Environmental Impact Assessment Review 60 (2016) 148–155

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

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

Regionalization of land use impact models for life cycle assessment: Recommendations for their use on the global scale and their applicability to Brazil

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ARTICLE INFO

Article history:
Received 2 August 2015
Received in revised form 7 April 2016
Accepted 2 May 2016
Available online 21 May 2016

Keywords:
Life Cycle Assessment
Life Cycle Impact Assessment
Regionalization
Land use
Brazil

ABSTRACT

Life Cycle Assessment (LCA) is the main technique for evaluate the environmental impacts of product life cycles. A major challenge in the field of LCA is spatial and temporal differentiation in Life Cycle Impact Assessment (LCIA) methods, especially impacts resulting from land occupation and land transformation. Land use characterization modeling has advanced considerably over the last two decades and many approaches have recently included crucial aspects such as geographic differentiation. Nevertheless, characterization models have so far not been systematically reviewed and evaluated to determine their applicability to South America. Given that Brazil is the largest country in South America, this paper analyzes the main international characterization models currently available in the literature, with a view to recommending regionalized models applicable on a global scale for land use life cycle impact assessments, and discusses their feasibility for regionalized assessment in Brazil. The analytical methodology involves classification based on the following criteria: midpoint/endpoint approach, scope of application, area of data collection, biogeographical differentiation, definition of recovery time and reference situation; followed by an evaluation of thirteen scientific robustness and environmental relevance subcriteria. The results of the scope of application are distributed among 25% of the models developed for the European context, and 50% have a global scope. There is no consensus in the literature about the definition of parameters such biogeographical differentiation and reference situation, and our review indicates that 35% of the models use ecoregion division while 40% use the concept of potential natural vegetation. Four characterization models show high scores in terms of scientific robustness and environmental relevance. These models are recommended for application in land use life cycle impact assessments, and also to serve as references for the development or adaptation of regional methodological procedures for Brazil.

1. Introduction

Land use changes have been shown to potentially trigger significant effects on environmental impacts, not only through greenhouse gas (GHG) emissions (Castanheira and Freire, 2012; Hörtenhuber et al., 2014; Moreira et al., 2014) but also through habitat destruction, which is one of the most important direct drivers of change in ecosystems and biodiversity (MEA, 2005).

Brazil, which is known as one of the five most forest-rich countries in the world, contains 13% of the global forest area and has the largest extent of tropical rainforest (FAO, 2011). Historically, Brazil's economic activities have been closely tied to the exploitation of resources and the natural potential contained in its territory. The demand for food production, for example, has been one of the main drivers of deforestation in the country, especially in the 1990s and early 2000s (Boucher et al., 2011; FAO, 2006; Morton et al., 2006). Therefore, the evaluation of land use impacts poses a challenge to the sustainability and preservation of Brazilian biodiversity, ecosystems and the services they provide.

Environmental management tools such as Life Cycle Assessment (LCA) have begun to include impact categories (i.e. classes representing environmental issue of concern) and specific methodologies to evaluate land use-related impacts, since all impacts occurring throughout the entire value chain should be accounted for (Bare, 2011; Beck et al., 2010; Brentrup et al., 2002; de Baan et al., 2013a,b; Geyer et al., 2010; Milà i Canals et al., 2007). By definition, LCA is the "compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle." Although LCA is still a young discipline (mainly developed from the mid-1980s until now) it has the great advantage of focusing on products and services in a life cycle perspective, providing a holistic approach. Thus, compared to others environmental management tools, is also noteworthy that LCA is fundamental to avoid problem-shifting, from one phase to another, or from an environmental problem to another (Finnveden et al., 2009).

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http://dx.doi.org/10.1016/j.eiar.2016.05.001
0195-9255/

LCA consists of 4 phases: Goal and Scope definition; Life Cycle Inventory (LCI); Life Cycle Impact Assessment (LCIA) and Interpretation (ISO, 2006a, 2006b). The third step, LCIA, evaluates the magnitude and significance of the potential environmental impacts of a product system (ISO 14044, 2006b). In this phase, characterization models are applied to model quantitatively the impacts of each emission or intervention, according to an environmental mechanism. Then, characterization factors, derived from the characterization models, are applied to convert the results of LCI in the common unit of the category indicator (ISO, 2006a, 2006b).

Regarding the land use category, two types of interventions are recorded in LCA: land transformation and land occupation (Koellner et al., 2013b). The term land occupation refers to the use of a land area for some activity, such as agriculture, pasture, building, whereas the term land transformation implies the change of a land area for a new type of occupation process (Milà i Canals et al., 2007). The consequences of these interventions (i.e., their environmental impacts) can be measured based on different indicators expressing the intrinsic value of biodiversity or the functional value of resources and ecosystems (services such as climate regulation or erosion regulation) (Koellner et al., 2013b).

It is recognized that LCA still faces many challenges such as high uncertainties due to the large amounts of simulated data and simplifications in modeling complex environmental cause-effect chains. Therefore, the application of regionalized assessments that consider site-specific production conditions and the sensitivity of ecosystems is crucial to overcome these issues and to improve the accuracy of LCA studies (Hellweg and Milà i Canals, 2014).

Spatial variability is also a critical feature in land use impact assessment, because it depends on many biogeographical factors involving landscape, vegetation patterns, climate, and soil properties (Milà i Canals et al., 2007). However, modeling approaches usually propose methods that use site-generic characterization factors limited to a particular geographical scope, mainly Continental Europe.

Despite the development of new methodologies involving land use impacts, regionalized characterization models and their applicability to the Brazilian context have not yet been systematically reviewed and evaluated. In view of this lack, an analysis was made of the main international characterization models currently available in the literature, with a view to recommending regionalized models applicable on a global scale for land use LCIA, and to discuss their feasibility for regionalized assessments in Brazil.

Section 2 of this paper described the methodological procedure in detail. Section 3 documents the results of the analysis, first with general characteristics and model parameters, and then with an evaluation of environmental relevance and scientific robustness. Section 4 outlines the conclusions of this study, which can be used to support more consistent and accurate results in land use LCIA, and discusses the relevance of an adequate regionalized land use LCIA in Brazil.

2. Methods

2.1. Identification of characterization models

An exploratory literature review was carried out, using a specific search protocol to identify the relevant literature. The general parameters for the literature searches were: English language articles from national and international peer-reviewed journals. The search was conducted on the Web of Science academic database, covering publications up to 2014. The keywords used in this review were: *Land Use*, *Biodiversity*, *Indicators*, *Life Cycle Assessment* (*LCA*), *Life Cycle Impact Assessment* (*LCIA*), *Methodology*, *Erosion*, *Land Occupation and Transformation*, *Land use change and Impact assessment*.

There was obtained, between articles and other publications (technical reports, reports, thesis, etc.), 519 studies, for which was applied a reading sequence of filters. First, the title, abstract and keywords of the obtained studies were read to filter the ones that were not relevant. Then, the "Introduction" and "Conclusion" sections of the 137 remaining articles were read. Finally, the full text of the remaining 36 studies was read and 19 models were shortlisted for further analysis by excluding the ones not pertaining to the area of interest. Moreover, a doctoral thesis (Souza, 2010) was added to the review in order to complement the discussion, since it proposes a land use LCIA model for Brazil, based on biodiversity indicators.

2.2. General classification

After identifying and selecting existing characterization models in the first step of this study, the second step consisted in defining a set of criteria in order to analyze them comparatively. The general features of the models were grouped according to the following topics:

- Environmental impacts assessed in each model.
- Environmental mechanism considered.
- Approach of the characterization model, classified according to: endpoint (when several steps are considered in environmental changes and their ultimate impact); or midpoint (when referring to intermediate measurement points along the environmental mechanism).
- Interventions evaluated: land occupation and/or land transformation.
- Implemented in LCIA methods: indicate whether the model is part of a methodology recognized by the scientific community or not.
- Scope of application, classified into global, continental (in this case, naming the continent in question) or national (in this case, naming the country in question).

2.3. Classification of characterization model parameters

The study of the impact pathway and the guidelines recently proposed by UNEP/SETAC (Koellner et al., 2013b) enabled us to identify key aspects that must be considered in modeling land use impacts. Therefore, the third step consisted in evaluating the models according to:

- Area of data collection.
- Level of biogeographical differentiation used for calculating characterization factors, e.g., biomes, ecoregions, ecozones, climatic regions and countries.
- Recovery time, i.e., time required after land occupation/transformation for a particular activity to achieve a specific level of quality.
- Reference situation, i.e., situation against which impacts are compared, in terms of land quality.

2.4. Analysis of environmental relevance and scientific robustness

To identify the strengths and weaknesses of characterization models in terms of scientific robustness and environmental relevance, a set of criteria were established based on Bare (2011); EC-JRC (2010) and EC-JRC (2011). Based on the recommendations found in these publications, the models were analyzed to determine their compliance with thirteen criteria:

I. Scientific robustness & Documentation

- A specific underlying model is used, which should be both scientifically defensible and practicable.
- The model's transparency and reproducibility.

II. General completeness

- Site-dependency, considering parameters that expresses characteristic of the location.