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International Bioenergy Trade

History, status & outlook on securing sustainable bioenergy supply, demand and markets

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Chapter 8
Medium and Long-Term Perspectives of International Bioenergy Trade

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Abstract In the coming decades, huge challenges in the global energy system are expected. Scenarios indicate that bioenergy will play a substantial role in this process. However, up to now there is very limited insight regarding the implication this may have on bioenergy trade in the long term. The objectives of this chapter are: (1) to assess how bioenergy trade is included in different energy sector models and (2) to discuss the implications and perspectives of bioenergy trade in different energy scenarios. We grouped scenarios from the models IMAGE/TIMER, POLES and GFPM according to their policy targets and increase of bioenergy use in "ambitious" and "moderate" bioenergy scenarios and compared results regarding bioenergy trade for solid and liquid biomass. Trade balances for various world regions vary significantly in the different models and scenarios. Nevertheless, a few robust trends and results can be derived up to the year 2050: Russia and former USSR countries could turn into strong biomass exporting countries. Moreover, Canada, South-America, Central and Rest-Africa as well as Oceania could cover another substantial part of the bioenergy supply. As importing countries, India, Western Europe and China might play a key role. The results show (1) the high relevance of the topic, (2) the high uncertainties, (3) the need to better integrate social, ecological, economic

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and logistical barriers and restrictions into the models and (4) the need to better understand the potential role of bioenergy trade for a sustainable, low-carbon future energy system.

8.1 Global Scenarios of Bioenergy Demand and the Question of Bioenergy Trade

In the coming decades big changes in the global energy system are expected. On the one hand, the insecure supply of fossil fuels might have a major impact. On the other hand, if the global targets of climate change mitigation are taken seriously, a huge transition of the overall energy system will be required. Therefore, a substantial effort has been taken in the last years to improve the modelling of regional and global energy systems, develop scenarios and show options and impact of climate mitigation measures. Bioenergy plays a crucial role in these studies and scenarios.

The IPCC report on renewable energy (IPCC 2011) includes a comprehensive comparative analysis of global energy scenarios. In particular, this investigation includes an assessment of the relevance of biomass in 137 scenarios up to 2050. Starting from the historic level of 50 EJ (about 1,200 Mtoe) of bioenergy use in 2008, most of the scenarios show a considerable increase of bioenergy use. The median of mitigation scenarios (440–600 ppm and <440 ppm) show an increase to about 70–80 and 120–155 EJ in 2030 and 2050, respectively.

According to the IEA World Energy Outlook 2012, primary demand for modern bioenergy in the scenario "new policy" will more than double up to the year 2035. Moreover, the patterns of bioenergy use are expected to change substantially. Power generation and production of biofuels for transport will constitute a larger share of biomass use.

Such a strong expansion of bioenergy use in the next decades requires the exploitation of additional bioenergy sources. A significant part of these potential sources might be not located in the same region or even continent where the demand takes place. So, it seems obvious that these scenarios would imply an impact on the regional balance of demand and supply of bioenergy leading to a change in trade patterns in various world regions. However, up to now these implications on regional supply and demand gaps and the related trade of bioenergy have been documented only in a very few cases (e.g. WEO 2012; Raunikar et al. 2010).

Only recently, with the new World Energy Outlook 2012, a bioenergy trade module has been implemented in the IEA World Energy Model (WEM). The results show that the volumes, routes, fuels, logistics of bioenergy trade will hence look quite different to what we are used to today. However, different scenarios and models of the global bioenergy sector do not show the same picture of the future development of bioenergy use. The perspectives of bioenergy trade depend on different scenarios and impacts regarding energy markets, technological development, energy and climate change policies.

Despite of the crucial role of bioenergy for future energy scenarios, bioenergy trade between countries and world regions usually is not investigated and documented explicitly. Compared to the profound global energy modelling approaches, the analyses of future perspectives of bioenergy trade are still in an early phase of their development. In this chapter, we take a closer look at the implications of global energy model scenarios on bioenergy trade. Based on a broad set of scenarios, we discuss perspectives of international bioenergy trade in the coming decades, we derive robust trends and corresponding conclusions.

The main objective of this chapter is twofold:

1. to assess how bioenergy trade is included in different energy sector models covering bioenergy, and
2. to analyse the implications and perspectives of bioenergy trade in different energy market scenarios

The comparative investigation of models and scenarios of international bioenergy trade leads to a higher insight of patterns of bioenergy trade, drivers and dependencies. So, the objective is to learn about the key linkages, relations and interdependencies. The quantification of traded volumes in various scenarios is an important aspect, but not the primary objective of this chapter. Moreover, we want to emphasize that our objective here is not a comprehensive model comparison of selected energy models. This would require much higher effort in terms of defining consistent framework conditions and investigate model results in terms of the specific modeling approach.

We will start with a brief overview of the reviewed studies. A few of these studies have been selected for a closer investigation. For these scenarios, we provide a comparison of scenarios which leads to an analysis of model based drivers of bioenergy trade.

The work presented here is based on a literature review of articles and reports that describe quantitative models with an international coverage that include bioenergy. The more in depth analysis of selected models is based on data made available by researchers involved in the given models.

8.2 Global Models of Bioenergy Trade

Many studies have been undertaken to assess the potential of biomass to contribute to future energy supply. A smaller number of studies deals with the gap between regional bioenergy demand and supply and bioenergy trade. Conclusions from these studies vary significantly. We have indentified 28 models and/or studies dealing with bioenergy trade in some form. The models have different scopes with some focusing specifically on biomass markets and trade, while others are more general energy models which also include international bioenergy trade. For this chapter, we screened these models and studies in order to identify models suited for in-depth analysis of international biomass trade. Out of the 28 identified bioenergy trade models, 22 models were selected according to their potential to model global bioenergy trade on a sufficient regional resolution (Fig. 8.1). Relevant literature which has been screened for this task was: (Berndes et al. 2003; Bouwman et al. 2006; Gielen et al. 2003; Hamelinck and Hoogwijk 2007; Hansson and Berndes 2009;

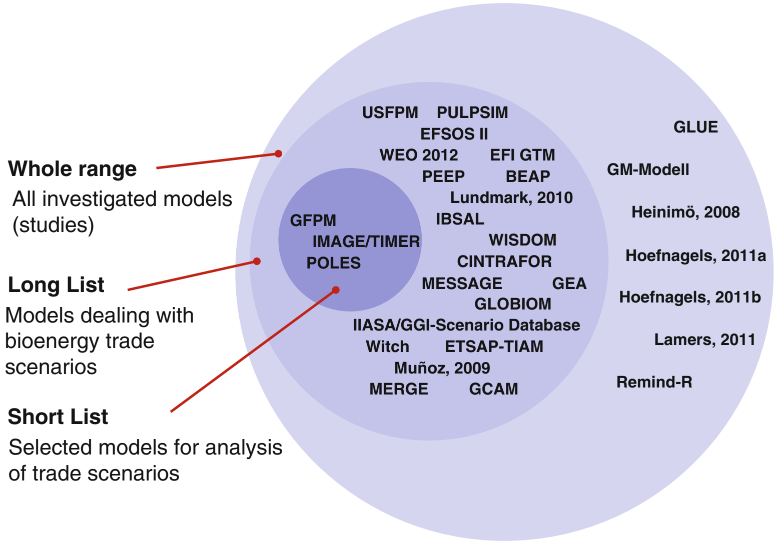

Fig. 8.1 Three-stage model selection process

Havlík et al. 2011; Heinimö et al. 2008; Hoefnagels et al. 2011a, b; Ince et al. 2011; Kallio et al. 2004; Lamers et al. 2011; Lundmark 2010; Masera et al. 2006; Muñoz et al. 2009; Smeets et al. 2007; Sokhansanj et al. 2006; Szabó et al. 2009; Yamamoto et al. 2001).

The models identified for further analysis ("long-list") have been characterized according to specific criteria regarding bioenergy trade, based on available literature and, where not specified in sufficient detail, a questionnaire has been sent out to the respective modelling groups. The following criteria for model selection have been analysed: the extent to which the model does cover biomass trade and if regional or global trade patterns are assumed, sectoral coverage, geographical regional aggregation and scenario time frame. In most models a scenario timeframe until year 2100 is considered. More detailed information on these models is provided in Matzenberger et al. (2013).

8.2.1 Selected Models for Scenario Comparison

Three models have been selected for a detailed comparison of scenarios and their impact on global bioenergy trade: GFPM, TIMER and POLES.

The TIMER model is a dynamic energy system simulation model developed by the Netherlands Environmental Assessment Agency (PBL) (van Vuuren et al. 2007). It has bottom-up engineering information as well as top-down investment behavior rules and technological change. It is part of the larger integrated assessment model IMAGE, from which it gets its biophysical data and in turn provides energy and industry related emissions. The simulation process is dynamic recursive on a year-by-year basis. Energy demand is determined from economic activity and population increase and is calculated over five end-use sectors (Industry, transport, residential, services and 'other') as well as three transformation sectors (electricity, hydrogen and heat). This energy demand can be met from a number of energy carriers which compete with each other on a relative cost basis. Thus demand for energy carriers including bioenergy is price elastic. Primary biomass resources include energy crops (sugar, starch, woody) as well as organic residues.

The POLES model provides a complete system for the simulation and economic analysis of the sectoral impacts of climate change mitigation strategies. The POLES model is not a General Equilibrium Model, but a dynamic Partial Equilibrium Model, essentially designed for the energy sector but also including other GHG emitting activities, with the 6 GHG of the "Kyoto basket". The simulation process is dynamic, in a year by year recursive approach of energy demand and supply, with lagged adjustments to prices and a feedback loop through international energy prices that allow describing full development pathways from 2005 to 2100. There is an explicit breakdown of total land surface across main categories for each country/region of the model. Primary biomass resources have been divided into three categories (forest residues, short rotation crops, other energy crops like sugar or bio-oil crops).

The GFPM model is a spatial partial equilibrium model for forest products based on price endogenous linear programming (Buongiorno et al. 2003). In the analyses of bioenergy development, fuelwood demand in each country is represented by a price-elastic demand function with exogenously specified long-run shifts of demand based on scenario assumptions about global expansion in fuelwood consumption (Raunikar et al. 2010; Buongiorno et al. 2011). Demand for final products are defined by demand at last year's price and price elasticity of demand. Demand changes in each country due to changes in GDP and elasticity of demand with respect to GDP. The model is limited to the forest and forest biomass sectors and covers 14 principal categories of forest products of which fuelwood includes wood used for heating, cooking, power and fuel production.

8.2.2 Scenario Settings

POLES and TIMER scenarios correspond closely to each other. The scenarios presented for the TIMER model are based on the OECD environmental outlook (OECD 2012). In all cases, the development of population growth, GDP growth, land availability and crop yields are the same. Since in the TIMER model energy demand is elastic to energy prices, total final energy demand varies across scenarios. The results of POLES are derived from scenarios initially developed for EMF27. Population & GDP are consistent across all scenarios. The main scenarios are the following:

- *Reference scenario*: OECD Environmental Outlook baseline for TIMER and BAU for POLES.
- *Scenarios for different levels of CO_2-prices*: $20\$_{2005}/tCO_2$ & $100\$/tCO_2$: Global carbon tax is applied to the carbon content of fuels instantaneously in 2015 and

remains throughout simulation period. All energy consuming sectors and fuels are affected.

- *Climate mitigation scenarios:* resulting in different CO_2-concentration levels of 450 and 650 ppm, respectively. Global carbon taxes are gradually applied uniformly across all fuels and sectors in order to ensure carbon concentration targets are met.
- *Trade barriers:* Transaction costs for bilateral trade are increased to such a level that interregional trade becomes unattractive. Thus, bioenergy consumption is stronger limited by local production.

GFPM-Scenarios are based on Buongiorno et al. (2011):

- *IPCC scenario A1B/high fuelwood demand*: Continuing globalization would lead to high income growth and low population growth, and thus the highest income per capita by the year 2060. Eighty percent increase in biofuel demand up to 2030 from 2006.
- *Low fuelwood demand*: 20 % increase in fuelwood demand up to 2030, other assumptions as in the high fuelwood demand scenario (50 % of the fuelwood demand growth in scenario A1B).

More details regarding the scenario settings and assumptions are documented in Matzenberger et al. 2013.

8.3 Perspectives of International Bioenergy Trade: Selected Scenarios

The model scenarios outlined above have been compared in terms of the following results:

- Global bioenergy demand and production,
- Bioenergy demand and production in 20 world regions,
- Net trade balance of bioenergy in 20 world regions.

Key results of this comparison are shown in the following graphs. Figure 8.2 shows that scenarios lead to significant growth of bioenergy production and demand on a global scale. The current level of about 50 EJ (1.2 Gtoe) of world bioenergy production increases to a level of up to 150–170 EJ (3.6–4.1 Gtoe) in 2050 and 170–220 EJ (4.1–5.3 Gtoe) in 2070. However, it is not only the amount of bioenergy, also the structure of bioenergy use and mix of resources, fuels and conversion technologies changes. Traditional biomass reduces in all scenarios and step by step is replaced by modern biomass. The growth is clearly on solid biomass resources (the values for liquid biomass in the TIMER and POLES scenarios include second generation biofuels from solid biomass).

A few scenarios also indicate less growth in bioenergy demand, in particular, TIMER environmental outlook and other scenarios with low or moderate climate mitigation policies (20$/t CO_2 scenarios and 600 ppm concentration levels). Of course, also the regional distribution of supply and demand and thus trade balances vary among those scenarios. Thus, we distinguished moderate and ambitious

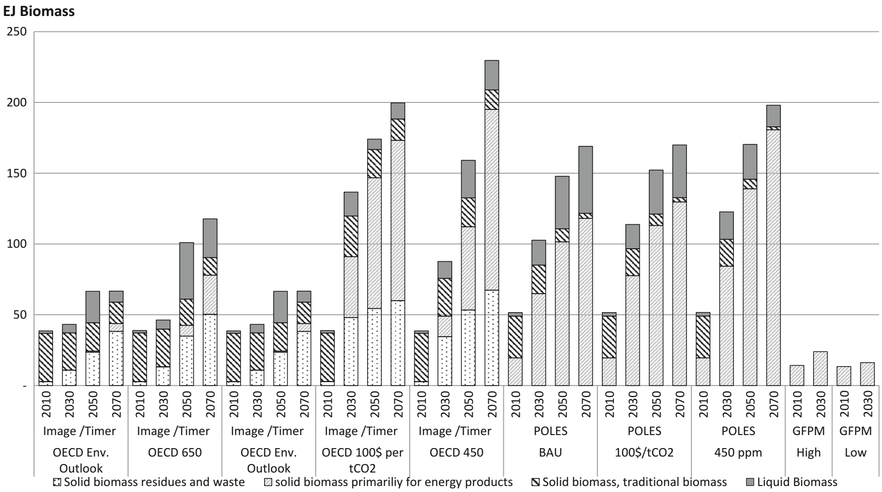

Fig. 8.2 World bioenergy production in selected scenarios. Note: GFPM covers forestry products only. Traditional biomass is only distinguished in TIMER and is not considered in GFPM

bioenergy scenarios. The ambitious scenarios comprise those achieving the 450 ppm scenario or assuming a carbon price of 100$ per t CO_2, i.e.:

- TIMER: OECD 450 ppm scenario, OECD 100$ per t CO_2 scenario
- POLES based on EMF scenarios: 450 ppm, 100$ per t CO_2
- GFPM: high

The other scenarios are grouped as "moderate" bioenergy scenarios:

- TIMER: OECD environmental outlook, OECD EO trade barriers, OECD 650 ppm, OECD 20$ per t CO_2
- POLES: based on EMF scenarios G1 Reference, G4 BAU, BAU + trade barriers, 650 ppm, 20$ per t CO_2
- GFPM: low

Global overall bioenergy demand in moderate bioenergy scenarios is distributed more evenly than in the ambitious scenarios. In the average of the moderate scenarios the regions USA, Central and Rest Africa, Western Europe, India, China and South East Asia show a demand in the range of 6–10 EJ (140–240 Mtoe) and 10–16 EJ (240–382 Mtoe) in 2030 and 2050, respectively. In contrast, the ambitious scenarios are dominated by the demand in India and China (14–17 EJ and around 25 EJ in 2030 and 2050, respectively). China also shows the largest range within the investigated scenarios: Ambitious scenarios result in a range of 20 to more than 40 EJ in 2050. This overall increase of bioenergy demand is developing in a different way for liquid and solid fuels: The share of liquid biofuels on total bioenergy (sum of solid and liquid) for the median of the ambitious scenarios is 18 % (2030) and 14 % (2050). The maps in Fig. 8.3 show the global distribution of bioenergy demand for solid and liquid biofuels in the median of ambitious scenarios.

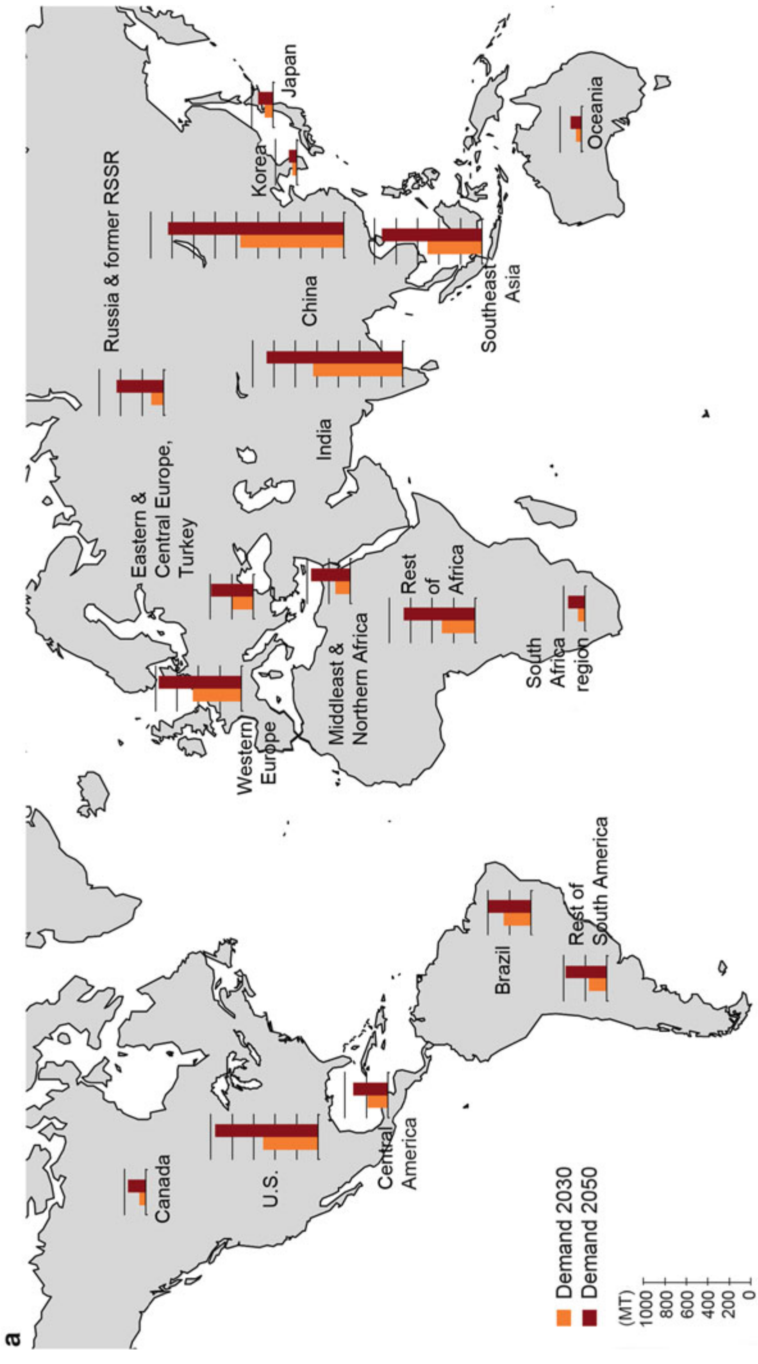

Fig. 8.3 Regional bioenergy demand in the median of ambitious model scenarios 2030 and 2050. (**a**) solid biomass, (**b**) liquid biomass (Unit: Mt)

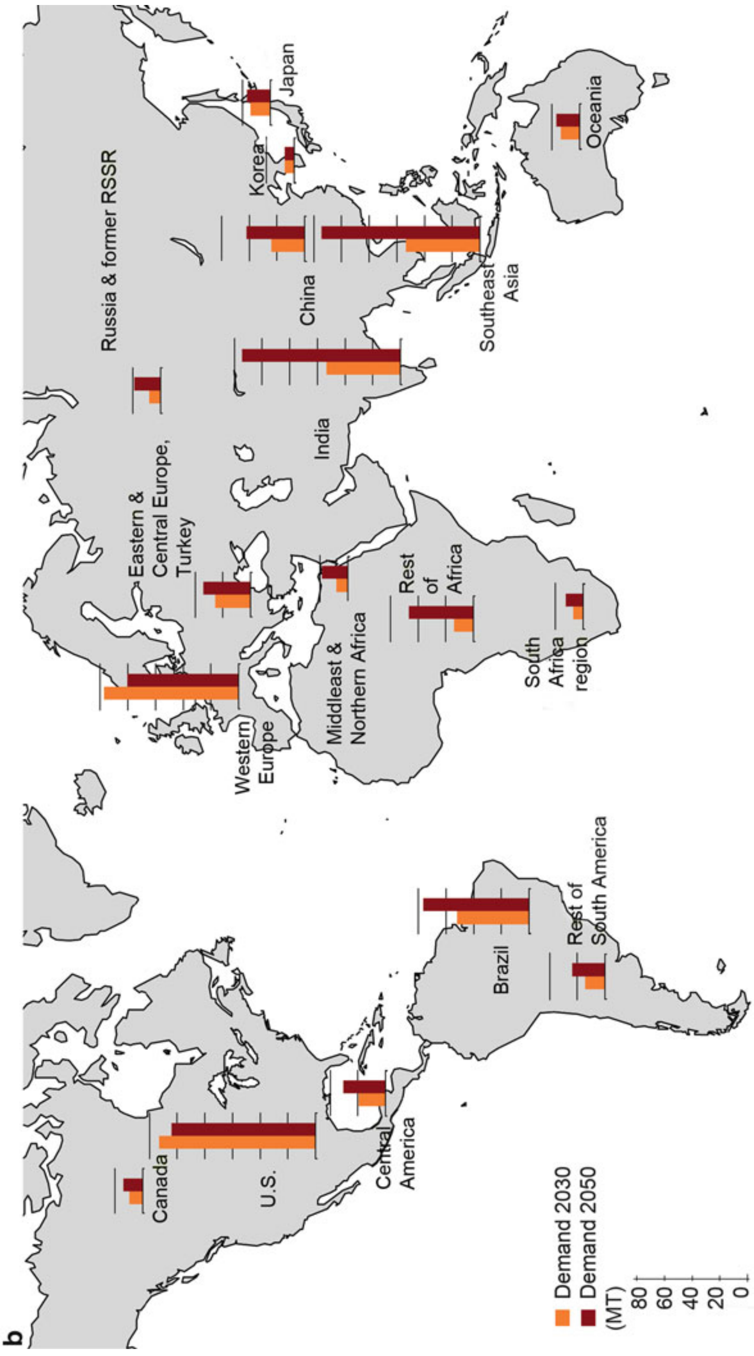

Fig. 8.3 (continued)

So, where does the biomass come from? To which extent are these regions with a high bioenergy demand depending on biomass imports? The following figures show the range of trade balances for selected ambitious and moderate scenarios (Fig. 8.4).

In ambitious scenarios, 14–26 and 14–30 % of global bioenergy demand is traded between regions in 2030 and 2050, respectively. In more detail, the model scenarios show a huge range of potential bioenergy trade: for solid biomass, in ambitious scenarios bioenergy trade ranges from 700 Mt to more than 2,500 Mt in 2030 and from 800 Mt to almost 4,200 Mt in 2050. These values only take into account TIMER and POLES scenarios since GFPM covers forest products only. In the scenario "high" of GFPM, in 2030, 25 % of forest based global bioenergy demand is traded between world regions. For liquid biomass, the ambitious scenarios show a bioenergy trade in the range of 65 Mt to more than 360 Mt in 2030 and from 40 to 520 Mt in 2050.

In moderate scenarios, 0–20 and 7–26 % of global bioenergy demand is traded between regions in 2030 and 2050, respectively. For solid biomass, this corresponds to an amount of 3–1,500 and 100–2,000 Mt in 2030 and 2050, respectively. These values only take into account TIMER and POLES scenarios since GFPM covers forest products only. In the scenario "high" of GFPM, in 2030 21 % of global bioenergy demand from forestry products is traded between world regions. For liquid biomass, the range of bioenergy trade in moderate scenarios amount to 1–360 and 12–820 Mt in 2030 and 2050, respectively.

For comparison, as shown in Chap. 2, trade volumes of liquid fuels (ethanol and biodiesel) did not exceed 5 Mt in 2011. Net woody biomass trade in 2010 amounted to roughly 18 Mt (mainly wood pellets fuel wood and wood waste). Thus, the model results show a huge increase of bioenergy trade in the coming decades in most of the scenarios (in particular in the more ambitious bioenergy scenarios).

For a proper interpretation of these results, one should take into account that these values underestimate the international trade that would actually occur for the following reasons: (1) trade streams are only reported between world regions; most of these world regions consist of a number of different countries with export and import activities between individual countries which are not estimated in this analysis; (2) only net trade balances are reported; whereas in reality, often both import and export between two regions are observed.

8.4 Synthesis and Conclusions: Future Challenges and Perspectives of Global Bioenergy Trade

8.4.1 Analysis and Discussion of Robust Trends and Trade Patterns

The models and scenarios show considerable differences for bioenergy demand and for trade balances in different world regions. Nevertheless, the results shown above allow us to derive some robust trends and trade patterns.

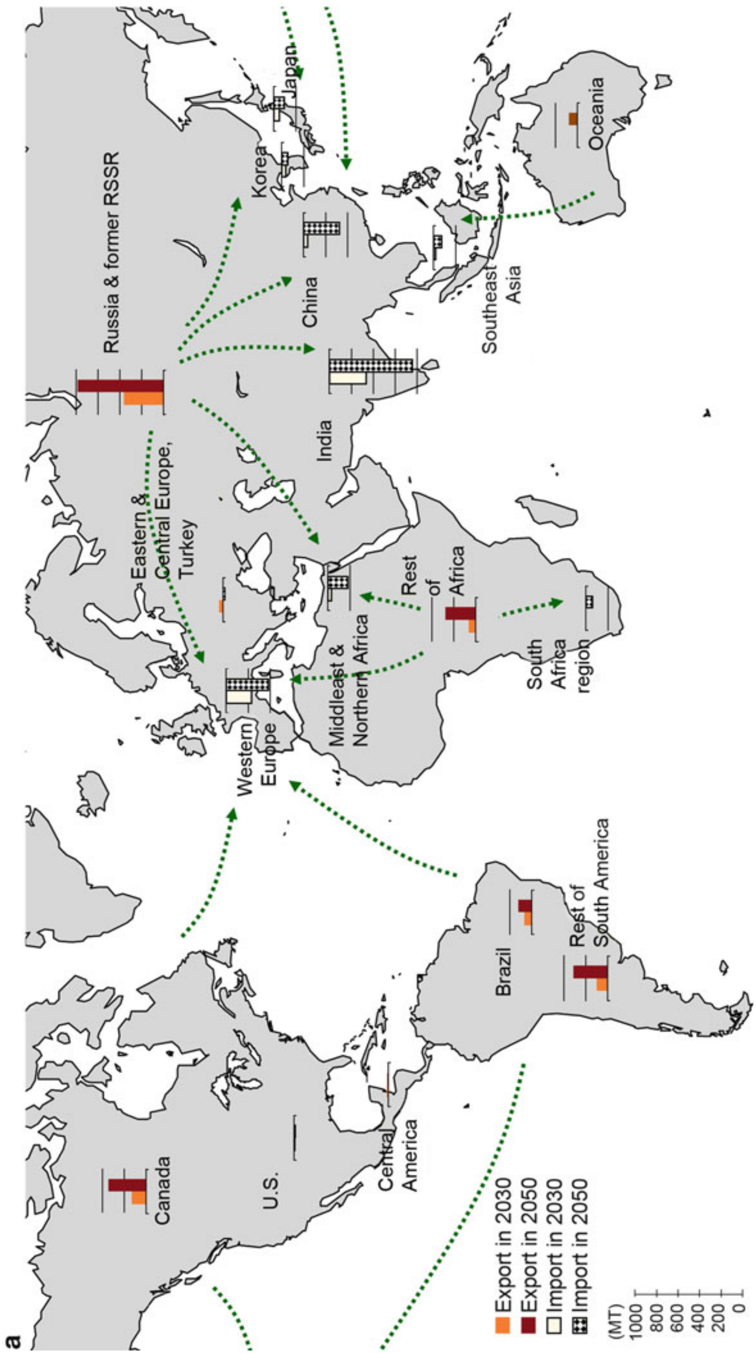

Fig. 8.4 Trade balances in median of *ambitious* scenarios by world regions 2030 and 2050. (**a**) solid biomass, (**b**) liquid. GFPM results are only included for 2030 and include only energy products based on forest biomass (Unit: Mt)

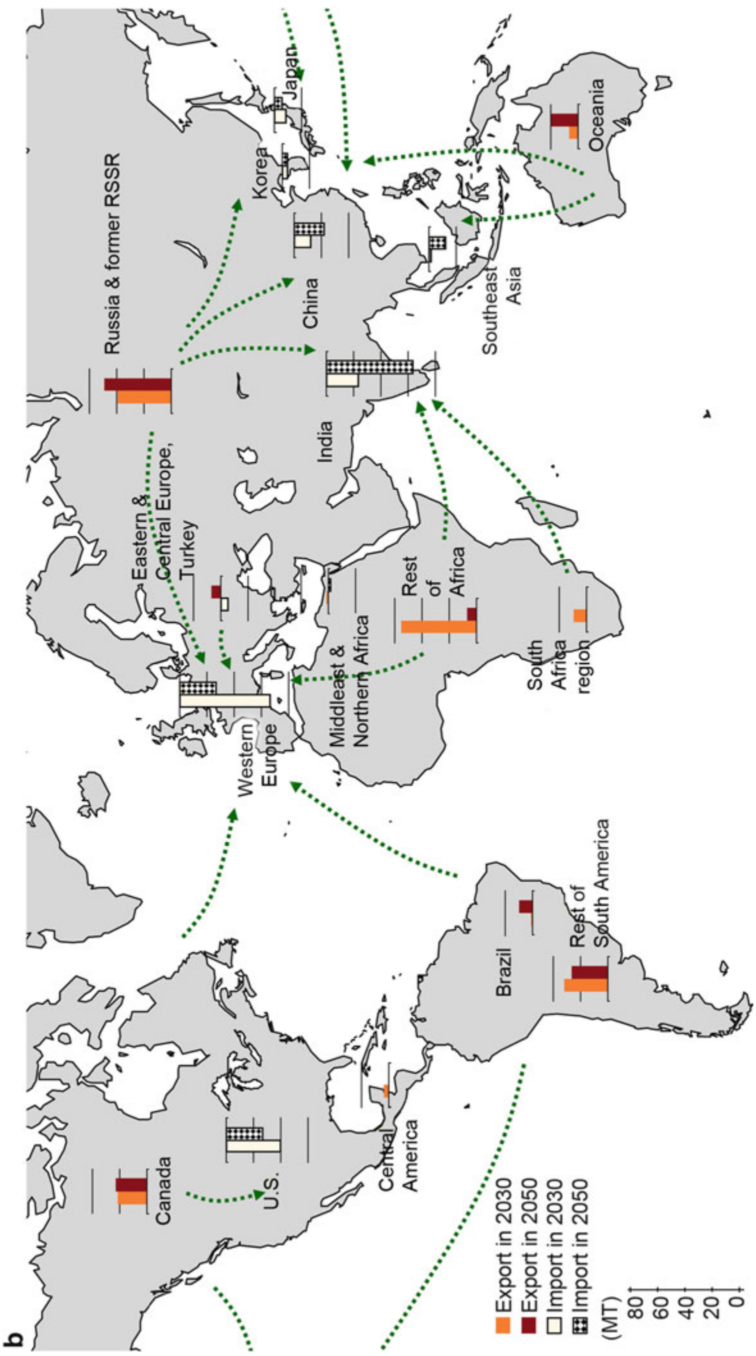

Fig. 8.4 (continued)

In ambitious scenarios, the key potential future bioenergy export regions in 2050 are Russia and former USSR countries (40 % of trade, 10 % of global demand) and Canada, South-America, Central and Rest Africa, Oceania (40 % of trade, 10 % of global demand). This general pattern also holds for the moderate scenarios with slightly shifted figures: Russia and former USSR (33 % of trade, 6 % of global demand), Canada, South-America, Central and Rest Africa, Oceania (60 % of trade, 12 % of global demand). For the USA, there is a significant difference in the trade balance of liquid vs. solid biomass. Where the scenarios show a quite balanced (or slightly positive) trade balance for solid biomass, the trade balance for liquid bioenergy is clearly negative.

Regarding the key future import regions in scenarios up to 2050, mainly India, Western Europe and China are dominating. In ambitious scenarios these three regions import more than two thirds of all global inter-regional trade: India (33 % of trade, 8 % of global demand), Western Europe, China (39 % of trade, 9 % of global demand). USA is a relevant importer of liquid biofuels, however this is partly compensated by exports for solid biomass. The moderate scenarios show a more balanced picture: India (42 % of trade, 8 % of global demand), Western Europe (33 % of trade, 4 % of global demand), several world regions holding a share of about 3–6 % of global trade and about 1 % of global demand, e.g. Japan, China, South-East Asia and Rest of South-Asia, Middle-East and North Africa, USA, Korea, Turkey. For India, the scenario results are in a very close range, whereas for China a high difference between model results can be observed. This indicates the substantial uncertainties regarding biomass potentials and future exploitation of these potentials in China.

In the long-term (i.e. after 2030), the scenarios show a declining demand for liquid biofuels in Europe and the USA which reduces the imports from these regions.

In particular, the results regarding the relevance of Asia as importing region are also supported by Raunikar et al (2010) as well as IEA 2012.

However, one should keep in mind that the trade flows identified above are from models that are in first instance not made to analyse bioenergy trade. They are simply a consequence of where the models predicts demand for and supply of biomass. When comparing the trends identified above with current actual trade flows, the following observations can be made:

- Russia and other former USSR countries, whilst possessing very large biomass resources, have so far only been a minor exporter of solid biomass, whilst trade in liquid biofuels is virtually non-existent. In between 2010 and 2012, wood pellet production capacities have been expanded strongly, especially in North-West Russia, but also in Russia's East (aiming to feed the East Asian markets) so this could indeed be a start of substantial solid biomass exports in the years to come.
- Canada has been one of the pioneers of solid biomass exports, and the expected major role as a biomass supplier fits current trends quite well.
- Latin America and Africa on the other hand virtually do not export any solid biomass at the moment, and are also not likely to do so in any significant volume until 2020. Thus, huge exports of solid biomass from these regions in the near

and mid-term future are rather unlikely. Significant barriers would have to be overcome and logistical, social, ecological and economic challenges would have to be solved. Exports of liquid biofuels from Latin America on the other hand are already significant (see Chap. 2), and could likely expand further in the decades to come. For Sub-Saharan Africa, which has experienced a number of failed biofuel projects in recent years, this still remains to be seen.
- One market (pending current and future policy developments) to increase its liquid and solid bioenergy imports further is the EU, as also the models anticipate. This is probably one of the most robust trends identified. The largest uncertainty perhaps are the future additional sourcing areas, i.e. if Latin America and the African West coast may become important suppliers in the future as well.
- To some extent, India and China still remain wild cards. Both countries have shown little or no bioenergy imports or exports so far, partly due to the lack of strong supporting policies stimulating demand and at the same time limited amounts of agricultural land and forests that could be used to produce biomass for energy. Both countries have large potentials of agricultural residues, but these are likely to be used locally. It remains to be seen, if the large bioenergy imports expected by the model results will materialize. If so, from a logistical point of view it would make sense if India and China might increasingly source biomass from the east-coast of sub-Saharan Africa, while China might also utilize the forest biomass in East Russia. However, both bioenergy trade routes are virtually non-existent today, and thus would have to be developed from scratch. Again, any scenarios (implicitly) expecting large trade flows following these routes in the short and mid-term should be considered with caution.

Finally, it should be pointed out that model outcomes of these trade flows depend on how a number of issues are included in the models. These include bioenergy availability and cost, bioenergy demand and bioenergy trade barriers and logistics. The details of how these trade-flows happen and what parameters drive/limit them should be investigated. Typically, when trying to mobilize such potentials, the initial costs are typically much higher than originally anticipated – also because significant cost reductions can usually only be obtained with increases in scale. Transaction costs for bioenergy trade are rarely included in global models, and if so are included in a crude manner. Underlying assumptions and sensitivities may significantly affect the results. It is therefore deemed worthwhile investigating if the costs of transport should also be modeled as a function of scale and cumulative production.

8.4.2 Future Challenges and Open Questions for International Bioenergy Trade

In this chapter, a comparative investigation was carried out of selected model scenarios regarding bioenergy demand, production and the implication on bioenergy trade between world regions. Those model scenarios with an ambitious increase of bioenergy demand imply a huge increase in bioenergy trade, an increase by a factor of 70 between 2010 and 2030 for liquid biofuels, and by a factor of 80 for solid biomass. It has to be taken into account that these results refer to trade between world regions. International trade within these regions (e.g. within Europe) would have to be added to these values. Such an increase would result in quantities of internationally traded biomass commodities which would be higher than the current total global bioenergy demand (i.e. larger than 50 EJ). Considering the currently very small share of internationally traded bioenergy, this would result in huge challenges and tremendous changes in terms of production, pretreatment of biomass and development of logistic chains. While both liquid and solid international biomass trade has grown exponentially between 2000 and 2010, it is rather doubtful that this speed can be maintained and reach the levels of trade anticipated by the models. As an illustration, worldwide coal trade amounted to 1,142 Mt in 2011 (world coal 2013), i.e. roughly the size that solid biomass would need to grow to within 20 years in the ambitious bioenergy use scenarios. However, coal infrastructures have been developed for over 200 years, coal does not require any pretreatment before transport, and logistics typically originate from large point sources (mines).

From the above, two conclusions can be drawn:

1. Current global energy models seem to overestimate the amounts of liquid and solid biomass that can be traded especially in the medium term (2030), as it would require extremely high annual growth rates, which could only be accommodated with very high investments in production facilities and logistic infrastructure. However, it should be taken into account that the models do not make predictions. They provide scenarios based on biophysical trends and observed historic behavior under certain conditions and assumptions. The models tell what is potentially possible. Their objective is not to give advice how to overcome certain barriers. So, one reason of this overestimation could be that barriers for trade are not sufficiently covered in the models. If this is true, the question arises: How would global scenarios change if bioenergy trade barriers would be taken into account? To which extent would this change our picture of future global bioenergy use? So far, only a few number of global energy models explicitly simulate international bioenergy trade. Nevertheless, all global energy scenarios need to make an assumption on the future development of bioenergy trade. Mostly, this is only implicitly the case and is not clearly documented. A further investigation and integration of international bioenergy trade, barriers and drivers into existing modeling frameworks is crucial for a proper understanding of bioenergy in the future energy system. We recommend that modellers investigate their model–specific assumptions and outcomes for international bioenergy trade, and analyse whether the required growth rates in international bioenergy trade can be deemed realistic. Also users of the model results (e.g. industry, and policy makers that follow the IPCC reports) should be made aware of these model limitations.
2. The level of international bioenergy trade shown in the model scenarios is necessary to fill the anticipated regional gap between demand and supply. Without significant bioenergy trade between world regions, a much less pronounced

growth of bioenergy is achievable. Hence, either major challenges regarding amongst other technical, logistical and economic aspects of international bioenergy trade will have to be solved, or the objectives of significant higher bioenergy use have to be reduced. Policy makers should thus realize that next to incentives to promote production and consumption of bioenergy also policies to deal with the (rapid) growth of bioenergy trade will need to be put in place.

The insight into future scenarios and perspectives of bioenergy trade revealed that substantial challenges for the future development of global and international bioenergy trade may be expected in the coming decades if a low carbon energy system is to be developed. Some of these, such as the development of logistics, the required investments to realize production and trade, and the need to govern sustainable production of bioenergy are addressed in this book. Others are still open for further research, e.g. the implications of bioenergy trade for specific regions and for different biomass commodities in terms of social, ecological and economic impacts or the effect of fluctuating exchange rates, regional development of economic and policy side conditions.

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