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Impact of agricultural-based biofuel production on greenhouse gas emissions from land-use change: Key modelling choices

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ABSTRACT

Recent regulations on biofuels require reporting of greenhouse gas (GHG) emission reductions related to feedstock-specific biofuels. However, the inclusion of GHG emissions from land-use change (LUC) into law and policy remains a subject of active discussion, with LUC–GHG emissions an issue of intense research. This article identifies key modelling choices for assessing the impact of biofuel production on LUC–GHG emissions. The identification of these modelling choices derives from evaluation and critical comparison of models from commonly accepted biofuels–LUC–GHG modelling approaches. The selection and comparison of models were intended to cover factors related to production of agricultural-based biofuel, provision of land for feedstock, and GHG emissions from land-use conversion. However, some fundamental modelling issues are common to all stages of assessment and require resolution, including choice of scale and spatial coverage, approach to accounting for time, and level of aggregation. It is argued here that significant improvements have been made to address LUC–GHG emissions from biofuels. Several models have been created, adapted, coupled, and integrated, but room for improvement remains in representing LUC–GHG emissions from specific biofuel production pathways, as follows: more detailed and integrated modelling of biofuel supply chains; more complete modelling of policy frameworks, accounting for forest dynamics and other drivers of LUC; more heterogeneous modelling of spatial patterns of LUC and associated GHG emissions; and clearer procedures for accounting for the time-dependency of variables. It is concluded that coupling the results of different models is a convenient strategy for addressing effects with different time and space scales. In contrast, model integration requires unified scales and time approaches to provide generalised representations of the system. Guidelines for estimating and reporting LUC–GHG emissions are required to help modellers to define the most suitable approaches and policy makers to better understand the complex impacts of agricultural-based biofuel production.

Contents

Table of abbreviations: AB, agent-based; AEZ, agro ecological zone; CET, constant elasticity of transformation; dLUC, direct land-use change; EPA, Environmental Protection Agency; EPPA, Emissions Prediction and Policy Analysis; EU, European Union; GE, general equilibrium; GES, greenhouse gas emission saving; GHG, Greenhouse gas; GTAP, global trade analysis project; iLUC, indirect land-use change; KLUM, Kleines Land-Use Model; LUC, land-use change; MAGNET, modular applied general equilibrium tool; PE, partial equilibrium; POLYSIS, Policy Analysis System; RED, Renewable Energy Directive; RFS, Renewable Fuel Standard; SD, system dynamics; USA, United States of America

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1. Introduction

Concerns about biofuel sustainability have pushed governments and international agencies to develop sustainability criteria for biofuels that producers must respect [1]. Special attention has been given to reporting the greenhouse gas (GHG) emission savings (GES) of biofuels [2]. Several countries have issued regulations that require reporting the GHG emission performance of biofuels. These regulatory schemes include the Renewable Transport Fuel Obligation in the United Kingdom (UK), the Renewable Energy Directive (RED) in the European Union (EU), the Low-carbon Fuel Standard in the State of California, and the Environmental Protection Agency's (EPA) Renewable Fuel Standard (RFS) in the United States of America (USA) [3–5].

A major point of discussion in the assessment of biofuel GES is the impact of feedstock production on land-use change (LUC) [6,7]. In the case of agricultural-based feedstock for biofuels, recent studies point to the significance of LUC–GHG emissions for the overall GHG emission balance of biofuels [2,8–14]. When LUC occurs, the GES of biofuels may be offset by the direct or indirect contribution to carbon stock changes in land [15]. Consequently, in recent years, the number of studies dealing with biofuels, LUC, and GHG emissions has grown sharply [16].

Quantitative estimates of LUC–GHG emissions vary significantly because of the variety of biofuel production pathways being considered and the complexity of the system being addressed [17]. The current lack of reliable and unified methodologies and consistent data to perform the estimate has caused governments to become cautious when considering inclusion in biofuel standards and policy [18]. This combination of factors may have contributed to the considerable variation in regulatory schemes that address LUC–GHG emissions. Possibly as a response to this uncertainty, estimation of LUC–GHG emissions from the production of feedstock for biofuels has become a significant focus of research while debate on policy inclusion continues [19–21].

The literature on these issues is vast and not well cross-referenced, opening the possibility that modellers will be unaware of related work in complementary fields. Indeed, reviews of LUC–GHG emissions from biofuel production have focused mainly on the comparison of global economic approaches and their simulation results [17].

This paper provides a broader assessment of commonly used modelling approaches. Through comparison of models, two key features are identified: (1) important modelling parameters for assessing LUC–GHG emissions from biofuels, and (2) the adequacy of each modelling approach in the assessment of nexus issues in the fields of biofuels, LUC, and GHG emissions. Also provided is comment on the limitations of common modelling approaches, with exploration and discussion of possibilities for improvement.

2. Methodological approach

2.1. Selection of modelling approaches

This review of modelling approaches highlights conceptual aspects of the different modelling procedures; results of simulation approaches are not reported or discussed. Other authors have acknowledged the diversity of model-based results and the uncertainty linked to the estimation [7,17,19,22], and the current review is not needed as a contribution to that work. For this paper, the main factors influencing the measurement of LUC–GHG emissions from biofuel production have been studied, and previous reviews on the subject have been analysed, leading to the conclusion that a broader assessment of modelling approaches is needed to overcome current limitations.

Measuring LUC–GHG emissions from biofuel production is a major issue for two specific needs: the inclusion of the estimation in government regulations, and the certification of sustainable biofuels at the producer level. Three methodologies have been applied to measure LUC–GHG emissions caused by feedstock production of biofuels: empirical observations, causal–descriptive assessments, and modelling and simulation (Fig. 1).