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A framework for modelling indirect land use changes in Life Cycle Assessment

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ABSTRACT

Around 9% of global CO_2 emissions originate from land use changes. Often, these emissions are not appropriately addressed in Life Cycle Assessment. The link between demand for crops in one region and impacts in other regions is referred to here as indirect land use change (iLUC) and includes deforestation, intensification and reduced consumption. Existing models for iLUC tend to ignore intensification and reduced consumption, they most often operate with arbitrary amortisation periods to allocate deforestation emissions over time, and the causal link between land occupation and deforestation is generally weakly established. This paper presents the conceptual framework required for a consistent modelling of iLUC in Life Cycle Assessment. It reports on a novel and biophysical iLUC model, in which amortisation is avoided by using discounted Global Warming Potentials (GWPs). The causal link between demand for land and land use changes is established through markets for land's production capacity. The iLUC model presented is generally applicable to all land use types, crops and regions of the world in typical LCA decision-making contexts focusing on the long-term effects of small-scale changes. The model's strengths and weaknesses are discussed.

1. Introduction

Approximately 9% of global carbon emissions in 2011 originated from land use changes (LUC) (Le Quéré et al., 2012). Often, these emissions are not addressed in Life Cycle Assessment (LCA) because the causal link between land use and deforestation is not well understood and because there is a lack of consensus on how to establish this link. Given that a significant part of global GHG emissions has traditionally been excluded from LCA, their inclusion may significantly change the results for some products. Furthermore, increased demand for crops is met not only by deforestation but also through cropland intensification and reduced consumption at other consumers.

Several attempts to estimate LUC emissions in LCA have been done. As demonstrated in Section 1.1, the variability of results of these studies is significant. We assess that this is mainly due to the absence of a common framework for determining the indirect effect of land use via LCA modelling. The main purpose of this paper is to provide a conceptual framework for this as a basis for a novel biophysical model. An example of the operationalization of the model is provided in Schmidt and Muñoz (2014, chapter 3.5) where the model is quantified with inventory data. Further, examples of the use of the model on agri-food products are available in Dalgaard et al. (2014) and Schmidt (2015). The new model divides the causal link from land use to its effects into manageable building blocks. Each of these blocks is flexible for inclusion of different modelling assumptions and data inputs, and is open for adaptation to new scientific evidence. The model is generally applicable to all land use types (cropland, grassland, forest and other) and to all regions of the world. The model only addresses long-term changes in supply caused by changes in demand. Hence, short-term effects on prices and subsequent price-elasticity effects are not included.

There are two types of land use changes: direct land use changes (dLUC) and indirect land use changes (iLUC). Both dLUC and iLUC are caused by the use or occupation of land; land use (LU). In this paper, dLUC are defined as those changes that occur on the same land as the land use, while iLUC are defined as the upstream life cycle consequences of the land use, regardless of the purpose of the land use. Examples of dLUC include changes in soil carbon content due to a certain cultivation practice, while examples of iLUC can be

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deforestation and cropland intensification that take place somewhere else than the land use. iLUC effects have previously been referred to as competition effects (Lindeijer et al., 2001).

1.1. Approaches for estimating iLUC

Several methods have been developed for estimating iLUC and associated GHG emissions. Although, the purpose of this paper is not a detailed comparison of our method with other models that have been developed for the same purpose, an overview of existing approaches and models is provided below.

Three types of iLUC models can be identified: biophysical, economic, and rule-based.

There are several biophysical models with different degrees of complexity (e.g. Bird et al., 2013; Audsley et al., 2009; Cederberg et al., 2011). The biophysical models can be characterised by their attempt to establish a link between the demand for land/crops and deforestation/intensification with the use of physical data on crop yields, and statistical data on deforestation and land use changes. For example, Audsley et al. (2009) identify one of the driving factors of LUC as commercial agriculture. Based on this, the share of global annual GHG emissions from land use changes that is caused by agriculture is evenly distributed on all agricultural lands on a hectare basis. This method resulted in a single emissions factor for agricultural land, i.e. 1.43 t CO_2-eq./hectare of agricultural land used. The model presented in this paper is a further development of this class of models.

Economic models are many and include Leip et al. (2010) (which uses the CAPRI model), Searchinger et al. (2008) (which uses the FAPRI model) and models using the several other partial- or general-equilibrium models available (GTAP, FAPRI-CARD, AGLINK-COSIMO, LEITAP, IMPACT, etc.). The different models were originally developed for different applications but have all been used for the purpose of estimating iLUC (see Edwards et al., 2010). Common to all the economic models is that they establish a link between demand for land/crops and deforestation/intensification/reduced consumption by using partial or general economic-equilibrium models. The economic models consider factors like land price, maps of land suitability, proximity to infrastructure and existing cultivation. These models normally consider that any land expansion first displaces abandoned or fallow cropland and grassland, before forests are converted.

The rule-based models include PAS 2050 (2011), the PEF-guide (European Commission, 2012), the GHG-protocol (WRI/WBCSD, 2011). The LUC models in those standards/guidelines can be characterised by being based on normative rules rather than on causalities. The models are typically referred to as dLUC where the focus is on the historical land cover of the specific plot of occupied land during the last 20 years. Usually LUC is amortised over an (arbitrary) period of 20 years.

1.2. Uncertainties of existing models

The level of uncertainty of all models is high, which is reflected in the high variability of iLUC estimates per MJ biofuel from the different models, from significant reductions in climate impacts (−150 g CO_2-eq./MJ, e.g. corn ethanol and rapeseed biodiesel from Lywood, 2008) to significant increases (150 g CO_2-eq./MJ, e.g. soybean biodiesel from Lywood, 2008, GTAP, LEITAP, FAPRI, Searchinger et al., 2008 and Dumortier et al., 2009). A major reason for this significant variation is the lacking common basis of the models – even at the conceptual level. The identified major differences between the models are:

- They operate with different causal relationships from the demand for land or crops to deforestation,
- They adopt different geographical boundaries (the rule-based models tend to be very narrowly associated with the specific field where the studied crop is grown – whereas the economic models and some biophysical models operate with global effects mediated through global markets for land),
- They handle temporal issues differently (e.g. amortisation of LUC),
- Some models take into account the productivity of the land under study while others do not,
- Not all models consider crop intensification and reduced consumption, and
- Some models consider crop and biofuel life cycle inventories as part of iLUC effects, e.g. substitutions caused by by-products.

It cannot *a priori* be determined if biophysical or economic models will result in the lowest overall uncertainty, since this depends on the quality of the input data that each model requires and the uncertainty of the causal relationships. Generally, economic models are more complex and thus have more data and relationships, but the uncertainty on these may in the end exceed those of the coarser, but simpler, biophysical models. We therefore believe that both types of models have a role to play. In this paper, we focus our contribution on the biophysical models.

2. Methods

2.1. Definitions and classifications

2.1.1. Definition of the function of land in iLUC modelling

Indirect land use changes can be estimated in different ways. Most of the existing models (biophysical, economic and rule-based) are crop and country-specific, i.e. iLUC depends on the production of a specific amount of a given crop (or biofuel) in a specific country. Since the same plot of land, with the same inherent properties, can be occupied by different crops (or for other purposes than crop production), we argue that this is not a desirable approach. Instead, we define land as a factor of production; Land is needed to cultivate crops, land is needed for operating an open-pit mine, for physically supporting residential areas, etc. Obviously, land occupation by human activities may also change the eco-system services supported by the land, such as erosion protection, carbon sequestration, water reservoirs, and biodiversity support. However, in an LCA context, changes in eco-system services are measured as impacts from the human occupation, rather than being part of the production function, unless the change in eco-system services is part of the purpose of the land occupation. When defining land as a factor of production, all land using activities in an LCA product system need to have inputs of this factor. Since the marginal use of land is for biomass production (food, fibre, fuel etc.), because biomass production is the least competitive use of land compared to other purposes (such as residential, industry, infrastructure, raw material extraction, recreation etc.), the use of land in general can be measured in terms of the land's potential for biomass production, which allows including the efficiency of the land use in the assessment, in parallel to other forms of capital utilization. This can be compared with wind power production; in a less windy region more wind capacity needs to be installed in order to generate the same amount of electricity as in a more windy area. In the same manner, more land is needed to produce the same amounts of crops in a region with lower potential biomass production than in a more fertile region.

In iLUC models, the underlying mechanism that causes effects outside the occupied land is via crop displacements (Schmidt, 2008; Kløverpris et al., 2008). Therefore, despite the fact that land may be used for something else than biomass production, the