BIOMASS AND BIOENERGY 56 (2013) 166–178

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Effects of land-use change on the carbon balance of 1st generation biofuels: An analysis for the European Union combining spatial modeling and LCA

Florian Humpenöder [a,b,1], *Rüdiger Schaldach* [a,*], *Yalda Cikovani* [c], *Liselotte Schebek* [c]

[a] *Center for Environmental Systems Research (CESR), University of Kassel, Wilhelmshöher Allee 47, D-34109 Kassel, Germany*

[b] *Potsdam Institute for Climate Impact Research (PIK), P.O. Box 60 12 03, D-14412 Potsdam, Germany*

[c] *TU Darmstadt, IWAR, Chair of Industrial Material Cycles, Petersenstrasse 13, D-64287 Darmstadt, Germany*

ARTICLE INFO

Article history:
Received 16 December 2011
Received in revised form
4 March 2013
Accepted 3 May 2013
Available online 31 May 2013

Keywords:
Biofuels
Spatial model
Land-use change
GHG emissions
LCA
European Union

ABSTRACT

Biofuels are considered as an important option for the mitigation of climate change. However, the negative impact of land-use change (LUC) on soil and vegetation carbon pools may jeopardize the potentially achievable savings of greenhouse gas (GHG) emissions. In this study the impact of GHG emissions from LUC on the overall GHG performance of 1st generation biofuels was analyzed for the European Union (EU). The scenario-based analysis was done by coupling a spatial land-use model to a Life Cycle Assessment (LCA) of biofuels. The biofuel demand in the scenarios was derived from figures for the transport sector of the EU-27 Member States. The calculation of GHG emissions was performed with a Geographic Information System. Finally, these results were integrated into the LCA approach of the EU Renewable Energy Directive (RED). Without taking LUC into account, the average GHG emission saving compared to fossil fuel use amounts to ~50%. In this case the mandatory 35% emission saving target laid down in the RED would be fulfilled. If LUC is considered, this target is reached under none of the simulated biofuel scenarios. In the most realistic scenario the GHG emission savings from 1st gen. biofuel use compared to fossil fuel use range between −2% and 13%. Based on our findings, we conclude that national policy plans for biofuel use should be reconsidered and revised as in their current form they do not provide an adequate measure for the mitigation of global warming on EU-level.

* *Corresponding author*. Tel.: +49 5618046130.
E-mail addresses: florian.humpenoeder@pik-potsdam.de (F. Humpenöder), schaldach@usf.uni-kassel.de (R. Schaldach), Y.Cikovani@iwar.tu-darmstadt.de (Y. Cikovani), liselotte.schebek@iwar.tu-darmstadt.de (L. Schebek).
[1] Tel.: +49 331 288 26 77.

0961-9534/$ – see front matter
http://dx.doi.org/10.1016/j.biombioe.2013.05.003

1. Introduction

The Renewable Energy Directive (RED)[2] *on the promotion of the use of energy from renewable sources* [1] includes a specific target for the European Union (EU) transport sector. 10% of the Energy consumption in transport has to be covered by renewable sources in each Member State by 2020. Besides reducing the dependency on oil imports and fostering the development of rural areas, the aim of this regulation is to diminish transport related greenhouse gas (GHG) emissions. This study addresses the last issue. Currently the share of renewable energy sources in EU road transport amounts to 3.5%, with 1st gen. biofuels as the most important renewable source [2]. Of all 1st gen. biofuels consumed in EU road transport, biodiesel makes up the largest share (72%), followed by bioethanol (19%) and other biofuels (9%). The major part of 1st gen. biofuels consumed in the EU is produced domestically from crops such as rapeseed, wheat, maize and sugar beet. Biodiesel imports, primarily from the US, account for 22%, bioethanol imports, primarily from Brazil, account for 35%. The GHG emissions associated with biofuels are often assessed with the help of Life Cycle Assessment (LCA), a technique intended to take into account "the potential environmental impacts of a product system throughout its life cycle" [3]. But common LCA practice typically does not assess impacts resulting from direct or indirect land-use change (LUC) [4–7]. When GHG emissions from LUC are *not* taken into account IEA [8] estimates GHG emission savings from 1st gen. biofuel use compared to fossil fuel use between −20% and 120%, while European Commission and UK RFA [1,9] estimate a range of 16–71%.

Direct LUC due to biofuel production occurs if land (e.g. forest or grassland) is converted to cropland for the production of biofuels. Direct LUC is strictly regulated in the sustainability criteria of the RED [1]. Indirect LUC occurs if biofuel production takes place on existing cropland and for the production of food additional non-cropland has to be converted to cropland. In this study we account for both, direct and indirect LUC, but we do not explicitly differentiate between them. Since the carbon stocks in soil and vegetation are closely linked with the land-use type, they also change if LUC takes place. A decrease in these carbon stocks results in the release of carbon dioxide to the atmosphere [10]. Therefore LUC has an impact on the GHG performance of biofuels.

According to Annex V of the RED [1] GHG emissions resulting from LUC have to be included in the LCA of biofuels. Since the location of LUC is relevant for the calculation of GHG emissions, the assessment of LUC should be spatially explicit [4].

There are several studies concerning GHG emissions associated with LUC due to biofuel production. Bowyer [11] estimates GHG emissions from LUC between 44 and 77 $MtCO_{2eq}\ a^{-1}$ on EU-level by applying conversion factors to biofuel figures taken from the National Renewable Energy Action Plans (NREAPs) of the EU Member States [12]. The usage of conversion factors represents a non-spatially explicit form of accessing LUC and associated GHG emissions. DG Energy [13] carried out a literature review, taking into account 22 LUC modeling exercises, for the European Commission concerning the impact of LUC on the GHG performance of biofuels. They criticize that all of the reviewed models neglect the option of biofuels not being produced at all and that it is unclear throughout all evaluated models how the assumed quantities of biofuel production are obtained. Moreover, none of the reviewed models considers the mandatory EU GHG emission saving target laid down in the RED and the possibility of GHG emission saving improvements by 2020. Finally, there are numerous differences in the method of carbon stock calculation among the reviewed models.

In this paper we describe our approach to overcome the shortcomings listed above. We use the spatially explicit simulation model LandSHIFT [14,15] to determine LUC due to 1st gen. biofuel production on a 5 arc minutes grid map of the EU-27 Member States.[3] Based on standard values for carbon stocks in soil and vegetation taken from the EU's RED [1] we calculate the GHG emissions from LUC for each grid cell by employing Geographic Information System (GIS) software. We couple the spatial model to an LCA of biofuels by integrating the calculated GHG emissions from LUC, as an elementary flow, into the LCA approach of the EU's RED. In order to determine the overall GHG performance of biofuels we calculate the GHG emission saving indicator, which is directly comparable to the mandatory target laid down in the RED. Our analysis uses scenarios of 1st gen. biofuel production and compares them to a baseline scenario without biofuel use. The biofuel demand in the biofuel scenarios is based on figures for the period 2005–2020 taken from the NREAPs. Moreover, we assume that technological change (TC) increases crop yields and decreases GHG emissions in the biofuel industry.

In the Methods and materials section we describe the LCA approach of the RED, the LandSHIFT model and its validation, the design of our study, the calculation of GHG emissions from LUC and the impact assessment. Section 3 presents the results of our study on aggregate EU-level as well as on Member State level: LUC, GHG emissions from LUC and an indicator for the GHG performance of biofuels. In Section 4 the study results are discussed. The paper ends with a short conclusion.

2. Methods and materials

2.1. *Life cycle assessment*

In the RED [1], the LCA of fuels and biofuels regarding GHG emissions is defined as shown in equation (1).[4] All emissions are expressed in $gCO_{2eq}\ MJ^{-1}$.

[2] RED: Renewable Energy Directive, EU: European Union, GHG: Greenhouse gas, LCA: Life Cycle Assessment, LUC: land-use change, NREAP: National Renewable Energy Action Plan, GIS: Geographic Information System, SUE: Sustainability Eventually, TC: Technological change.

[3] The study area comprises the EU-27 Member States except Malta, Cyprus and Luxembourg which have been excluded because the 5 arc minutes resolution we use does not allow for analysis of LUC in those countries.

[4] In the framework of this study emission savings from carbon capture, excess electricity and soil carbon accumulation via improved agricultural management are assumed to be zero. Therefore the corresponding terms have been excluded from the equation.