Documentation for the Agricultural LCI Model in GaBi

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1 Introduction

Due to the determinantal influence of environmental conditions being variable in time and space at a high heterogeneity of site conditions, agrarian systems belong to the most complex production systems, due to:

- the variety of different locations
- small scale soil variability within locations
- the large number of farms
- the variety of agricultural practices
- no determined (or at least controlled) border to the environment
- complex and indirect dependence of the output (harvest, emissions) from the input (fertilizers, location conditions)
- variable weather conditions within and between different years
- variable pest populations (insects, weeds, disease pathogens)
- different crop rotations
- land use and land use change
- water use

Considering the inherent complexity characterizing agricultural systems, a nonlinear complex agrarian model is used for plant production (originally developed by Sphera and the University of Stuttgart, Germany). At the same time, detailed data on many of these factors and their specific interaction is not known or measured, except for single geographical locations and in research projects or in production trials. Nevertheless, this model covers a multitude of input data, emission factors and parameters, and explicitly depicts key management factors and effects, including different crop rotations, land use and land use change and water use.

The agricultural model that is used to develop datasets of agriculture and plantation products for the GaBi Databases is:

- a mixed-balance model with different compartments and a simplified time resolution
- a flexible, useful model
- highly parameterized
- contains many background processes
- applicable for any agrarian and plantation product in the world.

2 System boundary

The model includes cradle-to-gate burdens for all relevant input materials in the cultivation process itself (commercial fertilizer, including lime, organic fertilizer, pesticides and seeds, and their production and transportation). The model includes the cradle-to-gate emissions for consumed fuel and the direct emissions to air from combustion. The production of pesticides and emissions occurring during and after their application are also included.

The model includes irrigation when relevant and excludes agricultural infrastructure and farm buildings. All processes taking place in the area under cultivation, including emissions into air and ground water (lower limit of rooted soil zone), are considered.

Heavy metals remaining in the soil are considered as emissions to agricultural soil. Integration of erosive loss of N_{org} (organic nitrogen) and C_{org} (organic carbon) as well as of nutrients (e.g., phosphorus) to water are considered.

3 Time reference

For annual crops, a cultivation period is considered beginning immediately after the harvest of the preceding crop and ending after harvest of the respective cultivar. In the case of perennial cultivars (i.e., plantations), the process starts with plantation preparation (ground clearing) and lasts until the respective cultivar must be cleared for further uses.

4 Input seeds/seed stock

Seeds and/or seed stock is considered based on specific data about the amount and kind of seeds/seed stock. Information on the production of seeds/seed stock is based on literature data and modelled separately in GaBi.

5 Irrigation

Water use is modelled based on the calculations of PFISTER S, ET AL. A generic water model allows the selection of different plant water requirements and irrigation regimes, depending on the specific regional conditions (e.g., precipitation, irrigation demand and irrigation technique). For details, please refer to PFISTER S, ET AL. (2011).

Results describe water usage in terms of [m^3 / 1000 kg product]. This indicator consists of groundwater, river and surface water used for irrigation, as well as upstream water, such as water use related to electricity production. Please refer to the GaBi Documentation: “Introduction to water assessment in GaBi Software”[1] for details on terminology and methodology of water assessment in GaBi.

6 Crop protection

Pesticide production is covered, among others, by data from ANDREAE MO AND MERLET P (2002) and AUDSLEY E, ET AL. (2009) . Representative datasets for herbicides, insecticides, fungicides, seed treatments and plant growth regulator production were modelled in GaBi based on patents and literature data.

In cases when pesticide is sprayed, the amount of diesel consumption is based on primary data, verified literature data or — in case primary and literature data is unavailable — based on KTBL (2009) data estimations. Pesticide applications and the impact of the pesticide itself on the environment are based on the PestLCI approach developed by DIJKMAN TJ, ET AL. (2012).

PestLCI is a Life Cycle Inventory model for estimating pesticide emissions from the techno-sphere, which is defined as from the field to the air, to the surface water and to the groundwater. PestLCI defines the techno-sphere as the agricultural soil down to 1 meter of depth and the air column above it, up to 100 meters above the soil. Only when a pesticide crosses these system boundaries it is considered an emission. Within this techno-sphere, a number of processes are modelled. Some of these processes (for example volatilization and runoff) lead to emissions to the environment. Other processes (such as degradation) result in the removal of the pesticide from the system.

Using PestLCI, more than hundred realistic scenarios are created considering input parameters, such as crop, active ingredient and location. Out of these scenarios, average emission factors are derived from pesticide emissions to air, surface and groundwater. Some specific input parameters can result in a high variability of results. To cope with this, the median of emission factors derived out of the performed scenarios is chosen, because this value is more robust against outlier values.

7 Slash and Burn

The process of slash and burn comprises of three sub-models modelled in the same process:

- The first sub-model refers to the use of machines for surface preparation, such as clearing

[1] http://www.gabi-software.com/fileadmin/Documents/Introduction_to_Water_Assessment_V2.2_03.pdf

- The second sub-model refers to the amount of burned biomass: nitrogen, carbon and sulphur content of the bio-mass and also to the amount that transitions into combustion gases
- The third sub-model is based on a publication with many field measurements from the USA (ANDREAE MO AND MERLET P (2002)), in which the composition of the flue gases of uncontrolled biomass combustion is published as factors. Thus, the emission profile, for example, a slash-and-burn or the burning of straw after the harvest, can be calculated and inventoried.

8 Reference system

The reference system is an inverse process used to assess the behaviour of land that is not used agriculturally or influenced anthropogenically. In particular, losses of nitrate to groundwater and emission of gaseous nitrogen compounds that result from nitrogen deposition into this land are considered. This takes place in both the main cropping system as well as on land not under cultivation. Therefore, not all occurring emissions can be assigned to the crop, because they also occur on non-cultivated land, for example, if the land is fallow or a nature reserve. Here it is assumed that the nitrogen balance is neutral for the reference system, as any entry of nitrogen with rainfall is re-emitted from the systems in various forms into ground water and air.

In addition to the emission of nitrogen compounds, soil erosion is mapped in a way that includes the associated conditional entries of organic carbon contained in the soil and some heavy metals in surface waters. It is assumed that this erosion occurs to a lesser extent in non-utilized natural systems and therefore cannot be assigned completely to the main crop.

9 Land Use

Inventory data on crop and country-specific kinds of land use is provided for the foreground system using the ILCD/EF land use flows for “occupation,” “transformation to” and “transformation from”. The LANCA® characterization factors version 2.5, as published by HORN AND MAIER 2018, are integrated into the GaBi databases. The LANCA® impact categories of erosion resistance, mechanical filtration, physicochemical filtration, groundwater regeneration and biotic production are considered (BOS U, ET AL. (2016A)). For further information, please also refer to the specific documentation: “Documentation of Land Use Inventory in GaBi”.[2]

[2] http://www.gabi-software.com/fileadmin/Documents/Land_use__LANCA__in_GaBi_V1.1.pdf

10 Land Use Change

Direct land use change (dLUC): Emissions from direct land use change are calculated for the approach "weighted average" (as required for compliance with the ENVIFOOD protocol; and can be applied for compliance with WRI GHG Protocol) based on the approach from PAS 2050-1:2012 and WRI GHG protocol. The calculations for carbon stock changes are based on IPCC rules: The basic approach is to determine the total carbon stock change by assessing the difference between carbon stocks of the agricultural area — including both, soil and vegetation — of the previous and the changed situation. The assumptions for carbon stocks depend on country, climate and soil type. The approach is crop-specific: The impacts from land use change are allocated to all crops for which the 'area harvested' increased over time in a specific country. This depends on the crop's respective share of area increase. There are three different calculation approaches that can be applied (1: country is known and the previous land use is known, 2: the country is known and the previous land use is unknown, 3: the country is unknown and the previous land use in unknown). For all GaBi datasets the following situation is applied: The country is known (as defined by the respective dataset), but the previous land use is by default unknown. The emissions occurring due to the land use change are distributed over a period of 20 years.

Underlying sources for the calculations are statistical data from:

- FAOSTAT for crop yields, harvested area of crops and area of forest and grassland,
- FAO's global forest resource assessment for carbon stocks (in case former land use is unknown)
- IPCC Guidelines, Volume 4, for climate zones and soil type map
- IPCC 2006 for above-ground mass carbon stock (if land use change is known), values of soil organic carbon stock and stock change factors.

This methodology takes changes in soil organic carbon stock into account. The emissions that are calculated are connected in the model per hectare and are scaled per reference unit respectively. The emissions are reported separately with the flow "carbon dioxide from land use change" as required by certain standards. The emissions are per default directly released as carbon dioxide. In case different information is available, partly incineration is applied and is explicitly described in the respective dataset.

Indirect land use change (iLUC): iLUC is not considered.

Please refer to the document "Documentation for Land Use Change Emissions Evaluation in GaBi" for further details[3].

[3] http://www.gabi-software.com/index.php?id=8375

11 Carbon modeling

Carbon-based emissions, such as CH_4, CO and CO_2, are considered in foreground and background datasets. Background datasets include emissions resulting from the production of fertilizer, pesticides, electricity and diesel, while foreground datasets contain emissions such as CO_2 due to combustion of fossil fuels by the tractor or irrigation engines and application and decomposition of urea fertilizer in the soil.

Aside from emissions, positive effects (sinks) due to natural conversion of gases in the soil are considered. The biogenic CO_2 sequestered in the plant and its further products is accounted for in the inventory. The biogenic CO_2 is manually calculated following the carbon dioxide equation mentioned below, and thus some of the CO_2 flows have to be corrected:

$$C\_CO_{2\ in} = C\_CO_{2\ out} + C\_CO_{2\ accumulated\ in\ the\ product} + C\_CH_4\ biogenic$$

Four carbon dioxide flows are reported in the inventory:

- The carbon dioxide uptake by growing biomass: Carbon dioxide [Resources]
- Carbon emissions to air: Carbon dioxide [Inorganic emission to air]
- Biogenic carbon emissions to air: Carbon dioxide (biogenic) [Inorganic emission to air]
- Biogenic methane emissions to air: Methane (biogenic) [Organic emission to air]

12 Nitrogen modeling

Nitrogen plays a fundamental role for agricultural productivity and is also a major driver for the environmental performance of an agricultural production system, according to EICKHOUT B, ET AL. (2006). For these reasons it is essential to evaluate all relevant nitrogen flows within, to and from the agricultural system. Sphera's agricultural model accounts for the nitrogen cycle that occurs in agricultural systems, as shown in Figure 1.

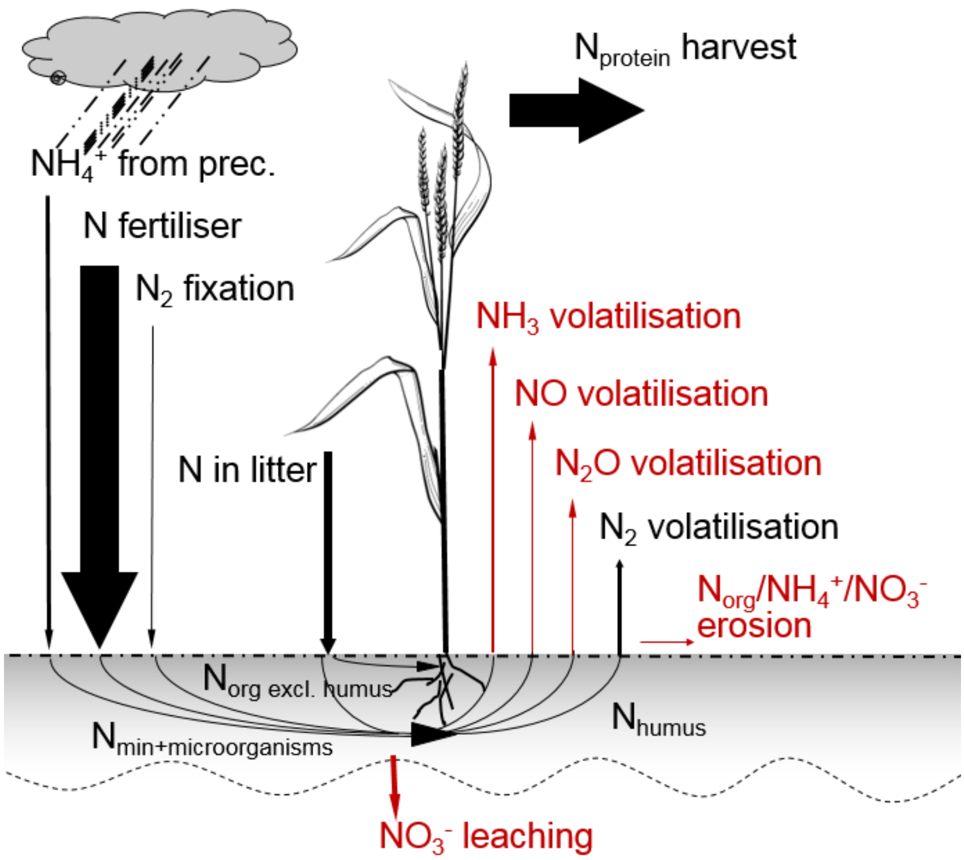

Figure. 1: N-flows in agricultural systems, schematic. Red = LCA-relevant emissions pathways © Sphera

The agricultural model consists of several sub-models. The actual processes are interconnected and therefore modelled together in just one process.

In principle, the model considers two themes:

- Allocation of fertilizer in crop rotations.
- The N losses as NO_3- into the groundwater and NH_3, N_2O and N_2 into the air and on soil erosion as NO_3- and N_{org} in surface waters during the cultivation of the main crop.

Moreover, the model ensures that nitrogen emissions are consistent for the cultivated species. Specifically, the model includes emissions of nitrate (NO_{3-}) to water and nitrous oxide (N_2O), nitrogen oxide (NO) and ammonia (NH_3) into air. The model ensures that emissions from erosion and nutrient transfers within crop rotations are modelled consistently. The figure above shows the most important nitrogen flows illustrated by an intensive cultivation system of an example grain.

The different N-based emissions are calculated as follows:

- NH_3 emissions to air from mineral and organic fertilizers are adapted from the model of BRENTRUP F, ET AL. (2000) and modeled specifically for the cropping system, depending on the fertilizer-NH_4^+ content, the soil-pH, rainfall and temperature. The following emission factors are used by default and adjusted in case more specific information is available. For ammonium nitrate, calcium ammonium nitrate, monoammonium phosphate, diammonium phosphate 2% of fertilizer N input, for ammonium sulphate 10%, for urea ammonium nitrate 8% and for urea 15% of N inputs are emitted. These values are identical with data from DÖHLER H, ET AL. (2002) (with exception NH_3-N).
- N_2 is the final product resulting from denitrification. Denitrification is a process of microbial nitrate reduction that ultimately produces molecular nitrogen through a series of intermediate gaseous nitrogen oxide products. N_2 emissions are assumed to be 9% of the N-fertilizer input based on a literature review made by VAN CLEEMPUT O (1998). N_2 emissons need to be modelled to ensure the overall N balance is complete.
- NO is an intermediate product produced in microbial denitrification. NO emissions are calculated from the reference system after N-input from air plus 0.43% of the N-fertilizer input specific for the cultivation system as NO according to BOUWMAN AF, ET AL. (2002).
- N_2O is an intermediate product produced in microbial denitrification. According to IPCC (2006), N_2O emissions are calculated as 1% of all nitrogen available, including nitrogen applied with fertilizers, atmospheric deposition, microbial nitrogen fixation, nitrogen available from previous crop cultivation and indirect emissions.
- NO_3^- emissions to groundwater is calculated based on available nitrogen (N not lost in gaseous form or taken up by the plant, stored in litter, storage in soil, etc.). Depending on the quantity of leaching water and the soil type, a fraction of this available nitrogen is calculated as leached nitrate. When available, N is calculated and the result is negative (for instance due to a higher extraction in the crop than fertilizer input), a minimum N-loss factor is used on the applied fertilizer and N_{min} quantity, that is, a minimum loss of NO3- with percolating water is always considered.
- N_{org} and NO_3^- emissions to water also occur due to erosive surface run-off. It is very difficult to generalize erosion rates and deposition rates, because they are highly dependent on regional conditions, such as climate, relief, soiltype and crop cultivated and downslope vegetation. Soil erosion rates are estimated based on WURBS D AND STEININGER M (2011). It is assumed that 10% of the eroded soil accesses the waters, based on an evaluation of different literature sources like FUCHS S AND SCHWARZ M (2007), HILLENBRAND T, ET AL. (2005), HELBIG H, ET AL. (2009), NEARING MA, ET AL. (2005), while the rest accumulates to colluviums on other land surfaces and is assumed irrelevant in the life cycle assessment.

13 Phosphorous modeling

Besides nitrogen-based emissions to water and air, phosphorus emissions are taken into consideration in the model. However, phosphorus is a stable compound that does not significantly leach into groundwater but is mostly washed out with surface runoff of soil to surface water, causing eutrophication of water bodies. Erosion rates are taken from literature. Based on the erosion rate, it is assumed that 10% of the eroded soil accesses the water while the rest accumulates in colluviums on other surfaces and is assumed irrelevant in the life cycle assessment.

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