Chapter 7
Land-Use Change and Food Supply

Jevgenijs Steinbuks and Govinda R. Timilsina

7.1 Introduction

Large-scale deployment of biofuels has a profound effect on allocation of land resources. The expansion of biofuels industry requires a greater amount of crop lands for producing biofuel feedstocks. This additional crop lands could be supplied through (1) reallocation of existing crop lands from other crops (e.g., rice, fruits and vegetables, tobacco, cotton) towards production of biofuel feedstocks (e.g., corn, sugarcane, jatropha, rapeseed), (2) conversion of forest and pasture lands to crop lands. The land-use change thus occurs directly and indirectly. For example, when forest land is converted to produce sugarcane, such conversion is termed as *direct* land-use change. When biofuels displace existing crop lands in one part of the world, and production of food crops increases in other parts of the world (e.g., by converting forest lands to crop lands), this conversion is termed as *indirect* land-use change.

Starting from pioneering works of Fargione et al. (2008) and Searchinger et al. (2008), a large number of studies have examined the impact of expansion of biofuels on land-use change at national, regional, and global levels (Al-Riffai et al. 2010; Banse et al. 2008; Dicks et al. 2009; Fabiosa et al. 2010; Gurgel et al. 2007; Hertel et al. 2010, 2013; Lotze-Campen et al. 2010; Melillo et al. 2009). These studies use increasingly sophisticated partial and general equilibrium modeling tools to examine the impacts of biofuels on land-use change. Khanna and Crago (2012) presents an exhaustive review of literature assessing land-use change impacts of biofuels. This chapter will therefore not attempt to summarize all of the forgoing work on

J. Steinbuks • G.R. Timilsina (✉)
The World Bank, 1818 H Street, N.W., Washington, DC 20433, USA
e-mail: jsteinbuks@worldbank.org; gtimilsina@worldbank.org

G.R. Timilsina and D. Zilberman (eds.), *The Impacts of Biofuels on the Economy, Environment, and Poverty*, Natural Resource Management and Policy 41,
DOI 10.1007/978-1-4939-0518-8_7, © Springer Science+Business Media New York 2014

biofuels and land-use change. Instead, it employs two novel and distinct frameworks to discuss some short- and long-term implications on land use of meeting biofuel mandates and targets announced by 40 plus countries around the world.

We start with the discussion of short-term land-use impacts based on Timilsina et al. (2012), which analyzes land-use impacts of meeting biofuel blending mandates and targets in the near decades using a global, multi-sector, multi-region computable general equilibrium (CGE) model. The study focuses on first generation biofuel technology given the dim perspectives of introducing second generation biofuels in the near decades (NRC 2011). We then proceed with long-run economic assessment, extending the work of Hertel et al. (2013) using FABLE, a dynamic optimization partial equilibrium model for the world's land resources over the next century (Steinbuks and Hertel 2012). The model solves for the intertemporal paths of alternative land uses which together maximize global economic welfare. Alternative land uses incorporated into the model include: food crops, livestock feed, pasture lands, protected natural lands, managed (commercially exploited) forests, unmanaged forests, and first and second generation liquid biofuels.

7.2 Land-Use Change due to Biofuels in the Short Run

This section discusses near-term (by 2020) impacts of biofuels on land-use change based on Timilsina et al. (2012). The baseline and the scenarios simulated in Timilsina et al. (2012) are the same as presented in Chap. 5 of this book, where economic impacts of those scenarios were discussed. The model is a global, multi-country, multi-sector CGE model. The detailed description of the model is available in Timilsina et al. (2012) or Timilsina et al. (2011). In the model, the baseline projects economic development, population growth, and biofuel production at a "business as usual" rate since 2004. Key exogenous variables in this and most other dynamic CGE models include:

- Labor supply is determined through exogenous population growth and the fixed ratio between working age population and total population.
- Productivity growth (total factor productivity) is exogenous.
- Exogenous energy price growth.[1]

The *biofuels mandate and target* scenario considers the implementation of biofuel targets by acceding nations. The CGE model computes which and where biofuel feedstocks should grow most efficiently so as to reallocate land for optimal returns. Different countries have set different years for meeting their targets by 2020.

[1] A module that can represent both conventional and unconventional 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.

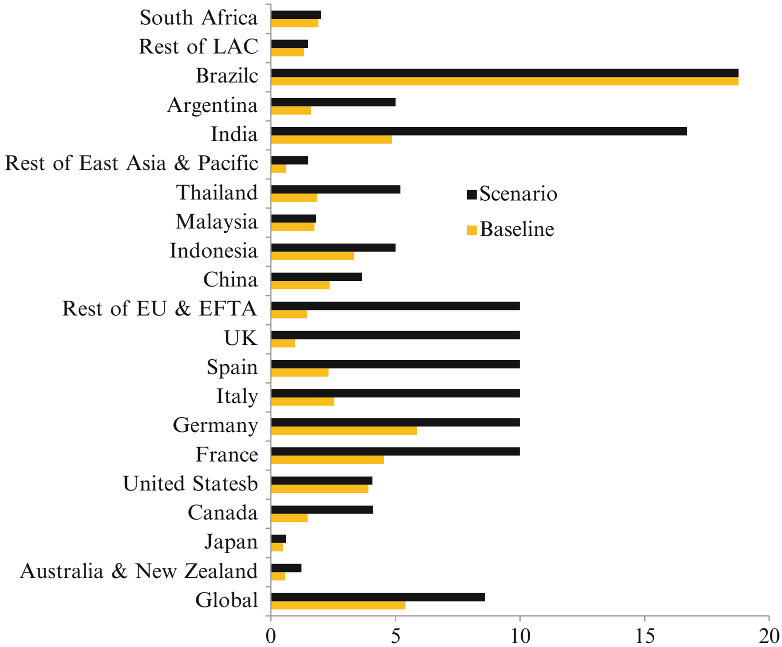

Fig. 7.1 Biofuel penetrations in the baseline and the target scenario. *Source*: Timilsina et al. (2012)

Countries that have target dates prior to 2020 are assumed to maintain the targets once they meet. In other words, once percentage targets are reached, the shares remain constant but the physical volumes change as the total transportation energy consumption increases over time. Figure 7.1 presents projected penetration of biofuels, defined as the share of biofuels in the total liquid fuel for road transportation on energy equivalent basis, for various countries and regions. In the baseline, the global penetration of biofuels, which is roughly 3 % at present, is expected to reach 5.4 % in 2020 due to policies already in place before 2009 and due to increasing oil prices. If the targets announced by all countries are realized by 2020, the global penetration of biofuels is expected to reach about 9 % by 2020.

Figure 7.2 summarizes aggregate land allocation under the biofuels mandate and target scenario for 2020 as compared to that happened otherwise in the baseline. As the figure demonstrates, land use shifts away from pasture, forestry, and non-feedstock crops towards crops that serve as feedstock for biofuels. Most of the conversion to crop land comes at the expense of forests and pastures. In aggregate, global forests recede 0.2 % and pastures decline by 0.2 % under the biofuel expansion scenario. The agricultural boom and deforestation effects are more pronounced in EU countries, Thailand, South Africa, India, and Brazil. The highest rate of deforestation due to land conversion is found in France. France also substitutes rice cultivated lands in favor of sugar and oilseed production. The high income nations make more rapid conversion of lands than do middle and lower income nations.

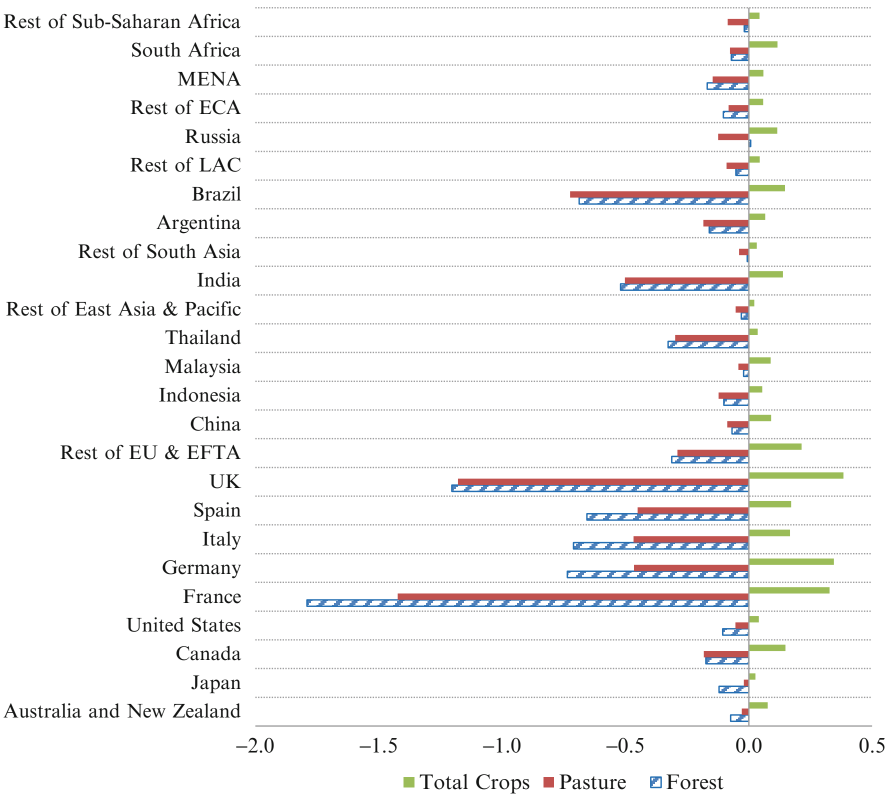

Fig. 7.2 Change in land Supply due to biofuel targets relative to the baseline in 2020 (%)

Due to market price signals, sugar crops expand the most in production around the world, while rice tends to contract in production. For more details on deforestation and land conversion, please refer to Fig. A.1 and Table A.1 in the Appendix to this chapter.

The model predicts additional diversion of lands within the crop category, especially from rice and fruits and vegetables and other non-biofuel feed stocks to sugar crops and other biofuel feed stocks (see Fig. 7.3). Although the price signals favor the production of sugar and coarse grains, other sectors lose in demand for agricultural goods. The changes in world food supply consequent to the reallocation of land uses are illustrated in Fig. 7.4. Globally, more than US$6 billion worth of food supply would decrease as compared to baseline in 2020. However, in percentage terms the global loss is relatively small. The impacts on food supply are significant in regions like India and Sub-Saharan Africa where food deficit is a persistent problem. Growing crop prices and reductions in food supply render greater vulnerability to nutritional needs in several countries, especially among their indigent populations.

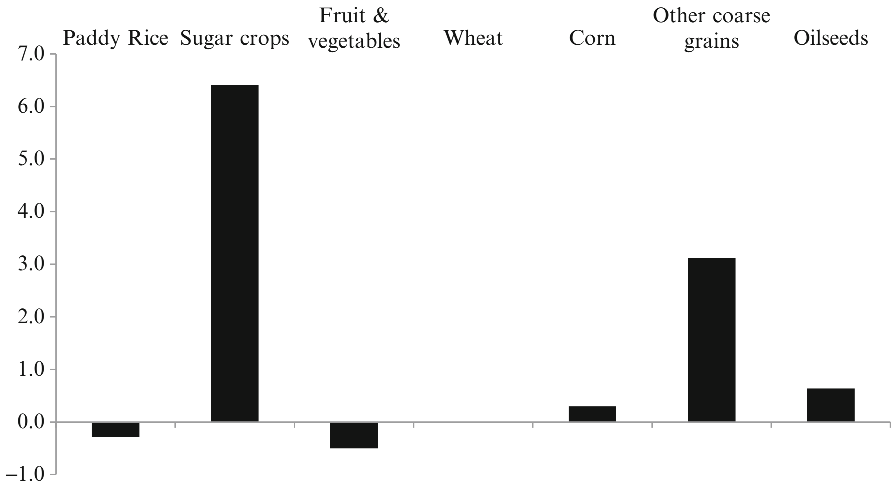

Fig. 7.3 Change in crop land supply due to biofuel targets relative to the baseline in 2020 (%). *Source*: Timilsina et al. (2012)

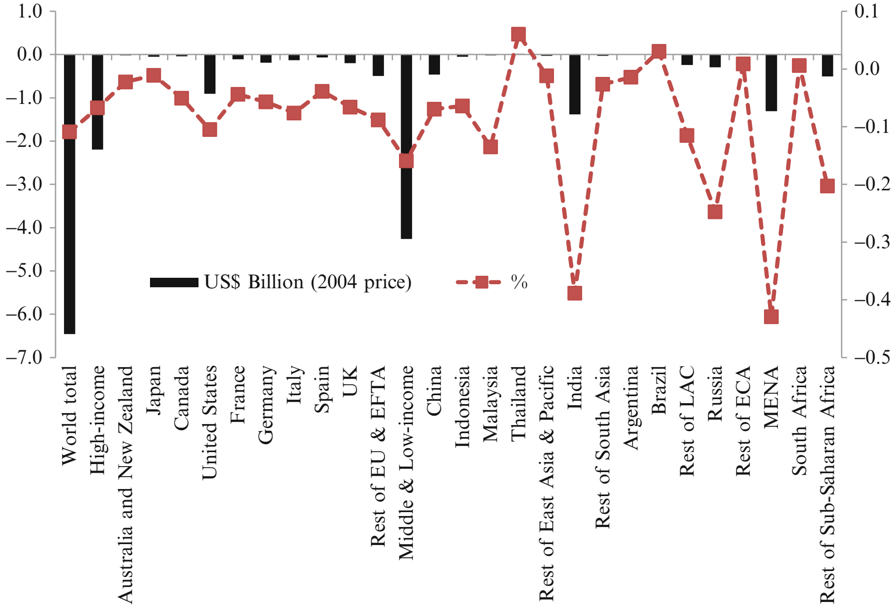

Fig. 7.4 Change in food supply due to biofuel targets relative to the baseline in 2020

7.3 Land-Use Change due to Biofuels in the Long Run

In the preceding CGE analysis of biofuels, the biofuels' growth in near decades was mainly driven by policies, such as subsidies and government mandates. However, in an environment of constrained budgets and slower economic growth, the long-run prospects for biofuels are likely to hinge on their economic and environmental contributions to global well-being. Biofuels could be attractive in the environment of high energy prices, and advances in both agricultural yields and cellulosic conversion technology for producing drop-in biofuels. In such circumstances, biofuels can have a potential to displace petroleum products and to reduce the Greenhouse Gas (GHG) emissions associated with combustion of liquid fuels (NRC 2011). For these reasons, it is useful to explore the *optimal* path of global land use for biofuels over the next century, accounting for key drivers such as increasing oil prices and potential GHG emission targets, as well as potential changes in technology and evolving consumer preferences for food, fuel, and biodiversity. Such an analysis offers a valuable guide to how global land use will be impacted by biofuels in the very long run.

The results from this section are drawn from FABLE (Forest, Agriculture, and Biofuels in a Land-use model with Environmental services), a dynamic optimization partial equilibrium model for the world's land resources over the next century (Steinbuks and Hertel 2012). The model solves for the intertemporal paths of alternative land uses which together maximize global economic welfare, potentially subject to a constraint on global GHG emissions. Alternative land uses incorporated into the model include: food crops, animal feed, pasture lands, protected natural lands, managed (commercially exploited) forests, unmanaged forests, and first and second generation liquid biofuels.

Key exogenous drivers include:

- Population growth which we assume will plateau at ten million people by 2100
- Global per capita income which rises at a rate of 2.25 %/year
- Oil prices which are assumed to rise at about 0.9 %/year over the twenty-first century
- Technological progress in the agriculture, forestry, energy, and recreation sectors
- Yields in agriculture grow linearly over most of the century, flattening when getting closer to their potential (Cassman et al. 2010)
- Energy efficiency, which grows at a rate of 1.6 %/year

Complete documentation of the model's structure, including equations, variables, and parameters is offered in technical documentation (Steinbuks and Hertel 2012).

Figure 7.5 shows the optimal allocation of lands between the alternative uses over this century *in the absence of binding biofuels mandates*. Protected forests expand in response to growing consumer demand for ecosystem services as households become wealthier. Cropland for food expands until 2035 due to increasing population and evolving consumption patterns, but declines thereafter as population and per capita demand growth would be slow and will be overtaken by technological progress in agriculture. Improvements in crop technology and agricultural yields

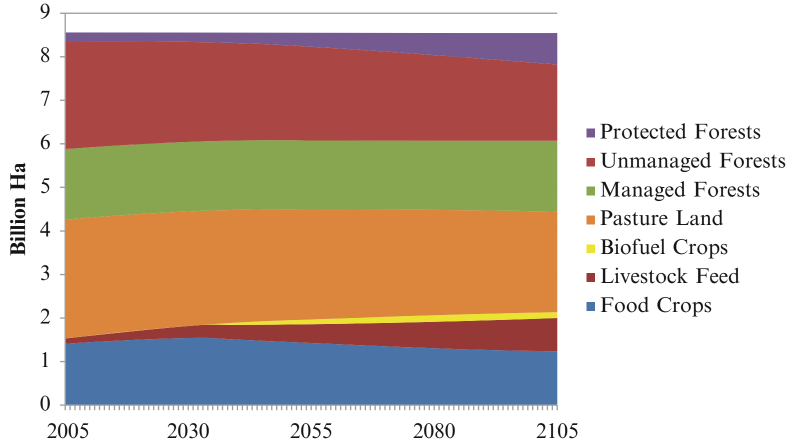

Fig. 7.5 Optimal allocation of global land resources, 2005–2105. *Source*: Steinbuks and Hertel (2012)

result in greater intensification of livestock production. As a result the area dedicated to animal feed expands considerably, whereas the pasture land declines over the course of next century. Managed forest area would change a little. Land devoted to biofuels expands steadily—particularly after second generation biofuels become commercially competitive in 2035.

Thus, even without subsidies, GHG targets, or biofuels mandates, our baseline does suggest that, if oil prices continue to grow (0.9 %/year) throughout the century, the globally optimal land area devoted to biofuel feed stocks would amount to about 150 Mha by the end of the century and biofuels would account for about 30 % of global liquid fuel consumption—mostly from second generation, drop-in biofuels at the end of the century. Of course this result is quite sensitive to the path of oil prices (Steinbuks and Hertel 2013).

As seen above, in the context of the dynamic-recursive CGE analysis, policies aimed at boosting deployment of biofuels can have a significant impact on biofuel production and global land use in the near decades. Accordingly, we wish to explore, within the context of this forward-looking model, the comparative dynamic impacts of a global biofuels mandate on global land use. We target an 8 % share of first- and second-generation biofuels in total liquid fuel consumption, which corresponds to predicted result from the CGE model if all current biofuel mandates and targets are implemented. This fully binding mandate is announced in advance, and is introduced in 2020. The consequences for land use change are shown in Fig. 7.6.

As expected, implementation of this biofuels mandate leads to increased supply of biofuels crops, and decline in land areas dedicated to food crops and pasture land. The optimal path of forest lands is largely unaffected by the mandate. With the binding biofuels mandate, the second generation biofuels will enter the market as early as 2020, and require additional 17 million hectares of land. Overall, areas dedicated to non-biofuels crops decline by about 1 % in 2020, as compared to baseline scenario. However, the impact of the biofuels mandate is relatively short lived.

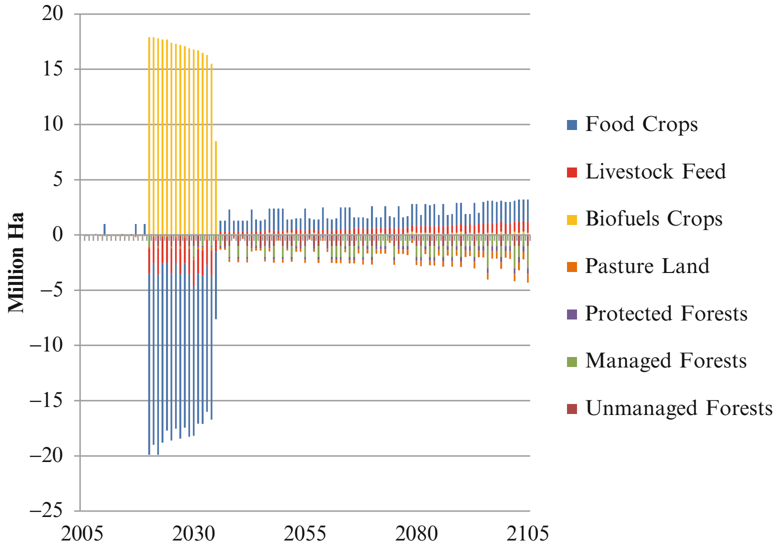

Fig. 7.6 Change in land use relative to the baseline in 2005–2105

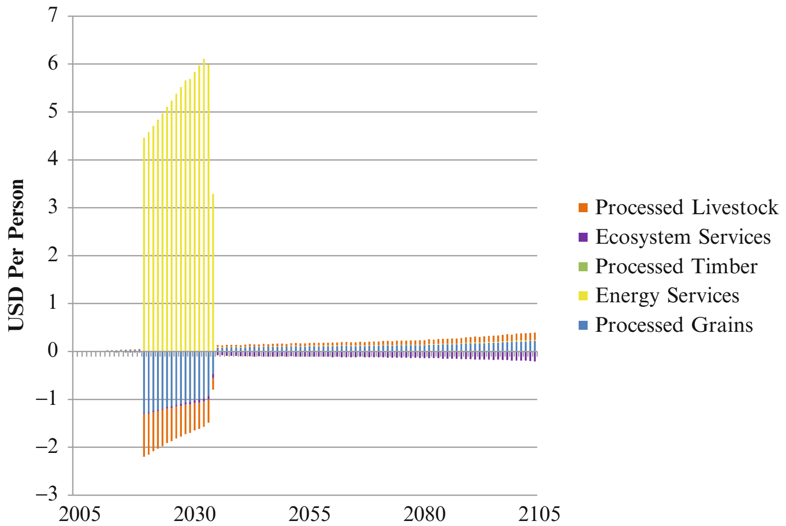

Fig. 7.7 Change in per capita land-based goods and services relative to the baseline in 2005–2105

As energy prices continue to increase over the course of this century, the biofuels mandate becomes slack in 2035. Introduction of biofuels mandate thus has very small effect on the optimal path of global land use in the long term.

Figure 7.7 shows implications of global biofuels mandate on the consumption side. Increased competition for land resources translates into reduced consumption of services from processed grains and livestock, which cumulatively fall by about $2 per person (about $13 billion at 2004 population level) in 2020. As explained above, this reduction in food supply is caused by diversion of land resources from food crops, animal feed, and pastures to biofuels feed stocks. The global consumption of land-based energy services increases over the period 2020–2035 compared to baseline scenario, reaching its maximum of $6 per person (about $38 billion at 2004 population level). When the biofuel mandate becomes slack in 2035, the consumption of land-based goods and services is little changed.

7.4 Conclusions

This chapter employs two different modeling approaches to demonstrate complex interactions between forest, pasture, and crops that affect allocation of global land use in the context of large-scale deployment of biofuels. We first show the results from the recursive-dynamic CGE model, aimed at investigating land-use implications of biofuels deployment in the near decades. Under the scenario of meeting biofuel targets and mandates announced by 40 plus countries around the world, rapid expansion of biofuels leads to increased deforestation and conversion of pasture lands in many countries. This expansion also causes diversion of lands from other food crops (e.g., rice, fruits, and vegetables) to those used for biofuels (sugar crops, corn). While planned biofuel targets are not expected to significantly affect global aggregate food supply, national food supplies would suffer in the near decades, especially for developing and poverty-stricken countries and regions, such as Sub-Saharan Africa and India.

We then proceed with the analysis of biofuels deployment in the long run, using a dynamic, forward-looking partial equilibrium model and found that even without subsidies, aggressive climate policies, or biofuels mandates, there will be a significant expansion in the globally optimal land area devoted to biofuel feed stocks. Our baseline does suggest that, if oil prices continue to grow throughout the century, land areas dedicated to biofuels feedstock would amount to about 150 Mha by the end of the century. And biofuels would account for about 30 % of global liquid fuel consumption, at the end of the century, when second generation, drop-in biofuels become competitive. Along this optimal path of global land use, biofuels mandate have a very small effect on global land use and consumption of land-based goods and services in the long term. Of course this result is quite sensitive to the path of oil prices.

Appendix

Table A.1 Deforestation due to global expansion of biofuels—% change from the baseline in 2020

Country/Regions	Forest	Pasture	Rice	Sugar crops	Fruits and vegetables	Wheat	Corn	Other grains	Oilseeds
World total	−0.2	−0.2	−0.3	6.4	−0.5	0	0.3	3.1	0.6
High-income	−0.4	−0.3	−0.2	6.3	−0.7	0.4	−0.2	7.8	3
Australia and New Zealand	−0.1	0	−0.1	0	0	0.5	0.6	0.4	1.2
Japan	−0.1	0	−0.2	0.1	0	0.4	0	0.5	0.3
Canada	−0.2	−0.2	0	−0.2	−0.3	0	2.7	0.2	0.4
United States	−0.1	−0.1	−0.1	−0.1	−0.1	0.5	0.3	0.3	0.5
France	−1.8	−1.4	−3.2	37	−2.8	0.8	−2.8	3.1	17.3
Germany	−0.7	−0.5	0	−0.4	−0.9	3.3	−0.8	3.9	11
Italy	−0.7	−0.5	−0.7	−0.8	−0.8	−0.4	−1.4	−0.4	8.6
Spain	−0.7	−0.5	−1	−0.6	−0.8	−0.1	−1.1	25.4	0.5
UK	−1.2	−1.2	0	10.8	−2.1	−4.3	0	40	4.9
Rest of EU and EFTA	−0.3	−0.3	−0.3	1.4	−0.5	0.7	−1.4	6.2	5
Middle and low-income	−0.1	−0.2	−0.3	6.5	−0.3	−0.3	0.7	−0.1	−0.3
China	−0.1	−0.1	−0.1	0	−0.2	0.4	3.3	−0.7	−0.6
Indonesia	−0.1	−0.1	−0.1	6.3	−0.2	0	−0.1	0	0
Malaysia	0	0	0.1	0.1	0	0	0	1.1	0.2
Thailand	−0.3	−0.3	−0.7	15.2	−0.6	0	0.2	−0.3	−0.6
Rest of East Asia	0	−0.1	−0.1	2.2	0	0.2	0.7	0.3	0.2
India	−0.5	−0.5	−0.9	10	−1.1	−0.7	−0.7	−0.6	−0.8
Rest of South Asia	0	0	0	0.6	0	0.1	0.1	0.1	0.8
Argentina	−0.2	−0.2	0	−0.4	−0.2	0	0.8	−0.2	0
Brazil	−0.7	−0.7	−1.1	10.7	−1.3	−1.3	−1.5	−1.1	0.4
Rest of LAC	−0.1	−0.1	−0.1	0	0	0.2	0	−0.1	1.2
Russia	0	−0.1	−0.1	0	0.1	0	0.1	0.2	1.1
Rest of ECA	−0.1	−0.1	−0.1	0.1	0	0.2	0.2	0.3	1.1
MENA	−0.2	−0.1	−0.2	0.2	0	0.5	0.7	0.3	0.7
South Africa	−0.1	−0.1	0	0.2	0.1	1	0	0.7	0.2
Rest of Sub-Saharan	0	−0.1	0	0.1	0.1	0.7	−0.1	−0.1	0.1

Source: Timilsina et al. (2012)

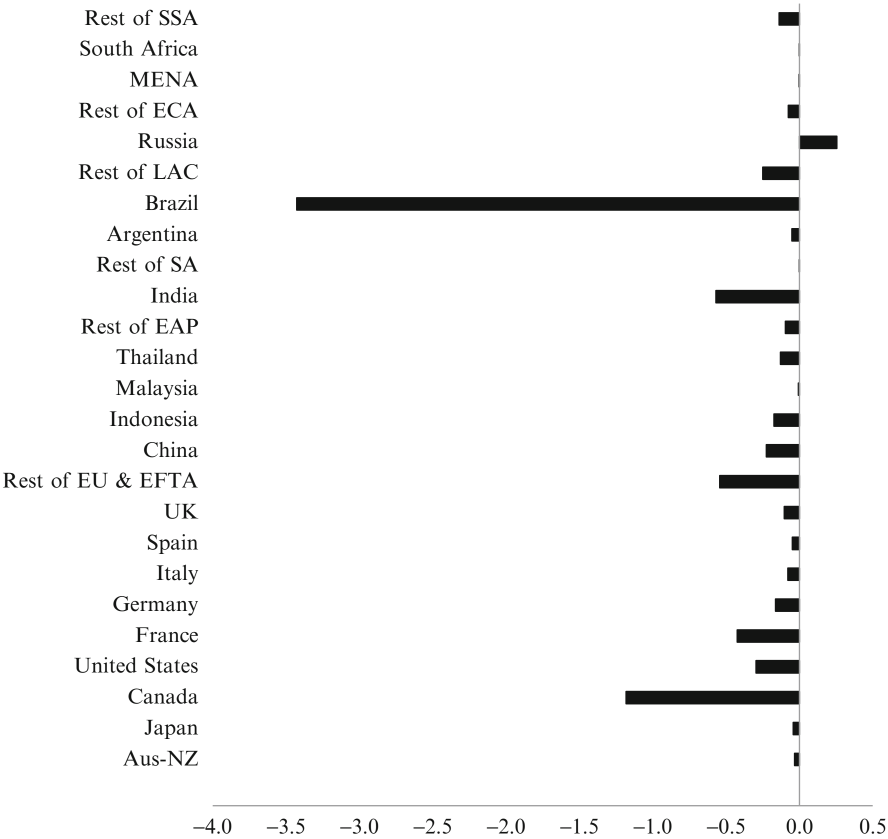

Fig. A.1 Deforestation due to global expansion of biofuels—change from the baseline in 2020 (million ha.). *Source*: Timilsina et al. (2012)

References

Al-Riffai, P., Dimaranan, B., & Laborde, D. (2010). *Global trade and environmental impact study of the EU biofuels mandate*. Washington, DC: International Food Policy Research Institute. Retrieved from http://environmentportal.in/files/biofuelsreportec.pdf

Banse, M., Meijl, H. van, Tabeau, A., & Woltjer, G. (2008). *Impact of EU biofuel policies on world agricultural and food markets*. Presented at the 107th Seminar of the European Association of Agricultural Economists, Sevilla, Spain.

Cassman, K. G., Grassini, P., & Wart, J. V. (2010). Crop yield potential, yield trends, and global food security in a changing climate. In D. Hillel & C. Rosenzweig (Eds.), *Handbook of climate change and agroecosystems* (pp. 37–51). London, England: Imperial College Press.

Dicks, M. R., Campiche, J., Ugarte, D. D. L. T., Hellwinckel, C., Bryant, H. L., & Richardson, J. W. (2009). Land use implications of expanding biofuel demand. *Journal of Agricultural and Applied Economics*, *41*(02). Retrieved from http://ideas.repec.org/a/ags/joaaec/53091.html

Fabiosa, J. F., Beghin, J. C., Dong, F., Elobeid, J., Tokgoz, S., & Yu, T.-H. (2010). Land allocation effects of the global ethanol surge: Predictions from the international FAPRI model. *Land Economics, 86*(4), 687–706.

Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. *Science, 319*(5867), 1235–1238.

Gurgel, A., Reilly, J. M., & Paltsev, S. (2007). Potential land use implications of a global biofuels industry. *Journal of Agricultural & Food Industrial Organization*, *5*(2). Retrieved from http://ideas.repec.org/a/bpj/bjafio/v5y2007i2n9.html

Hertel, T. W., Golub, A. G., Jones, A., O'Hare, M., Plevin, R., & Kammen, D. (2010). Global land use and greenhouse gas emissions impacts of US maize ethanol: Estimating market-mediated responses. *BioScience, 3*, 223–31.

Hertel, T. W., Steinbuks, J., & Baldos, U. L. (2013). Competition for land in the global bioeconomy. *Agricultural Economics, 44*(s1), 129–138. doi:10.1111/agec.12057.

Khanna, M., & Crago, C. L. (2012). Measuring indirect land use change with biofuels: Implications for policy. *Annual Review Resource Economics, 4*(1), 161–184.

Lotze-Campen, H., Popp, A., Beringer, T., Müller, C., Bondeau, A., Rost, S., et al. (2010). Scenarios of global bioenergy production: The trade-offs between agricultural expansion, intensification and trade. *Ecological Modelling, 221*(18), 2188–2196. doi:10.1016/j.ecolmodel.2009.10.002.

Melillo, J. M., Gurgel, A. C., Kicklighter, D. W., Reilly, J. M., Cronin, T. W., Felzer, B. S. et al. (2009). *Unintended environmental consequences of a global biofuels program* (No. 168). MIT Joint Program on the Science and Policy of Global Change.

National Research Council (NRC). (2011). *Renewable fuel standard: Potential economic and environmental effects of U.S. biofuel policy*. The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13105

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J. et al. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science, 319*(5867), 1238–1240.

Steinbuks, J., & Hertel, T. (2012). Forest, Agriculture and biofuels in a land use model with environmental services. Center for Global Trade Analysis Working Paper. Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3988

Steinbuks, J., & Hertel, T. W. (2013). Energy prices will play an important role in determining global land use in the twenty first century. *Environmental Research Letters, 8*(1), 014014. doi:10.1088/1748-9326/8/1/014014.

Timilsina, G. R., Beghin, J. C., van der Mensbrugghe, D., & Mevel, S. (2012). The impacts of biofuels targets on land-use change and food supply: A global CGE assessment. *Agricultural Economics, 43*(3), 315–332.

Timilsina, G. R., Csordas, S., & Mevel, S. (2011). When does a carbon tax on fossil fuels stimulate biofuels? *Ecological Economics, 70*, 2400–2415.