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A consequential assessment of changes in greenhouse gas emissions due to the introduction of wheat straw ethanol in the context of European legislation

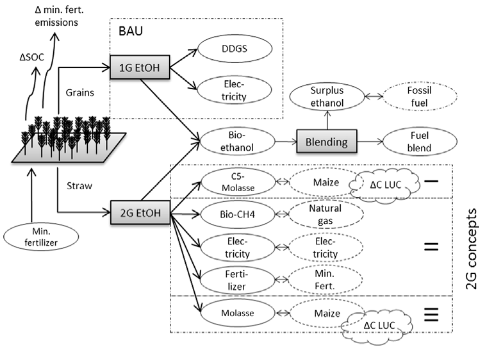
Benedikt Buchspies*, Martin Kaltschmitt

Hamburg University of Technology (TUHH), Institute of Environmental Technology and Energy Economics (IUE), Eissendorfer Str. 40, D-21073 Hamburg, Germany

HIGHLIGHTS

- The shift from 1st generation to 2nd generation bioethanol from straw is assessed.
- Resulting GHG emissions are evaluated in the context of European legislation.
- Emissions might increase if 2nd generation ethanol replaces 1st generation ethanol.
- A detailed analysis of land-use change mechanisms confirms results.
- Consequently, proposed EU legislation might provoke unintended consequences.

GRAPHICAL ABSTRACT



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ABSTRACT

Until today, first generation (1G) biofuels dominate the market for alternative fuels. The European Commission decided to cap 1G biofuels and promote second generation (2G) biofuels with the intention to reduce greenhouse gas (GHG) emissions, to limit the competition of food, feed and biofuels, as well as to improve societal approval. The assessment of consequences entailed to a shift from 1G to 2G biofuels is required to judge whether such a shift is advisable or not. According to the renewable energy directive (RED), GHG savings, need to be determined for all biofuels. By the end of 2020, fuel blends need to achieve a GHG reduction of 6%. Thus, GHG savings will determine the quantity of biofuel to be blended with fossil fuels and thereby eventually define the demand for biofuels. In this paper, the consequences of a shift from a 1G to a 2G biofuel is assessed by the example of bioethanol from wheat grains and straw. In total, three concepts of 2G ethanol production from wheat straw are considered: fermentation of C6-sugars with (1) co-production of feed, (2) coupled with biogas production and (3) co-fermentation of C5- and C6-sugars with co-production of feed. To determine the effect of the introduction of 2G ethanol, GHG savings according to RED are calculated first, and, in a second step, consequences of the shift from 1G to 2G ethanol are assessed by accounting for substitution mechanisms and emissions from direct and indirect land-use change (LUC). GHG savings of these 2G concepts according to RED methodology range from 103 to 105%. The shift from 1G ethanol to these 2G concepts is assessed by two scenarios: (1) additional production of 2G ethanol and (2) the replacement of 1G ethanol by 2G ethanol. Results indicate that GHG emissions decrease in scenario 1 if all surplus ethanol replaces fossil fuels. Under the given assumptions, the reduction in emissions ranges from 9.0 to 12.1 kg CO_2-eq./GJ ethanol-gasoline blend. If 1G ethanol is replaced by 2G ethanol, GHG emission increase in a range from 7.5 to 16.5 kg CO_2-eq./GJ fuel blend. This is mainly due to the provision of feed that needs to be supplied as a consequence of the shift in production: 1G ethanol production

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* Corresponding author.
E-mail addresses: benedikt.buchspies@tuhh.de (B. Buchspies), kaltschmitt@tu-harburg.de (M. Kaltschmitt).

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provides a high protein feed that needs to be provided by other means. Hence, the main driver for an increase in emissions is the provision of soybean meal and entailed emissions from LUC. A sensitivity analysis shows that these results are robust regarding input parameters and LUC assumptions. These findings point out that it is of utmost importance to assess changes induced by the introduction of novel fuels rather than assessing them isolated from market conditions. Based on these findings, it can be concluded that current and proposed legislation might trigger effects opposed to those intended.

1. Introduction

As a consequence of the crude oil crises in 1973 and 1979/80, the production of liquid biofuels was expanded with the purpose of reducing the dependency on fossil fuels. In recent decades, the search for non-fossil alternatives has been propelled by the objective to reduce anthropogenic GHG emissions. Fuels based on vegetable oil, starch and sugar crops, named first generation (1G) biofuels, were the first biofuels that were brought to market maturity. Simultaneously, an increasing world population and changing consumption patterns have led to an increase in demand for agricultural commodities. As a consequence, second generation (2G) biofuels obtained from organic residues and wastes were strongly promoted as an alternative to 1G biofuels. The European Commission decided to cap the use of 1G biofuels to promote their phasing out [1,2]. In order to facilitate a reduction in GHG emissions, the European Commission decided that biofuel-fossil fuel blends are required to achieve a reduction in GHG emissions of 6% by 2020 [3]. The quantity of a biofuel to be blended with fossil fuel to achieve this target is determined by the GHG savings that are estimated through a calculation method defined in the RED [4]. As of 2017, only Germany has adopted this mechanism, while other countries still rely on fixed blending rates [5]. However, in the future, other European countries will transpose this mechanism into national legislation. At the moment, the European Commission is revising the RED for the period of 2021–2030 and the current draft indicates that a reduction in the share of 1G biofuels is envisaged [2]. In contrast, minimum targets of 2G biofuels are implemented and a trajectory is defined to facilitate an increase of the share of 2G/advanced biofuels. The predicted decrease in the energy demand of the transport sector by 7% from 2015 to 2030 should therefore result in a replacement of 1G biofuels with its 2G counterpart [6]. Among 2G biofuels, straw-based bioethanol presents one of the most promising concepts [7].

In this context, the present paper assesses the transition 1G to 2G biofuels, using the example of bioethanol production from wheat grains and straw cultivated in Germany. Thereby, the implications of the blending regulation based on GHG savings, as well as the proposed transition from 1G to 2G bioethanol, are discussed.

2. Literature overview and motivation

Recent political decisions have been accompanied by the interest to evaluate the environmental impacts of 1G and 2G biofuels (among other means of providing energy for transportation). In recent years, numerous studies addressed the environmental impacts of 2G biofuels by life cycle assessment (LCA). The reviews of Gerbrandt et al. [8], Morales et al. [9] and Borrion et al. [10], analyzing studies on bioethanol production from lignocellulosic feedstock covering for the time period from 1999 to 2015, indicate a reduction in GHG emissions due to the use of 2G bioethanol in comparison to fossil fuel. The studies comprised in these reviews show a high variation of important parameters such as the quantity of fertilizer that is applied, N_2O emissions resulting thereof, as well as ethanol and co-product (mainly electricity) yields [8–10]. Furthermore, the application of different LCA methodologies leads to complication when comparing various studies. The handling of arising co-products, the selection of a reference system and the functional unit have the highest impacts on results among methodological aspects. The chosen methodology usually depends on the type of analysis that is conducted: On the one hand, an attributional LCA (aLCA) seeks to analyze the environmental impacts of a specific product system or service and to provide an evaluation of environmental implications of different stages of the life cycle of a product [11]. The analyzed system is limited to the assessed product system. On the other hand, a consequential LCA (cLCA) seeks to assess changes in environmental impacts as a consequence of a change in a product system or as a result of a specific decision [11,12]. In this case, the analyzed system is expanded and accounts for market effects and other consequences that might occur.

In recent years, the focus has shifted to the use of LCA as a means to support (political) decision making [13]. This trend, reflected in the increased interest in cLCA studies, has been a driver and a consequence of the discussion on (indirect) land-use change (iLUC) triggered by biofuel demand. A vital debate evolved that revolves around the key question: which method is best to support robust (political) decision making? Due to its ability to reflect potential consequences of certain decisions, cLCA is considered by some to be a useful method to support policy making, cf. [14,15]. However, the fact that cLCA cannot accurately account for all market effects, that its results and hypotheses cannot be confirmed or falsified, and that emission reductions predicted by cLCAs do not result in emission reductions if not accompanied by appropriate political measures, has led to criticism [16,17]. In practice, the distinction between these two models is not that clear and a constructive dialogue leading to modeling frameworks that allow better support of decision making is needed [18].

This debate reflects the need of investigations that discuss both approaches in the context of political decision making. Recent studies on novel fuel production concepts applying aLCA or the RED methodology, mainly presenting a aLCA approach, report a reduction in GHG emissions in comparison to fossil reference systems [19–23]. However, the omission or inconsistent inclusion of substitution effects and other consequences on connected markets inhibits the drawing of a conclusion as to whether an introduction of the analyzed fuel is likely to result in a reduction in GHG emissions. The aLCAs of straw-based fuel and energy production conducted by Whittaker et al. [21] and Weiser et al. [23] present detailed discussions of methodological aspects regarding straw removal. In both cases, authors concluded that changes in energy and agricultural markets need to be addressed by means of cLCA to improve the understanding of consequences entailed to the analyzed system. Monteleone et al. [24] provide such a cLCA of straw-based electricity production in Southern Italy. A comparison of two conventional (agro-ecological and energetic valorization of straw) and one “innovative” concept (no-tillage practice, crop rotation) yields that the latter is the most preferable in terms of GHG emissions and the reduction of fossil energy demand. Lopes de Carvalho [25] assessed environmental impacts of the production of bioethanol in Brazil and its effect on the Brazilian economy and show that positive effects induced by 1G and 2G ethanol production can be counterbalanced by negative effects occurring elsewhere in the economy. Hamelin et al. [26] assessed the consequences of the production of biogas in Denmark and found a reduction in GHG emissions due to a shift from a fossil reference system to the production of biogas. Tonini et al. [27] conducted a detailed cLCA of bioelectricity, biomethane and bioethanol from 24 substrates produced in Northern Europe. The assessment of 1G and 2G substrates considers emissions from feedstock provision to the final use of the energy carrier in case of biofuels. The results indicate that only