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Land use and land use change in agricultural LCAs and carbon footprints – the case for regionally specific LUC versus other methods

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ABSTRACT

The supply chain of a product is essential for understanding its environmental impacts. As parts of agricultural product supply chains, land use (LU) and land use change (LUC) are considered to be major contributors to global CO_2 emissions. Nevertheless, LU and LUC (LULUC) are rarely included in GHG estimations for food and feedstuffs. Here we propose a method which can be used to derive emissions from LU and LUC on a regional level. Emissions are distributed over an accounting period chosen to match the physically occurring carbon fluxes. As fluxes from soil organic carbon persist for years or even for decades after a LUC episode, depending on the climatic conditions of the region, we apply 10 and 20 years as suitable accounting periods for tropical and temperate climate zones, respectively. We compare the proposed method with two other methods proposed in the literature. Using two types of feedstuffs (Brazilian soybean-meal and Austrian barley) as examples, we find that the other two methods produce mostly lower emission estimates in the case of Brazilian soybeans, and higher estimates for Austrian barley. We conclude that these differences are caused mainly by different accounting periods and by a (non)consideration of regional specificities. While analysing life cycles necessarily entails a well supported – but still arbitrary – setting of such system boundaries, we argue that the methodology presented here better reflects actually occurring carbon fluxes that we understand to be the foundation of any environmental product assessment.

1. Introduction

Agriculture, and especially animal husbandry, cause considerable emissions of greenhouse gases (GHGs). In addition to the emissions from the livestock itself, its supply chain, specifically the production of feed, needs to be considered. This was found to contribute considerably to overall GHGs from animal husbandry, both from direct cultivation-related emissions (from soil or fuels) and from indirect emissions (e.g. Leip et al., 2010; Weiss and Leip, 2012). The term "indirect" here refers to emissions that do not occur at the location or time of feedstuff cultivation; they include for example those caused by land use change (Hörtenhuber et al., 2011), or from fertilizer manufacturing. This impact of feed may strongly differ by region (Plassmann et al., 2010; Van Middelaar et al., 2013). As opposed to previous findings (e.g. Dalgaard et al., 2008), information on characteristics of supply chains and on specified regions of origin of raw materials is increasingly available, for example on a national scale (due to traceability or certified agricultural goods traded; see e.g. UNIDO, 2010). The information can be used to estimate product-specific GHG emissions. This permits the development of a product- and region-specific approach for emissions from the supply chains of most livestock production systems; in this work, we specifically address GHGs related to land-use and land-use-change (LULUC) originating from the production of feedstuffs.

Land use change (LUC) is also termed "land conversion" or "land transformation" in life cycle assessments (LCAs). It describes emissions caused by a change from a previous use to a current use,

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such as the change from grasslands, savannahs or forests to cropland. Land use change and – to a much lesser extent – land use (LU, also termed "land occupation") are thought to be among the major contributors to global CO_2 emissions, especially in the tropical regions of South-America, Asia and Africa. Emissions from LUC are reported to have contributed approximately 20% of total global CO_2-emissions during the 1980ies and 1990ies (Denman et al., 2007). For the 2000 to 2010 decade the proportion of CO_2-emissions originating from LUC decreases from roughly 19% to about 12% (Poruschi et al., 2010), or even 10% (Harris et al., 2012). However, this decrease is on the one hand caused by a decreasing amount of CO_2-emissions from deforestation and on the other hand by a strongly increasing CO_2 emission load from fossil sources which occurred in most years of this time period (see e.g. Le Quéré et al., 2013; Poruschi et al., 2010). On the one hand, LUC from vegetated land is usually associated with a large, loss of carbon from (perennial) aboveground biomass, and on the other hand, soil organic carbon (SOC) is typically mineralized and emitted as a consequence of soil disturbance during LUC and LU. Furthermore, LUC and to a lesser extent LU cause other negative environmental effects, as they usually result in a significantly reduced biodiversity, especially in tropical regions (ten Brink et al., 2009). Additionally, LUC leads to a loss of water in the global water cycle (Avissar and Werth, 2005).

Despite their large contribution to global GHG emissions, the effects of LU and LUC have rarely been accounted for in previous LCAs or carbon footprints of food and feedstuffs (Garnett, 2009; De Vries and de Boer, 2009). Dalgaard et al. (2008) state that this is due to both conceptual and methodological limitations. The conceptual limitation refers to the feasibility of consistently quantifying all changes in SOC that occur in an agricultural production chain, not just those from LUC. Furthermore the authors note the inconsistencies in considering LULUC emission only for feedstuffs from Brazil and Argentina, but not for inputs from European farmland. Concerning methodological limitations, Dalgaard et al. (2008) note that the origin of feedstuffs and therefore the affected ecosystems are frequently not known, preventing a region-specific estimate of quantitative changes in above-ground and below-ground carbon. Additionally, the authors note that it is not clear whether LUC-related emissions should be completely ascribed to the crops cultivated during the first year or distributed over a debatable period of years of cultivation. Furthermore, a study published by Morton et al. (2006) mention a lack of data on the type of land use after conversion or on the specific crops being established on newly converted cropland. A mere lack of availability of data together with their uncertainty may also hamper inclusion of LULUC in LCAs or carbon footprints (Dalgaard et al., 2008; Plassmann et al., 2010; Van Middelaar et al., 2013).

In contrast to many feed and food supply chains, a number of studies on biofuels already includes GHG emissions from LUC due to a detailed description of carbon cycles. For example, Fargione et al. (2008) calculated the time required for biofuels to cancel a "carbon debt" from LUC to be 0–423 years; Searchinger et al. (2008) found for ethanol produced from maize that this payback time would be 167 years, and 34 years under optimistic assumptions. The issue of LULUC is critical for biofuels as the extent of net GHG savings from their use is a key argument for their production and political support (EP/EC, 2009). Since mitigation strategies for GHG are intensely discussed in agriculture in general, carbon emission or sequestration from LULUC might similarly be considered in feedstuff and food supply chains, especially as parts of their ingredients are derived from co-products of biofuels production.

In recent years, a few frameworks for estimation of carbon footprints, e.g. for food, have provided methods to deal with LULUC-related emissions. However, a consistent foundation is partly missing. For example, PAS2050-guidelines (BSI, 2011) rely on carbon emission factors per hectare of land given in IPCC (2006), but they provide no scientific explanation for suggesting a discounting period of 20 years for the resulting emissions.

Earlier methodological studies typically focused on the broader impacts of LULUC on biodiversity and the life-support function of ecosystems (e.g. Lindeijer et al., 1998; Milà i Canals et al., 2007). A literature review identified several recent studies that attempted to establish methodological foundations for assessing LULUC-related contributions to GHG emissions for food and feedstuff LCAs: Zaks et al. (2009) provide a methodological basis for the calculation of LULUC-related emissions from agricultural products and conducted case studies for Brazilian soybeans and beef. Müller-Wenk and Brandão (2010) investigated ways to integrate the impact of land use on climate impacts into LCAs. Ponsioen and Blonk (2012) calculated LUC-related carbon footprints for agricultural products, while Kool et al. (2009), Meul et al. (2012), Van Middelaar et al. (2013) and Schmidinger and Stehfest (2012) specifically addressed LULUC emissions from feedstuffs. Furthermore, Cederberg et al. (2011), Leip et al. (2010) and Weiss and Leip (2012) analysed LULUC-related emissions from livestock which originate from feedstuff production. However, in the majority of publications on feed and food product chains, no consideration of LULUC was found when estimating GHG emissions. This underlines a methodological gap particularly concerning accounting periods which are essential for an allocation of direct, product- and region-specific LULUC-related emissions. The latter is addressed in this study.

Clearly, there is a need for further developing LULUC quantification methods beyond those suggested so far in literature. The objective of this paper was to propose a method that is based on a consideration of actually occurring LULUC-related CO_2-emissions. This is accomplished by addressing appropriate system boundaries as well as accounting periods (temporal system boundaries) separately for LU and LUC (see chapter 2.1). In chapters 3 and 4 we apply this method to estimate LULUC effects and their contributions to the overall GHG emissions from the supply chain for soybeans and barley (see "Results" and "Discussion", chapters 3 and 4). We also compare these results to those derived from two other methods from literature and to a "default" variant without LULUC-related emissions. Chapter 5 presents our conclusions.

2. Materials and methods

2.1. Proposed method – scope and system boundaries

This paper presents a method to estimate LULUC-related regionally specific emissions for agricultural lands (grassland, cropland, and perennial grassland) and assign these emissions to products. While the aim is to look at European livestock products, their supply chain includes products that may have been derived from overseas. Specifically, crops such as oil seeds quantitatively dominate the agricultural imports (European Commission, 2013). LUC from forests to grasslands is also linked to European food production via imports of grass-fed beef, and large LUC-related emissions from these imports (see Cederberg et al., 2011) can also be calculated with the method described herein.

System boundaries for crop-specific emissions from LULUC have been developed based on modelling and a literature review (Hörtenhuber, 2011). There, it was concluded that system boundaries for agricultural LUC should be defined broadly when estimating GHG emissions from agricultural production in general. Therefore, the proposed method includes both short-term CO_2 emissions from the removal of above-ground biomass and longer-lasting emissions from mineralized SOC (including below-ground biomass from cleared vegetation). The latter can last decades but