

Biofuel Investments and Implications for the Environment in Ethiopia

An Economy-wide Analysis

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Abstract

Biofuels production has received increasing focus by developed and developing countries due to rising fossil fuel prices and the need to mitigate greenhouse gas emissions. The net economic and environmental impacts of biofuel programs have become an important question of public policy. In particular, the anticipation that biofuels may have a lower environmental footprint than fossil fuels is one of the important drivers. This study investigates the economy-wide impact of biofuel investment in Ethiopia with the focus on greenhouse gas (GHG) emissions and the forest sector. In order to capture the intersectoral linkages between biofuels, crops, and livestock as well as energy activities, this study uses a recursive dynamic computable general equilibrium model calibrated on the revised version of the 2005/06 SAM that includes GHG emissions, energy, and forestry products. The results suggest that an increase in biofuel investments would lead to an increase in GHG emissions, although the effects varied by biofuel feedstock types. These results have important implications for policies related to climate change mitigation as well as forestry.

Key Words: biofuels, ethanol, biodiesel, GHG emissions, forestry, CGE model, impacts

JEL Codes: Q42, Q48, Q54, Q16, D58

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1. Introduction

Biofuels have been promoted as part of the global energy mix to meet the climate change challenge. By the end of the 20th century, global commercial energy consumption was about 400 exa-joules (EJ) per year, with fossil fuels contributing about 85% of the total (Melillo et al. 2009). Global energy demand projections indicate that energy demand could be in the range of 550-1000 EJ per year in 2050, depending on factors such as resource availability and policies (Clarke et al. 2007).

The scarcity and rising prices of fossil fuel, together with apprehension about the environmental harm created by them, have resulted in increasing efforts to search for alternative energy sources. Biofuels are among the options considered as renewable and relatively cleaner substitutes for conventional energy sources. An increasing number of developing countries initiated biofuel production to meet domestic market and international demand. Reasons for engaging in biofuels production include, among others, diversifying energy sources, alleviating dependence on imported fossil energy, and reducing greenhouse gas (GHG) emissions (FAO-OECD 2008; Elbehri et al. 2009). Increasing fossil oil prices opens the way for potential biofuels industries in developing countries and this is accompanied by development of new technologies for using biomass for biofuels (Slater 2007).

Globally, only a few countries dominate the domestic use and export production of biofuels. In terms of spatial spread of biofuels production, ethanol, production of which began in the 1970s, is still produced in much larger volumes than biodiesel, for which production started in the 1990s. The US and Brazil are the largest producers of ethanol, generating over 70% of the world's total production (Slater 2007), whereas the EU produces almost 95% of the world's biodiesel. Global production has increased gradually over time. The largest increases in

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production volumes are expected in Brazil, the US, the EU, China, India, Indonesia and Malaysia, with annual global production of ethanol projected to increase to 120 billion liters by 2020, and that of biodiesel to 12 billion liters (IEA 2004). The most significant increases in biodiesel trade, from a much lower base, will probably be exports from Malaysia and Indonesia to the EU, which aims to reach a 10% blend of biofuels in transport fuel by 2020.

Ethiopia has an estimated potential area of about 25 million hectares of land suitable for production of biodiesel feedstock (Gebremeskel and Tesfaye 2008). The government of Ethiopia has issued a biofuel strategy to encourage domestic biofuels production with the objective of reducing the dependence on high-cost fossil oil (MoME 2007). Given generally high (and rising) world prices of fossil oil, the biofuel industry has developed a very significant national presence. Accordingly, there are biofuels investment activities in different regions of Ethiopia with a focus on ethanol and biodiesel production. However, increased production of biofuels has been the subject of considerable policy debate (Searchinger et al. 2008). Given the mixed impacts of biofuels investment activities, it is imperative to investigate the environmental impacts of such investments. That is, the unintended effects on the environment (e.g., forests, greenhouse gas emissions, and biodiversity) emanating from the expansion of biofuel production need to be thoroughly evaluated. Biofuel investment initiatives have yet to be assessed in terms of their environmental impacts on the forest sector, greenhouse gas emissions and biodiversity in Ethiopia. Such an assessment would inform policy makers about the possible implications of biofuel investments for the climate resilient green economy (CRGE) strategy of Ethiopia. There are also activities on the ground, as Ethiopia has also started blending biofuels with gasoline, which recently started with 5% and was then increased to 10%.

While expansion of biofuels across the world has been well documented (e.g., Monsalve et al. 2008; Oxfam 2008; Cotula et al. 2009; von Braun and Meinzen-Dick 2009), the environmental impacts of biofuel initiatives have not been explored in developing countries. In particular, amidst the anticipation that biofuels may have a lower environmental footprint as compared to fossil fuels, there is a dearth of empirical studies that consider the synergy and complementary effects of biofuels production on environmental changes in sub-Saharan Africa in general and in Ethiopia in particular. This raises the following two research questions that we attempt to address in this study: (i) What is the effect of biofuel production on the forestry subsector? (ii) To what extent will biofuels production affect GHG emissions?

The following needs are, therefore, identified. First, it is necessary to assess how biofuels production affects the forest subsector. There are two channels through which biofuel production can potentially affect the forest subsector: direct and indirect (Fargione et al. 2008). The direct

link occurs when forests are cleared to establish biofuels crops. The indirect link is when biofuels production moves on to croplands or pastures, and causes new forest clearing to relocate farming activities (Searchinger et al. 2008). Second, it is also important to examine how biofuels production affects GHG emissions.

The main objective of this study is, therefore, to investigate the environmental impacts of biofuel investment in Ethiopia, focusing on GHG emissions and forestry using an economy-wide analysis. Specifically, this study attempts to:

- (i) examine the net effect of biofuels investment on greenhouse gas emissions; and
- (ii) assess the effect of biofuels production on the forest subsector.

The rest of the paper is organized as follows. Section 2 presents a brief literature review. Section 3 presents the methodology, and Section 4 discusses results. Finally, Section 5 concludes.

2. Literature Review

An increasing number of developing countries initiated biofuel production to meet domestic market and international demand. Reasons for engaging in biofuels production include, among others, diversifying energy sources, alleviating dependence on imported fossil energy, and reducing greenhouse gas emissions (FAO-OECD 2008; Elbehri et al. 2009; Timilsina et al. 2012; Timilsina and Mevel 2013). Increasing fossil oil prices open the way for a potential for biofuels industries in developing countries and this is accompanied by developments of new technologies for using biomass for biofuels (Slater 2007). Biofuels may have a lower environmental footprint than fossil fuels because their use releases fewer greenhouse gases into the atmosphere. However, the environmental impacts of biofuels are heavily determined by the type of pathway used to produce ethanol and biodiesel. Notice that developing countries pursue different feedstock-biofuel (bioenergy) pathways: some focus on few key biomass drivers (e.g., palm oil, sugarcane, cassava, etc.), and others on strictly non-food feed stocks (e.g., jatropha, castor bean, etc). Studies (e.g., Zah et al. 2007; Mortimer et al. 2008) indicate high variation in the benefits of the different production pathways. In addition, the choice of biofuel feedstock matters for the environment. For instance, some production pathways (e.g., corn ethanol) have negative environmental impacts because of the high emissions of some ethanol refineries (Mortimer et al. 2008).

Apart from the direct emissions generated by crop production, transformation and distribution, studies (e.g., Searchinger et al. 2008; Fargione et al. 2008) have indicated that land

use changes due to biofuel production would bring about negative overall impacts on the environment. Growing biofuel crops could induce diversion of other crops dedicated to food and feed needs. Biofuel expansion could accelerate deforestation. For instance, studies (e.g., Gouverneur 2009; Borras et al. 2010) indicate that about 80% of Indonesia's rainforest has already disappeared due to a combination of massive expansion of palm oil and exploration of timber.

Notice, however, that the amount of land used for biofuel production depends both on the ability of local environmental conditions to support crop productivity and on the demand for land to provide adequate food for the local population. As the land supply is squeezed to make way for vast areas of biofuels crops, the local landscape can be affected by either clearing of large swathes of forests or the intensification of agricultural operations. In addition, increased biofuels production could require conversion of uncultivated land, with resulting carbon emissions, threats to biodiversity, and possible likely increased use of fertilizers and pesticides (Tilman et al. 2006; Fargione et al. 2008; Andrade de Sá et al. 2012). A study by Stenberg and Siriwardana (2006) provides key drivers of deforestation such as annual allowable cut, which would generate a greater effect on deforestation rate than would other factors such as population growth and off-farm employment opportunities. This also implies that, if uncultivated lands are cleared to produce feedstock, it would take a longer time to offset the carbon released (Branca et al. 2013; Fargione et al. 2008).

Of the two channels through which biofuel production could affect the forest subsector, the direct link occurs when forests are cleared to establish biofuels crops. The indirect link is when biofuels production moves onto croplands or pastures, and causes new forest clearing to relocate farming activities (Searchinger et al., 2008).

There are few studies on economy-wide impacts of biofuel production in Ethiopia (e.g. Gebreegzabher et al., 2013; Ferede et al., 2013). However, there are no studies that quantitatively examine the effects of biofuels production on GHG emissions and forests in Ethiopia. This is an important omission given that the Ethiopian government is promoting a green growth development path. In this paper, we present an economy-wide approach to evaluating effects of biofuels expansion on GHG emissions, forests and other economic impacts in Ethiopia.

3. Methodology

3.1 Conceptual Framework on Environmental Implications of Biofuels

The framework for analyzing environmental implications of biofuels is based on general equilibrium theory. Key underlying issues involved are that net GHG emissions are potentially important for African countries. Net impacts on GHG emissions depend on production technologies employed and on a combination of direct and indirect impacts. Biofuel investment is expected to impact deforestation because, in a land-constrained setting, biofuel crop production involves land use changes, i.e., substitution of forest land for biofuel crop production. This entails two effects (Timilsina and Mevel 2013). First, as forest land is converted into the production of biofuels, it increases GHG emissions. Second, substitution of biofuels for fossil fuels may reduce GHG emissions. Hence, the net effect of biofuels on GHG emission depends on the relative magnitudes of these two effects, and a general equilibrium framework can help identify the net effects.

3.2 The Model and the Emission Block

At the empirical level, a CGE model will be used for the environmental impact analysis. The environmental impact of biofuel investment could be envisaged to have both static and dynamic effects. The static effects represent the immediate effects depending on the types and nature of environmental effects and agents involved. These effects are what the commonly employed static CGE models can capture. On the other hand, the environmental impact of biofuel investments, like any other investment activities, includes effects that last longer. Consequently, using static CGE models to estimate the impact of biofuel investment underestimates the effects because that would fail to capture the growth (dynamic) effect. This implies that estimation of the environmental impacts of biofuel investment requires dynamic CGE modelling, where the rules of accumulation of some variables and updating of others are built into the model so that it can be solved for sequences of periods forward. Such a recursive dynamic CGE model analysis allows us to capture the dynamic effects on the environment of biofuel investments and facilitates the assessment of both short-run and long-run impacts through time.

A remark is in order on modeling the impact of biofuels on deforestation in a CGE framework. Land use changes can be included in the model through different uses of land across agro-ecological zones (AEZs) (Timilsina and Mevel 2013; Huang et al. 2009; Banse et al. 2008). Accordingly, the total land in each AEZ is allocated between food crops, biofuels and forests. In

the second stage, crop land and biofuels are further divided into different categories. For instance, crop land can be allocated to the production of different food crops (e.g., teff, wheat, maize, rice, etc.). Similarly, biofuel land can be used for producing different biofuel crops (e.g., jatropha, castor bean, palm oil, etc.). Notice that land use change can be induced by changes in the relative returns to land and this entails reallocation of land to the various categories. This reallocation of land between the different uses results in land use changes. For instance, deforestation occurs if biofuels expansion is accompanied by withdrawing forest land. In this study, land is allocated to different uses based on market principles, i.e., agents allocate land to different crops based on their relative returns based on a profit maximization motive.

There are few CGE models developed so far for Ethiopia. These include Gelan (2007), Diao and Pratt (2007) and World Bank (2004). Similarly to earlier work on economy-wide impacts of biofuel production in Ethiopia (Gebreegziabher et al. 2013; Ferede et al. 2013), this research also uses the SAM (social accounting matrix) developed by the Ethiopian Development Research Institute (EDRI). Moreover, in relation to the practical application of the CGE model, the level of disaggregation (spatially, sectorally and institutionally) turns out to be important.

Given that the focus of this paper is on impacts of biofuels on GHG emissions and forests, the SAM has been updated to include these. Moreover, the CGE model has also been adjusted to include emissions and forests.

3.3 Extension to the Standard CGE Model: The Emission Block

The inclusion of emissions and related equations is the main addition to the standard CGE model developed by the International Food Policy Research Institute (IFPRI) (see Lofgren et al. 2002). In order to link emissions with accounts in the SAM, we divide emissions into three categories.

1. Emissions whose sources are properly identified in the commodity accounts of the SAM (e.g., petroleum). These emissions are called stationary emissions (Meng et al. 2013) and can be linked to respective activities by calculating input emission coefficients, defined as emission per unit of input used, as:

$$emiscoefA_{ca} = \frac{QEMISA_{ca}}{QINTA_{ca}}$$

where $emiscoefA_{ca}$ is the input emission coefficient, which means, for activity a , emission per unit of input used; $QEMISA_{ca}$ is quantity of emission by activity a from using commodity (intermediate input) c ; and $QINTA_{ca}$ is quantity of commodity c (intermediate input) used by

activity a . Note that the input coefficient of an activity using commodity c is zero if that commodity does not generate emissions.

2. Emissions whose sources are not identifiable and are not found in the commodity accounts of the SAM (e.g., land clearance) are called activity emissions (Meng et al. 2013). In this case, emissions are assumed to be linearly related to the level of output in each activity. The linkage of these emissions with output levels of each activity is made possible by way of calculating output emission coefficients as:

$$emiscoefA_a = \frac{QEMISA_a}{QA_a}$$

where $emiscoefA_a$ is the activity emission coefficient, which means, for activity a , emission per unit of output produced; $QEMISA_a$ is quantity of emission by activity a whose sources are not found in the commodity accounts of the SAM; and QA_a is output produced by activity a .

3. Household emissions, which are also called consumption emissions, are linked to household accounts by way of calculating consumption emission coefficients (emission of household h per unit of commodity consumed). There are no household emissions whose sources are not identified in the data set. Household emissions can be expressed as:

$$emiscoefH_{ch} = \frac{QEMISH_{ch}}{QH_{ch}}$$

where $emiscoefH_{ch}$ is the household emission coefficient, which represents emission of household h per unit of commodity c consumed; $QEMISH_{ch}$ is quantity of emission by household h from consuming commodity c ; and QH_{ch} is quantity of commodity c consumed by household h .

It should be noted that the emission coefficient of a household from consuming commodity c is zero if that commodity does not cause emissions.

It is important to note that emission coefficients are pre-calculated from the emission matrix and SAM data. Then these emission coefficients are used to generate sectoral emissions.

Stationary emissions: $QEMISA_{ca} = emiscoef_{ca} * QINTA_{ca}$

Activity emissions: $QEMISA_a = emiscoef_a * QA_a$

Total quantity of emissions of activity a ($TQEMISA_a$):

$$TQEMISA_a = \sum_c QEMISA_{ca} + QEMISA_a$$

Household emissions: $QEMISH_{ch} = emiscoefH_{ch} * QH_{ch}$

Total quantity of emissions of household h : ($TQEMISH_h$). $TQEMISH_h = \sum_c QEMISH_{ch}$

Total quantity of emissions of all activities: ($TQEMISA$). $TQEMISA = \sum_a QEMISA_a$

Total quantity of emissions of all households: ($TQEMISH$). $TQEMISH = \sum_h QEMISH_h$

Total quantity of emissions in the economy ($TOTQEMIS$):

$$TOTQEMIS = TOTQEMISA + TOTQEMISH$$

3.3.1 A Note on the Revised SAM

As part of assessing the economy-wide effects of biofuel investment in Ethiopia, it was necessary to revise the 2005/06 social accounting matrix (SAM) which had been constructed by EDRI and the University of Sussex's IDS with support from the IFPRI (Tebekew et al., 2009). In so doing, the SAM has been extended along two directions: inclusion of GHG emission and of forestry and energy sectors. The SAM has been extended to incorporate CO₂ emissions by calculating the amount of CO₂ emissions that take place in the production of the various economic activities.

The estimation of GHG emissions by production activities and by household final consumption is based on the 2005/06 social accounting matrix of Ethiopia. The SAM distinguishes 99 activities and 14 household sectors, among other accounts. Production activities generate emissions due to the direct and indirect use of fossil fuels and chemical transformations in production processes. Although indirect emissions in the production chain and final consumption are important, this study does not estimate indirect emissions.

Direct emissions for each activity are calculated using the typical direct emission coefficients for various production pathways as indicated in Ethiopia's Climate-Resilient Green Economy (CRGE). In the estimation, the GHGs included in Ethiopia's CRGE, which are mainly carbon dioxide (CO₂), methane and nitrous oxide, are taken into account (FDRE 2011). Emissions of non-carbon greenhouse gases are converted to CO₂-equivalents using the 100-year Global Warming Potentials (GWPs) defined by the Intergovernmental Panel on Climate Change.

The major factors that generate GHG emission in Ethiopia include, among others:

- Energy consumption in production activities that involve combustion which generates GHG emissions as a result of the use of hydrocarbons for energy in various production processes.
- The emission of GHG in chemical transformation of production processes. This includes emissions in production due to factors other than energy use. In Ethiopia, the major GHG emissions from this factor are GHG (methane in particular) emissions related to livestock activity as a result of enteric fermentation and decomposition of manure; nitrogen-related emissions from soil due to fertilizer use in crop production; and emission of methane and nitrous oxide in clinker cement production activity and other GHG emissions from chemical industries.
- Final consumption: GHG emissions from this factor involve the use of energy through combustion in household operations.

Note that the emission of GHGs from government consumption is excluded because, unlike the household sector, government consumes services of public administration in which the direct GHG emission as a result of energy use in the production process is already taken into account in the ‘public administration’ activity account.

In revising the SAM, it was necessary to identify energy commodities to see energy flows among industries (intermediate demand), between industries and consumers (final demand including household consumption), etc. Accordingly, new accounts such as firewood, charcoal and dung have been introduced in the SAM, in addition to the already existing commodity accounts of petroleum, electricity, coal and natural gas.

The next step involves estimating GHG emissions for each of the activities of the SAM account based on the emissions estimate in Ethiopia’s Climate Resilient Green Economy strategy report and other relevant information (FDRE 2011; B & M Development Consultant 2006). In the CRGE strategy, the country’s total emission of CO₂ equivalent is 150 Mt, which represents less than 0.3% of global emissions. Because this estimated emission represents emissions of all production activities, it does not include emissions outside of the production process, such as emissions related to household consumption. The emission from household consumption of energy is estimated based on the information on quantity of energy products consumed, including petroleum (mainly kerosene for cooking), firewood, charcoal and dung and the associated emission factors of each product in household use.

In addition, the CRGE includes emission of GHG from forestry, but it does not include biomass degradation associated with fuel wood consumption. It is necessary to estimate direct

emissions by activity by reallocating the amount of emission from ‘deforestation for agricultural land’ to the crop activity because the direct actor of the biomass degradation of the process is crop production activity. Likewise, the amount of emission from fuel wood production needs to be reallocated partly to household consumption and partly to intermediate use of other activities because the direct GHG emission from such engagement arises, not when the firewood is produced in the forestry activity, but when the firewood is consumed in combustion by household operations or by other producing sectors.

For forestry products, the disaggregation of consumption expenditure of households into energy and non-energy commodities is based on the expenditure proportion of firewood, charcoal and sawdust from the total consumption of forestry products by different household categories. For rural households, the household type classification is further made based on the agro-ecological zone in which the households reside, in the same way as the original EDRI SAM was constructed. The proportion of energy consumption from total spending on forestry commodities is also estimated separately for marketed commodities and own produced forestry commodities.

Assumptions in disaggregating the energy and forestry activities and commodities in the new SAM include:

- In calculating intermediate input for the disaggregated forestry activity, it is assumed that similar technology is used in forestry activities for both firewood and non-energy use. Thus, the same input-output ratios and commodity input proportions are assumed for both forestry activity for energy and forestry activity for non-energy use.
- Because of the similarity between the nature of firewood and other forestry products, it is assumed that the proportion of the trade and transport margin from total marketed supply for both types of commodities is the same.
- Although only about 4% of animal dung cake consumption is purchased with cash, the purchase is usually made directly from the producer itself, as there is no observable trading or market of the commodity. It is therefore assumed that there is no trade margin on animal dung cake.
- There is neither export nor import of dung cake in the country. All the value of import and export of animal products in the original SAM are thus categorized to animal products other than dung cake. For forestry products, there is some record on the value of

import, as revealed in the original SAM. Hence, this import value is assumed to be entirely forestry products other than firewood and charcoal.

Hence, the revised SAM includes energy and forestry accounts and CO₂ emissions that have been calculated for the various economic activities distinguished in the SAM.

3.3.2 Other Sources of Data

A survey was conducted on ‘biofuels investment in Ethiopia’ in 2010 by the Environmental Economics Policy Forum for Ethiopia (EEPFE) of the Ethiopian Development Research Institute (EDRI). The purpose of the survey was to generate sector/crop-specific primary data/information to calculate (derive) the input-output coefficients in relation to the biofuels sector for the CGE analysis. A list of companies with investment permit for biofuels, comprising over 45 companies, was obtained from the Ethiopian Investment Agency. Then, 15 biofuels companies and 2 NGOs involved in biofuels were approached to fill in the questionnaire (with 6 non-responses). Besides calculating the input-output coefficients, the survey also helped to characterize the biofuels sector in Ethiopia. Table 1 provides an overview of the biofuels sector in Ethiopia.

As for the production characteristics, while large-scale sugarcane is mainly plantation-based, jatropha and castor bean production activities are undertaken by a combination of plantation-based and smallholder production through out-growers schemes. In addition, jatropha and castor bean production activities are labour-intensive, as they require more labour per land compared with sugarcane (Table 1). According to this recent biofuels investment survey, sugarcane accounted for a larger share of the total land allocated to biofuel crops (Figure 1). However, it is important to note that a small proportion of the total land allotted to biofuels production was utilized in 2007. For instance, while a fifth of the total land was utilized in castor bean, the figures for jatropha and palm oil were very small in 2009 (Figure 2). A little more than half of the total land allotted to sugar cane has been utilized over the same period. This suggests that there is room for further expansion of production by bringing more land into cultivation until full-scale operation is reached without displacing smallholders, at least in the short- and medium-term.

The sector has attracted both foreign and local investors, but the dominance of foreign companies features prominently in the sector. Although the Ethiopian government has allocated a large amount of land to different biofuel crops, companies have utilized only a fraction of the total land (Figure 1). Field observations also indicate that companies engaged in the sector have

not been able to fully cultivate their respective land for growing biofuel crops. In fact, most of the companies that obtain investment permits didn't enter into operation.

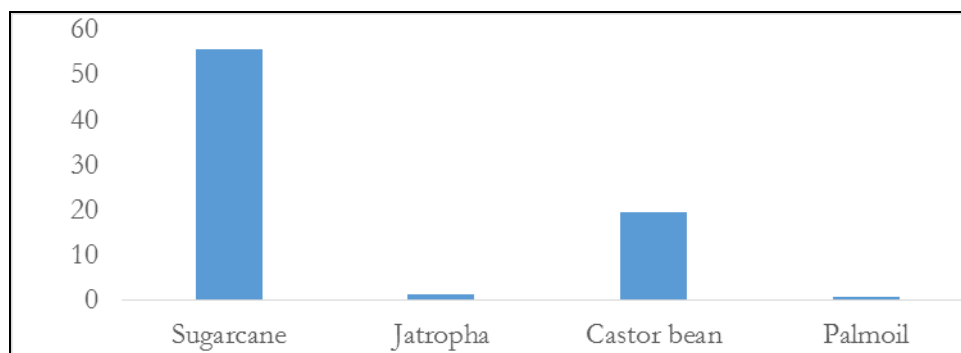
The survey revealed that there is one company that started exporting biodiesel, at least once, and that there are companies at the product testing stage. The survey also showed that there are complementary local innovations going on in the biofuels sector, including invention/innovation of biodiesel stoves, processors/distilleries, and biogas-powered vehicles/cars.

Table 1. Overview of the Biofuels Sector in Ethiopia

	Sugarcane and ethanol	Jatropha/castor bean diesel
Land employed (ha)	11,248.00	3,284.00
Biofuel crop production (tons)	569,168.00	200.00
Farm workers employed (in number)	5,365.00	4,384.00
Land yield	50.60	0.06
Farm labour yield	106.09	0.05
Land per capita	2.10	0.75
Capital per hectare	16.46	0.00
Labour-capital ratio	0.029	0.00
Biofuel produced (liters)	5,323,866.05	2,880.69
Processing workers employed	27	0.00
Feedstock yield (L/ton)	9.35	14.40
Processing labour yield	197,180.22	

Source: Biofuel investment survey, 2010

Figure 1. Ratio of Utilized Land to Total Land Allocated to Each Biofuel Crop (%)



Source: Biofuel investment survey, 2010

4. Simulations

4.1 Scenarios

The production of biofuels from feedstocks that do not compete for land with food, feedstocks, and fiber generally does not induce land use changes (Plevin and Kammen 2013). These feedstocks include crop and forestry residues, municipal waste, and crops grown on land that is not favourable for viable production of other crops or on land not cultivated by smallholders. However, increased production of biofuel crops has the potential to compete with food production for arable land, and could potentially require conversion of native land and natural forests, with resulting carbon emissions, threats to biodiversity, and possibly increased use of fertilizers and pesticides.

Based on these arguments and on available information on biofuel investments in the country, the following scenarios have been considered (see Gebreegziabher et al. 2013 for details).

Sugarcane Scenario (SIM1): Expansion of land allocated to sugarcane cultivation by 5116.44 hectares per year over the period 2005-2020;

Jatropha scenario (SIM2): Expansion of land allocated to sugarcane cultivation by 2,153.62 hectares per year over the period 2005-2020;

Castor bean scenario (SIM3): Expansion of land allocated to sugarcane cultivation by 2,033.33 hectares per year over the period 2005-2020;

Palm oil scenario (SIM4): Expansion of land allocated to sugarcane cultivation by 2,000 hectares per year over the period 2005-2020;

Jatropha plus spillover effect scenario (SIM5): This includes **SIM2** with improved productivity of the smallholder crop sector, which is intended to capture the spillover effects of biofuel investment on smallholder agriculture. Such an effect can arise, for instance, through improved farming practices or access to other agricultural inputs (e.g., chemical fertilizer, improved seeds, insecticides, etc.);

Castor bean plus spillover effect scenario (SIM6): includes S3 with spillover effects of biofuel technology on smallholder crop agriculture. This induces improved productivity of the smallholder crop sector; and

Combined scenario (SIM7): This is the last scenario, which captures the combined effect of all biofuel interventions on the structure of the economy.

It should be noted that, initially, a certain quantity of land, which is not cultivated by smallholders, has been allocated to large-scale biofuel farms. Biofuel survey data and field observations indicate that large-scale biofuel farms have not utilized their allotted land, i.e., a large tract of land given to biofuel farms has remained unutilized. In fact, most of the companies that obtained investment permits didn't enter into operation. Scenarios 1 to 4 consider the likely economy-wide effects of utilizing the existing unused land initially allocated to each of the biofuel crops. In these scenarios, it is assumed that biofuels do not displace other activities. When no displacement is allowed, then all biofuel crops are produced on already-allocated lands. Scenarios 5 and 6 intend to capture the effect of biofuels on smallholder agriculture, such as through the out-grower scheme, which likely either enhances or retards productivity of smallholder agriculture. To capture spillover effects, higher technological improvements in smallholder agriculture are imposed through the technological change variables in the model.

Note that the various biofuel scenarios have been modelled under different land mobility assumptions to capture the likely impacts of biofuel expansion on the GHG emissions and forestry sector. Specifically, three land mobility assumptions have been imposed on the model: fully employed and activity specific (immobile), not fully employed and mobile across sectors, and fully employed and mobile across sectors. A recent study by Fargione et al. (2008) shows that land-use conversion from native land uses to biofuel crops leads to GHG emissions.

4.2 Reference Scenario

Before running the different biofuel scenarios, we perform a reference scenario, which serves as a benchmark or baseline against which other biofuel scenarios can be compared. The reference scenario provides a characterization of growth of the economy up to 2020 but without the biofuels policy scenarios that are of interest in this study.

5. Results and Discussion

5.1 Descriptive Statistics: Extent of Emission by Sector

Direct emissions by activity have been calculated primarily using direct emission coefficients for various production pathways. Additional sources were used for the relevant emissions coefficients data (EPA 2009).

The total estimated emission in Mt of CO₂ equivalents is 174.56, which is different from the 150 Mt emission estimate of the CRGE strategy. This is the result of the inclusion of GHG emissions from household operations, which are not included in the CRGE strategy (Table 2).

The emission from production activities in this study (which is 130.32 Mt) is also different from the CRGE estimate because emissions from firewood, which are considered emissions of the forestry sector in the CRGE strategy, are reallocated to the household sector and other industries in order to be consistent with the SAM framework. Emission by source indicates that petroleum, which is used by both production activities and households, generates the largest quantity of emissions, accounting for half of the total emissions (Table 3).

Disaggregating consumption of forestry products by households indicates that the poor depend more on forests compared with non-poor households (Figures 2 and 3). For instance, in rural areas, the share of consumption expenditure by poor households for marketed energy and non-energy forestry products accounts for 68.3%, compared with 61.1% for non-poor households (Figure 2). The figure for urban poor is even higher, indicating poor households' dependence on forest products for their energy needs.

Table 2. GHG Emissions of Ethiopia from Energy and Non-energy Factors (Mt CO₂ Equivalent)

Sector	GHG emission (Mt CO ₂ equivalent)		
	Energy use	Non-energy	Total
Production Activities	22.57	107.75	130.32
Agriculture	0.00	106.62	106.62
Industry	14.79	1.13	15.92
Service	7.78	0.00	7.78
Final demand (Households)	44.23	0.00	44.23
Total	66.81	107.75	174.56

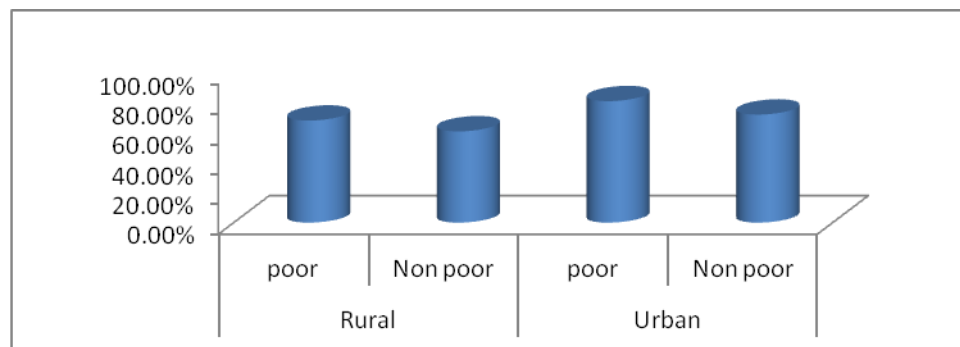
Source: Revised SAM

Table 3. GHG Emissions of Ethiopia by Energy Commodities (Mt CO₂ Equivalent)

Sector	Petroleum	Natural gas	Firewood and charcoal	Dung	Total
Production Activities	19.90	0.00	2.67	0.00	22.57
Agriculture	0.00	0.00	0.00	0.00	0.00
Industry	13.15	0.00	1.64	0.00	14.79
Service	6.75	0.00	1.03	0.00	7.78
Households	13.49	2.28	21.71	6.76	44.23
Total	33.39	2.28	24.38	6.76	66.81

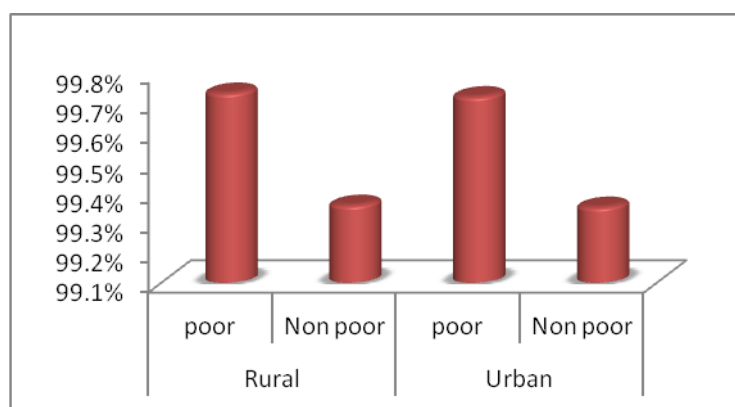
Source: Revised SAM

Figure 2. Share of Household Consumption Expenditure of Marketed Energy and Non-Energy Forestry Products (%)



Source: Revised SAM

Figure 3. Share of Household Consumption Expenditure of Non-marketed Energy and Non-energy Forestry Products (%)



Source: Revised SAM

5.2 Assessing the Economy-wide Effects of Biofuels

5.2.1 Biofuels and GHG Emissions

Table 3 presents the effects of biofuel investment on sectoral and household emissions as percentage changes from the baseline growth rate. These effects are reported as averages over the period 2005-2020 relative to the baseline. Aggregate effects on agriculture, industry and services are indicated for each scenario as well as for combined scenarios. Moreover, effects for specific sectors in agriculture are also reported.

We note from Table 4 that, relative to a baseline, overall emissions from all economic activities would grow by 0.81% due to expansion of biofuels, i.e., emissions would increase. The highest emissions correspond to the jatropha scenario with spillover effects, with a 0.151% increase in emissions, followed by the castor bean scenario with spillover effects (0.119%). Sugarcane and the combined (i.e., sugarcane scenario, jatropha with spillover effects, and castor bean plus spillover effects) also contribute to the total emissions. For the four sectors considered (i.e., agriculture, industry, services and households), we find that the jatropha and castor bean scenarios generate large emissions compared with the baseline. Overall emissions would also grow on average by about 0.06% in the sugarcane scenario. In terms of sectoral aspects, the effects on GHG emissions will be positive, except for industry and services, where there would be negative effects associated with the sugarcane scenario. With improved production of sugarcane locally, ethanol availability would increase, which would reduce dependence of industries and services on fossil fuel. Less consumption of fossil fuel by key economic sectors would imply less GHG emissions, i.e., reduction of GHG emissions due to the replacement of fossil fuels with biofuels. This impact would be stronger in the industrial sector compared with other sectors (e.g., services). GHG emission by livestock would be dampened in the sugarcane scenario, as this would imply improved availability of livestock feedstock from by-products of sugarcane industry, i.e., livestock dependence on crops and forests would be minimized. GHG emissions would be the highest in agriculture in the jatropha with spillover effects scenario (0.21%), followed by the castor bean with spillover scenario (0.178%). While the magnitude of the effects differs, we also find similar results for industry, services and households. Overall, while biofuels expansion would reduce GHG emissions in the industrial and services sectors, it would increase GHG emissions in agriculture and households. Thus, when biofuels and other economic sectors, especially agriculture, are competing for land, the expansion of biofuels would cause an increase of GHG emissions in all biofuel scenarios.

Table 5 presents the results of the various biofuels scenarios when land is not fully employed and mobile across sectors. When biofuels and other economic sectors are not competing for land (i.e., land is not fully employed and mobile across sectors), expansion of biofuels would not lead to GHG emissions compared with the case of competition for use of land (i.e., land fully employed and fixed). The livestock sector would experience a reduction in GHG emissions under scenarios 5 and 6 which could be linked to improved availability of alternative animal feed. On the other hand, these scenarios would lead to a rise in GHG emissions in other sectors such as agriculture, industry, etc. The conversion of land into productive agricultural land could lead to GHG emissions. Studies (e.g., Gibbs et al. 2008; Fargione et al. 2008) indicate that

the expansion of biofuels into productive ecosystems will lead to carbon emissions, while expanding into degraded or already cultivated land will provide almost immediate carbon saving.

Table 4. Effects of Biofuel Investment on Sectoral and Household Emissions (Percentage Changes from the Base-average over the Period 2005-2020) - Land Fully Employed and Immobile Across Sectors

	Initial value in Mt CO ₂ e (2005)	Baseline growth	SIM1	SIM2	SIM3	SIM4	SIM5	SIM6	SIM7
All activities	133.982	8.446	0.081	0.000	0.000	0.000	0.151	0.119	0.081
Agriculture	110.280	7.040	0.132	0.000	0.000	0.000	0.212	0.168	0.132
Cereal crops	21.263	5.218	0.044	0.000	0.000	0.000	1.175	0.935	0.044
Cash Crops	10.902	5.639	0.047	0.000	0.000	0.000	0.025	0.020	0.047
Livestock	65.000	7.646	-0.017	0.000	0.000	0.000	0.020	0.035	-0.017
Other Agriculture	10.145	7.147	0.013	0.000	0.000	0.000	0.032	0.023	0.013
Industry	15.919	13.172	-0.043	0.000	0.000	0.000	0.016	0.013	-0.043
Services	7.783	12.294	-0.007	0.000	0.000	0.000	0.011	0.009	-0.007
Households	44.232	8.096	0.008	0.000	0.000	0.000	0.044	0.036	0.008
Overall	178.215	8.360	0.063	0.000	0.011	0.011	0.135	0.109	0.057

Source: DCGE simulation result

Table 5. Effects of Biofuel Expansion on Sectoral and Household GHG Emissions (Percentage Changes from the Baseline Growth Rate-average 2005-2020)- Land Not Fully Employed and Mobile Across Sectors

	Initial value of CO ₂ e (2005)	Baseline growth rate	SIM1	SIM2	SIM3	SIM4	SIM5	SIM6	SIM7
All activities	133.98	8.53	0.000	0.000	0.000	0.000	0.220	0.185	0.000
Agriculture	110.28	7.19	0.000	0.000	0.000	0.000	0.311	0.262	0.000
Cereal crops	21.26	5.46	0.000	0.000	0.000	0.000	2.749	1.450	0.000
Cash crops	10.90	7.99	0.000	0.000	0.000	0.000	0.142	0.117	0.000
Livestock	65.00	7.29	0.000	0.000	0.000	0.000	-0.004	-0.004	0.000
Other agriculture	10.15	7.69	0.000	0.000	0.000	0.000	0.043	0.031	0.000
Industry	15.92	13.08	0.000	0.000	0.000	0.000	0.010	0.008	0.000
Services	7.78	12.30	0.000	0.000	0.000	0.000	0.012	0.010	0.000
Households	44.23	7.95	0.000	0.000	0.000	0.000	0.034	0.028	0.000
Overall	178.215	8.36	0.00	0.000	0.000	0.000	0.000	0.176	0.148

Source: DCGE simulation result

5.2.2 Impact of Biofuels Expansion on Forestry

One of the challenges to the expansion of biofuels is its effects on GHG through land use change, especially in land-scarce settings.¹ Table 6 presents effects of investment in biofuels on forest products under two land mobility scenarios. Note that if expansion in biofuels is undertaken in forest areas, this would lead to deforestation, which would entail a reduction in forest products. On the contrary, if biofuels expansion takes place in marginal areas, this would enhance forest coverage.

The results show percentage changes from the baseline growth rate for the period 2005-2020 (as averages). When land is fully employed and immobile across economic sectors, the sugarcane scenario would lead to greater reduction in forest products, i.e., forest products would experience a decline on average of about 0.04% between 2005 and 2020. Note that sugarcane is largely plantation-based, which requires relatively large tracts of land and is often undertaken in areas where there are large forests. Expansion of sugarcane would require conversion of forest land, which would increase GHG emissions. On the other hand, the jatropha and castor bean scenarios with spillover effects would increase forest products, as these biofuel crops do not require a large amount of land compared with the sugarcane scenario. The jatropha and castor bean biofuel crops are often undertaken in marginal areas as well as in out-grower schemes by smallholders.

These biofuel crops with spillover effects would enhance forests through reversal of deforestation. Normally, because out-growers use grazing land for growing jatropha and castor bean crops, they become increasingly dependent on forests, not only for livestock grazing but also for fuelwood, which would lead to more GHG emissions. However, this will not be the case when jatropha and castor bean biofuels activities are undertaken in marginal areas, or when out-grower schemes are undertaken by smallholders on farm boundaries, as shelter belts/fences or in backyards. The combined scenario would lead to a reduction in forest products; this could be due to a large and negative effect of sugarcane expansion. A slightly different result is obtained when land is not fully employed and mobile across sectors, i.e., when biofuels and other economic

¹ Studies (e.g., Moges 2010; Gebreegziabher et al. 2013) indicate that biofuel expansion, especially by out-growers, has been accompanied by diversion of land from other food crops towards biofuels. Gebreegziabher et al. (2013) discuss the welfare effects.

sectors are not competing for land. Forest products would experience a rise in scenarios 5 and 6 (SIM5 and SIM6), but at a lower rate compared with the land immobility case.

Although the forest sector would experience a reduction in the sugarcane scenario (under the land mobility restriction), this scenario would contribute to reducing GHG emission due to its indirect effects of reducing emissions, such as increasing availability of ethanol supply, livestock feedstock, etc.

Table 6. Effects of Biofuel Investment on Forestry (Percentage Changes from the Base-average over the Period 2005-2020)

Land mobility scenarios	Initial value in million Birr (2005)	Baseline growth	SIM1	SIM2	SIM3	SIM4	SIM5	SIM6	SIM7
Land fully employed and immobile	1.891	10.496	-0.042	0.000	0.000	0.000	0.037	0.029	-0.043
Land not fully employed and mobile	1.891	10.496	0.000	0.000	0.000	0.000	0.016	0.011	0.000

Source: DCGE simulation result

6. Conclusions

Biofuels production has received increasing focus by developed and developing countries due to rising fossil fuel prices and the need to mitigate greenhouse gas emissions. Following the expansion of biofuel farms, the biofuel industry also has a very strong global presence. The net economic and environmental impacts of these biofuel programs have become an important question of public policy. The Ethiopian government also has been promoting biofuels as part of its development efforts. Unlike other previous studies in Africa (see Arndt et al 2008 & 2010), this paper has attempted to examine the environmental implications of biofuel investments with a focus on forests and greenhouse gas (GHG) emissions, taking Ethiopia as a case in point. In order to capture the intersectoral linkages between biofuels and food crops and livestock as well as energy activities, this study uses a recursive dynamic computable general equilibrium model. The analysis is based on primary data on biofuels collected in 2010, in addition to a social accounting matrix (SAM) that was initially prepared by the Ethiopian Development Research Institute (for the year 2005/06) and was modified for this study.

We find that the effects of biofuel investments on GHG emissions from the different sectors are positive (i.e., GHG emissions increase), with the exception of some results for the sugarcane scenario. As for the sectoral aspects, the effects of biofuel expansion on GHG emissions are positive (increased emissions), except for industry and services, where there are negative effects (i.e., reduced emissions) associated with the sugarcane scenario. With improved production of sugarcane locally, ethanol availability would increase, which could reduce dependence of industries and services on fossil fuel. Less consumption of fossil fuel by key economic sectors would imply less GHG emissions, i.e., reduction of GHG emissions due to the replacement of fossil fuels with biofuels. While biofuels expansion would reduce GHG emissions in the industrial and services sectors, it would increase GHG emissions by agriculture and households. We also find that expansion of biofuels would cause an increase of GHG emissions in all biofuel scenarios. Although the forestry sector would experience a reduction under the sugarcane scenario, this scenario would reduce GHG emission due to its indirect effects of reducing emissions, such as increasing availability of ethanol supply, livestock feedstock, etc. It should be noted that one of the challenge to the expansion of biofuels is its effect on GHG through land use change, especially in land-scarce settings. These results have important implications for policies related to mitigation of climate change as well as forestry.

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