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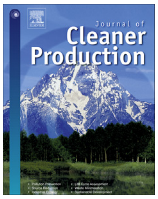

Review

A comparison of Land Use Change models: challenges and future developments

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A R T I C L E I N F O

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A B S T R A C T

Land demand is driven by an increasing population and changing consumption patterns. When land is required Land Use Changes (LUC) are triggered, causing several environmental and social impacts. Particularly topical is the assessment of indirect LUC effects. Several methodological approaches have been proposed for carrying out the assessment. In this paper we classified LUC models for Life Cycle Assessment (LCA) applications into three main categories: Economic, Causal–Descriptive and Normative models. Six models were selected as representative of these three categories and compared according to fifteen criteria covering: modeling framework, impact categories assessed and model transparency. The results show that, progresses have been made in the Economic General Equilibrium Models and the Causal–Descriptive Models compared. Causal–Descriptive models appear more suitable for long-term assessments in the LCA context while the compared economic models are more suitable for short/medium-term assessments of LUC consequences. As LUC dynamics involve interdisciplinary knowledge, a combination of economic, biophysical and statistical data is however required to achieve a robust assessment of complex LUC dynamics.

There is still considerable scope for improving current LUC models. In particular, there is room for improving precision of data, identification of marginal land and inclusion of a broader range of impact categories. Current models mainly focus on GHG emission-related impacts and rarely on other environmental impacts such as nutrient leaching, biodiversity impacts and water resource depletion. Socio-economic analyses of LUC patterns are currently excluded from LCA analysis, preventing a holistic assessment of land occupation impacts.

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1. Introduction

Since humans began using agricultural techniques for food production, the land surface has been shaped and affected by anthropogenic activities. With the industrialization of the agricultural sector the impact of these activities has become significant. Currently farmed land supplies food, feed and pastures for a global population that is increasing in number and affluence and it is production site for the supply of fibers, fuel wood and, more recently, industrial-scale biofuels. These activities are responsible for both environmental and social impacts.

Land use was long underestimated or ignored in environmental assessments (Lindeijer, 2000) but is increasingly being included in impact assessments. Land Use Change (LUC) impacts have recently been introduced in environmental (Banse et al., 2008) and economic analyses (Hertel et al., 2009a). The debate around LUC effects accelerated with the publication of two articles by respectively Fargione et al. (2008) and Searchinger et al. (2008). Until then the term LUC referred to direct Land Use Change effects (dLUC), such as greenhouse gas (GHG) emissions from the actual locality where the land use was changed. Fargione et al. (2008) and Searchinger et al. (2008) instead investigated the relevance of indirect LUC (iLUC) effects which is a change in land use caused indirectly as an upstream consequence of a direct LUC taking place somewhere else in the world. ILUC and dLUC were defined in ISO standards only in 2012 (ISO/TS-14067, 2013): dLUC as a “change in human use or management of land within the boundaries of the product system being assessed”; iLUC as a “change in the use or management of land which is a consequence of direct land use change, but which occurs outside the product system being assessed”. Yet, this definition is ambiguous: if iLUC impacts are to be considered as outside of the product system (system boundaries in LCA), there would be no reason to account for them.

Different approaches and models have been proposed in recent years to solve these controversies but a broad consensus on them still needs to be reached (Warner et al., 2014). The controversies include the theoretical framework as well as the modeling approaches for the complex global land use dynamics, where difficulties relate to: the identification of the marginal land; establishing the relationship between the demand for agricultural products and land use changes; accounting for the effect of by-products; and the overall level of uncertainty caused by the multiple modeling assumptions (Marelli et al., 2011). The first rather high GHG emissions estimations caused by iLUC gave rise to serious concern (Searchinger et al., 2008; Fargione et al., 2008). Further research has downgraded the importance of the assessed effects: recent works show, for example, lower estimated iLUC GHG emissions from corn ethanol in newer studies (Dunn et al., 2013) due to the refinement and improvement of models. Some authors conclude that iLUC emissions might even be irrelevant (Kim and Dale, 2011); other studies have found iLUC effects to have neither disappeared nor to be considered as negligible (USA-EPA, 2010; Escobar et al., 2014; Moreira et al., 2014; Prapaspongsa and Gheewala, 2014). Indeed, with the current ethanol and biodiesel production trend, increasing population and per-capita consumption, it seems difficult to challenge the hypothesis that iLUC is taking place. Tyner et al. (2010) estimated that in the USA a third of corn production is intended to supply the demand of ethanol. In the meantime, the annual yields are stationary or declining while crop demand is increasing, leading to a constant increase in crop prices (Brandão, 2012). Moreover, there remain challenges in measuring the magnitude of iLUC and related effects, and models still contain a fair level of uncertainties, mainly related to data availability and modeling constraints.

With regard to the models, following the mature debate around climate change mitigation strategies they have mainly focused on GHG emissions from land use changes. There are, however, also other effects associated with increasing land use such as environmental impacts in the form of soil and water resources depletion, air quality, biodiversity loss (Wicke et al., 2012), but also social and economic impacts with effects on local communities and their economy, on indigenous rights and land use rights. In life cycle assessments they are often not included, or only partially, in the assessment of LUC impacts (Gawel and Ludwig, 2011). Therefore, recommendations suggested by such models might be biased and imbalanced towards a vision built into the models' framework.

A complete product/process assessment is often carried out within the framework of a Life Cycle Assessment (LCA) and the debate on LUC modeling has become central in the LCA community. Analyses of LUC effects in LCA make often use of case studies and are thus limited in scope to a determined product, e.g. biofuels (Hansen et al., 2014; Warner et al., 2014) and animal feeds (van Zanten et al., 2015), or geographically to a specific region (Vázquez-Rowe et al., 2013; Reinhard and Zah, 2011). Comparisons of LUC assessment results show that LUC estimates have a high range of variability (e.g. Ahlgren and Di Lucia, 2014). A comparison of methodological frameworks would be appropriate for an investigation of the reason beyond this variability and the potential for harmonizing LUC in LCA. This paper therefore aims at scrutinizing and comparing six LUC modeling approaches, each representing a different model category and respective subcategories. Strengths and weaknesses are discussed with regards to their application and integration within the LCA framework, of which the LUC modules form an integral part.

2. Materials and methods

Broadly speaking, three main approaches for LUC analysis can be recognized more or less explicitly in the literature: (1) Analyses that rely primarily upon economic models and data (e.g. Searchinger et al., 2008; Weiss and Leip, 2012; Stevenson et al., 2013); (2) analyses that rely equally on multiple approaches and data to determine cause–effect relationships (e.g. Cherubini, 2010; Schmidinger and Stehfest, 2012; Schmidt et al., 2015); and (3) role-based analyses where a norm is established to allocate LUC-related impacts (e.g. Audsley et al., 2009; Vellinga et al., 2013; Persson et al., 2014). The category of bio-physical models has also been used in literature (Nassar et al., 2011) and a rough distinction has also been made between economic or bio-physical LUC methodologies (Fritsche et al., 2010).

2.1. Mapping LUC modeling frameworks

Any sharp distinction between LUC modeling frameworks can certainly be disputed, since analyses of land transformation rely on interdisciplinary knowledge: bio-physical models may be integrated in other methodologies to incorporate geo-spatial information, especially on land cover, land availability land characteristics and suitability; economic information may be used to describe market trends and relationships between substitutable products; and normative models also ground their role-based approach on information drawn from statistical analysis and studies of different nature. Yet, for the purpose of this manuscript, it is useful to make a general distinction between LUC models to reflect the main (though often not unique) characteristics of their methodologies as follows: Economic Equilibrium Model (EEM), Causal–Descriptive Model (CDM) and role-based normative Model (NM).

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