Proceeding of the 7th Int. conference on life cycle assessment in the agri-food sector, Bari, Italy, 22-24 September 2010, pp. 433-438

The advantages of generic LCA tools for agriculture: examples SALCAcrop and SALCAfarm

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ABSTRACT

Due to the large variability and small-scale structures of agricultural production, numerous LCA calculations are required to properly represent the actual situation. This calls for efficient procedures. Generic LCA tools enable to standardise and automate the calculations and to ensure a consistent modelling of all situations. This paper presents the LCA tools SALCAcrop and SALCAfarm developed within the Swiss Agricultural Life Cycle Assessment framework. They enable batch calculations for dozens of crops and farms respectively. In a first step, the direct field and farm emissions are calculated by modules for erosion, nitrate, heavy metals, other field emissions, and emissions from animal husbandry. In a second step the full LCI and LCIA are calculated with standard LCA software. The impacts on biodiversity and soil quality are assessed by separate modules.

Keywords: crop LCA, farm LCA, calculation tool, module

1. Introduction

In contrast to some industries dominated by relatively few big companies with large, standardised production facilities, farms are quite small and there thousands of production units for the same product (e.g. milk) exist in general. In 2007, over 5 million farms were counted in EU-27 (FADN, 2010). Several LCA studies highlight the huge variation of the environmental impacts between farms for a given product (e.g. Alig *et al.*, 2008; Mouron *et al.*, 2006; van der Werf *et al.*, 2009). This means that large samples are needed to get reliable estimates of environmental impacts of the agricultural production. The same situation applies if environmental impacts of crops are studied. Due to the diversity of pedo-climatic conditions, management practices, cultivars, etc. the variability of impacts is considerable (Nemecek & Kägi, 2008).

Efficient procedures are thus needed to handle such a big number of datasets. Case by case modelling of each individual situation is not feasible and bears furthermore the risk of errors and inconsistencies, since not all situations are handled equally. To remediate this situation, ART has been working since ten years on generic LCA calculation tools for crops and farms.

2. The LCA tools SALCAcrop and SALCAfarm

Two LCA tools have been developed within the SALCA (Swiss Agricultural Life Cycle Assessment) framework:

- SALCAcrop: a generic tool to calculate LCAs of agricultural crops. It covers about 140 arable crops, vegetables, permanent crops as well as different types of grassland and animal pasturing. It is valid for conditions of Central Europe. By simultaneous consideration of several crops, including cover crops, SALCAcrop is also used to calculate crop rotations LCA.

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- SALCAfarm: a generic tool to calculate farm LCAs under Swiss conditions. The tool covers all types of farms. In addition to farm LCA results, the tool is also appropriate to calculate product LCAs like for animal products. The considered time period is one year.

2.1. IT implementation

Parameters describe the management of the farm or the crop under investigation; up to several thousand parameters may be needed to describe complex farms, depending on the number of fields and the degree of diversification. These parameters quantify inputs like machinery, fuel, buildings, fertilisers, pesticides, feedstuffs, purchased animals and management issues like the timing of nitrogen application or the type of the animal husbandry system. A modular structure (see Figure 1) enables to manage the complexity. Each module has a clear input and output interface and can be used within the SALCAcrop and SALCAfarm tools as well as for independent calculations.

The tools are implemented as a combination of EXCEL sheets, macros and standard LCA software. They are currently being migrated from the software TEAM to SimaPro. SALCAbiodiversity is a standalone Java-based application.

For SALCAfarm, we implemented a complete workflow covering data collection at the farm (with farm management software), data extraction with plausibility tests, LCA calculation, validation, interpretation and data export towards the Swiss FADN database (Nemecek *et al.*, 2009).

Figure 1 shows the workflow of the SALCAcrop tool. The data entry is performed in an EXCEL template, called production inventory; each of its columns represents a crop. A macro copies the data from the production inventory to the so-called PI transfer file, from which the parameters required for each module are extracted. The respective macros then copy the input parameters into each of the modules that calculate heavy metal emission, erosion losses, nitrate leaching and other field emissions. The results of these calculations are transferred back into the PI transfer file. In the case of crop rotation LCA this procedure is repeated for each crop present in the production inventory. As a next step the amounts of inputs required as well the direct emissions are passed on to the LCA software. The latter calculates the final LCI results and performs the impact assessment. The assessments of soil quality and biodiversity are processed separately; the former is integrated in the automated processing, while the latter is not (yet) integrated. The different modules can be used within the automated processing, but also as stand-alone applications.

The more complex calculations of SALCAfarm are performed at four different levels:

- *Whole farm*
- *Product group* (14 products groups like cereals, milk or pig meat were defined to describe the different outputs of agriculture; most of the farms have only a few of these product groups). The sum of all product groups equals the whole farm.
- The *fields* represent the crops grown on a field during one year. There can be several crops at the same time (spatial division) or a sequence of crops and catch crops (temporal division). Each field belongs to one or several product groups, depending on the use of the products. The calculation is repeated for each field on the farm.
- The *crops* are the smallest unit. The calculation is repeated for each crop on the field.

Calculation at field and crop level are performed only where strictly required, like for erosion losses, nitrate leaching or other field emissions. Calculation of heavy metals and emissions from animal husbandry are performed only at farm level. Therefore, the calculation of SALCAfarm needs to observe a certain order, as represented by Figure 2.

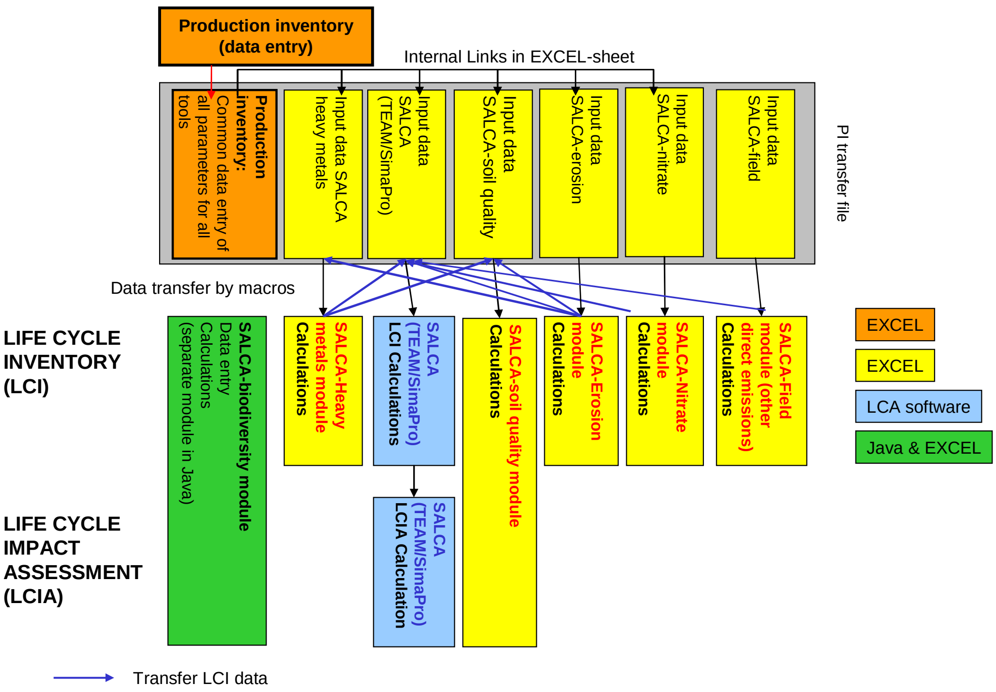

Figure 1: Modular architecture of the SALCAcrop calculation tool.

	Calculation level		
Module	**Crop**	**Field**	**Farm / product group**
SALCAerosion	↻	↻	
SALCAnitrate	↻	↻	
SALCAfield	↻	↻	
SALCAheavyMetals			↻
SALCAanimal			↻

Figure 2: Order of calculation of the different modules in SALCAfarm.

2.2. LCI databases

The LCI data stem from the ecoinvent database (ecoinvent Centre, 2007) or from the SALCA database, which itself relies on the ecoinvent database and follows the ecoinvent quality guidelines. The SALCA database contains specific datasets for agricultural inputs, outputs and processes.

2.3. Calculation of direct field and farm emissions

The tools contain modules for the calculation of direct field and farm emissions:

- The losses of *ammonia* (NH_3) from mineral nitrogen fertilisers are calculated with constant emission factors according to Menzi *et al.* (1997), ranging from 2% to 15% (from Asman, 1992), dependent on the type of fertiliser. For the application of farmyard manure, the ammonium content, the quantity applied and the application technique are considered. For slurry and liquid manure we included further the saturation deficit of the air (calculated in monthly steps). Ammonia volatilisation from slurry and liquid manure can be very high. In unfavourable conditions most of the ammonium can be volatilised as ammonia. The emission factor for total nitrogen excreted on pastures is 5%. The emissions from animal husbandry and manure management are calculated by considering the animal category, the housing system, manure (liquid or solid) and pasture.
- Direct and induced emissions of *nitrous oxide* (N_2O) are considered according to the IPCC method version 2006 (updating is currently perfomed). Direct emissions come from the application of nitrogen fertiliser (factor 1% of N released as N_2O), incorporation of crop residues (1% of the N released as N_2O). In addition to the direct emissions, induced emissions from ammonia and nitrate losses were considered. The respective factors are 1% for ammonia-N and 0.75% for nitrate-N. Emissions from manure storage are 0.5% of the N in slurry and liquid manure and 2% of the N in solid manure.
- Three paths of *phosphorus* emissions to water are included, namely run-off as phosphate and erosion as phosphorus to rivers as well as leaching to ground water as phosphate (Prasuhn, 2006). The land-use category, the type of fertiliser, the quantity of P spread, characteristics and duration of soil cover (for erosion) are considered.
- *Nitrate* (NO_3^-) leaching is estimated on a monthly basis by accounting for N mineralisation in the soil and N-uptake by the vegetation, specific to each crop (Richner *et al.*, 2006). If mineralisation exceeds uptake, nitrate leaching can potentially occur. In addition, the risk of nitrate leaching from fertiliser application during unfavourable periods is calculated, taking into account the crop, month of application and the potential rooting depth.
- *Heavy metal emissions* (Cd, Cr, Cu, Hg, Ni, Pb, Zn) are assessed by an input-output balance (Freiermuth, 2006). The following inputs were considered: seed, fertilisers and pesticides. Outputs by harvested products, erosion and leaching were included. Only part of the quantities lost to the aquatic environment by erosion or leaching was considered, since the farmer controls these processes to some extent only due to the deposition of heavy metals. The allocation factor was derived from the share of agricultural inputs in the total inputs (including deposition).
- *Methane* (CH_4) *emissions* from enteric fermentation and manure management are calculated by using emission factors from IPCC (2006) and considering the amount and quality of the feed and the manure management system.

2.4. Impact assessment methodology

Within the SALCA framework impact categories and impact assessment methods relevant to agricultural systems have been selected. The selection is based on mid-point categories, mainly from the methods EDIP2003 (Hauschild *et al.*, 2006) and CML01 (Guinée et al., 2001). The following environmental impacts are considered:

- Demand for non-renewable energy resources (oil, coal and lignite, natural gas and uranium), using the upper heating or gross calorific value for fossil fuels according to Frischknecht et al. (2004).
- Global warming potential over 100 years (according to IPCC, 2007).

- Ozone formation potential (so-called "summer smog" according to the EDIP2003 method).
- Eutrophication potential (impact of the losses of N and P to aquatic and terrestrial ecosystems, according to the EDIP2003 method).
- Acidification potential (impact of acidifying substances released into ecosystems, according to the EDIP2003 method).
- Terrestrial and aquatic ecotoxicity potentials (according to the CML01 method). Characterisation factors for about 400 pesticide active ingredients were complemented (Kägi *et al.*, 2008).
- Human toxicity potential (impact of toxic pollutants on human health, according to the CML01 method, Guinée et al., 2001).

In addition to these impact categories typically considered in LCAs, two new categories with high relevance for agricultural systems were included: the SALCA biodiversity method (Jeanneret *et al.*, 2006; Jeanneret *et al.*, 2008) assesses the impacts of cultivation practices on eleven groups of indicator organisms (flora, birds, mammals, amphibians, snails, spiders, carabids, butterflies, wild bees, and grasshoppers) by considering two characteristics, namely 1. the overall species diversity and 2. the diversity of ecologically very demanding species (stenotopic) and those of high conservation value (red list). The biodiversity score can be normalised on a scale ranging from 0% to 100% in order to place the results within a span of potentially obtainable results. The SALCA soil quality method assesses the impacts of cultivation practices on nine soil quality indicators, representing physical (rooting depth, macropore volume, aggregate stability), chemical (Corg content, heavy metal content, organic pollutants) and biological properties (earthworm biomass, microbial biomass, microbial activity) of the soil (Oberholzer *et al.*, 2006).

2.5. Interpretation and communication of results

Stakeholders are usually less familiar with the environmental information provided by LCA. Therefore it is important to integrate the environmental results delivered by the tools in interpretation schemes for agricultural LCA. An example of such a scheme is the interpretation and communication concept for environmental farm management developed by (Alig *et al.*, 2008).

3. Conclusions

The advantages of using generic LCA tools are manifold: the calculation procedure is faster and can be automated and standardised. This ensures consistent modelling and LCA calculations. It is more reliable and errors can be detected more easily, since the tools can be used by many practitioners. Developments of the methodology and improvement of the tools can be rapidly applied to all types of LCA calculations. We are convinced that the construction of such generic tools is a prerequisite for the handling of large datasets, and dealing with variability and complexity of agricultural systems, and therefore for further progress in agricultural LCA.

4. References

Alig M., Gaillard G., Müller G. (2008): LCM in agriculture: enhancing the self-responsibility of farmers. In: Proceedings of the 6th International Conference on LCA in the Agri-Food Sector – Towards a sustainable management of the Food chain. Nemecek T., Gaillard G. (eds.). November 12–14, 2008, Zurich. Agroscope ART, pp. 312-317.

Asman W.A.H. (1992): Ammonia emission in Europe: updated emission and emission variations. National Inst. of Public Health and Environmental Protection, Bilthoven, Report.

ecoinvent Centre (2007): ecoinvent Data - The Life Cycle Inventory Data. Swiss Centre for Life Cycle Inventories, Dübendorf, ISBN 3-905594-38-2 Available at http://www.ecoinvent.org/documentation/reports/.

FADN (2010): Farm Accountancy Data Network - FADN Public Database. Accessed 8.4.2010. Available at http://ec.europa.eu/agriculture/rica/database/database.cfm.

Freiermuth R. (2006): Modell zur Berechnung der Schwermetallflüsse in der Landwirtschaftlichen Ökobilanz. Agroscope FAL Reckenholz, 42 p., Available at http://www.agroscope.admin.ch/oekobilanzen/01194/.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Hellweg S., Hischier R., Nemecek T., Margni M., Spielmann M. (2004): Implementation of life cycle assessment methods - ecoinvent data v1.1. Swiss Centre for Life Cycle Inventories (ecoinvent), Dübendorf, ecoinvent report, 116 p..

Hauschild M.Z., Potting J., Hertel O., Schöpp W., Bastrup-Birk A. (2006): Spatial differentiation in the characterisation of photochemical ozone formation. The EDIP2003 methodology. *Int J LCA*, 11, pp. 72-80.

IPCC (2006): IPCC guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry and other land use. Kanagawa.

IPCC (2007): Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 p.

Jeanneret P., Baumgartner D., Freiermuth R., Gaillard G. (2006): Méthode d'évaluation de l'impact des activités agricoles sur la biodiversité dans les bilans écologiques – SALCA-BD. Agroscope FAL Reckenholz, 67 p., Available at http://www.agroscope.admin.ch/oekobilanzen/01194/.

Jeanneret P., Baumgartner D.U., Knuchel R.F., Gaillard G. (2008): A new LCIA method for assessing impacts of agricultural activities on biodiversity (SALCA-Biodiversity). In: Proceedings of the 6th International Conference on LCA in the Agri-Food Sector – Towards a sustainable management of the Food chain. Nemecek T., Gaillard G. (eds.). November 12–14, 2008, Zurich. Agroscope ART, pp. 34-39.

Kägi T., Bockstaller C., Gaillard G., Hayer F., Mamy L., Strassemeyer J. (2008): Multicriteria comparison of RA and LCA toxicity methods with focus on pesticide application strategies. In: Proceedings of the 6th International Conference on LCA in the Agri-Food Sector – Towards a sustainable management of the Food chain, Nemecek, T. & Gaillard, G. (eds.). November 12–14, 2008, Zurich. Agroscope ART, pp. 169-177.

Menzi H., Frick R., Kaufmann R. (1997): Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotentials. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau, Zürich-Reckenholz, Schriftenreihe der FAL, 107 p.

Mouron P., Nemecek T., Scholz R.W., Weber O. (2006): Management influence on environmental impacts in an apple production system on Swiss fruit farms: Combining life cycle assessment with statistical risk assessment. *Agriculture, Ecosystems and Environment*, 114, pp. 311-322.

Nemecek T., Blaser S., Dux D., Gaillard G. (2009): What are the key factors for successful integration of life cycle assessment into FADN? In: Int. Conf. "Integrated Assessment of Agriculture and Sustainable Development, Settig the Agenda for Science and Policy", Egmond aan Zee, The Netherlands. AgSAP Office, Wageningen University, pp. 334-335.

Nemecek T., Kägi T. (2008): Ecoinvent-based extrapolation of crop life cycle inventories to new geographical areas. In: Proceedings of the 6th International Conference on LCA in the Agri-Food Sector – Towards a sustainable management of the Food chain, Nemecek T., Gaillard G. (eds.). November 12–14, 2008, Zurich. Agroscope ART, pp. 40-48.

Oberholzer H.-R., Weisskopf P., Gaillard G., Weiss F., Freiermuth R. (2006): Methode zur Beurteilung der Wirkungen landwirtschaftlicher Bewirtschaftung auf die Bodenqualität in Ökobilanzen – SALCA-SQ. Agroscope FAL Reckenholz, 98 p., Available at http://www.agroscope.admin.ch/oekobilanzen/01194/.

Prasuhn V. (2006): Erfassung der PO_4-Austräge für die Ökobilanzierung - SALCA-Phosphor. Zürich, 22 p., Available at http://www.agroscope.admin.ch/oekobilanzen/01194/.

Richner W., Oberholzer H.-R., Freiermuth R., Walther U. (2006): Modell zur Beurteilung des Nitratauswaschungspotenzials in Ökobilanzen - SALCA-NO3. Unter Berücksichtigung der Bewirtschaftung (Fruchtfolge, Bodenbearbeitung, N-Düngung), der mikrobiellen Nitratbildung im Boden, der Stickstoffaufnahme durch die Pflanzen und verschiedener Bodeneigenschaften. Agroscope FAL Reckenholz, 25 p., Available at http://www.agroscope.admin.ch/oekobilanzen/01194/.

van der Werf H.M.G., Kanyarushoki C., Corson M.S. (2009): An operational method for the evaluation of resource use and environmental impacts of dairy farms by life cycle assessment. *Journal of Environmental Management*, 90, pp. 3643-3652.