Journal of Cleaner Production 112 (2016) 2472–2484

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Spatial differentiation in Life Cycle Assessment LCA applied to an agricultural territory: current practices and method development

Laure Nitschelm [a, b], Joël Aubin [a, b, *], Michael S. Corson [a, b], Valérie Viaud [a, b], Christian Walter [b, a]

[a] INRA, UMR 1069 Sol Agro et hydrosystème Spatialisation, F-35000 Rennes, France
[b] AGROCAMPUS OUEST, UMR 1069, F-35000 Rennes, France

A R T I C L E I N F O

Article history:
Received 6 February 2015
Received in revised form
6 August 2015
Accepted 29 September 2015
Available online 22 October 2015

Keywords:
Life Cycle Assessment
Territory
Spatial differentiation
Agriculture

A B S T R A C T

Life Cycle Assessment (LCA) is a methodological framework that estimates environmental impacts of products, systems or services in a life cycle perspective (from cradle to grave) at local to global levels. Some environmental impacts 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 environmental 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 developed a method for spatialized territorial LCA (STLCA) that combines spatialized LCA and territorial LCA to study land-use planning in an agricultural territory. An agricultural territory is defined as a geographically delimited area in which the majority of land use or economic activity is based on agriculture. STLCA can estimate potential environmental impacts of an agricultural territory for land-planning purposes, such as which agricultural activities should be developed and where to locate them. The method consists of six steps: (1) defining boundaries and functions of the territory under study and identifying the human activities to include, (2) defining and locating activity and environment typologies within the territory, (3) determining the spatialized life cycle inventory by locating emissions using regional data, if possible, (4) determining spatialized life cycle impact assessment for all regional impacts considered, (5) mapping impacts inside and outside the territory, and finally (6) analyzing results using sensitivity and uncertainty analysis. Objectives of this method are to (1) give more accurate results than a territorial LCA without spatial differentiation, (2) help decrease environmental impacts within a territory while avoiding transfer of impacts to other territories and (3) help avoid or minimize impacts of exchanges of resources or products with other territories.

1. Introduction

The relevance of a territorial approach to addressing environmental concerns about agricultural areas is being increasingly recognized (Payraudeau and van der Werf, 2005). In the scientific community, the definition of "territory" varies among and within scientific communities and countries. The concept of a "territory" was first developed by French scientific communities (Giraut, 2008). The concept of a "territory" as a complex and dynamic system goes beyond that of a "region". While a region can be defined as a spatially contiguous area, a territory can be defined as a region claimed by the population that lives in it (Le Clanche, 2010). Although the concept of "territory" is still debated, much of the scientific community agrees on a definition based on three main concepts: a geographic space, stakeholders' decision-making processes, and regional identity (Caseau, 2003; Cerceau et al., 2014; Etienne, 2014; Le Clanche, 2010). Therefore, we adopt Moine's (2006) definition of "territory": a geographically contiguous area in which human activities occur that is managed by local stakeholders, whose representations (individual, ideological, and societal) of the territory influence their decisions. The main distinction between "region" and "territory" is the inclusion of the stakeholders in the latter. A territory is therefore a place where decisions are made and where stakeholders gather around common questions (e.g., environmental, economic, societal). In this article, we

* Corresponding author. INRA, UMR 1069, F-35000 Rennes, France.
E-mail address: joel.aubin@rennes.inra.fr (J. Aubin).

http://dx.doi.org/10.1016/j.jclepro.2015.09.138
0959-6526/

focus on agricultural territories, which we define as territories in which most land uses or economic activities are based on agriculture. In an agricultural territory, stakeholders focus on questions such as the trade-off between agricultural production and the environment.

Several analytical tools, such as environmental risk mapping, multi-agent systems, linear programming, Material Flow Analysis, or Emergy accounting, have been used to assess environmental burdens of agricultural territories (Payraudeau and van der Werf, 2005; Loiseau et al., 2012). In particular, Loiseau et al. (2012) and Payraudeau and van der Werf (2005) identified Life Cycle Assessment (LCA) as a suitable method to perform environmental analysis of an agricultural territory (called farming region in this article) due to its life-cycle and multicriteria perspectives (ISO, 2006). LCA is a methodological framework developed to assess environmental burdens of a product, service, or system during its life cycle ("from cradle to grave") (ISO, 2006). Recently, the scientific community has started adapting LCA to assess environmental burdens of entire territories (Loiseau et al., 2013). The current state-of-the-art of territorial LCA does not include fine-scale spatial differentiation (Loiseau et al., 2013). Due to the size of agricultural territories, and since many emissions and impacts arising from them depend on their surroundings (Potting and Hauschild, 2006), using spatially explicit data is necessary to estimate territorial environmental impacts accurately. Although LCA was developed as a spatially independent approach, these adaptations seem relevant since decisions (e.g., administrative, environmental) are increasingly made at the local (e.g., territorial) level. It thus seems relevant to develop a method to estimate environmental impacts of activities within a territory ("territorial LCA") by considering their locations in a spatially explicit manner (i.e., "spatialized territorial LCA"). Agricultural territories have been analyzed spatially for years. For example, methods 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). In contrast, 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). Some studies have integrated regionalization in agricultural LCA, such as regional land-use impacts on biodiversity (Saad et al., 2012; Elshout et al., 2014) or on climate change (Hortenhuber et al., 2014; Humpenoder et al., 2013), regional impacts on biodiversity due to water use (Verones et al., 2012) or biofuel production (Urban et al., 2012), or potential desertification due to agricultural activities at the country level (Civit et al., 2013). These studies highlight the need for regionalized data and assessment to obtain more accurate results than those of classic LCA studies. Indeed, addition of spatial differentiation could make assessment of overall territorial impacts more accurate and comprehensive.

The objective of this article is therefore to develop a new method, the spatialized territorial LCA (STLCA) for agricultural territories. We chose to focus on agricultural territories for three main reasons: (1) changes in agricultural land-use influence environmental impacts of agriculture (Cederberg et al., 2013), (2) some of these impacts depend on the biophysical context in which pollutants are emitted (e.g., weather, soil type), and (3) many choices that influence these impacts are made at the farm level but can be influenced by public policies at the territorial level (mainly via subsidies or regulations). Consequently, developing a method to estimate spatialized environmental impacts of a territory seems a relevant goal. The objective is therefore to propose a new approach called spatialized territorial LCA (STLCA). After a brief state of the art on territorial and spatialized LCA, we describe the methodology based on 6 steps.

2. Territorial and spatialized LCA: a brief state of the art

2.1. Territorial LCA

Territorial LCA can be defined as assessment of the eco-efficiency of a territory (Seppäläa et al., 2005). To perform a territorial LCA, every human activity that occurs within the territory, along with every background process linked to these activities, is assessed. In the literature, territorial LCA has been studied at every stage of the LCA framework. For example, at the LCI stage, Pradeleix et al. (2012) developed a method based on Agrarian System Diagnosis to build territorial LCIs for agriculture. Until the development of a territorial LCA method by Loiseau et al. (2013), territorial LCA only focused on one activity or process. Azapagic et al. (2007, 2013) and Yi et al. (2007) studied environmental impacts of human activities in a city or at the regional level using LCA. Bjorklund (2012) and Finnan et al. (2012) assessed environmental impacts of energy-source choices at the regional (i.e., municipal and country) level. Covering all the LCA stages, Loiseau et al. (2013) developed a territorial LCA method to assess land-use planning impacts on a territory, which was then applied to a case study (Loiseau et al., 2014). The method developed considers the territory as a "black box" that interacts with other black-box territories via a variety of inputs and outputs. This method includes: (1) definition of the functional unit(s), (2) selection of boundaries of the territory, (3) regional data collection, and (4) consideration of the local context when evaluating impacts. This method, however, did not include spatial differentiation. As emphasized by Yi et al. (2007), it is necessary to consider regional characteristics (i.e., human and environmental-based) when performing a regional assessment (i.e., territorial LCA). Including spatial differentiation method is therefore recommended in territorial LCA.

2.2. Spatialized LCA

Environmental impacts caused by a pollutant emission depend on the quantity emitted, its properties, characteristics of the emitting source, as well as 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 mid-point 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. Spatialized LCA can be defined as the inclusion of spatial information, at a chosen spatial resolution, within one or more LCA stages (i.e., goal and scope definition, LCI, life cycle impact assessment (LCIA), result interpretation). In literature most case studies concern the LCIA step.

In the literature, spatially explicit LCA has been addressed at every LCA stage. In goal and scope definition, Laurent et al. (2014) developed a systemic method to identify the most important functions of a collective anaerobic-digestion system within each of two distinct territories using GIS. Spatialized LCI has mainly been based on spatially explicit databases and use of Geographic Information Systems (GIS) to geolocate processes (Dresen and Jandewerth, 2012; Dufossé et al., 2013; Engelbrecht et al., 2013; Geyer et al., 2010a,b; Núñez et al., 2010; Tabata et al., 2011; Tessum et al., 2012). Spatialized LCIA, on the other hand, has focused on spatial differentiation of characterization factors (CFs)