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Biofuels and Climate Change Mitigation

A CGE Analysis Incorporating Land-Use Change

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Abstract

The question of whether biofuels help mitigate climate change has attracted much debate in the literature. Using a global computable general equilibrium model that explicitly represents land-use change impacts due to the expansion of biofuels, this study attempts to shed some light on this question. The study shows that if biofuel mandates and targets currently announced by more than 40 countries around the world are implemented by 2020 using crop feedstocks, and if both forests and pasture lands are used to meet the new land demands for biofuel expansion, this would cause a net increase of greenhouse gas emissions released to the atmosphere until 2043, since the cumulative greenhouse gas emissions released through land-use change would exceed the reduction of emissions due to replacement of gasoline and diesel until then. However, if the use of forest lands is avoided by channeling only pasture lands to meet the demand for new lands, a net increase of cumulative greenhouse gas emissions would occur but would cease by 2021, only a year after the assumed full implementation of the mandates and targets. The study also shows, contrary to common perceptions, that the rate of deforestation does not increase with the rate of biofuel expansion; instead, the marginal rate of deforestation and corresponding land-use emissions decrease even if the production of biofuels increases.

Biofuels and Climate Change Mitigation: A CGE Analysis Incorporating Land-Use Change[1]

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1. Introduction

The question of whether or not biofuels help mitigate climate change has attracted a long debate in the literature. If indirect emissions, such as those released through land-use change during the expansion of agricultural lands for biofuels production, are ignored, biofuels, undoubtedly, reduce emissions of greenhouse gases (GHGs) through the replacement of fossil fuels (see e.g., OECD, 2008; RFA, 2008; Goldemberg et al. 2008; Macedo et a. 2008)[2]. On other hand, if land-use change related emissions are accounted for, there is no consensus in the literature on the impact of biofuels on net GHG emissions. Searchinger et al. (2008) argue that the use of current agricultural land for biofuel production will release, mainly through indirect land-use change, as much GHG emissions as corn-based ethanol can mitigate in 167 years through fossil fuel replacement in the US. Ogg (2008) blames European biofuel subsidies for rainforest loss in Indonesia. Fargione et al. (2008) assert that it would take 48 years to repay the 'carbon debt' incurred if Conservation Reserve Program land is converted to corn ethanol production in the US; over 300 years to repay if Amazonian rainforest is converted for soybean biodiesel production; and over 400 years to repay if tropical peatland rainforest is converted for palm-oil biodiesel production in Indonesia or Malaysia. Similarly, Danielsen et al. (2009)] show that 75 to 93 years of biofuel use would be necessary before carbon savings could be gained from forest conversion[3].

In the context of this ongoing debate, this study aims to investigate further the effects of large-scale biofuels expansion on GHG emissions, accounting for both the reduction of fossil fuel based emissions and the increase in emissions through land-use change. In contrast to most existing studies, which employ a partial equilibrium approach, we employ a global computable general equilibrium (CGE) model of the world economy, representing multiple countries or regions. The advantage a CGE model has over a partial equilibrium model is that it captures the interactions between various sectors and agents and reveals the economy-wide

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[2] Menichetti and Otto (2009) review 30 studies that estimate, using a life-cycle approach, the GHG mitigation potential of various biofuel feedstocks. Most studies they considered found net mitigation of GHG emissions when emissions related to land-use change were excluded.

[3] Please see existing studies, such as Timilsina & Shrestha (2010), for detailed review of literature on the climate change impacts of biofuels.

impacts of a policy or activity (e.g., large-scale expansion of biofuels). On the other hand, a partial equilibrium approach examines an issue in an isolated market (or sector) under a *ceteris paribus* assumption, thereby neglecting the economy wide interactions of a policy or activity. Another key limitation of the existing literature examining the climate change mitigation impacts of biofuels including indirect emissions through land-use change is that they are often based on isolated case studies that consider producing biofuels from particular, and in many cases, the most vulnerable, land types. For example, Fargione et al. (2008) consider conversion of the Brazilian Amazon to produce soybean based biodiesel; Malaysian and Indonesian lowland, as well as peat land tropical rain forests, to produce palm oil based biodiesel; and U.S. central grassland to produce ethanol. Instead of assigning a particular land type to a specific biofuel feedstock, our model follows the market principle in reallocating lands based on farmers' choice of agricultural commodities to maximize their profits.

We analyzed two scenarios: (i) the implementation of already announced biofuel targets, and (ii) the implementation of an enhanced target scenario that doubles the announced targets and also sets a 10% biofuel targets for countries which have not announced any targets yet. Our analysis shows that the cumulative GHG emissions from land-use change exceed the emission reductions caused by the substitution of biofuels for fossil fuels in the short to medium turn, thereby causing a net release of emissions into the atmosphere. The reverse would happen over a longer time horizon, leading to a net reduction of emissions.

This paper is organized as follows. Section two briefly describes the CGE model employed in the study, followed by discussion of annual GHG emissions during the study period. Section 4 presents the emission balance from a cumulative perspective for a better comparison of emissions reduction through fossil fuel replacement and emissions release through deforestation. Section 5 discusses whether land use emissions can be reduced. Section 6 concludes the paper.

2. The Model and Data

2.1. A Brief Description of Model Structure

For our simulations, we utilize a dynamic global CGE model developed at the World Bank. The basic information for the calibration of this model is derived from the GTAP 7.0 database with base year 2004. All results presented are derived from a version of the model with 28 sectors and 25 countries/regions.

The 28 sectors are depicted by a set of nested constant elasticity of substitution (CES) production functions. At the top level of the production structure, that is, in the final goods sectors, firms minimize costs, i.e., maximize profits, by choosing an optimal combination of *non energy intermediate input* (ND) and *value added + energy input* (VAE). The inputs are assumed to be perfect complements so that the elasticity of substitution between the two factors equals 0 as dictated by a Leontief function. Based on the demand for ND and VAE, the firms on the second level of the production tree again minimize costs by choosing combinations of inputs that are supplied by firms on the next lower production level, and so forth. In total, the economy is represented by 7 production tiers (see Figures 1a-1c).

The government derives revenues from a number of indirect taxes, import duties and a direct tax on households. Government expenditures are an exogenously determined share of nominal GDP. Government revenues equal the sum of government expenditures and government savings; the direct tax on households is adjusted each period to ensure a balanced public budget.

Households maximize utility, which is represented by a non-homothetic Constant Difference of Elasticities (CDE) function[4], subject to the budget constraint. The households' disposable income consists of the factor incomes (net of taxes) minus the direct tax. A household savings rate determines the fraction of disposable income that is saved and thus

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[4] See Surry (1993) for details on this functional specification .

available for investments. Hence, total national income goes to government expenditures, household expenditures, and investments.

International trade is modeled by a system of Armington demands that give rise to flows of goods and services between the regions. At the national/regional level, import demand is driven by CES functions of domestic and imported components of demand for Armington commodities. Export supply is depicted by a two tier constant elasticity of transformation (CET) function, where, on the first tier, the total output of a sector is designated either to total exports or to domestic supply, and, at the second tier, total exports are partitioned according to their destinations.

The endogenous driver of the dynamics in the model is the vintage capital structure. The capital stock is composed of old and new capital, where new corresponds to the capital investments at the beginning of the period and old corresponds to the capital installed in previous periods. The ratio of new to old capital is also a measure of the flexibility of the economy as new capital is assumed to be perfectly mobile across sectors. Furthermore, a fraction of the old capital depreciates each period.

Population and productivity growth are exogenous drivers of the model's dynamics. The former is taken from the projections of the United Nations Population Division, where labor force growth corresponds to the growth of the population aged 15-64 years. Productivity growth is modeled as factor neutral for agricultural sectors and labor augmenting for industrial and service sectors. Productivity of energy follows an autonomous energy efficiency improvement (AEEI) path so that there is no endogenous technological change in the model.

To ensure equilibrium in the model, three sets of market clearing conditions are met. First, total production of each commodity equals the sum of domestic consumption and exports so that the goods and services markets clear. Second, total investment equals total savings, where savings are composed of private (household) savings, public (government) savings and exogenously fixed foreign savings. Third, factor markets clear, which implies full employment.

As biofuels are not a proper sector in the original GTAP 7.0 database, we modified it in a way that allowed us to introduce biofuels sectors in our CGE model. This was done according to the following procedure. Based on detailed information collected on production, consumption and trade, a total of seven new sectors[5] have been created by splitting existing GTAP sectors. The Splitcom[6] software developed by Horridge (2005) was used to process the splits and keep the global social accounting matrix balanced. In the next step, the energy bundle of the model was augmented in order to integrate the new biofuel and fossil fuel sectors (see Figure 1c). A detailed description of the biofuel module used here can be found in Timilsina et al. (2010).

Land use changes are incorporated into the model via a CET representation of land supply for each country/region and for eighteen Agro-Ecological Zones (AEZs). The land data are based on the GTAP 7.0 database and were derived analogously to Lee et al. (2008). Following Huang et al. (2004) and Banse et al. (2008), we develop a land use module based on a nested structure. In line with Birur et al. (2008), at the top level of this module, total available land area is allocated to forest land, pasture and crop land. At the second level, crop land is further divided into four different categories: rice, sugar-crops, grains and oilseeds, and fruits and vegetables. Finally, the grains and oilseeds category is partitioned into wheat, corn, other coarse grains, and oilseeds (see Figure 1b). This nested structure seems reasonable as, in reality, not all crops stand in direct competition. For instance, rice typically does not compete directly with other crops for available land.
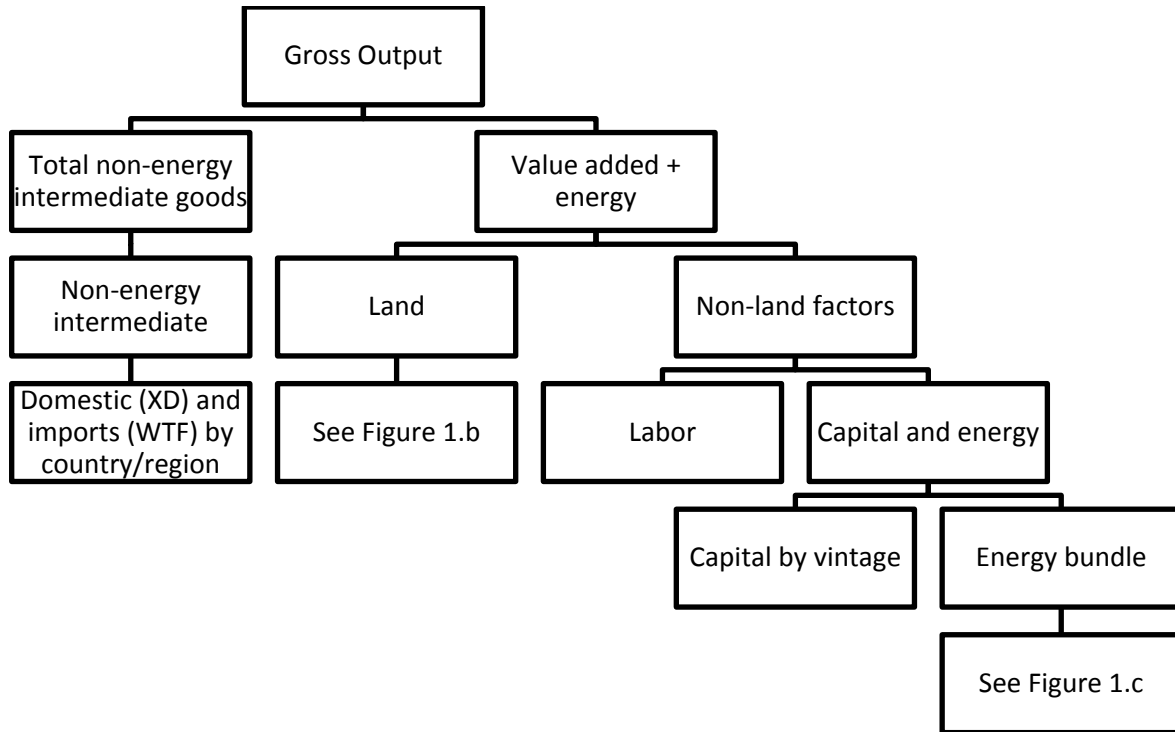
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[5] Corn, gasoline, diesel and biofuels (three ethanol and one biodiesel) sectors are introduced.
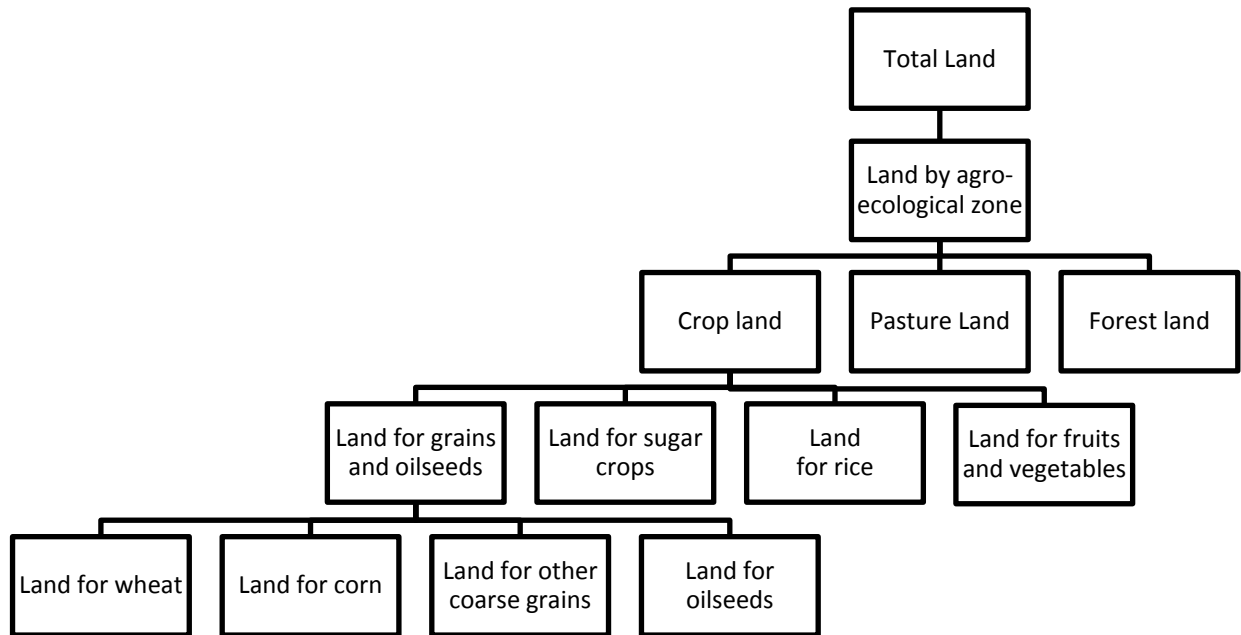[6] This software and a detailed description can be freely downloaded at
http://www.monash.edu.au/policy/splitcom.htm.

Figure 1: Model structure

(a) Production Sectors

(b) Land Supply
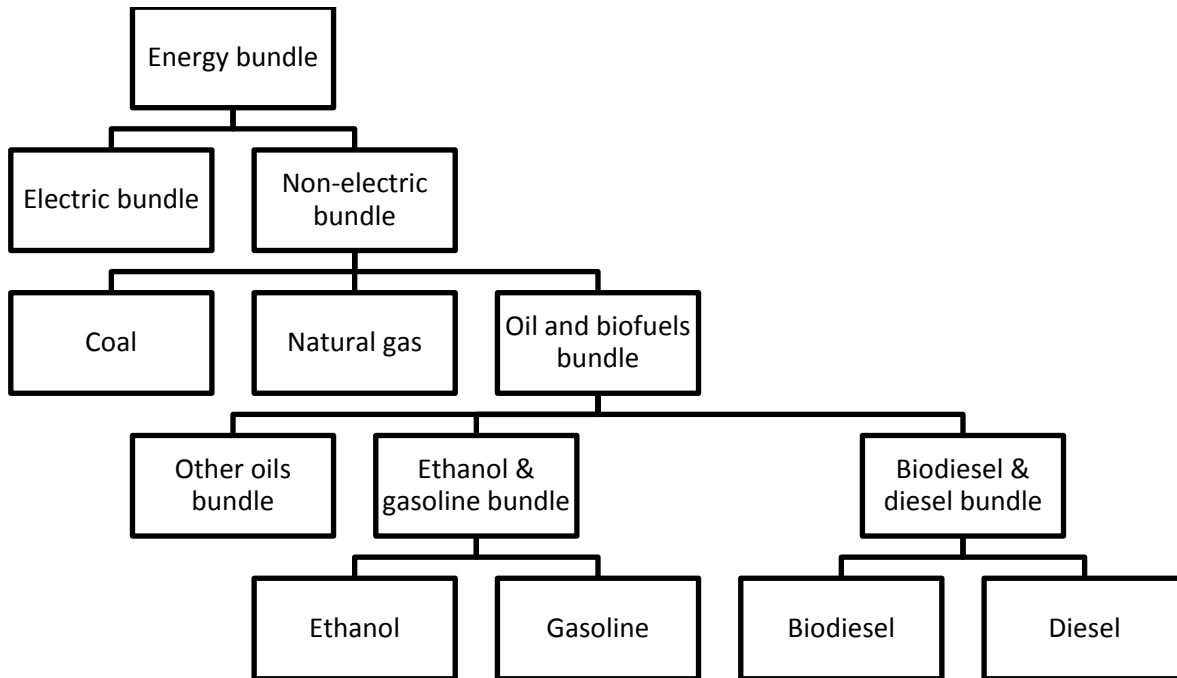
(c) Biofuel Demand

Land use change is induced by changes in the relative returns to land. Within each of the CET nests of our land module, agents maximize payoffs by optimally allocating the fixed land area for this nest to the various competing crops. Hence, at the first level, land is optimally divided between forests, pasture and crop land. Given these allocations, profit maximization takes place at the second tier, thus allocating the total available crop land to the four crop categories. Finally, the area designated to grains and oilseeds is optimally allocated among its four sub-categories. This means that changes in the relative returns to land use types lead to the reallocation of acreage to the various categories, thus instigating land use changes such as deforestation.

Like in any CGE model, the main data needed are in two folds: (i) social accounting matrix (SAM) and (ii) elasticity parameters. Please refer to Timilsina et al. (2010) for detailed information on data and their sources.

2.2. Methodology for GHG Emission Accounting

Emissions from fossil fuel consumption are estimated by multiplying fuel consumption by their emission coefficients or carbon content. The emission coefficients are calibrated using fuel consumption and CO_2 emissions data maintained by International Energy Agency (IEA, 2009). Fossil fuel related CO_2 emissions reduction under a scenario is calculated by subtracting emissions under the scenario from that in the baseline.

GHG emissions from land-use change are calculated by multiplying the amount of forest land converted to crop land by the carbon stock change entailed in the conversion. We followed the IPCC Tier I approach, according to which, three types of carbon pools are accounted for: (i) change in carbon stock from aboveground biomass; (ii) change in carbon stock from below ground biomass and (iii) change in soil carbon stock. While calculating CO_2 emissions from deforestation, we differentiated CO_2 emissions per hectare of land across agro-ecological zones (AEZ). Emission stocks by type of AEZ are presented in the Appendix.

While estimating GHG emissions from aboveground and underground biomass, special care is taken to differentiate between the cumulative and annual emissions. This is an important issue as emission accounting for fossil fuel consumption and land-use change are different. For fossil fuel, the difference in emissions between the scenario and the baseline in a year is annual emissions, whereas the same in the case of land-use change is cumulative emissions. In other words, the change in land-use related GHG emissions between a biofuel scenario and baseline in a year cannot be directly added to the similar change in emissions from fossil fuel consumption as the former is a cumulative emission whereas the latter is an annual emission. Figure 2 helps illustrate the difference between the cumulative and annual emissions from land-use.

Figure 2: Illustration of cumulative vs. annual GHG emissions from land-use change
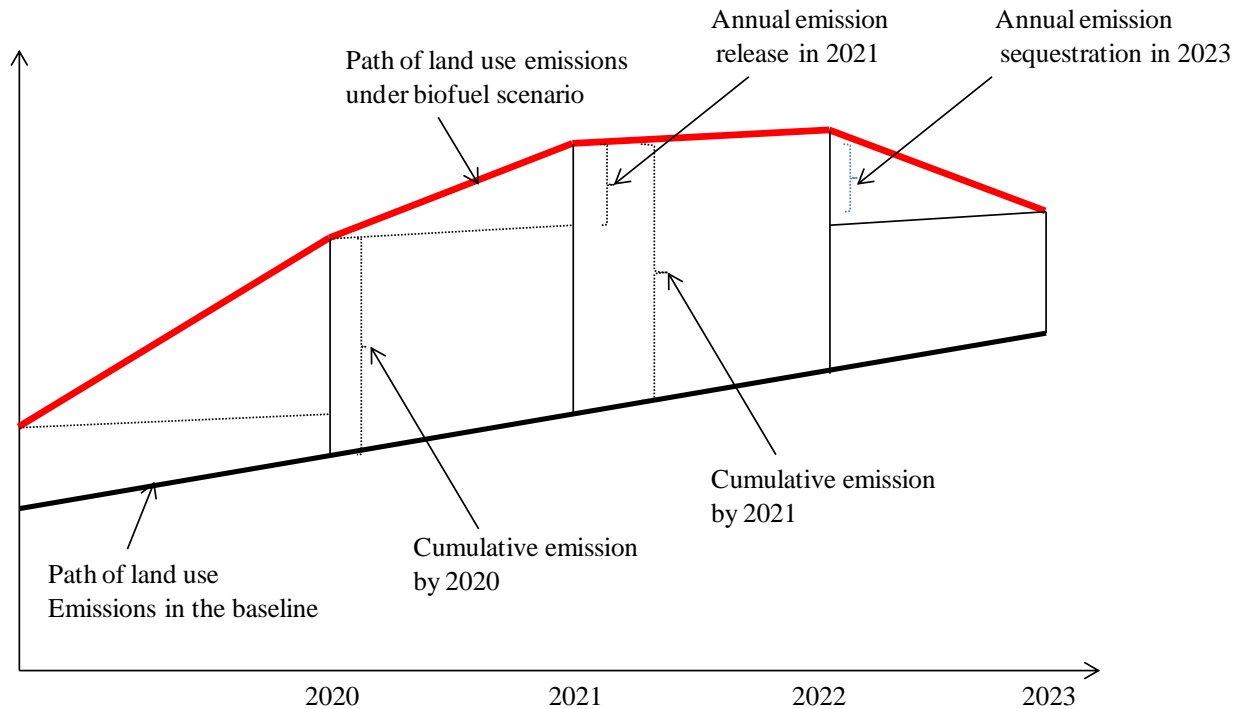
In the figure, the baseline emission from the land-use change is assumed to be increasing as deforestation or expansion of agriculture lands might occur even in the absence of biofuel mandates. The land-use emissions under the biofuels scenario would be higher than that in the baseline as deforestation under the former case would be higher than that in the latter. The cumulative GHG emissions released from land-use change by a year is proportional to the difference in forest and pasture stocks between the baseline and the biofuel scenario in that year. The annual GHG release (sequestration) in a year is proportional to the difference in the stock change (between the baseline and scenario) in that year from the stock change in the previous year. A positive difference causes GHG release (see for year 2021 in Figure 2), whereas a negative difference causes GHG sequestration (see year 2023 in the figure). One might interpret that annual GHG release in a year would be positive as long as forest and pasture stock under a biofuel scenario is lower than that in the baseline in that year. This is not true; an annual GHG release could be negative (see year 2023 in the figure) while cumulative GHG release remains still positive.

In the case of soil carbon, emissions flow in a year also counts emissions released over the last 20 years since soil carbon emissions from land-use change occur over time for 20 years (IPCC, 2006). Alternatively, particularly to calculate carbon debt or payback period, soil carbon related emissions from land-use change activities in a year also count the emissions for the next 20 years. Although either approach gives the same amount of cumulative emissions over the 20-year period, we used the first approach to calculate emissions in a given year.

3. Definitions of Baseline and Scenarios

The baseline[7] represents continuation of business as usual for economic development, population growth and biofuel development. Existing biofuel policies (e.g. already implemented mandates, subsidies and import duties) are part of the baseline[8]. Future mandates for increased biofuel use compared to existing mandates are included in the scenarios. Like in most dynamic CGE models, three variables -- population growth, savings and investment and productivity -- are the key drivers to generate a baseline. Population growth, depreciation rate of capital stock and productivity growth are exogenous to the model. Growth in aggregate labor supply tracks the working age population (defined as those between 15 and 65 years). Savings and investment determines the overall level of the capital stock along with the rate of depreciation. Sectoral productivity growths are consistent with recent trends (World Bank, 2009). Another exogenous variable in the model baseline is the growth of energy prices, which are calibrated with projections made by the Energy Information Administration of the U.S. Department of Energy[9].

For the purpose of the study we define two scenarios. The first scenario considers the implementation of biofuel use targets consistent with what countries already have announced (hereafter "AT" scenario). The second scenario generally considers a doubling of the

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[7] The base year for calibrating the model is 2004, the year for which the social accounting matrices, the main database for the model, were constructed. Although our base year is 2004, the model is calibrated to replicate major historical statistics until year 2009.

[8] Impacts of removal of subsidies and import duties have been analyzed in detailed in a separate paper.

[9] A module that can represent both conventional and un-conventional oil and gas reserves and production would be ideal; however, the model used here does not have that capacity. Hence, we used energy price forecasts from other sources instead of generating them endogenously in the baseline.

announced targets keeping the timing of the implementation of the targets unchanged. We refer to this scenario as the enhanced target scenario (hereafter the 'ET' scenario). In India, however, we retain the AT target level, because it is already extremely high (16.7% in 2020). The shares of biofuels, calculated in terms of energy content, under the baseline and scenarios are presented in Figure 3.

To implement the mandates, we follow standard practice with CGE modeling by calculating the level of per-unit domestic consumption subsidies needed to achieve the desired biofuel demands. We assume that governments tax gasoline and diesel to find additional revenue to finance the subsidies required to realize the targets. The taxation of gasoline and diesel does not only provide needed revenue, but also helps lower the level of subsidies on biofuels because it induces lower total demand for fuels. The revenue neutral tax rates, however, turn out to be very small due to the large tax base. For more information on level of subsidies and corresponding revenue neutral tax rates, please refer to Timilsina et al. (2010). Some countries, such as U.S., Brazil, Malaysia and South Africa, meet their announced targets before 2020 due to existing policies (current mandates and subsidies). For these countries we assumed that the AT scenario follows the baseline starting from the year they first become binding. For example, Brazil meets the announced targets before 2009; therefore we do not impose an additional policy requirement prior to 2020 in Brazil. In the United States, the baseline would be equal to AT scenario by 2015 and we assumed that they be the same thereafter until 2020.

Figure 3: Share of biofuels in the total liquid fuel demand for road transportation (biofuel penetration or target) in year 2020
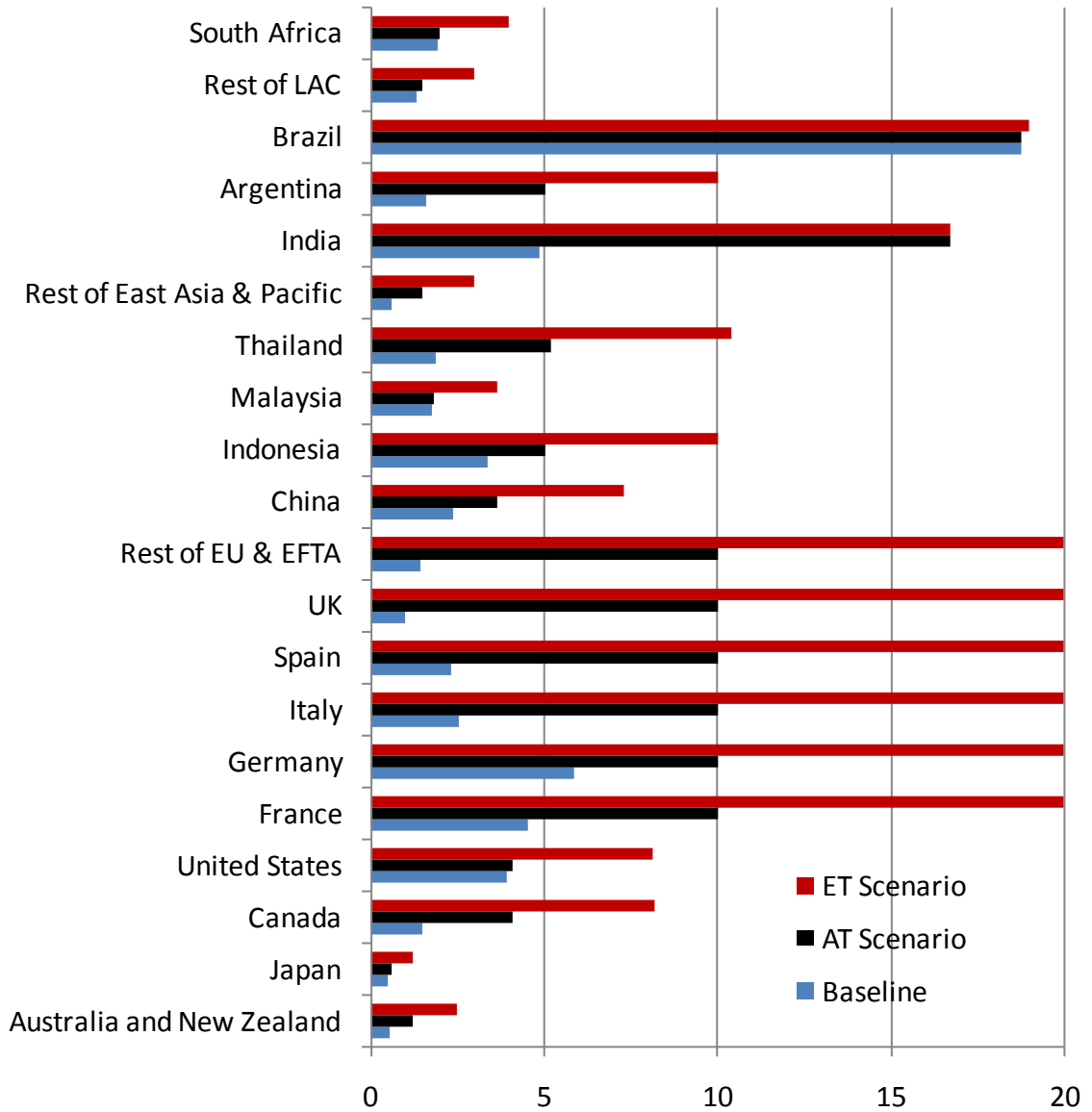
Notes: EFTA stands for European Free Trade Association; LAC, EAC and MENA refer to respectively, Latin America and Caribbean, Eastern Europe and Central Asia and Middle East and North Africa. Mandates for cellulosic ethanol are not included.

4. GHG Emissions from Biofuel Expansion

We calculate GHG emissions from two types of activities: (i) consumption of fossil fuels in various economic sectors, such as power, industry and residential and commercial; and (ii) deforestation caused by the expansion of cultivated area for biofuels. We then compare these emissions under a scenario with the corresponding emissions in the baseline to determine whether an expansion of biofuels would cause a net increase or decrease of emissions to the atmosphere.

Figure 4 presents, under both announced and enhanced target scenarios: (i) CO_2 emissions reduced due to the replacement of fossil fuels with biofuels; (ii) the emissions released from land-use change, mainly from the conversion of forest lands to crop lands; and (iii) the net result of the aforementioned emissions. If the net value is positive, there is an increase of atmospheric emissions from the baseline; if it is negative, there is a decrease of emissions from the baseline.

Figure 4: Change in annual CO_2 emissions under the biofuel expansion scenarios as compared to the baseline scenario (Million tons of CO_2)
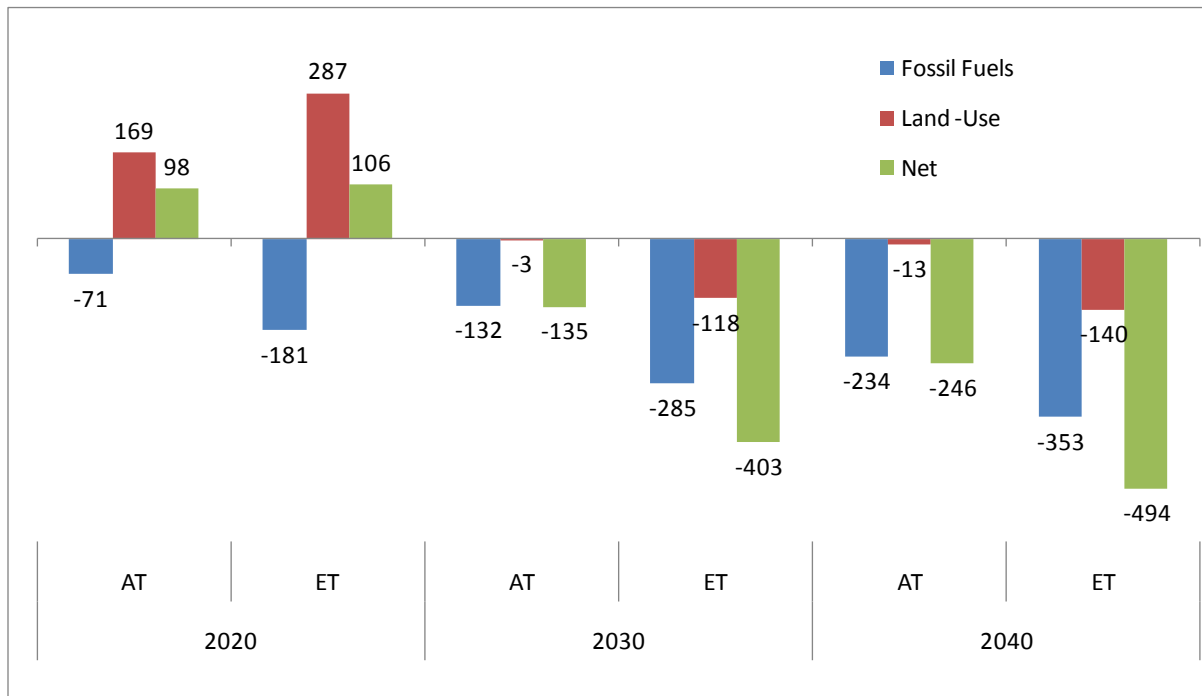
The figure clearly illustrates that the annual emissions released from deforestation due to biofuel expansion would be higher than emission avoided through the replacement of fossil fuels with biofuels until 2023. Thus, the expansion of biofuels would cause a net increase of annual CO_2 emissions to the atmosphere until 2023. However, the net annual emission released to the atmosphere is decreasing overtime despite the fact that the production of biofuels is increasing. If we extend the trends of biofuel penetration beyond 2020, the net annual emissions start to turn to negative after 2023 thereby causing the net reduction of annual CO_2 emissions from the baseline level[10].

The reason as to why biofuels causes net reductions of GHG emissions in the long-run is as follows. The increasing penetration of biofuels would mean greater replacement of fossil fuels with biofuels. While the total land required to produce biofuels does increase over time, the incremental land requirement would be decreasing each year. This implies that the marginal rate of land conversion or deforestation[11] due to the expansion of biofuels is decreasing over time as depicted in Figure 5. The figure shows that the rate of marginal deforestation would diminish to zero by 2040. This implies that if biofuels targets were to met by 2020 and no additional targets were imposed after 2020, deforestation will still occur until 2040, but the rate of deforestation will be decreasing and cease to zero by 2040. In other word, it would take another 20 years to "pay back" the carbon emissions caused by deforestation due to the biofuel targets. More interesting observation in Figure 5 is that the "payback period" is independent to the level of biofuel targets as marginal rate of deforestation would diminish in 2040 in both AT

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[10] Note that annual emissions from land-use change are negative in the years after 2025 even though forest stocks in those years are still smaller under biofuels scenarios as compared to that in the baseline. This is because annual emissions from land-use change refer to the actual flow of emissions from land-use change activities in a year. While forest stocks in a year under biofuel scenarios could still be smaller than that in the baseline in that year, the forest stock in that year would be larger as compared to that in the previous year, implying that forest stock has increased in that year from level of previous year. Actually, there occurs sequestration of CO_2 emissions due to the increase in forest stock. However, in contrast to emissions release from land clearing (i.e., conversion of forest lands to croplands), the conversion back (i.e., conversion of croplands to forest lands) takes a few years to grow enough biomass to fully sequester CO_2 emissions, this reality is, however, not reflected in the model.

[11] We defined marginal rate of land conversion or deforestation (MRF) in year as the percentage change in land-conversion or deforestation from that in the previous year. This is different from the percentage change in land conversion or deforestation from that in the baseline. While the MRF decreases overtime in the former case, this is not necessarily true in the latter case.

and ET scenarios. This is because, although the higher the biofuel target requires more lands for biofuel production, it would also replace more fossil fuel consumption.

Figure 5: Marginal rate of deforestation due to expansion of biofuels
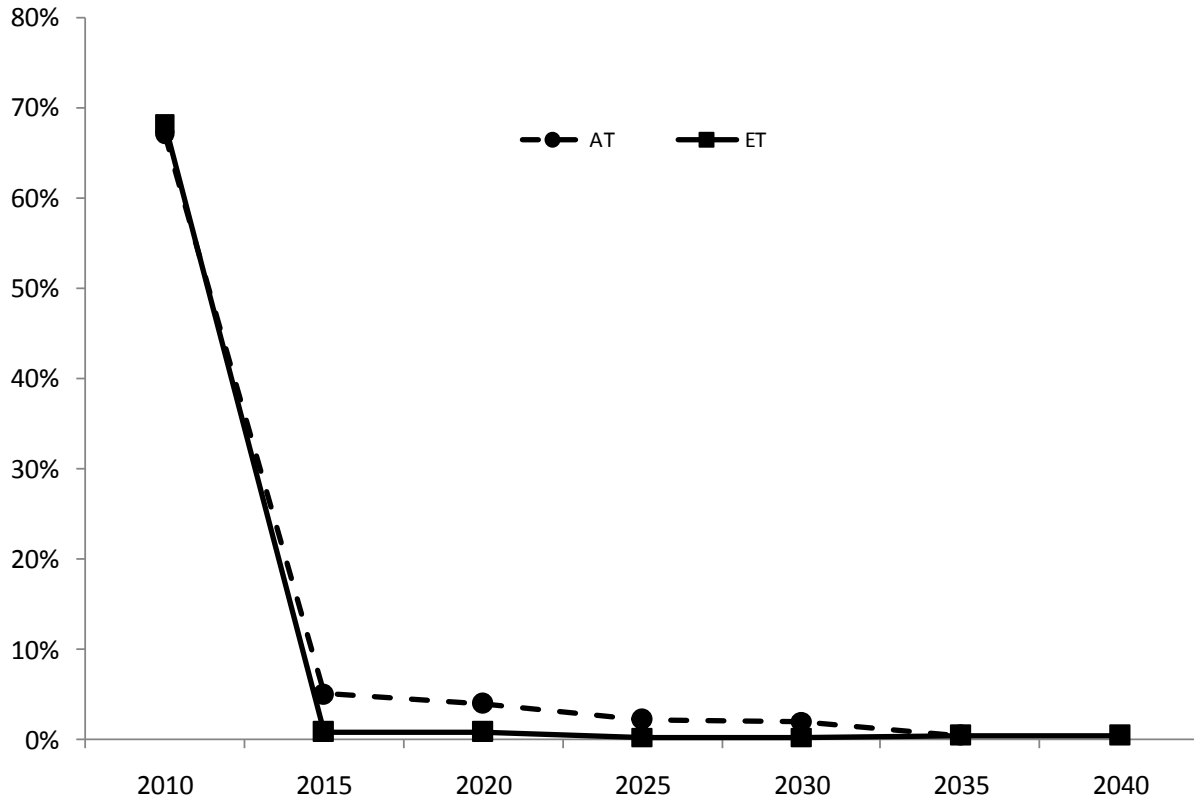
Whereas GHG emissions from land-use change are mostly incurred at the time of land conversion (with the exception of emissions from soil that occur over the next 20 years), GHG savings through the replacement of fossil fuels with biofuels accumulate gradually overtime. Therefore, it would be more appropriate to present GHG emissions or mitigation in cumulative terms instead of annual terms. Moreover, different countries have different timeframes to meet their biofuel targets. For example, Australia, New Zealand and Canada have targets to meet by 2012. On the other hand, China, India, Indonesia and the EU have targets for 2020. The cumulative account of emissions also makes it easier to aggregate the climate change mitigation impacts of these time-varying targets at the global level. Figure 6 illustrates the relationship between biofuel penetration and cumulative CO_2 emissions from the consumption of fossil fuels and from land-use change. The bottom panels of the figures show the number of

years required to balance the land-use related emissions with CO_2 emissions reduction through the replacement of fossil fuels with biofuels[12].

As can be seen from the figure 6, initially the number of years is quite large. However, it quickly drops and stabilizes overtime. For example, it would take about 50 years to generate enough GHG mitigation that compensates for the GHG increases due to deforestation activities in 2010. However, as we move ahead in time, less conversion of forest lands to agricultural lands would be needed to meet increasing biofuel demand. By 2020, only 9 more years would be needed to counterbalance the emissions from land-use change with GHG mitigation resulting from fossil fuel substitution if penetration of biofuels is not increased from the level of 2020. In reality, however, penetration of biofuels would be continuously increasing. We assumed that, after year 2020, the level of incentives (i.e., subsidy) for biofuels will remain the same at the level in year 2020 (or no additional incentive was provided, whereas incentives were increasing yearly between 2009 and 2020).

In the baseline, the global penetration of biofuels would reach 7.1% in 2040 as compared to 5.4% in 2020 and 2.9% in 2010. Under the AT and ET scenarios, the penetrations in 2040 would be 9.6% and 13.8%, respectively. On the other hand, the emissions from land-use change start to decline from the year 2030 although the net GHG emissions still remain positive until 2040. This implies that if the announced biofuel targets are met by 2020 and maintained thereafter, the net GHG emissions would remain positive for more than next two decades.

There is a general perception that higher the biofuel penetration the longer would be carbon payback period. Our study, however, shows that the higher penetration of biofuels does not necessarily increase the carbon payback period. This is because a higher penetration of biofuels causes more GHG emissions from land-use change, but at the same time, it also reduces more GHG emissions through fossil fuel substitution.

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[12] This is termed as carbon payback period in some literature (e.g., Fargione et al. 2008).

Figure 6: Biofuel penetration, GHG emissions and carbon payback period

Biofuel penetration

Change in cumulative CO2 emissions from the baseline (Million Tons)

Carbon debt (Year)
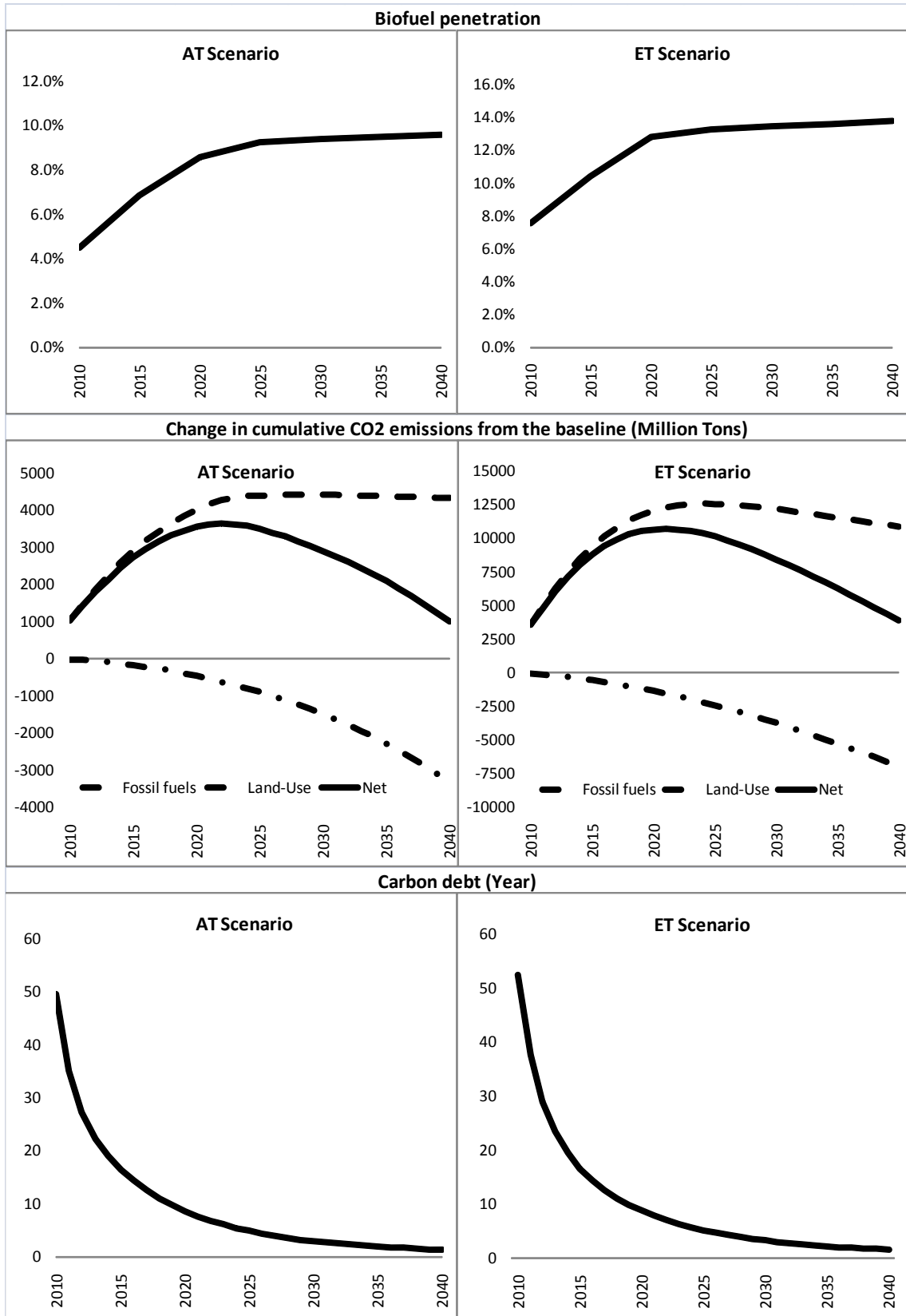
Other studies, such as Fischer et al. (2009), also find similar results from CGE analyses. They show that the implementation of announced targets for biofuels would release 4.1 to 5.3 billion tons of CO_2 equivalent cumulative GHG emissions during the 2000-2020 (20 years) period. In order to meet the same targets, our study finds a net release of about 1.2 billion tons of CO_2 over the 2009-2020 period (11 years). The different estimates can be attributed to a number of differences in these two studies. First, Fischer et al. (2009) freeze production of biofuels at the current level (i.e., 2008 level) in the baseline. We do not artificially freeze biofuel production but instead assume that biofuel production will continue in the baseline following market signals and existing policies. Second, the period for the accumulation of emissions is different: while the cumulative GHG emissions referred to above is for 20 years (2000-2020) in Fischer et al. (2009), it is for 11 years in our study. Due to these differences, Fischer et al. (2009) find the emission payback period or carbon debt of implementing announced targets to be 30 to 50 years whereas our study finds it to be about 17 years.

5. Can Land-use Emissions be Reduced?

The key challenge to the expansion of biofuels from a climate change mitigation perspective is the emissions released to the atmosphere through land-use change, particularly deforestation. Table 1 presents deforestation caused by the expansion of biofuels to meet announced and enhanced targets in various countries or regions. While meeting the announced targets would cause deforestation of about 5 million hectares in 2020, deforestation would increase by more than 5 times that amount if the targets are doubled. Most of the deforestation would occur in Brazil, Canada, India, Thailand and Eastern Europe.

Some results look rather surprising, for example, huge deforestation in Canada, though not in percentage, and reverse deforestation in Russia. The reason might lie in the data as the model uses a huge database including 113 countries, 57 sectors, and 18 agro-ecological zones in each country. it is thus possible that there might be some issues with the data. Nevertheless, small errors in data for a country are not expected to affect the big-picture results. In fact, the

change for Canada may not be a surprise considering the biofuel targets of the country and its duties on biofuel imports. For Thailand, we noticed a lot of diversion of lands not only from forests but also from other crops, such as rice, towards biofuels.

Table 1. Land deforested due to biofuel expansion in 2020

Country/Region	Million hectares		% change from the baseline	
	AT	ET	AT	ET
World total	**4.8**	**26.3**	**0.1**	**0.5**
High-income	**2.7**	**11.4**	**0.2**	**1.0**
Aus-NZ	0.0	0.2	0.1	0.4
Japan	0.0	0.3	0.1	1.0
Canada	1.3	6.6	0.2	1.2
United States	0.2	1.1	0.1	0.5
France	0.3	0.8	1.3	3.8
Germany	0.1	0.4	0.6	1.9
Italy	0.1	0.2	0.6	1.7
Spain	0.0	0.1	0.6	1.7
UK	0.1	0.3	1.2	3.3
Rest of EU & EFTA	0.5	1.5	0.3	0.9
Middle & Low-income	**2.2**	**14.9**	**0.1**	**0.4**
China	0.2	1.2	0.1	0.5
Indonesia	0.2	0.8	0.1	0.6
Malaysia	0.0	0.1	0.1	0.3
Thailand	0.4	1.9	1.1	5.2
Rest of EAP	0.1	0.8	0.0	0.3
India	0.7	1.8	0.7	2.0
Rest of SA	0.0	0.0	0.0	0.2
Argentina	0.0	0.1	0.1	0.6
Brazil	1.5	7.4	0.3	1.6
Rest of LAC	0.1	1.4	0.0	0.3
Russia	-1.2	-2.1	-0.1	-0.1
Rest of ECA	0.1	0.4	0.1	0.6
MENA	0.0	0.0	0.1	0.5
South Africa	0.0	0.2	0.1	6.8
Rest of SSA	0.1	0.7	0.0	0.1

However, in some countries like India and Thailand, natural forests are taken to be successfully protected and it is unlikely that demand for biofuels would change the forest protection policy. This implies that if the production of biofuels causes any conversion of land, the new land should come from pasture, not from forest. To capture this, we have developed a scenario where all new lands required for production of biofuels under the AT and ET scenario

would come from pasture. In order to check if this scenario a viable one, we compare the available pasture land with deforested land due to biofuel production in the previous AT and ET scenarios (see Table 2).

Table 2. Comparison of land deforested due to biofuel expansion with available pasture land

Country/Region	Deforested land as percentage of available pasture land	
	AT	ET
World total	**0.2**	**0.9**
High-income	**0.4**	**1.9**
Aus-NZ	0.0	0.1
Japan	5.8	73.0
Canada	6.2	31.0
United States	0.1	0.5
France	2.9	8.7
Germany	2.1	7.5
Italy	1.4	4.2
Spain	0.5	1.4
UK	1.0	2.7
Rest of EU & EFTA	1.6	5.1
Middle & Low-income	**0.1**	**0.7**
China	0.1	0.4
Indonesia	6.8	32.5
Malaysia	6.0	31.6
Thailand	170.8	815.8
Rest of EAP	0.1	0.9
India	5.4	14.5
Rest of SA	0.0	0.1
Argentina	0.0	0.1
Brazil	0.9	4.4
Rest of LAC	0.1	0.6
Russia	-1.5	-2.5
Rest of ECA	0.0	0.1
MENA	0.0	0.0
South Africa	0.0	0.2
Rest of SSA	0.0	0.1

It is interesting to note that the total land deforested at the global level to meet biofuel targets are 0.2% and 0.9% of the total pasture land available under the AT and ET scenarios. In most countries, the deforested lands are a small fraction of total pasture land. This demonstrates that if proper policies are put in place to encourage farmers to use pasture land

instead of forest land to produce biofuel feedstock[13], deforestation could be avoided. Pasture land is used in very inefficient way in many countries, and productivity of pasture land can be improved through many approaches such as integration of pasture and crops, or pasture and forestry. Intensification of livestock production could also help release pasture land needed for production of biofuel feedstocks. However, in some countries, such as Thailand, deforested land would be much higher than the pasture land available[14]. Deforested lands also account for a large fraction of available pasture land in other countries like Canada, Japan, Indonesia, Malaysia and India.

Figure 7 compares GHG emissions between previous scenarios where land-use emissions originate from both forests and pasture lands (i.e., Deforestation Case) and new scenarios where land-use emissions originate only from pasture lands (i.e., No Deforestation Case). As can be seen from the figure, if entire land-use emissions originate from pasture land instead of both forest and pasture land, cumulative land-use emissions in the former case would be more than 80% smaller than that in the latter case. The carbon debt in year 2020 reduces from 9 year to just one year as the cumulative net GHG emissions would start to be negative starting from year 2021 (see Figure 8).

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[13] One policy instrument could be certification of biofuels; only biofuels produced from non-forest land would be traded or consumed.
[14] This implies that Thailand cannot meet its biofuel demand through its own production unless productivity of biofuel feedstocks (e.g., sugarcane) is increased substantially.

Figure 7: Comparison of GHG emissions between Deforestation and No-Deforestation Cases (Million tCO₂)
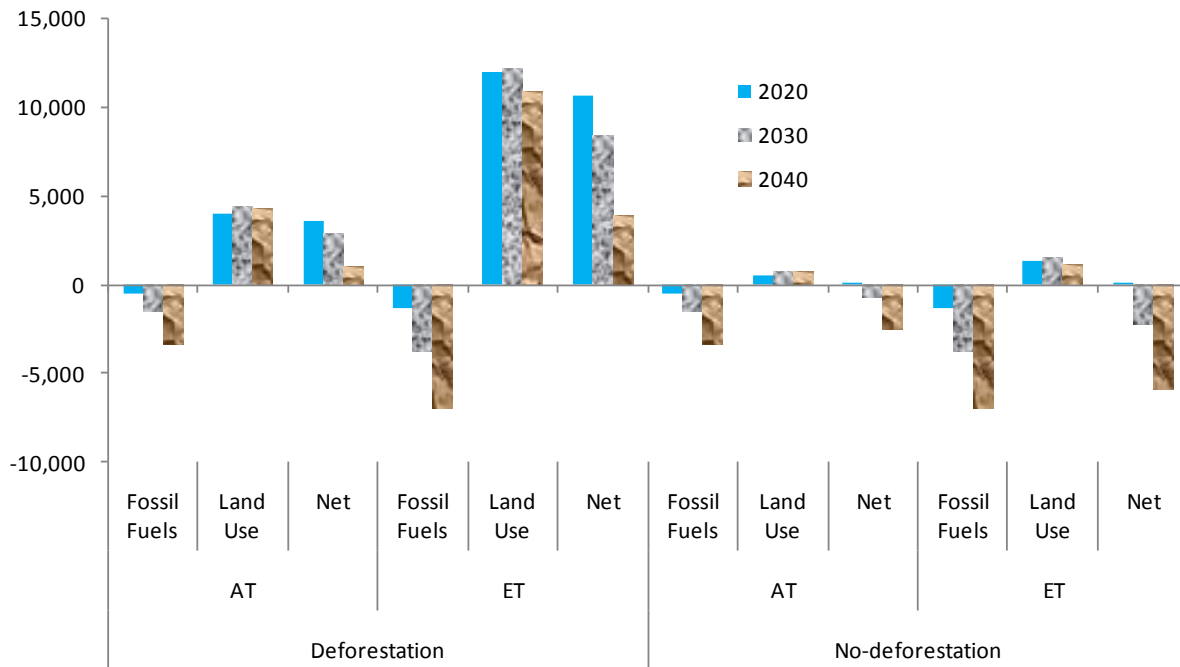
Figure 8: Comparison of carbon payback periods between Deforestation and No-deforestation cases

Note in the scenario that assumes meeting biofuels targets without causing deforestation that GHG emissions from land-use change would not be neutralized by GHG mitigation through fossil fuel substitution until 2021 at the global level. This may not be true in some countries where biofuels targets are met b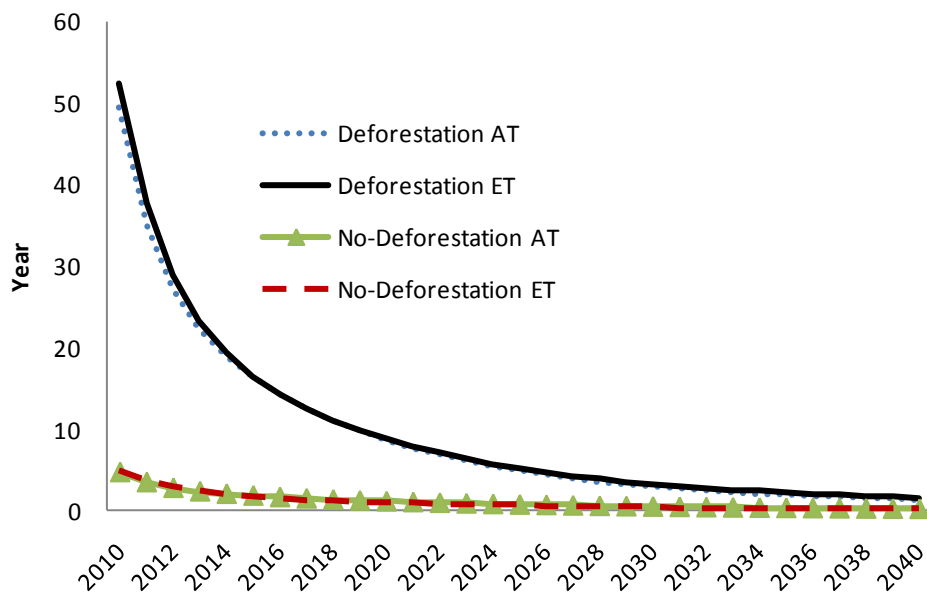efore 2020. In those countries carbon neutrality would occur before 2020 but not before the year by which targets will be implemented. This implies that it takes some years to achieve the carbon neutrality of biofuels even if the new land demand for biofuel expansion is met through pasture lands.

6. Conclusions and Final Remarks

Using a global computable general equilibrium model that explicitly represents land-use change impacts due to the expansion of biofuels, this study attempts to shed light on the biofuels vs. climate change mitigation debate. Our study shows that whether or not meeting the announced or higher biofuel targets reduce global GHG emissions depends mainly on the timeframe involved. Meeting the announced targets by 2020 through first generation biofuels would not cause reduction of GHG emissions until 2020 no matter whether new lands needed for the expansion of biofuels comes from existing forests or pasture lands. On the other hand, meeting the biofuel targets would cause net reduction of GHG emissions in the longer run. However, the number of years to occur the GHG reductions depends on the types of land conversion needed by the expansion of biofuels. If new lands needed for biofuel expansion is supplied through the existing forest and pasture, the number of years to realize GHG mitigation (also called carbon payback period) would be more than 20 years after the year 2020. On the other hand, if the land is supplied through pasture thereby avoiding deforestation, GHG reduction will occur since 2021, a year after the biofuels targets are met. The results thus imply that the carbon payback period of implementing announced biofuel targets vary between 1 to 23 years depending on how new land demand is met. The scenario of meeting entire new land demand through pasture (i.e., without deforestation) might look unrealistic based on past experience where avoiding deforestation remains as a serious challenge in many countries around the world. Expansion of biofuels might act as a new incentive for further deforestation.

Our study also finds that the annual rate of deforestation does not increase proportionally along with annual rate of biofuel expansion; instead, marginal deforestation and corresponding emissions decrease even if the production of biofuels increases. This is because, a higher target of biofuels causes more GHG emissions from land-use change, but at the same time, it also reduces more GHG emissions through fossil fuel substitution.

This study has some limitations, such as the restriction of GHG emissions to CO_2. Other GHG emissions, particularly methane emissions from rice plantation and emission of nitrous oxide from fertilizer use, could be significant. However, land use for rice plantation decreases due to the expansion of biofuels, implying a reduction in total methane emissions from rice fields. The estimates of GHG reduction are thus likely to be conservative.

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Appendix

CO$_2$ emission factors for land-use change

	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18
Pasture Lands																		
Above ground biomass (t dry mat/ha)	25.20	25.20	11.20	11.20	11.20	11.20	25.20	25.20	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Coef. for carbon mass by dry matter	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Above ground biomass (emission factor)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Above ground biomass (released)	**5.92**	**5.92**	**2.63**	**2.63**	**2.63**	**2.63**	**5.92**	**5.92**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**	**6.58**
Above ground/Below ground ratio	9.00	9.00	7.00	7.00	7.00	7.00	9.00	9.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Below ground biomass (t dry mat/ha)	2.80	2.80	1.60	1.60	1.60	1.60	2.80	2.80	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Coef. for carbon mass by dry matter	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Below ground biomass (emission factor)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Below ground biomass (released)	**1.32**	**1.32**	**0.75**	**0.75**	**0.75**	**0.75**	**1.32**	**1.32**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**	**1.88**
Soil carbon	38.00	38.00	38.00	38.00	47.00	60.00	38.00	50.00	95.00	95.00	66.50	88.00	0.00	68.00	68.00	68.00	68.00	68.00
Soil carbon (emission factor)	0.42	0.42	0.42	0.42	0.52	0.52	0.20	0.20	0.31	0.31	0.31	0.31	0.20	0.20	0.31	0.31	0.31	0.31
Soil carbon (released)	**15.96**	**15.96**	**15.96**	**15.96**	**24.44**	**31.20**	**7.60**	**10.00**	**29.45**	**29.45**	**20.62**	**27.28**	**0.00**	**13.60**	**21.08**	**21.08**	**21.08**	**21.08**
Forest Lands																		
Above ground biomass (t dry mat/ha)	70.00	70.00	130.00	130.00	180.00	300.00	70.00	70.00	120.00	120.00	155.00	220.00	0.00	15.00	40.00	40.00	40.00	40.00
Coef. for carbon mass by dry matter	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Above ground biomass (emission factor)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Above ground biomass (released)	**16.45**	**16.45**	**30.55**	**30.55**	**42.30**	**70.50**	**16.45**	**16.45**	**28.20**	**28.20**	**36.43**	**51.70**	**0.00**	**3.53**	**9.40**	**9.40**	**9.40**	**9.40**
Below ground / Above ground ratio	0.40	0.40	0.30	0.30	0.22	0.37	0.32	0.32	0.30	0.30	0.30	0.22	0.30	0.30	0.30	0.30	0.30	0.30
Below ground biomass	28.00	28.00	39.00	39.00	39.60	111.00	22.40	22.40	36.00	36.00	46.50	48.40	0.00	4.50	12.00	12.00	12.00	12.00
Coef. for carbon mass by dry matter	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Below ground biomass (emission factor)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Below ground biomass (released)	**13.16**	**13.16**	**18.33**	**18.33**	**18.61**	**52.17**	**10.53**	**10.53**	**16.92**	**16.92**	**21.86**	**22.75**	**0.00**	**2.12**	**5.64**	**5.64**	**5.64**	**5.64**
Soil carbon	38.00	38.00	38.00	38.00	47.00	60.00	38.00	50.00	95.00	95.00	66.50	88.00	0.00	68.00	68.00	68.00	68.00	68.00
Soil carbon (emission factor)	0.42	0.42	0.42	0.42	0.52	0.52	0.20	0.20	0.31	0.31	0.31	0.31	0.20	0.20	0.31	0.31	0.31	0.31
Soil carbon (released)	**15.96**	**15.96**	**15.96**	**15.96**	**24.44**	**31.20**	**7.60**	**10.00**	**29.45**	**29.45**	**20.62**	**27.28**	**0.00**	**13.60**	**21.08**	**21.08**	**21.08**	**21.08**

Source: Authors' computations based on IPCC (2006) and Al-Riffai et al. (2010).