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Greenhouse gas balances and land use changes associated with the planned expansion (to 2020) of the sugarcane ethanol industry in Sao Paulo, Brazil

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ABSTRACT

Brazil is expected to increase its sugarcane production in the coming years. Almost 60% of the Brazilian sugarcane production in 2012 was situated in the state of São Paulo, where production is expected to increase further. This paper reports estimated direct land use changes and greenhouse gas balances (including soil carbon stock changes) associated with expanding production of sugarcane-based ethanol in São Paulo state. Geographic information about the location of existing and planned sugarcane mills and existing land use in these locations is used. Almost all of the sugarcane expansion in 2004–2008 took place on roughly equal shares of cropland or pasture land. The locations of the planned mills indicate that most new sugarcane might be planted on cropland unless the sugarcane is sourced from longer distances than has typically been the case. These results confirm that sugarcane expansion does not cause much direct deforestation but contrast with the view that direct competition for prime cropland is generally avoided since sugarcane is mostly planted on extensively used pasture lands. Analyses of greenhouse gas emissions and savings support the view that expansion of sugarcane ethanol in Brazil will likely bring about substantial savings – unless the expansion causes significant emissions associated with indirect land use change.

1. Introduction

Brazil is one of the world's largest ethanol producers [1]. Brazilian ethanol is produced from sugarcane, and almost 60% of the production in 2012 was located in the state of São Paulo (São Paulo) [2] where roughly one-third of the agricultural area is used for sugarcane production (for Brazil as a whole, the figure is 4%) [2]. The sugarcane area in São Paulo increased from 2.7 to more than 5 million hectare (Mhectare) during 2002–2010 [3] and is projected to increase further, to reach almost 6 Mhectare in 2021/2022 [4], driven by increased demand for both ethanol and sugar [5].

Governments have started to include greenhouse gas (GHG) considerations in their policies (e.g. [10,11]) and many studies (e.g. [6–9]) have quantified the GHG balance of Brazilian sugarcane ethanol. These studies consider activities that are associated with practically all forms of biofuel production (e.g., production and use of fossil fuels, fertilizers and other inputs, and sometimes also the production of machines

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and other equipment used in the production chain) and – to a varying degree – activities specific to the sugarcane ethanol system, such as pre-harvest field-burning and use of the lignocellulosic by-product bagasse as process fuel. The available studies indicate that when gasoline is displaced by Brazilian sugarcane ethanol this results in substantial GHG savings – if GHG emissions associated with land use change (LUC) can be kept low.

The connection between biofuel expansion and LUC has caused concern, and studies have pointed to a range of undesirable impacts, including GHG emissions associated with LUC ([12,13]). Studies of LUC emissions associated with biofuels report widely different results, and especially the inclusion of indirect LUC (iLUC) adds greatly to the uncertainty in quantifications of LUC effects ([14,15,13]). Existing quantification methods either employ approaches where global LUC is allocated to specific biofuels/feedstocks grown on specified land types (e.g. [16–18]), or economic equilibrium modeling that integrates biophysical information and/or biophysical models (e.g. [19–22]).

Estimates cannot be expected to converge towards narrow ranges supporting a globally agreed ranking of biofuels with regard to LUC and associated emissions as methodology develops. The causes behind LUC are multiple, complex, interlinked, and change over time. This makes quantification inherently uncertain since it is sensitive to many factors that can develop in different directions, including land-use productivity, trade patterns, prices and elasticities, and use of by-products associated with biofuels production. Policies and legal measures that directly or indirectly influence land use can have a strong influence on future LUC and associated emissions (see, e.g. [23–31], for the case of Brazil). Energy system change is another indirect effect that so far has received less attention, but results (which diverge, as for iLUC) indicate that the magnitude of the influence of this market-mediated effect – whether positive or negative – on the GHG savings of biofuels could be similar to that of iLUC ([32–35]).

This paper reports results from a study that quantifies LUC and GHG balances associated with a Brazilian sugarcane ethanol production expansion scenario. The scenario was developed based on combining (i) an assessment of approved licenses to build sugarcane mills (approved mills); (ii) an inventory of relevant policies and laws; and (iii) a mapping of historic LUC associated with the construction and start-up of sugarcane mills. The rationale for this approach is that real-world plans are developed under consideration of a multitude of factors (biophysical, technical, socioeconomic and legal conditions, biofuel and food markets, company strategies, etc.) that might be difficult to capture in the techno-economic models commonly used to produce biofuel expansion scenarios. The ambition was to produce a scenario that corresponds to the development judged "most likely". Rather than produce a suite of scenarios to reflect possible development pathways, we investigate uncertainties by varying selected parameters in the sensitivity analysis.

Due to the uncertainties involved, iLUC and other indirect effects are not considered since their inclusion would introduce an element of uncertainty counteracting the ambition to make quantitative estimates for a scenario developed based on real-world observations. While not providing new iLUC estimates, this study contributes insights by presenting information about land displacement patterns associated with the sugarcane ethanol expansion. The implications of these patterns are discussed in the context of the development of Brazilian agriculture and how this development could be influenced.

2. Materials and methods

2.1. *Increase in sugarcane ethanol production capacity*

At the end of 2008, approval had been granted for the construction of 21 sugarcane mills in São Paulo [36]. In 2012, the number of mills in operation was the same as at the end of 2008 ([36,37]). Ethanol markets can change rapidly depending on ethanol and petroleum prices and policy developments (e.g., tax exemptions and import tariffs). If growth in ethanol demand and attractive ethanol prices are considered likely, already approved sugarcane mill projects may be implemented relatively rapidly. We assumed that the sugarcane plantation area associated with each of the existing mills was constant during the 20-year modeling period (ethanol output from these mills increases due to increased cane yields and improved ethanol output per unit cane). We also assumed that the 21 approved mill projects are implemented in the first three years of the modeling period. This would imply an average expansion rate similar to the period 2002–2010.

2.2. *Direct land-use change associated with sugarcane expansion*

The dLUC associated with planting sugarcane to provide feedstock for each of the 21 approved mills was estimated based on information about land use surrounding the existing operating mills and the 21 approved mills ([38,39,36]) and a methodology for modeling land allocation around the mills, as described below.

2.2.1. *Demand for sugarcane from the approved mills*

The average new mill in São Paulo in the 08/09 season could process about 2 million tonnes (Mt, 1 tonne (t) = 1000 kg) of sugarcane, ranging from 60 kt to 8 Mt [40]. Assuming an average sugarcane yield at 85 t ha^{-1} y^{-1} (based on [41]) and an average approved mill capacity corresponding to 2.3 Mt sugarcane processed per season (slightly higher than the average in 08/09), about 27 1000 hectare (k hectare) y^{-1} of sugarcane needs to be harvested to supply the average approved mill. Sugarcane is usually replanted every sixth year and is not harvested the first year; i.e., six years of sugarcane cultivation yields five harvests. To service the plantation there is about 400 m^2 ha^{-1} of plantation allocated to roads (Assunção A., MSc. University of São Paulo, personal communication, 2012-03-16 [68]). This means that almost 34 land will be needed to supply the average approved mill with sugarcane, and about 700 k hectare is needed to supply the 21 approved mills. This can be compared with the existing (2010) sugarcane area of about 5 Mhectare [3] and the projected expansion for São Paulo up to 2021/2022 of almost 1 Mhectare [4].