Utility of spatially explicit LCA for agricultural territories

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ABSTRACT

Life Cycle Assessment (LCA) is a methodological framework that estimates environmental impacts of products, systems or services in a life cycle perspective at local to global scales. Some environmental impacts, however, can vary depending on the characteristics of their surroundings and therefore on the location of the activity. This variability can be taken into account in impact assessment using spatialized LCA. Spatial differentiation is especially relevant when studying territories (ca. 100-10,000 km^2), which often have high heterogeneity in environmental characteristics. In this study, we focus on defining a method to apply spatialized LCA to study land-use planning in an agricultural territory. In light of agricultural impact assessment, we suggest a future method for spatialized territorial LCA, which is currently being tested on an agricultural territory, the *Lieue de Grève* watershed in Brittany, France.

Keywords: life cycle assessment, spatialization, territory, land-planning, agriculture

1. Introduction

Currently, most agricultural and urban land-planning decisions are made at the territorial level. Since rural and urban development is increasingly addressed at the territorial level, developing a method to estimate environmental impacts of a territory seems important. The concept of "territory" is still debated and varies among and within scientific communities and countries. We focus on agricultural territories, defined as geographically delimited areas in which the majority of land use is based on agriculture. Agriculture contributes to a range of impacts on the environment, and some of these impacts vary depending on the biophysical context in which potential pollutants are emitted (climate, soil type, slope, hedgerow presence …).

In Life Cycle Assessment (LCA), potential environmental impacts are calculated through all stages of a product's or system's life (from cradle to grave). Many LCA studies of agricultural production focus on the field or farm level (Brentrup et al. 2004a,b; Nguyen et al. 2013; Prudêncio da Silva et al. 2014; van der Werf et al. 2009). Focusing on the territorial level, however, allows interactions between farms to be assessed.

Loiseau et al. (2012) highlighted the use of LCA to estimate potential environmental impacts of a territory for land-use planning purposes, such as where to locate different activities in a territory to reduce their environmental impacts. Due to the large size of territories (100-10,000 km^2), the use of spatialized data seems necessary to estimate environmental impacts accurately. This is especially relevant for an agricultural territory, where many emissions and impacts depend on their surroundings. It thus seems relevant to develop a method to estimate environmental impacts of activities within an agricultural territory ("territorial LCA") by considering their locations in a spatially explicit manner. The method developed can be called "spatialized territorial LCA".

We propose to apply the principles of spatialized territorial LCA to determine how and why it can support territorial approaches for assessing environmental impacts of an agricultural territory. The method developed will be illustrated with a case study: the *Lieue de Grève* territory, in Brittany, France. The objective of this case study is to help local stakeholders making decisions by determining which kinds of agricultural activities should be implemented in the studied territory, and where to locate them, to decrease their overall environmental impacts.

2. Spatialized LCA: a brief review

Environmental impacts caused by a pollutant emission depend on the quantity emitted, its properties, characteristics of the emitting source, and sometimes characteristics of receiving environment (Finnveden et al. 2009). In most LCA studies, the receiving environment is considered a standardized "unit world" with generic characteristics (Potting and Hauschild 2006). For some impact categories, such as climate change, this assumption holds true. However, some environmental impacts – such as acidification or eutrophication – vary depending on characteristics of the receiving environment and therefore on the location of the emissions. Spatialized LCA can take this variability into account in impact assessment.

In the literature, spatially explicit LCA has been addressed mainly at two levels: spatialized Life Cycle Inventory (LCI) and spatialized Life Cycle Impact Assessment (LCIA). While spatialized LCI is mainly based on the use of spatially differentiated databases and Geographic Information Systems (GIS) (Dufossé et al. 2013; Dresen and Jandewerth 2012; Engelbrecht et al. 2013; Geyer et al. 2010a,b; Núñez et al. 2010; Tabata et al. 2011; Tessum et al. 2012), spatialized LCIA focuses on spatial differentiation of characterization factors (CFs) for mid-point impacts such as acidification or eutrophication (Huijbregts et al. 2000; Krewitt et al. 2001; Potting et al. 1998; Shah and Ries 2009) or impacts of resource scarcity, such as that of water or soil (Boulay et al. 2011; Frechette-Marleau et al. 2008; Pfister et al. 2009; Saad et al. 2013; Verones et al. 2012). Spatialized LCIA has addressed mainly country, watershed or ecozone spatial scales (Pfister et al. 2009; Potting et al. 1998; Saad et al. 2011). Mutel et al. (2011) developed a computer program to combine spatialized LCI with spatialized LCIA. This technical solution still needs improvement, however, to be used by LCA practitioners. Spatialized LCA is increasingly common due to the use of GIS and the development of spatially differentiated CFs.

The debate about whether spatialized LCA reduces uncertainties in LCA studies remains open (Finnveden and Nilsson 2005). The amount of local data needed to spatialized LCA studies can indeed increase uncertainties in the LCI phase. Studies have shown, however, that using generic CFs can induce errors in LCIA, such as differences between site-specific CFs and site-generic CFs ranging from 2-4 orders of magnitude (Hellweg 2001; Hettelingh et al. 2005; Huijbregts et al. 2000). Therefore, taking the spatial variability of impacts into account seems necessary, especially when assessing the environmental burden of a territory.

3. Applying spatialized LCA to an agricultural territory

Few studies have used LCA to estimate a range of environmental impacts for an entire territory (e.g., Yi et al. 2007). Loiseau et al. (2013) developed a territorial LCA method but did not include spatial differentiation within the territory. We intend to develop a territorial LCA method that includes spatial differentiation within a territory for pollutant emissions and their associated impacts. For illustration purposes, we will apply this method to an agricultural territory.

To produce food or bioenergy for humans, agricultural territories induce environmental impacts that may vary depending on their surroundings where potential pollutants are emitted. Spatial analysis of agricultural territories has been performed outside the LCA domain for years. For example, models have been developed to predict spatially explicit dynamics of cropping systems (Leenhardt et al. 2010; Salmon-Monviola et al. 2012), spatial organization of land-use and rural territory dynamics (Benoit et al. 2012; Hinojosa and Hennermann 2012; Le Ber and Benoit 1998), or pesticide contamination risks in an agricultural watershed (Macary et al. 2014). The inclusion of a spatial differentiation in an LCA approach would provide a broader assessment of overall impacts.

3.1. Territorial LCA applied to an agricultural territory: the need for spatial differentiation

When estimating environmental impacts of a territory, one can consider it as a “black box” that interacts with other black-box territories via a variety of inputs and outputs. In this case, impacts of human activities are independent of location within the territory. We believe, however, that the territory should be considered as a system in which emissions occur at different places and impacts are influenced by the sensitivity of the receiving environment (Fig. 1). The need for spatial differentiation is especially relevant for land-use planning, where the location of certain activities may increase their environmental impacts. The method we develop thus aims to estimate spatialized impacts of an agricultural territory for land-use planning by coupling territorial LCA with spatialized LCA.

Although spatialized territorial LCA may require more data or time, it seems important to develop, especially for agricultural landscapes. It may help decrease impacts of a territory by estimating (1) what kinds of crop or livestock farming should be developed and where to locate them or (2) effects of land-use planning and how to minimize impacts of exchanges of resources or products with other territories, which may aid policy-making.

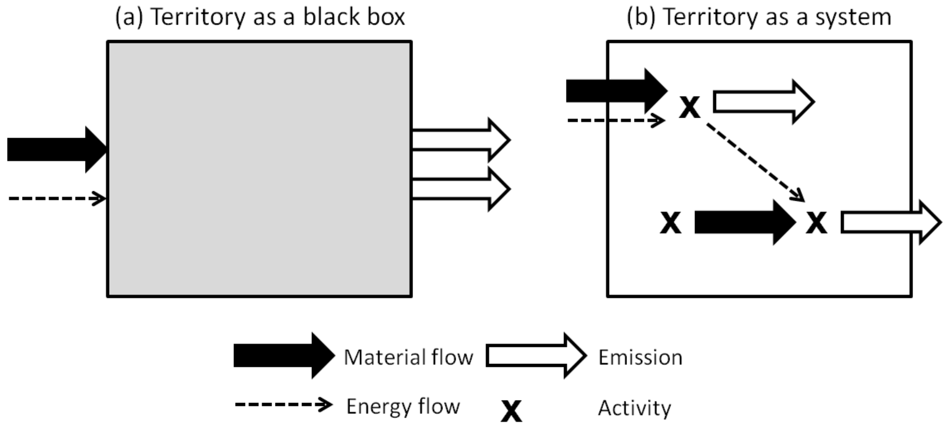

Figure 1. Two ways to estimate environmental impacts of a territory: (a) as a black box or (b) as a system whose activities, and inputs and outputs of those activities, are spatially explicit.

3.1.1. Defining the territory

The first step in a spatialized territorial LCA is to define the boundaries, functions, and issues of the territory under study. In agriculture, geographic boundaries of a territory are generally defined by the locations of farms and their fields but can be extended if entire agricultural sectors are studied. Next, defining territory functions and determining which of them is the most important is a crucial step in spatialized territorial LCA, since LCA is function-based. Loiseau et al. (2013) stated that territory functions can be mainly environmental, economic or societal. Functions of an agricultural territory may include producing food for human consumption or maintaining a certain living environment for the human population (Table 1).

Table 1. Examples of functions of agricultural territories.

Category	Functions
Environmental	Support biodiversity (e.g., reproduction and diversity of species)
	Support ecological processes (e.g., streamflow)
Economic	Produce revenue from agricultural activities
	Provide resources for industrial activities
	Support tourist activities
Societal	Produce food for human consumption
	Support livelihoods of the local population
	Maintain a certain living environment for the population (e.g., employment, quality of life)

The last step is to define issues at stake in the territory, such as to produce more food, to feed the local population or to decrease the amount of nitrate (NO_3) emitted to surface waters. Territory boundaries, functions, and issues, will influence which emissions and impacts will be studied (Fig. 2). They can be chosen iteratively (Goal and scope, Fig. 4) with the help of local stakeholders and experts, or with systemic analyses (pers. comm. Lynda Aissani, IRSTEA, Rennes, France).

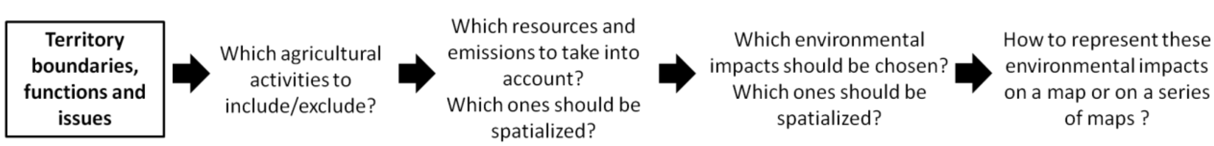

Figure 2. Effects of defining boundaries, functions, and issues of an agricultural territory on the LCA method.

3.1.2. Spatialized LCI

The next step is to spatialize the LCI, which requires distinguishing processes occurring within the territory from those occurring outside of it.

3.1.2.1. Processes occurring within the territory

Spatializing the LCI of the territory under study can be divided into three steps. The first step is to identify all agricultural and non-agricultural economic activities in the territory (e.g., with databases) and to geolocate them using GIS. It is important to include the non-agricultural activities, even though they will be examined in less detail. Since assessing the environmental burden of each human activity within a territory is too time-consuming, we propose developing a typology of agricultural activities, and use the typology proposed by Loiseau et al. (2013) for non-agricultural activities. The second step is to divide the territory under study into "zones of homogeneous environmental sensitivity" to each type of emission (e.g., nitrogen, phosphorous, and carbon compounds) using GIS. These zones (classified into an "environment" typology) should take into account environmental characteristics, such as the soil type, slope, and the distance to waterbodies. The third step is to calculate a spatialized LCI of activities within the territory. We propose to combine data from the activity and environment typologies to estimate spatialized emissions using appropriate models (Fig. 3). For example, nitrogen emissions from fields could be predicted using the TNT2 model (Beaujouan et al. 2002). Emission models should take into account pollutant fate as well as pollutant transport. Predicting transport is indeed crucial, since it will determine whether an emission (and thus its impact) will remain in the territory under study or travel to other territories. We propose performing LCA from the cradle to the territory gate, as suggested by Loiseau et al. (2013). A cradle-to-grave spatialized territorial LCA can be explored later.

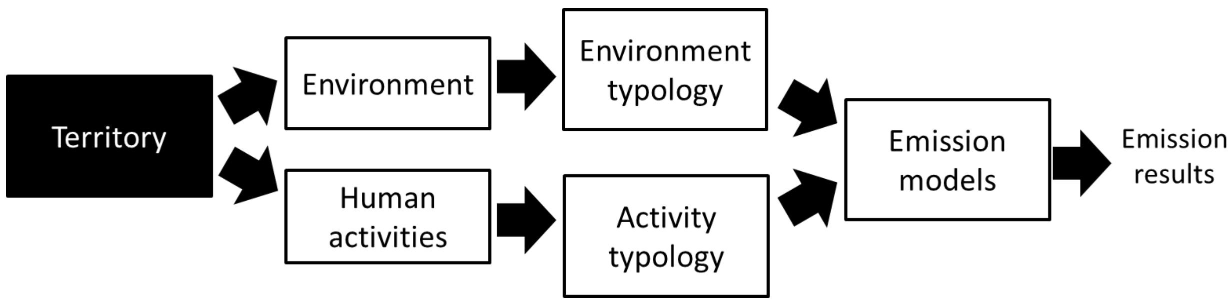

Figure 3. Spatialized life cycle inventory of activities within a territory

3.1.2.2. Processes occurring outside the territory

Indirect emissions from processes that occur outside the studied territory should also be included in the spatialized territorial study. The location of these emissions should be identified at least to the regional level, such as state or national level, when the origins of their contributing background processes are known

3.1.3. Spatialized impact assessment

Once emission locations, transport, and fate are determined, environmental impacts can be estimated. Spatialized environmental impacts will be estimated from spatialized emissions using spatially explicit characterization models. For each impact category, we propose assigning a CF to each zone of homogeneous environmental sensitivity. Environmental impacts in a given zone will be estimated from the emissions that end up there.

The appropriate spatial scale of each impact will depend on its impact category (Table 2). As a global impact, climate change does not need spatialization, unlike local impacts (e.g., eutrophication), which can be estimated more precisely with spatialization. For agriculture within a territory, we propose using a spatial scale at which a given impact is equivalent, such as a field for land-use impacts, homogeneous area of soil for terrestrial eutrophication and acidification, or homogeneous density of population for human toxicity (Nansai et al. 2005). A CF should be derived for each area of equivalent impact, which could be determined with GIS.

Table 2. Impacts categories and their spatial scales considered in spatialized impact assessment of an agricultural territory.

Impact category	Suggestion for spatial scale
Global warming	World
Eutrophication	
- Terrestrial	Homogeneous area of soil (e.g., type of soil, pH)
- Aquatic	Groundwater or surface water bodies
Acidification	
- Terrestrial	Homogeneous area of soil
- Aquatic	Groundwater or surface water bodies
Resource depletion	Location of resource extraction
Water consumption	Field
Land use	Field
Soil quality	Homogeneous area of soil
Energy consumption	Farm or homogeneous farm type
Human toxicity	Homogeneous density of population
Ecotoxicity	Ecozones

Larger spatial scales (e.g., watershed, region, or country) can be used for regions in which background processes occur. Importantly, the spatial scale of impact categories will depend on the impact category considered, the spatial scale of the environmental compartment (e.g., air, water, soil), and the type and quality of the environmental compartment (e.g., surface/ground water). If the agricultural territory under study is larger than the spatial scale of the impact categories, spatial differentiation within the territory seems necessary. In this case, site-dependent impact assessment can be used.

3.1.4. Interpretation

The final step, interpretation, can be a challenge, beginning with how to best map spatialized impacts to support decisions. We propose creating a detailed map of impacts within the territory along with a map of impact occurring throughout the world. To facilitate understanding, we recommend avoiding additional maps, showing only locations where impacts are the highest and reducing impacts on maps to a small number of scores. One objective of our method is thus to express spatially explicit environmental impacts in an optimal manner.

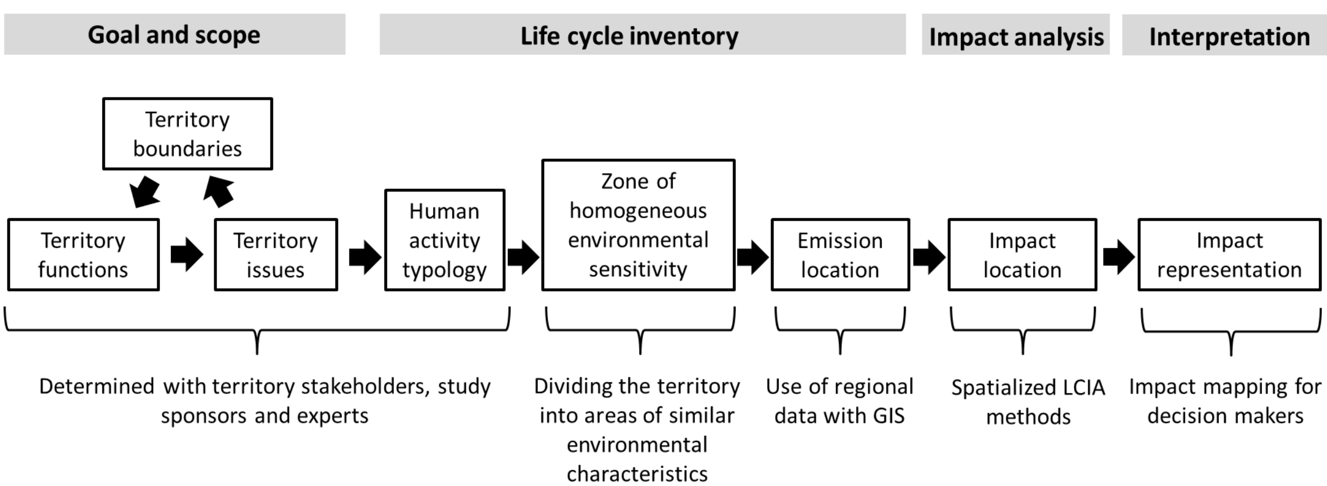

Figure 4. Spatialized territorial LCA steps

3.2. Case study: The *Lieue de Grève* watershed in France

Once methodological issues are addressed, we will apply the approach to the agricultural territory of the *Lieue de Grève* watershed in Brittany, France (Figs. 4 and 5). This territory was chosen because it is primarily agricultural with few urban areas, its main agricultural impacts define its boundaries (i.e., sub-watersheds of the

Saint-Michel-en-Grève Bay), and it has been studied before in research projects. Consequently, many descriptive data and a partnership with local stakeholders exist.

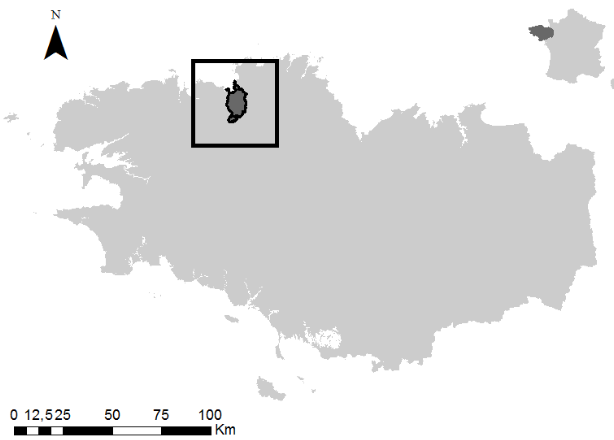

Figure 5. Location of the *Lieue de Grève* watershed (dark gray) in the region of Brittany, France.

Figure 6. Sub-watersheds in the *Lieue de Grève* watershed.

The *Lieue de Grève* watershed is composed of five sub-watersheds covering 120 km² and containing 12 towns and 13,500 inhabitants. Approximately 70% of the territory is covered by agricultural land, divided among 194 farms. Up to 85% of the agricultural land is used as dairy farms, while intensive pig/crop farming occurs on the eastern and western edges of the watershed.

The objective of the study is to analyze land-use planning scenarios to determine which kinds of agricultural activities should be implemented in the *Lieue de Grève*, and where to locate them, to decrease the territory's environmental impacts.

The main function of the *Lieue de Grève* agricultural territory is to produce agricultural products (mainly milk and beef), but this is common to all agricultural territories and does not represent a unique feature. One function with greater importance in the *Lieue de Grève* is the transfer of nutrients to the sea. Due to intensive agricultural practices and biophysical characteristics of land and bay, agricultural N and P that flow into the bay cause proliferation of green algae in the bay. Since this issue is important to the local population, we choose this function for the *Lieue de Grève* and define its geographic boundaries as its 5 sub-watersheds. In future research, the influence of changing the territorial function in LCA will be investigated.

The next step, spatialized LCI, is currently in progress, pinpointing with GIS locations of farms; their fields, emissions, and resource consumption; and environmental characteristics, using local datasets, on-farm surveys, and regional statistics. Transport and fate models will be used to determine the final locations of major emissions inside or outside the territory. The final steps will involve spatialized LCIA and interpretation of the spatialized results where scenarios of land-use planning will be compared.

4. Conclusion

Our method aims to combine spatialized and territorial LCAs to assess environmental impacts of an agricultural territory with a higher level of precision. This method refers to "spatialized territorial LCA". The key steps of spatialized territorial LCA are to: (1) define territory boundaries, functions, and main issues, since these characteristics will influence subsequent steps and results; (2) spatialize the LCI and LCIA using GIS; and (3) determine the best way to represent environmental impacts on a map to help stakeholders make decisions.

The objectives of this method are to: (1) give more accurate results than a territorial LCA without spatial differentiation, (2) help decrease impacts within a territory by determining which agricultural activities should be developed and where to locate them, and (3) help avoid or minimize impacts of exchanges of resources or products with other territories.

This method is still under development, and many methodological questions have yet to be resolved, particularly about the impact categories, and therefore the emissions, considered. The next step is to determine which indicators to use to define the zones of homogeneous environmental sensitivity. Another methodological issue is raised when combining these zones with the activity typology to determine the spatially differentiated LCI, particularly which emission models to choose to include spatial information in LCI calculations. It is also necessary to determine how to link the spatialized LCI to a spatially differentiated characterization method and how to best map impacts to aid decision making. For the latter, impacts occurring outside the territory must be represented.

The method will be applied to the *Lieue de Grève* territory, in Brittany, France, to assess its relevance from scientific and operational viewpoints. Ultimately, comparing spatialized and non-spatialized impacts will help us confirm – or disprove – the utility of the method.

5. References

Beaujouan V, Durand P, Ruiz L, Aurousseau P, Cotteret G (2002) A hydrological model dedicated to topography-based simulation of nitrogen transfer and transformation: rationale and application to the geomorphology-denitrification relationship. Hydrological Processes 16 (2):493-507. doi:10.1002/hyp.327

Benoit M, Rizzo D, Marraccini E, Moonen AC, Galli M, Lardon S, Rapey H, Thenail C, Bonari E (2012) Landscape agronomy: a new field for addressing agricultural landscape dynamics. Landscape Ecol 27 (10):1385-1394. doi:10.1007/s10980-012-9802-8

Boulay AM, Bulle C, Bayart JB, Deschenes L, Margni M (2011) Regional characterization of freshwater use in LCA: Modeling direct impacts on human health. Environ Sci Technol 45 (20):8948-8957. doi:10.1021/es1030883

Brentrup F, Kusters J, Kuhlmann H, Lammel J (2004a) Environmental impact assessment of agricultural production systems using the life cycle assessment methodology - I. Theoretical concept of a LCA method tailored to crop production. Eur J Agron 20 (3):247-264. doi:10.1016/s1161-0301(03)00024-8

Brentrup F, Kusters J, Lammel J, Barraclough P, Kuhlmann H (2004b) Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology - II. The application to N fertilizer use in winter wheat production systems. Eur J Agron 20 (3):265-279. doi:10.1016/s1161-0301(03)00039-x

Dresen B, Jandewerth M (2012) Integration of spatial analyses into LCA-calculating GHG emissions with geoinformation systems. Int J Life Cycle Assess 17 (9):1094-1103. doi:10.1007/s11367-011-0378-3

Dufossé K, Gabrielle B, Drouet J-L, Bessou C (2013) Using agroecosystem modeling to improve the estimates of N_2O emissions in the Life-Cycle Assessment of biofuels. Waste Biomass Valorization 4 (3):593-606. doi:10.1007/s12649-012-9171-1

Engelbrecht D, Biswas WK, Ahmad W (2013) An evaluation of integrated spatial technology framework for greenhouse gas mitigation in grain production in Western Australia. J Clean Prod 57:69-78. doi:10.1016/j.jclepro.2013.06.010

Finnveden G, Hauschild MZ, Ekvall T, Guinee J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S (2009) Recent developments in Life Cycle Assessment. J Environ Manage 91 (1):1-21. doi:10.1016/j.jenvman.2009.06.018

Finnveden G, Nilsson M (2005) Site-dependent life-cycle impact assessment in Sweden. Int J Life Cycle Assess 10 (4):235-239. doi:10.1065/lca2005.05.209

Frechette-Marleau S, Becaert V, Margni M, Samson R, Deschenes L (2008) Evaluating the variability of aquatic acidification and photochemical ozone formation characterization factors for Canadian emissions. Int J Life Cycle Assess 13 (7):593-604. doi:10.1007/s11367-008-0027-7

Geyer R, Lindner JP, Stoms DM, Davis FW, Wittstock B (2010a) Coupling GIS and LCA for biodiversity assessments of land use. Part 2: Impact assessment. Int J Life Cycle Assess 15 (7):692-703. doi:10.1007/s11367-010-0199-9

Geyer R, Stoms DM, Lindner JP, Davis FW, Wittstock B (2010b) Coupling GIS and LCA for biodiversity assessments of land use. Part 1: Inventory modeling. Int J Life Cycle Assess 15 (5):454-467. doi:10.1007/s11367-010-0170-9

Hellweg S (2001) Time- and site-dependent life cycle assessment of thermal waste treatment processes. Int J Life Cycle Assess 6 (1):46-46. doi:10.1007/bf02977597

Hettelingh JP, Posch M, Potting J (2005) Country-dependent characterisation factors for acidification in Europe - A critical evaluation. Int J Life Cycle Assess 10 (3):177-183. doi:10.1065/lca2004.09.182

Hinojosa L, Hennermann K (2012) A GIS approach to ecosystem services and rural territorial dynamics applied to the case of the gas industry in Bolivia. Appl Geogr 34:487-497. doi:10.1016/j.apgeog.2012.02.003

Huijbregts MAJ, Schöpp W, Verkuijlen E, Heijungs R, Reijnders L (2000) Spatially explicit characterization of acidifying and eutrophying air pollution in Life-Cycle Assessment. J Ind Ecol 4 (3):75-92. doi:10.1162/108819800300106393

Krewitt W, Trukenmuller A, Bachmann TM, Heck T (2001) Country-specific damage factors for air pollutants - A step towards site dependent life cycle impact assessment. Int J Life Cycle Assess 6 (4):199-210. doi:10.1007/bf02979375

Le Ber F, Benoit M (1998) Modelling the spatial organization of land use in a farming territory. Example of a village in the Plateau Lorrain. Agronomie 18 (2):103-115. doi:10.1051/agro:19980201

Leenhardt D, Angevin F, Biarnes A, Colbach N, Mignolet C (2010) Describing and locating cropping systems on a regional scale. A review. Agron Sustain Dev 30 (1):131-138. doi:10.1051/agro/2009002

Loiseau E, Junqua G, Roux P, Bellon-Maurel V (2012) Environmental assessment of a territory: An overview of existing tools and methods. J Environ Manage 112:213-225. doi:10.1016/j.jenvman.2012.07.024

Loiseau E, Roux P, Junqua G, Maurel P, Bellon-Maurel V (2013) Adapting the LCA framework to environmental assessment in land planning. Int J Life Cycle Assess 18 (8):1533-1548. doi:10.1007/s11367-013-0588-y

Macary F, Morin S, Probst JL, Saudubray F (2014) A multi-scale method to assess pesticide contamination risks in agricultural watersheds. Ecol Indic 36:624-639. doi:10.1016/j.ecolind.2013.09.001

Mutel CL, Pfister S, Hellweg S (2011) GIS-based regionalized life cycle assessment: How big is small enough? Methodology and case study of electricity generation. Environ Sci Technol 46 (2):1096-1103. doi:10.1021/es203117z

Nansai K, Moriguchi Y, Suzuki N (2005) Site-dependent life-cycle analysis by the SAME approach: Its concept, usefulness, and application to the calculation of embodied impact intensity by means of an input-output analysis. Environ Sci Technol 39 (18):7318-7328. doi:10.1021/es047951n

Nguyen TTH, Doreau M, Eugene M, Corson MS, Garcia-Launay F, Chesneau G, van der Werf HMG (2013) Effect of farming practices for greenhouse gas mitigation and subsequent alternative land use on environmental impacts of beef cattle production systems. Animal 7 (5):860-869. doi:10.1017/s1751731112002200

Núñez M, Civit B, Munoz P, Arena AP, Rieradevall J, Anton A (2010) Assessing potential desertification environmental impact in life cycle assessment. Int J Life Cycle Assess 15 (1):67-78. doi:10.1007/s11367-009-0126-0

Pfister S, Koehler A, Hellweg S (2009) Assessing the environmental impacts of freshwater consumption in LCA. Environ Sci Technol 43 (11):4098-4104. doi:10.1021/es802423e

Potting J, Hauschild MZ (2006) Spatial differentiation in life cycle impact assessment - A decade of method development to increase the environmental realism of LCIA. Int J Life Cycle Assess 11:11-13. doi:10.1065/lca2006.04.005

Potting J, Schöpp W, Blok K, Hauschild M (1998) Site-dependent Life-Cycle Impact Assessment of acidification. J Ind Ecol 2 (2):63-87. doi:10.1162/jiec.1998.2.2.63

Prudêncio da Silva V, van der Werf HMG, Soares SR, Corson MS (2014) Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. J Environ Manage 133 (0):222-231. doi:dx.doi.org/10.1016/j.jenvman.2013.12.011

Saad R, Koellner T, Margni M (2013) Land use impacts on freshwater regulation, erosion regulation, and water purification: a spatial approach for a global scale level. Int J Life Cycle Assess 18 (6):1253-1264. doi:10.1007/s11367-013-0577-1

Saad R, Margni M, Koellner T, Wittstock B, Deschenes L (2011) Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. Int J Life Cycle Assess 16 (3):198-211. doi:10.1007/s11367-011-0258-x

Salmon-Monviola J, Durand P, Ferchaud F, Oehler F, Sorel L (2012) Modelling spatial dynamics of cropping systems to assess agricultural practices at the catchment scale. Comput Electron Agric 81:1-13. doi:10.1016/j.compag.2011.10.020

Shah VP, Ries RJ (2009) A characterization model with spatial and temporal resolution for life cycle impact assessment of photochemical precursors in the United States. Int J Life Cycle Assess 14 (4):313-327. doi:10.1007/s11367-009-0084-6

Tabata T, Torikai H, Tsurumaki M, Genchi Y, Ukegawa K (2011) Life cycle assessment for co-firing semi-carbonized fuel manufactured using woody biomass with coal: A case study in the central area of Wakayama, Japan. Renew Sust Energ Rev 15 (6):2772-2778. doi:10.1016/j.rser.2011.02.042

Tessum CW, Marshall JD, Hill JD (2012) A spatially and temporally explicit Life Cycle Inventory of air pollutants from gasoline and ethanol in the United States. Environ Sci Technol 46 (20):11408-11417. doi:10.1021/es3010514

van der Werf HMG, Kanyarushoki C, Corson MS (2009) An operational method for the evaluation of resource use and environmental impacts of dairy farms by life cycle assessment. J Environ Manage 90 (11):3643-3652. doi:dx.doi.org/10.1016/j.jenvman.2009.07.003

Verones F, Bartl K, Pfister S, Vilchez RJ, Hellweg S (2012) Modeling the local biodiversity impacts of agricultural water use: Case study of a wetland in the coastal arid area of Peru. Environ Sci Technol 46 (9):4966-4974. doi:10.1021/es204155g

Yi I, Itsubo N, Inaba A, Matsumoto K (2007) Development of the interregional I/O based LCA method considering region-specifics of indirect effects in regional evaluation. Int J Life Cycle Assess 12 (6):353-364. doi:10.1065/lca2007.06.339

This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

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It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6