Chapter 9
Biofuels and Climate Change Mitigation

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9.1 Introduction

Many countries present climate change mitigation benefit as one of the main rationales to defend their policies to promote biofuels. However, the role of biofuels on climate change mitigation remains ambiguous. Whether or not biofuels save greenhouse gas (GHG) emissions depends on how the savings are estimated. The GHG mitigation potentials of biofuels are normally assessed through three different approaches: project level approach, life-cycle approach, and an approach that accounts for indirect land-use change (ILUC) effect. These approaches are discussed below.

Project level approach: It assigns the GHG contents of fossil fuels replaced by biofuels as their GHG savings. It does not account for the release of GHG emissions during any activities involved in the production and delivery process, such as land cultivation and transportation of final products (e.g., ethanol, biodiesel) to blending stations. The underlying assumption here is that GHG release occurred in the supply chain of biofuel production is equal to that released in the supply chain of production of fossil fuels that is replaced with biofuels. With this assessment, any type of biofuel can save GHG emissions when it replaces fossil fuels because the former is carbon neutral. A liter of ethanol produces around 67 % of energy or mileage compared to that of gasoline, implying that ethanol could save around 67 % of GHG through gasoline replacement. Similarly, biodiesel could save around 86 % of GHG through diesel replacement.

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Life-cycle assessment (*LCA*): It includes change in GHG emissions throughout the supply chains of biofuels and fossil fuels to be replaced with biofuels. For biofuels, GHG released in feedstock production (including land conversion if new land is used) and transportation, as well as GHG emissions in the refinery are accounted for. Similarly, for fossil fuels, GHG emissions in upstream petroleum activities, refining, and transportation are also included. Defining the supply-chain boundary and uncertainties on carbon coefficients at various stages of the supply chain are the key constraints to lifecycle approach.[1] GHG savings estimated through a LCA approach varies substantially across projects even if the feedstock is the same. This is because of varying assumptions on system boundaries, co-products accounting, energy sources used in the production of agricultural inputs and feedstock conversion, and the type of land (existing crop lands vs. newly converted from forest or pasture) used for feedstock production. Figure 9.1a, b illustrates the variations in GHG savings from different feedstocks.

Corn ethanol causes the lowest savings of life-cycle GHG emissions, whereas miscanthus-based second generation ethanol has the highest potential to reduce GHG emissions. Second generation or cellulosic ethanol produced from miscanthus, switchgrass, and corn stover could save more than 100 % of GHG emissions as they do not only replace gasoline but also sequester CO_2 emissions from the atmosphere. In the case of biodiesel, soybean has the highest potential for GHG reduction. As illustrated in Fig. 9.1, GHG mitigation potentials of most biofuels vary widely.

ILUC: This assessment is for capturing the ILUC effects of biofuels. The ILUC effects occur as food demand is ever increasing due to population and income growth. The increased demand for food and a new demand for agricultural commodities for biofuels would increase the overall demand for agricultural commodities. While part of this increased demand could be met through yield increase, the most of it would require a new land thereby causing deforestation and conversion of pasture lands. This implies that a biofuel program or policy in a country or region could cause land conversion not only in that region or country but in other regions of the world where production is most competitive. For example, diversion of European sugarbeet for biofuels could trigger expansion of sugarcane production in Brazil, where sugarcane production is competitive, in order to maintain the supply of sugar. The conversion of lands is associated with carbon release from soil and biomass. Some soils, such as peat land in Indonesia, are highly carbon-rich. Sometimes, the indirect carbon release might be higher than the direct release due to biofuel production.

[1] While a life-cycle approach could approximate GHG savings of a biofuel project, it does not trace GHG leakage caused beyond project boundary that normally occurs when biofuel expansion is carried out at a large-scale. For example, biofuel blending mandates in the US and Europe could increase biofuel production in Brazil and Indonesia. The production might come from feedstock grown in new lands supplied through conversion of forest or pasture lands. The conversion of lands releases GHG emissions and it is referred to as indirect land use change (ILUC) effect of biofuels.

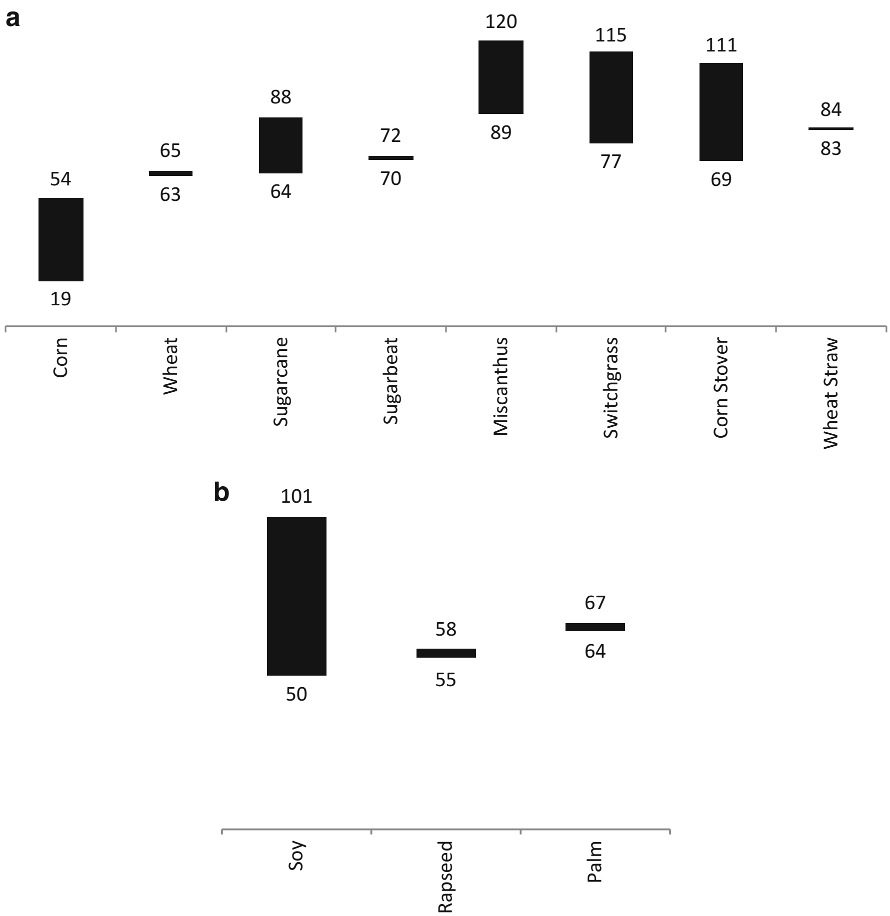

Fig. 9.1 GHG savings estimated through LCA approach. (**a**) Percentage savings of GHG emissions due to substitution of gasoline with ethanol. (**b**) Percentage savings of GHG emissions due to substitution of diesel with biodiesel. *Notes*: Calculated based on direct life-cycle emission intensities of various feedstocks compiled by Khanna and Crago (2012). Minimum value of GHG savings is calculated by subtracting maximum GHG intensity of biofuels (ethanol and biodiesel) from minimum GHG intensity of corresponding petroleum products (gasoline and diesel). Similarly, maximum value of GHG savings is calculated by subtracting minimum GHG intensity of biofuels from maximum GHG intensity of corresponding petroleum products

Two types of economic models are normally used in assessing the GHG mitigation potential of biofuels accounting for ILUCs: (1) partial equilibrium models and (2) general equilibrium models. Khanna and Crago (2012) present a good overview on the distinction of these models with examples. The first types of models are focused on agricultural sector and capture all aspects of production, consumption, and international trade of agricultural commodities and main inputs, such as fertilizers, used for production of agricultural goods and services. Since these models do

Table 9.1 Examples of studies estimating GHG savings of biofuels including ILUC effects

Study	Biofuel programs/policies	Model used	Main findings
Timilsina and Mevel (2011, 2013)	Implementation of biofuel mandates and targets announced by 40 plus countries around the world by 2020	Global CGE model	No GHG savings by completion of the program (2020); it would take 23 years after the completion of the program to realize GHG savings; if forest conversion is not allowed, GHG savings would be realized 1 year after the completion of the program
Laborde (2011)	Implementation of EU biofuel policies by 2020	MIRAGE-Biof	The ILUC effect of EU biofuels mandate eliminate more than two-thirds of the direct emission savings estimated for 2020
Fischer et al. (2009)	Meeting global biofuel targets and mandates through first and second generation biofuels	Global CGE model	If current global biofuel targets/ mandates are met it would take 30–50 years to offset the GHG emissions caused by ILUC effects
Dumortier et al. (2011)	Production of 55 billion liters of corn ethanol in United States over the 30 years period	CARD model	No GHG savings; depending on scenarios and data assumptions in the model, it takes 74–137 years to offset GHG emissions caused by ethanol directly and indirectly

not necessarily include every sector and agents of the economy, they are referred to partial equilibrium models. The FAPRI-CARD model developed by the Food and Agricultural Policy Research Institute (FAPRI) and the IMPACT model developed by the International Food Policy Research Institute (IFPRI) are two good examples of partial equilibrium models used for ILUC impacts of biofuels. The second types of model are referred to as general equilibrium models. These models represent the linkage between production sectors, between production sectors and other economic agents–such as households and governments–and fully capture international trade of all goods and services. These are the most common models used for assessing ILUC impacts of biofuels. Examples of these models include Timilsina et al. (2010); Al-Riffai et al. (2010); Hertel et al. (2010); Fischer et al. (2009).

Although a large number of studies have been carried out to estimate ILUC effects, there is no consensus on any estimate. This is because of high uncertainties involved in the estimations. Different studies use different models to estimate ILUC effects; these models vary on two fronts. First, the database and underlying assumptions are different; secondly key parameters such as projection of yield, treatment co-products, assumptions about the types of land use change, and the methods for estimating GHG emissions are different.

An assessment of ILUC for a single biofuel project in isolation may not be relevant as ILUC effect of a project would be too small and too cumbersome to trace. However, it is important to measure ILUC effects of biofuel programs or policies. Normally, global macroeconomic models with explicit representation of bilateral trades have been used to assess ILUC effects of biofuels. Some examples of studies investigating climate change mitigation effects of biofuels are presented in Table 9.1.

This chapter seeks to discuss the role of biofuels in global climate change mitigation based on Timilsina and Mevel (2011, 2013). We present a comparison of greenhouse gas emissions under the baseline and the scenario of full realization of biofuel mandates and targets announced by 40 plus countries around the world by year 2020. While the baseline assumes continuation of biofuel policies already implemented before 2009, the scenario considers the biofuel mandates and targets which have been already announced but yet to be implemented. The mandates and targets will be implemented by 2020 following the schedules specified in their announcement.[2] The baseline and scenario presented here is the same as presented in Chapter V with one distinction that both baseline and scenario are projected up to 2040 to capture the carbon payback period.

9.2 Methodology to Calculate GHG Emissions

The CGE model used by Timilsina and Mevel (2011, 2013) captures GHG emissions under the baseline and biofuel expansion scenarios through the following activities:

- *Consumption of fossil fuels*: multiplying the volume of a fossil fuel consumed by a production sector and an economic agent (e.g., households, governments) by emission coefficients or carbon content of that fuel. The national emissions from fossil fuels are the sum of emissions across the fuels and across production sectors as well as economic agents. Emission coefficients are based on 2009 CO_2 emissions data from the International Energy Agency (IEA). Reduced emissions due to expansion of biofuels are calculated by subtracting CO_2 inventory from fossil fuel consumption under the scenario from that under the baseline.
- *Land use change*: GHG release due to land-use change in a given year is calculated in four steps. First, the change in carbon stock on biomass due to expansion of biofuels is calculated by subtracting carbon stock on biomass under the scenario from that under the baseline. Second, the stock is then converted to annual flow (or annual GHG release) by subtracting previous years' GHG stock change from that of the current year. Third, the annual carbon flow from change in biomass stock is multiplied by oxidization rates and carbon to carbon di-oxide ratio (3.44) to get annual CO_2 change due to land-use. Fourth, annual CO_2 release from soil carbon is added to annual CO_2 release from biomass to get total CO_2 release from land-use change. The method follows the guidelines developed by the Intergovernmental Panel on Climate Change (IPCC 2006). Relying on the IPCC Tier I approach, calculations need account for three types of biomass: (1) above ground, (2) below ground, and (3) soil. Emission stocks are documented

[2] The authors also analyze a scenario where the mandates and target are doubled to further stimulate biofuel penetration in the global energy supply mix. For results of that scenario, interested readers may refer to Timilsina and Mevel (2011) or Timilsina and Mevel (2013).

for each agro-ecological zone (AEZ).[3] Soil carbon is a flow variable accounting for emissions over the past 20 years. When a land conversion occurs, GHG release is assumed to continue over the next 20 years.

9.3 The Impacts of Biofuel Expansion on GHG Emissions

9.3.1 Impacts on Annual Emissions

As explained in the preceding section, total GHG emissions are a composite of fossil fuel emissions and carbon release from land-use change. Compared to the baseline scenario, the global GHG emissions from fossil fuel decreases over the years as the replacement of fossil fuels with biofuels continue to increase due to the mandates and targets (Fig. 9.2). The global GHG emissions due to land-use change (i.e., deforestation and cultivation of pasture lands) would decrease over years. This is because, once land conversion occurs, the same land is utilized to produce biofuel feedstock again and again. The further we go, the less new lands we need as long as biofuel mandate remains the same. Although decreasing over time, the global emissions due to land use change would be much higher than the baseline level in earlier period. The reduction in emissions from the baseline through fossil fuel replacement is not sufficient to offset the increased emissions from the baseline due to land use change, Thus, net emissions would be higher than that in the baseline. But, by

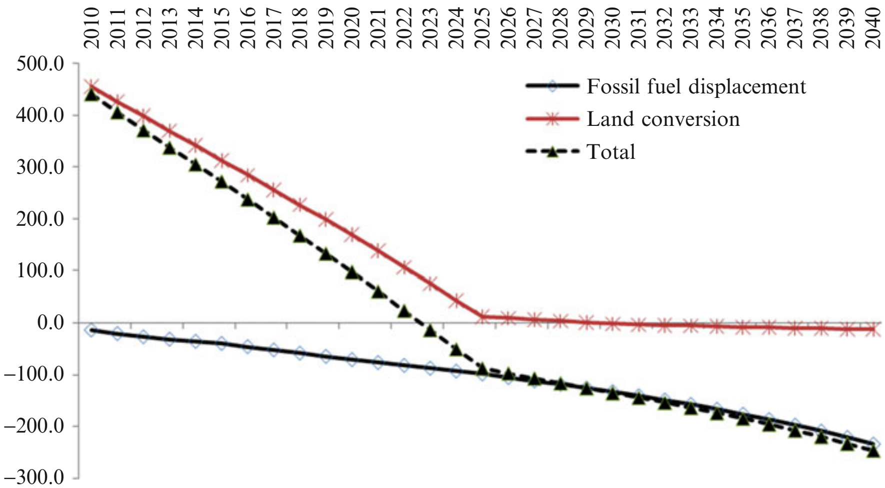

Fig. 9.2 Change in global annual CO_2 emissions from the baseline due to expansion of biofuels (million tons of CO_2)

[3] Please refer to Timilsina and Mevel (2011, 2013) for emission coefficients for various AEZs.

year 2023, the emission reduction due to fossil fuel displacement would be higher than that emission release due to land conversion thereby causing net reduction of GHG emissions. Starting 2032, there would be no more release of GHG emissions from land-use change as well, instead there would be reconversion of crop lands to pasture and forest lands thereby causing net sequestration of GHG emissions. This is because biofuel mandates and targets beyond 2020 are assumed to be kept at 2020 level. Thus, the analysis demonstrates that expansion of biofuels causes increase in global GHG emissions in the short-run but reduces GHG emissions in the long-run as long as biofuel mandates remain at the same level.

9.3.2 Impacts on Cumulative Emissions

Most GHG emissions from changes in land usage will incur at the time of land conversion with exception of emissions from soil carbon and harvested wood products. As GHG savings accumulate over time to offset the biomass release from land, it might be more useful to represent GHG emissions in cumulative terms, rather than in annual terms. Figure 9.3 shows the effects of meeting biofuel mandates and targets: biofuel penetration is weighed against concurrent GHG emission effects and CO_2 debt.

As illustrated in Fig. 9.3, up to 2020, the rate of biofuel penetration accelerates, causing emissions to continue rising (at a diminishing rate) and carbon debt to fall (at a diminishing rate). The global penetration of biofuels reaches 9.6 % by 2040 under the scenario to implement biofuel mandates and targets by 2020 and no incremental mandates and targets implemented thereafter. The relationship between biofuel expansion, emissions, and carbon debt all reach stabilization after 2020, as the biofuel promotional policies are held constant thereafter. The carbon debt graph shows how many years it would take to "pay off" land conversion due to biofuel promotion. It would take more than 23 years (i.e., 2043) after completion of implementing biofuel mandates (i.e., year 2020) to realize GHG savings from fossil fuels to compensate for GHG released through land conversion.

The bottom panel of Fig. 9.3 presents an interesting insight which is often ignored in the existing literature (e.g., Dumortier at al. 2011, Searchinger et al. 2008; Fargione et al. 2008). This ignorance might have resulted in heavy inflation of carbon payback periods in those studies. The insight is as follows. If an analysis is carried out for a particular year, for example, conversion of peat land in Indonesia to produce biofuels, most of the emissions release in the year of land conversion as all biomass is burned down during that year. The amount of GHG emissions would be very high. If carbon payback period is calculated by dividing this amount of emission by the amount saved through the replacement of fossil fuels, the resulted number would be very high. For example, in 2010 (the first year in Fig. 9.3), the carbon payback period is around 50 years. However, the same land is used to produce biofuel feedstocks again and again. Biofuels produced from this new feedstock also replaces fossil fuels. As we go further and further, more and more fossil fuels are replaced thereby decreasing the carbon payback period overtime.

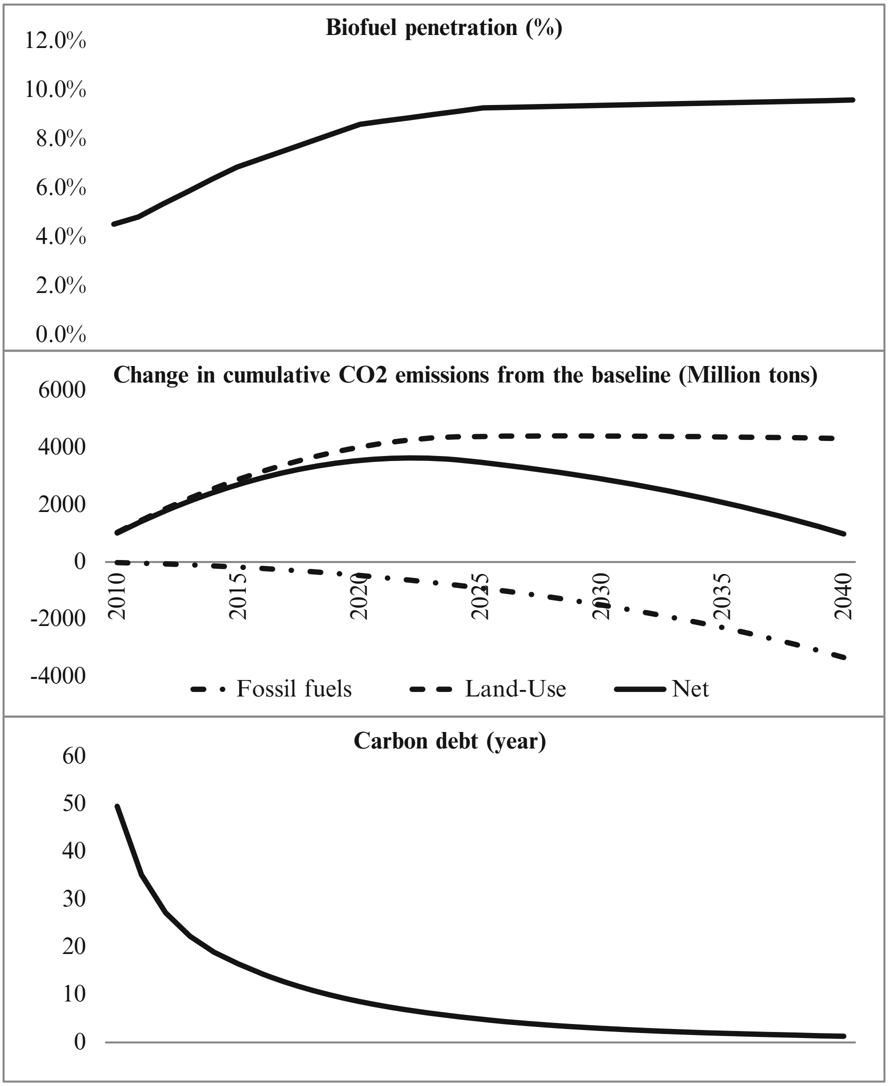

Fig. 9.3 Biofuel penetration, GHG emissions, and carbon payback period. *Source*: Timilsina and Mevel (2011, 2013)

9.4 Securing Climate Change Mitigation from Biofuels

One of the key challenges to biofuel expansion is how to limit the carbon debt that biofuel production causes. If biofuel mandates and targets are fully materialized by 2020, the global deforestation would reach about 5 million ha. that year. Table 9.2 details the deforestation impacts due to the implementation of the biofuels. Greater amounts of deforestation (i.e., million ha.) are identified for Brazil and Canada, whereas greater rates of deforestation are found in the UK, France, Thailand, and India.

Table 9.2 Change in Deforestation from the baseline due to expansion of biofuels

Country/Region	Deforestation		Deforested land as
	Million hectares	% Change from the baseline	Percentage of total pasture land
World total	4.8	0.1	0.2
High-income	2.7	0.2	0.4
Australia–NZ	0	0.1	0
Japan	0	0.1	5.8
Canada	1.3	0.2	6.2
United States	0.2	0.1	0.1
France	0.3	1.3	2.9
Germany	0.1	0.6	2.1
Italy	0.1	0.6	1.4
Spain	0	0.6	0.5
UK	0.1	1.2	1
Rest of EU and EFTA	0.5	0.3	1.6
Middle and low-income	2.2	0.1	0.1
China	0.2	0.1	0.1
Indonesia	0.2	0.1	6.8
Malaysia	0	0.1	6
Thailand	0.4	1.1	170.8
Rest of EAP	0.1	0	0.1
India	0.7	0.7	5.4
Rest of SA	0	0	0
Argentina	0	0.1	0
Brazil	1.5	0.3	0.9
Rest of LAC	0.1	0	0.1
Russia	−1.2	−0.1	−1.5
Rest of ECA	0.1	0.1	0
MENA	0	0.1	0
South Africa	0	0.1	0
Rest of SSA	0.1	0	0

Source: Timilsina and Mevel (2011, 2013)

Although Canada does not experience significant deforestation relative to its land endowment, the magnitude of its land conversion, expansion of its domestic biofuel sector, and instated import duties are substantive. In Thailand's case, land is converted from other crop uses—namely rice—to biofuel feedstock. In fact, Thailand and some other nations have forest preservation policies. Thus, biofuel feedstock demands would more likely require land conversion from pastures and other uses than forest.

The last column of Table 9.2 shows deforested lands in various countries/regions as percentage of their available pasture lands. This indicator shows whether or not a country/region has sufficient pasture lands to meet new land demands for biofuel expansion to meet the targets and mandates. At the global level, the land that comes from deforestation to meet the new land demand for biofuel expansion represents a small fraction (0.2 %) of the pasture land globally available. This indicates that biofuels expansion can be carried out without deforestation at the global level.

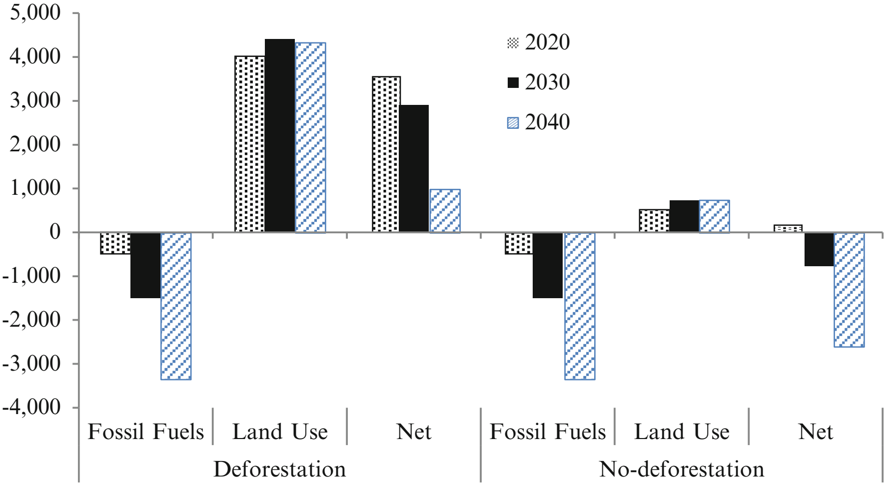

Fig. 9.4 GHG emissions under deforestation and no-deforestation cases (million tons CO_2). *Source*: Timilsina and Mevel (2011, 2013)

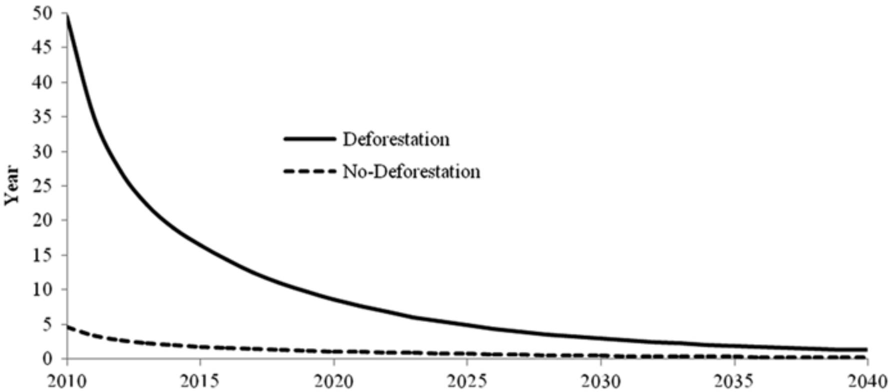

Fig. 9.5 Carbon payback periods under deforestation and no-deforestation cases. *Source*: Timilsina and Mevel (2011, 2013)

Pastures are not protected by regulation and seldom require deforestation. Thus, the carbon debt tradeoff between converting pasture land is less than for converting forests. There is some room for efficiency gains, as pastures begin to experience land-use competition and pressure. Eventually, receding pasture lands will require intensification of livestock activities and raise the cost for meats. However, there is not enough pasture lands available in some countries, particularly Thailand. In countries like Canada, Japan, Malaysia, and Indonesia, higher percentage of pasture lands are needed to avoid deforestation due to biofuel expansion.

Figures 9.4 and 9.5 extrapolate and compare GHG emissions and carbon debt under distinct sources for land conversion. Notably, if forests are converted, then deforestation causes over four billion tons of CO_2 emission in 2020. If forests are protected by regulation and pasture lands are converted to meet new land demand for biofuel expansion, net GHG release to atmosphere due to biofuels decreases by 60 folds in 2020 thereby reducing carbon debt from 30 plus year to just one year.

9.5 Closing Remarks

This chapter draws upon the Timilsina and Mevel (2011, 2013) studies to assess climate change mitigation impacts of meeting biofuel mandates and targets introduced by 40 plus countries around the world. International targets set for biofuel expansion require considerable land conversion in order to substitute fossil fuels by volume of consumption. Carbon neutrality will require more than 20 years from 2020, when the announced policies are to be fulfilled and maintained. Notably, this study focuses on first generation biofuels, which require greater land conversion from other activities. Second generation biofuels are not as commercially widespread and have not the robust data for this simulation. The results show that the first generation biofuels will not reduce GHG emissions until 2020 no matter if the new land demand is met from both forest and pasture or only from pasture. The estimates of GHG savings are conservative, since GHG emissions were constrained to CO_2 measurements in this study. Some other GHG savings would occur from rice crops (relatively methane intensive among crops) replacement by biofuel feedstocks (e.g., corn, sugar crops).

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