Biomass and Bioenergy 85 (2016) 187–197

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Consequential effects of increased biofuel demand in Spain: Global crop area and CO_2 emissions from indirect land use change

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ARTICLE INFO

Article history:
Received 26 March 2015
Received in revised form
16 October 2015
Accepted 7 December 2015
Available online xxx

Keywords:
Crop area
Consequential approach
iLUC
GHG emissions
Biofuel
CO_2 emissions

ABSTRACT

The indirect Land Use Change (iLUC) impacts of biofuels refer to the effects of additional emissions due to land-use changes triggered by the expansion of energy crops in response to increased biofuel demand. These emissions are mostly greenhouse gases (GHG), thus relevant to the climate change impact category. In order to address these effects, the European Commission (EC) has proposed the inclusion of feedstock type specific iLUC factors for different biofuel sources in the Renewable Energy Sources Directive 2009/28/EC (RED). The goal of this study is to quantify the indirect environmental impacts both in terms of global energy crop land area and the subsequent iLUC, if an additional demand of biofuel in Spain occurs, from a consequential approach. Results show a wide range of GHG emissions, in terms of CO_2, of biodiesel and bioethanol from iLUC effects, strongly influenced by the place where the potential biofuel is produced. Based on our study, two main aspects -determine the iLUC effects: the dedicated energy crops that are used to produce biofuels and the different coproducts obtained along the biofuels production process. Therefore, contrary to the EC proposal for including a single factor by type of crop, the development of origin-dependent iLUC factors seems to be a more appropriate alternative based on the current assessment. Other aspects that might affect the results, such as crop rotation or field management, have been excluded from the analysis in this work.

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1. Introduction

The current production of first generation biofuels, mainly from crops, has provided a chance for mitigating climate change by replacing conventional fossil fuels, which has also reduced the oil imports and therefore improved the energy security. Additionally, biofuels have other benefits to be considered such as the support of agricultural industries and rural [1,2].

Based on those perceived benefits, an overall target of renewable energy consumption in the transport sector in the European Union was set at 10% of final energy consumption by the Renewable Energy Sources Directive (RED) 2009/28/EC [3]. This target is going to be met mainly by the use of biofuels. At the national level, the compulsory target value of bioethanol and biodiesel consumption in Spain has been set by the Spanish government [4] in a 4.1% and 3.9% respectively for 2013 and subsequent years. These percentages translate into daily amounts of biofuel consumption of around 1.5 million l/day of biodiesel and 0.25 million l/day of bioethanol.

Because the production of biofuels is land-intensive, the potential impacts are related to land conservation, food supply, production of by-products and coproducts potentially useful for avoiding the production of other products [5]. The displacement of food crops by energy crops not only can lead to *direct Land Use Change* (dLUC), but it could also lead to *indirect Land Use Change* (iLUC). While dLUC refers to the direct transformation of previously untouched areas into crops for biofuel feedstock production, iLUC occurs when additional demand for biofuel feedstock induces a change in land use in other places to maintain the same production of food/feed crops as demanded in the market. The estimation of iLUC is difficult to quantify, since it usually occurs outside the country borders [6,7]. iLUC was rarely included in Life Cycle Assessment (LCA) studies due to the complexity and variability of the models for accounting its effects upon greenhouse gases (GHG) emissions, triggered by the loss of carbon stocks when prior land use such as forest, grassland or native ecosystem are cleared for the displaced food production. Nevertheless, several studies focused on the comparison of environmental assessments of biofuels, including iLUC, can be consulted in the review of Ben Aoun et al. [6].

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http://dx.doi.org/10.1016/j.biombioe.2015.12.009
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Generally, two types of modelling can be distinguished to calculate GHG emissions from iLUC: economic and deterministic models. Economic models were generally developed to predict impacts on the markets resulting from changes in the flow of trade of certain goods for political decisions using predefined scenarios. These models are usually complex and used to simulate the economic impacts of agricultural policy measures. If the macroeconomy as a whole is represented, the models are called general equilibrium (GE) (*e.g.* Global Trade Analysis Project −GTAP [8]-, or Modelling International Relations under Applied General Equilibrium −MIRAGE [9]-). In contrast, when only a single market is considered, the models are named partial equilibrium (PE) (*e.g.* Worldwide Agribusiness Linkage Program/Commodity Simulation Model −AgLink/COSIMO [10]-, Food and Agricultural Policy Research Institute −FAPRI [11]-, or Common Agricultural Policy Regional Impact Analysis −CAPRI [12]-). On the other hand, deterministic models (also called biophysical models) assume that additional biomass production results in additional land use, and take a simplified approach to quantify and relate it to biomass production [13].

In order to address iLUC effects in life cycle GHG emissions of biofuels, the European Commission (EC) has carried out several expert consultations and developed corresponding actions for revising and adapting the RED [3] and the Fuel Quality Directive (FQD) [14]. The proposal of EC [15] introduces iLUC factors for biofuels, only for reporting purposes, considering different feedstock sources: 12 g CO_2eq/MJ for cereals and starch rich crops, 13 g CO_2eq/MJ for sugars, and 55 g CO_2eq/MJ for oil crops.

Many comments and amendments to these estimated values have been made by stakeholders (governments, NGOs, researchers, biofuel companies, etc.), and the issue is still being debated within the scientific community. One of the most recent studies of Finkbeiner [16,17], about the scientific resilience of iLUC in LCA of biofuels, comes to the conclusion that the additional GHG values for raw materials used as biofuels feedstock, proposed by the EC, have not been estimated based on facts, and so they cannot be used as a basis for amending EU directives. This statement has been based on many analytical results, among which it is worth noting that iLUC cannot be observed or measured, but rather its quantification is based on theoretical models that mainly rely on hypothetical assumptions and market predictions. Furthermore, there is a broad consensus in the scientific community that iLUC factors are highly uncertain [16]. GHG emissions derived from iLUC have large ranges of variation (bioethanol from −116 to 350 g CO_2eq/MJ, and biodiesel from 1 to 1434 g CO_2eq/MJ) [16], and so the lack of scientific robustness and consistency of iLUC models and their underlying data make the provision of single values for iLUC factors rather speculative. These shortcomings are also properly reflected in the existing international standards for LCA and Carbon Footprint (CF), which state that "iLUC factors are a hasty reaction in method development and an arbitrary choice for decision-making" [16]. Moreover, a study applied to the United States stated that threshold values for biofuels are site-dependant and value choice-driven [18].

Regarding the previous concerns, the goal of this study is to estimate the indirect environmental impacts, both in terms of global energy crop land area and the subsequent GHG emissions derived from iLUC, if an additional demand of biofuel in Spain occurs. Relevant scenarios have been proposed and analysed from a consequential − approach.

2. Method and materials

There are two different life cycle approaches: attributional LCA (aLCA) and consequential LCA (cLCA). While aLCA method accounts for immediate physical flows involved across the life cycle of a product system, cLCA aims to describe how physical flows can vary as a consequence of variations in demand for the product system under study [19]. The cLCA uses marginal data in order to represent the effects of a minor change in the output of goods and takes into account the market and the economic implications. The cLCA modelling principles are widely described in Refs. [20,21]. An example of application of cLCA approach in alternative biofuel production in Spain is described in Ref. [22]. In this study, a consequential approach was chosen in order to describe the multiproduct scheme of biofuels production. The analysis focused only in carbon dioxide emissions derived from iLUC, without covering other potential impacts, so it cannot be called a complete cLCA.

2.1. System boundaries and life cycle inventory

The first step is the determination and selection of the main raw materials to satisfy the demand of biofuels in Spain. Assuming statistical data for the year 2011 from Refs. [23], biodiesel is produced from soybeans (55.19%), palm (43.03%), rapeseed (1.70%) and sunflower (0.09%), while bioethanol comes from maize (51.05%), sugar cane (25.53%), wheat (18.55%), barley (2.79%) and sugar beet (2.07%). Tables 1 and 2 show the origin of crops for producing each biofuel and the average yield considered for the subsequent calculations.

Life cycle inventory data for the production of each biofuel have been updated from several studies and databases. Data of the main ratios of production have been collected from previous CIEMAT's studies [25–27] and the study of Dalgaard et al. [28]. Ecoinvent [29] and BIOGRACE [30] databases have been selected to consider the ratios of production in the case of palm and the main physical properties of the biofuels and coproducts, respectively. Tables 3 and 4 show the main ratios of production for the biofuels.

2.2. Identification of goods or services affected by coproducts (or byproducts) and induced land use changes

According to ISO standards [31,32], explicit rules have to be applied in the processes where several coproducts (or byproducts) are originated. Whenever possible, allocation should be avoided. System limits expansion is an inherent procedure when a cLCA approach is applied. It pursues to consider the potential environmental changes in any influenced system as a consequence of a certain activity, i.e. it considers how the global market responds to increase or decrease in supply of coproducts, and models the potential environmental consequences (either positive or negative) of these changes. As previously mentioned, several coproducts are obtained together with the studied biofuels. These coproducts have a value in the market, and they might displace the production of other goods that provide similar services, therefore the system limits expansion procedure has been chosen for the biofuels under study.

In the case of biodiesel, two coproducts are produced along the life cycle. Meal is a coproduct obtained during the oil extraction that is used as animal feed due to its protein and energy content, according to the predictions of Schmidt and Weidema [33]. Other meals or goods displaced by this coproduct will be later identified. Additionally, glycerin is obtained in the transesterification process.

However, this co-product will probably have a negligible impact on iLUC. Positive impact on iLUC from the use of glycerin could be claimed if this product were used to produce biogas instead of dedicated energy crops. However, this situation is not likely to be produced in Spain where most biogas is obtained from residues [34]. In the case of biodiesel production, the expanded system includes the production and use of the meals resulting from the oil

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