIBALYSE® methodology (Koch and Salou, 2015), the WFLDB methodology (Nemecek et al., 2014) and the ecoinvent methodology (Nemecek and Schnetzer, 2011), emissions of phosphorous to water were calculated by applying the SALCA-P model (Prasuhn, 2006).

The SALCA-P model computes three types of emissions to water according to the mechanism generating them:

- Phosphorus to river (emission by soil loss)

- Phosphate to ground water (emission by leaching).
- Phosphate to river (emission by run-off)

4.7.1 Phosphorus to river (emission by soil loss)

Emissions of phosphorus by soil loss were calculated according to the following equation (Prasuhn, 2006):

$$P_E = A \cdot P_S \cdot F_R \cdot F_{SR} \cdot t$$

Where:

- P_E: phosphorus emitted by soil loss to rivers [kg.ha^{-1}.yr^{-1}]
- A: quantity of soil lost [kg.ha^{-1}.yr^{-1}]
- t: land occupation time (number of days/365)

Table 4.2: Parameters for calculating phosphorous emissions to river (Prasuhn, 2006)

Parameter	Definition	Default value	Units
P_S	Phosphorous content in the upper part of the soil	0.00095	kg P · kg soil^{-1}
F_R	Eroded particle enrichment factor	1.86	-
F_{SR}	Fraction of soil lost that reaches the river	0.2	-

4.7.2 Phosphate to ground water (emission by leaching)

Leaching of phosphate to ground water was calculated according to the following equation (Prasuhn, 2006):

$$P_L = P_{LM} \cdot F_{CSS} \cdot t$$

Where:

- P_L: leached phosphorus [kg.ha^{-1}.yr^{-1}]
- P_{LM}: average quantity of phosphorus leached depending on the land occupation category [kg P.ha^{-1}.yr^{-1}]

- F_{CSS}: correction factor for fertilization with slurry and/or sludge (see equation below)
- t: occupation time (number of days/365)

A conversion factor of 95/31 was applied to convert emissions of phosphorus into emissions of phosphate.

$$F_{CSS} = 1 + \frac{0.2 \cdot (P_2O_{5-slurry\ and\ sludge})}{80}$$

4.7.3 Phosphate to river (emission by run-off)

Emissions of phosphate to river by run-off were calculated according to the following equation (Prasuhn, 2006):

$$P_R = P_{RM} \cdot F_C \cdot F_S \cdot t$$

Where:

- P_R: phosphorus lost by run-off to the rivers [kg.ha^{-1}.yr^{-1}]
- P_{RM}: average quantity of phosphorus lost by run-off depending on the land occupation category [kg P.ha^{-1}.yr^{-1}]
- F_C: correction factor for the form of phosphorus applied (mineral, liquid/solid organic)
- F_S: slope factor. $F_S = 0$ if slope $< 3\%$, $F_S = 1$, otherwise.
- t: occupation time (number of days/365)

$$F_C = 1 + \frac{0.7 \cdot P_2O_{5-slurry\ and\ sludge} + 0.2 \cdot P_2O_{5-mineral\ fertilizer} + 0.4 \cdot P_2O_{5-manure\ and\ compost}}{80}$$

A conversion factor of 95/31 was applied to convert emissions of phosphorus into emissions of phosphate.

4.8 Heavy metal emissions to agricultural soil, surface water and ground water

Emissions of heavy metals to soil, ground and surface water are calculated based on a mass balance. The inputs considered are seeds, fertilizers, soil amendments, metal-based pesticides and air deposition. The outputs correspond to the emissions of trace metals into ground and surface water and the products harvested.

4.8.1 Heavy metal emissions to agricultural soils

The mass balance of trace metal *(TM) x* in soil is calculated according to the following equation (Koch and Salou, 2015):

$$\Delta F_{TMx} = \sum_{SFPI_y} IN_y \cdot C_{y,x} - \Big(\sum_{PLR_z} OUT_z \cdot C_{z,x} \Big) \cdot Alloc_x \quad \forall x \in \{Cd, Cu, Zn, Pb, Ni, Cr, Hg\}$$

Where:

- *ΔFTMx*: Flow into the soil of *Trace Metal x (TMx)*
- *INy*: Quantity of input *SFPIy* containing TMx:
  - Seed
  - Fertilizer (mineral, organic, farm, sludge)
  - Pesticides
  - Sundry Inputs
- *Cy,x*: Content of *TMx* in input *SFPIy*
- *OUTz*: Quantity of output *PLRz* carrying the trace metal *TMx*
  - Products harvested (including co-products and/or residues exported)
  - Leaching to groundwater
  - Run-off to surface water by soil loss
- *Cz,x*: Content of *TMx* in output PLRz
- $Alloc_x$: Allocation factor for TMx output flow. This allocation factor only takes account of part of the output flows from the deposition of trace metals. The allocation is calculated for each trace metal:

$$Alloc_x = \frac{\sum_{SFPIy} IN_y \cdot T_{y,x}}{\sum_{SFPIy} IN_y \cdot T_{y,x} + Dep_x}$$

4.8.2 Heavy metal emissions to river

Trace metal emissions through erosion are calculated according to the following equation (Koch and Salou, 2015):

$$M_{erosion,TMx} = A \cdot S_{TMx} \cdot F_R \cdot F_{SR} \cdot t \cdot Alloc_x$$

Where:

- $M_{erosion,TM}x$: emission of trace metal x to river [kg · ha^{-1} · yr^{-1}]
- A: amount of soil lost [kg · ha^{-1} · yr^{-1}]
- S_{TMx}: the content of trace metal x in the upper part of the soil
- F_R: eroded particle enrichment factor
- F_{SR}: fraction of soil lost which reaches the river
- t: land occupation time (number of days/365)
- $Alloc_x$: allocation factor for trace metal x

The amount of soil lost was calculated by applying the RUSLE equation. An average concentration of trace metals depending on the soil use was considered. The eroded particle enrichment factor and the fraction of soil lost that reaches the river took the default values considered in the AGRIBALYSE® methodology (Koch and Salou, 2015). Please refer to Section 4.7 to retrieve the last two parameters.

4.8.3 Heavy metal emissions to ground water

Trace metal emissions into ground water were calculated according to the following equation (Koch and Salou, 2015):

$$M_{leachng,TMx} = m_{leaching,TMx} \cdot Alloc_x$$

Where:

- $M_{leaching,TMx}$: emission of trace metal x to ground water [kg · ha^{-1} · yr^{-1}]
- $m_{leaching,TMx}$: average emission of trace metal x to ground water [kg · ha^{-1} · yr^{-1}]
- $Alloc_x$: allocation factor for trace metal x.

Bibliography

Durlinger, B., Koukouna, E., Broekema, R., van Paassen, M., and Scholten, J. (2017). Agri-footprint 4.0. part 2: Description of data. page 193.

EMEP-EEA (2009).

EMEP-EEA (2013).

Faist Emmenegger, M., Reinhard, J., and Zah, R. (2009). Sustainability quick check for biofuels–intermediate background report. *With contributions from T. Ziep, R. Weichbrodt, Prof. Dr. V. Wohlgemuth, FHTW Berlin and A, Roches, R. Freiermuth Knuchel, Dr. G Gaillard, Agroscope Reckenholz-Tänikon, Düendorf, Germany.*

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme.* IGES, Japan.

Koch, P. and Salou, T. (2015). *AGRIBALYSE: Rapport Méthodologique - Version 1.2.* ADEME, Angers, France.

Nemecek, T., Bengoa, X., Lansche, J., Mouron, P., Rossi, V., and Humbert, S. (2014). Methodological guidelines for the life cycle inventory of agricultural products. version 2.0, july 2014. *World Food LCA Database (WFLDB). Quantis and Agroscope, Lausanne and Zurich, Switzerland.*

Nemecek, T. and Schnetzer, J. (2011). Methods of assessment of direct field emissions for lcis of agricultural production systems. data v3.0 (2012). *Agroscope Reckenholz-Tänikon Research Station ART.*

Prasuhn, V. (2006). Erfassung der po4-austräge für die Ökobilanzierung. *SALCA-Phosphor. Zürich, CH, Agrocope FAL Reckenholz.*