Land Use Policy 72 (2018) 65–73

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Land use change and the carbon debt for sugarcane ethanol production in Brazil

Akenya Alkimim[a], Keith C. Clarke[b,*]

[a] Doutora em Solos e Nutricao de Plantas Pela Esalq-USP, Universidade Federal De Vicosa, Brazil
[b] Department of Geography, University of California, Santa Barbara, CA 93106-4060 USA

ARTICLE INFO

Keywords:
Carbon stock
Greenhouse gases
GIS
Pastures
Sugarcane

ABSTRACT

Farming sugarcane, as a renewable source of ethanol for use as a fuel, is a common practice in Brazilian agriculture. Despite being renewable, whether ethanol use actually reduces greenhouse gas (GHG) emissions depends on how the sugarcane is produced. Studies have shown that land use changes due to sugarcane farming are responsible for a substantial amount of the carbon emitted into the atmosphere, and may be equivalent to, or even greater than, the great "villains" of global warming–the fossil fuels. In the context of climate change, are there alternative land use changes that could create a lower overall carbon debt for ethanol and sugarcane production? In attempting to answer this question, this study aimed to: (i) map carbon stocks in the Brazilian biomes; (ii) quantify the carbon loss under different scenarios of land use changes for sugarcane-ethanol production; (iii) calculate the payback time for land conversion to sugarcane; and (iv) quantify the current areas of cultivated and degraded pasture by biome. The results show that the carbon debt from the deforestation of Brazilian biomes for ethanol production is equivalent to 608 Mg CO_2 ha^{-1} for the Amazon, 142 Mg CO_2 ha^{-1} for the Cerrado and 212 Mg CO_2 ha^{-1} for the Atlantic Forest with respective payback times of 62, 15 and 22 years. However, carbon emitted from the conversion of existing pasture land to sugarcane production rather than forest would be much smaller, with a shorter payback time. We conclude that pasturelands, especially those already degraded, would be the most suitable areas for land conversion to sugarcane production for ethanol. Pasture recovery would increase carbon stocks, reduce GHG emissions and reduce the negative direct and indirect land use changes associated with sugarcane expansion in Brazil.

1. Introduction

Brazil has been a world leader in the use of agriculture for ethanol production. Among the most common crops, sugarcane has emerged as an excellent source of ethanol. However, conversion of new lands for sugarcane production has been shown to create more carbon emissions than the use of biofuels saves (Fargione et al., 2008). In this study, we ask what alternative land use changes could create a lower overall carbon debt for ethanol and sugarcane production in Brazil? To address this question, we undertook four research steps, first to map carbon stocks in the Brazilian biomes; next to quantify the carbon loss under different scenarios of land use changes for sugarcane-ethanol production; third to calculate the payback time for land conversion to sugarcane; and finally to quantify and locate the current areas of cultivated and degraded pasture by biome that might be suitable for conversion to sugarcane-ethanol production.

There is increasing international concern about the world's overdependence on the use of petroleum and its derivatives, oil's increasing scarcity, and about the climate changes associated with the increase of greenhouse gases (GHG) in the atmosphere. Consequently, the search for alternative sources of low-carbon energy has become a global priority, with the goal of limiting the negative effects of these gases on the environment. In this context, sugarcane-ethanol has been proposed as a potential solution to global energy shortages, oil dependency, and air pollution. Ethanol has the advantages of being both renewable, and a more efficient source of energy with lower-carbon emissions.

Fargione et al. (2008) note that among the agricultural sources for ethanol and biodiesel (palm, soybean, sugarcane, corn, prairie biomass), ethanol has the highest ratio between renewable energy production and fossil energy consumption, with a reduction in carbon dioxide emissions of 91% compared to gasoline, according to Goldemberg (2007), and 80% according to Embrapa (2009). This positive energy balance makes ethanol an attractive biofuel, both for the economy of fossil fuel consumption and as a mitigator of greenhouse gases in the atmosphere. However, despite being an energy source with low CO_2 emission, its efficiency in the carbon economy depends heavily on

* Corresponding author.
E-mail address: kclarke@geog.ucsb.edu (K.C. Clarke).

https://doi.org/10.1016/j.landusepol.2017.12.039
Received 9 September 2016; Received in revised form 31 August 2017; Accepted 12 December 2017
0264-8377/

where and how sugarcane is produced.

In a global future scenario of much lower CO_2 from energy sources, Brazil stands out as having multiple physical characteristics that are highly favorable to the production of ethanol, with the capacity to meet both domestic and international demand for this type of fuel (OECD-FAO, 2010). Brazil in particular, has been a leader in extracting ethanol from sugarcane and converting it for use as a fuel in cars, trucks and other forms of transportation. According to OECD-FAO (2012), it is expected that Brazil will represent 28% of the global production of biofuels by 2021. However, while Brazil is attracting worldwide attention because of its potential for biofuel expansion (Barros, 2009; Alkimim et al., 2015), the country has also drawn concern due to the high deforestation rates associated with this expansion (Skole and Tucker, 1993; Morton et al., 2006).

Between 2000 and 2008, agricultural commodity prices were the major factor responsible for changes in Brazil's deforestation rates in the Amazon. The annual loss of land to deforestation went from 18,165 km^2 in 2001–27,772 km^2 in 2004. After reaching a peak in 2004, the annual deforestation rate began to decrease, but it was interrupted by another increase in 2008 (Barreto and Araújo, 2012). From 1990 and 2006, the deforestation in the Cerrado and Pantanal was mainly related to the expansion of pasture while the Atlantic Forest showed a combination of pasture, commercial cropland and tree crops (De Sy et al., 2015; Sparovek et al., 2009).

What is more concerning about these deforestation rates is the divergence in the context of global warming, considering that they delay the beneficial reductions of greenhouse gas resulting from the conversion to production of ethanol in Brazil. In addition, the deforested land eventually becomes underutilized. As reported by Barreto and Araújo (2012), 15% of the deforested area in 2008, nearly 11 million hectares, ended up being underutilized by agriculture.

Deforestation and conversion of lands for the expansion of agriculture has a negative effect on the environment, considering that forests and soil are a great reservoir of carbon stored in the terrestrial biosphere (Houghton, 2000; Ramankutty et al., 2007). According to Foley et al. (2011) and Davidson et al. (2012), such land conversion has been pointed out as the main cause of negative impacts on the soil, leading to the loss of biomass and organic matter, which in turn also contribute to the increase of GHG emissions. When sugarcane is produced on lands already occupied by other agricultural crops, it forces the expansion of agriculture into other areas, causing an increase in GHG emissions as a result of indirect land use changes (Gibbs et al., 2008; Searchinger et al., 2008; Romijn, 2011). So, losses of carbon from aboveground and belowground biomass, and from soil end up generating a net carbon debt during the conversion of land to biofuel production.

Studies of deforestation and the carbon debt of biofuels by Fargione et al. (2008) suggest that if sugarcane were produced by converting existing forest and shrublands, then producing and burning biofuels could actually emit more greenhouse gas than burning fossil fuels. This land use conversion would generate a carbon debt for a long period of time, and would raise doubt about the biofuels as a replacement for high-carbon energy sources. Can these differences be quantified, and what land use changes would lower the overall CO_2 emissions? Fargione et al. (2008) considered the issue for biofuels worldwide, but noted that for Brazil's wooded Cerrado, emissions of sugar cane were 165 Mg CO_2 ha^{-1} and 100% of the biomass created contributed to the carbon debt. Nevertheless, the 17 year timespan necessary to repay the carbon debt could be much reduced if, as was suggested for the US, abandoned or marginal cropland was converted.

Considering the low cattle occupancy rates in Brazil and the large herds, intensification of livestock production and the use of existing pasture lands, as opposed to the conversion of forest ecosystems, have been proposed as a strategy to avoid indirect land use changes and their related GHG emissions (Maia et al., 2009; Lapola et al., 2010). The conversion of pasture to sugarcane-based ethanol production offers many advantages regarding the carbon debt associated with direct and indirect land use changes. The use of these areas for agricultural expansion would reduce deforestation and the land use competition for production of food versus biofuels, which in turn would increase carbon stocks in the soil by removing CO_2 from the atmosphere, and sequestrating it into the biomass and soil. If only existing pastures were used for new ethanol production, they could function as an atmospheric carbon sink. Under such circumstances, the conversion of pastures–especially degraded pastures–to ethanol production could be considered as a viable strategy for Brazil to combat GHG emissions, since this practice would increase carbon stocks, and consequently mitigate the greenhouse effect.

It is ironic that the conversion of lands for biofuels production in Brazil can also represent a loss to the environment (Azadi et al., 2012). It is, therefore, necessary to identify and locate current and future land use changes and the associated carbon debt of future expansion of sugarcane-ethanol production in Brazil. Many studies include payback times for ethanol, mitigation potential for agriculture and livestock sectors, and greenhouse gas balance from cultivation and direct land use change of recently established sugarcane areas (Fargione et al., 2008; Searchinger et al., 2008; Cerri et al., 2010; Mello et al., 2014; De Oliveira Bordonal et al., 2015), however they lack detailed geographic data on the locations of the cultivated and degraded pasture lands that would be ideal for biofuel production. Therefore, in this study we sought to: (i) map the carbon stocks in the above and below ground biomass, and in the soils of the Brazilian biomes; (ii) quantify the carbon debt emitted as CO_2 by the biomass and soil due to land use changes in the 3 Brazilian biomes–Amazon, Cerrado (Savannah) and Mata Atlântica (Atlantic Forest) − that are the main regions of sugarcane-ethanol production in Brazil and also for cultivated and degraded pastures; (iii) calculate the time required for sugarcane-ethanol use to offset the carbon debt caused by the conversion of land for ethanol production in these zones; and (iv) quantify the cultivated and degraded pasturelands by biome to identify where land conversion would present a viable alternative for the further expansion of sugarcane-ethanol production in Brazil.

2. Material and methods

Estimations of carbon stocks, carbon debt and payback time followed two steps (Fig. 1). Step one was collecting spatial data on carbon stock in the above and belowground biomass and the soil and municipal data on land use. Step two consisted of a literature review on the percentage of carbon loss, carbon stock under pasture and annual carbon repayment rates. The results obtained through geospatial analysis were combined with data from the literature review, and estimates of carbon stocks, carbon debt and payback time were calculated. Maps were also created to show the carbon stocks in the Brazilian biomes and the spatial locations of cultivated and degraded pasturelands.

2.1. Carbon stock database formation and application of a geographic information system (GIS)

Public data about estimates of carbon stock in the above and belowground biomass and the soil were compiled. Geographical information on carbon stocks was normalized to create a database with best estimates of carbon stock in the 3 Brazilian biomes. The carbon stock data on above and belowground biomass were created by Ruesch and Gibbs (2008) as estimated for the IPCC GPG Tier-1, which was based on the methods and values of the aboveground biomass for each type of vegetation provided by the Intergovernmental Panel on Climate Change (IPCC). The belowground biomass data (t C ha^{-1}), as reported by these authors, were obtained using the ratio of root biomass and living matter aboveground including leaves, branches and trunks.

Carbon stock for each biome was extracted using the capabilities of ESRI's ArcGIS 10. Operations involving map algebra were necessary to