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Perspective

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Global biomass trade for energy—Part 2: Production and trade streams of wood pellets, liquid biofuels, charcoal, industrial roundwood and emerging energy biomass

Svetlana Proskurina, Lappeenranta University of Technology, Lappeenranta, Finland
Martin Junginger, Copernicus Institute of Sustainable Development, Utrecht, The Netherlands
Jussi Heinimö, Mikkeli Development Miksei Ltd, Mikkeli, Finland
Beysin Tekinel, Esa Vakkilainen, Lappeenranta University of Technology, Lappeenranta, Finland

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Abstract: Many countries have limited low-cost biomass resources to satisfy their own demand for bioenergy; consequently, international trade in biomass in various liquid and solid forms is increasing. The aim of this study is to present a quantitative overview of the development of international biomass trade for energy purposes. This paper focuses on the main biomass producing and consuming countries, as well as exporters and importers of liquid and solid biofuels, such as wood pellets, biodiesel, and bio-ethanol, and biomass products, for example industrial roundwood. The study discusses changes in trends that have occurred over the past decade, and investigates emerging energy biomass trade streams. Due to increased demand for wood pellets from the heating and industrial sectors, global wood pellet markets and international trade have increased significantly in the past decade. The United States and Brazil remain leaders in bio-ethanol production with about 45 Mt and 24 Mt respectively. In recent years, Asian markets such as China (industrial roundwood), South Korea (wood pellets), Malaysia, and Indonesia (palm oil) have developed considerably. In the EU-28, more than 60% of total palm oil consumption is used for energy purposes. The EU is the global leader in biomass for energy utilization and also the main importer of most biomass products, particularly wood pellets. © 2018 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: international biomass trade; bioenergy; biomass market; trade streams; wood pellets; bioethanol; biodiesel; palm oil; industrial roundwood; charcoal

Correspondence to: Svetlana Proskurina, LUT, PO Box 20, FIN-53851 Lappeenranta, Finland. E-mail: svetlana.proskurina@lut.fi; proskurina.s@mail.ru

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Introduction

Renewable energy sources have grown in importance in the world's energy mix because of increasing demand for low-carbon energy as a response to climate change, to address environmental concerns such as air-pollution emissions, and from a desire to decrease dependence on fossil fuels.[1] Bioenergy can be used to produce heat, electricity, or transport fuels. It accounts for approximately 11% (44.3 EJ) of the world's total primary energy supply. The modern supply of bioenergy is important in the heating sector, where biomass is the largest source of renewable heat. In 2015, in the heating sector, the consumption of bioenergy (mainly solid biomass) was 13.0 EJ, which is about 6% of global heat consumption. As regards electricity generation, total global bioelectricity production was 474 TWh (1.7 EJ) in 2015, which is approximately 2% of world electricity generation. In 2015, biofuels provided 4% of world road transport fuel demand.[2]

Many countries have limited biomass resources to satisfy their own bioenergy needs, whereas others produce a considerable biomass surplus. Thus, international trade in bioenergy products in the form of solid and liquid fuels has become increasingly important. Wood pellets, biodiesel, and bioethanol are examples of widely traded biofuels, particularly in currently expanding markets. Several studies[3–8] have presented analyses of global trade in biomass, often authored by Task 40 (Sustainable International Bioenergy Trade–Sustainable Biomass Markets and International Trade to support the biobased economy) of the International Energy Agency (IEA) Bioenergy Technology Collaboration Programme. Task 40 focuses on international bioenergy technology potential, bioenergy utilization barriers and trade, as well as their wider implications.

A number of studies have been presented that investigate trade in biomass for energy purposes. In 2007, Heinimö and Junginger[3] presented a first overview of the global status of production and trade of biomass for energy. Lamers et al.[5] assessed a bottom-up global trade model for analyzing future solid and liquid biomass trade. A review of past developments in liquid[6] and solid[7] biofuels markets was presented by Lamers et al. Goh et al.[8] described the global wood pellets market. Matzenberger et al.[9] presented bioenergy trade models and market scenarios for future perspectives of the international bioenergy trade. Goh et al.[10] investigated the sustainability of traded biomass flows, mostly for the Netherlands. Assessing the international biomass trade for bioenergy in the context of RE deployment scenarios for the EU-27, Hoefnagels et al.[11] concluded that the share of imported biomass is likely to increase. Work is required that updates and extends the findings of earlier studies.

Indirect trade in biomass for energy, which refers to biomass traded for the manufacture of primary products, such as sawn timber for building construction, rather than bioenergy, but whose by-products are used for energy, was first studied by Heinimö and Junginger[3] in 2007. Several other studies have also considered indirect trade. For example, Kalt and Kranzl[12] identify the most relevant indirect trade streams of foreign trade and wood flows for raw wood and wood products within Austria. Trømborg et al.[13] give an overview of biomass trade for Norway, including indirect trade; and indirect imports of biofuels in Sweden are studied by Ericsson and Nilsson.[14] The above studies, however, focus mostly on direct trade and specific products, e.g. wood pellets, or specific regions, e.g. the Netherlands, Austria, Norway, and the EU. Despite the significant number of studies, there is no comprehensive and up-to-date overview of the current state of international biomass trade covering recent developments in the major biomass commodities traded for energy.

This study aims to provide updated figures on production and biomass trade for energy, and discusses trends and changes in biomass markets that have occurred over the past decade. The study also investigates a number of emerging biomass trade streams. The paper is a continuation of a previous paper, which is also presented in this issue, 'Global biomass trade for energy—Part 1: statistical and methodological considerations.'[15]

Method and data collection

International biomass trade includes a significant number of cross-border streams. If the entirety of all biomass trade streams, that is, all forest products, agricultural products and biodegradable wastes, were to be investigated until the final end use for energy, the review would become unwieldy and overly complex. Consequently, the study concentrates on only the most significant biomass streams from the bioenergy perspective. The study focuses on trade streams for wood pellets, biodiesel, bio-ethanol, palm oil, and charcoal as the most important traded solid and liquid biofuels. The study also presents trade streams for industrial roundwood as an example of trade in biomass products whose by-products can be used for energy purposes. Palm oil and charcoal streams are relatively new in the evaluation of international biomass trade for energy and were shown also as an example.

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Other biomass products are excluded from the study. For example, wood chips as well as fuelwood are excluded from the study due to the difficulty of differentiating whether they are traded for energy or other purposes and the relatively small traded volumes. Fuelwood and wood chips are mostly used locally or traded over much shorter distances than, e.g., roundwood. Some crops (e.g. cereals or oils seeds) may be imported for biofuel production. Most agricultural products (other than palm oil) are excluded from our analysis due to lack of resources needed for comprehensive analysis. For similar reasons, trade in waste biomass (i.e. wood waste, municipal solid waste, agricultural residues etc.) is also excluded from this study. Depending on the crop, agricultural products may also partly involve indirect trade. For example, EU agricultural imports are primarily for food, but substantial amounts may end up indirectly as energy (e.g. husks, shells, peels, etc., from imported agricultural products processed in the EU and used for process heat production or animal manure from meat production based on imported soybeans used to produce biogas). This can be a subject for future research. Detailed in-depth analysis of specific agricultural supply chains from farm gate to final waste utilization and the amount of indirect trade for energy is excluded here to keep the scope of the paper focused, but could be a topic of interest for future studies. Given the complexity of the processing of the products and the assumptions required to determine the amount of indirect trade, this is recommended as a subject for future research.

Despite the importance of international trade in biomass and the large amount of research in the area, there is, as yet, no comprehensive unitary database for biomass trade streams. Thus, in this study, the estimated volumes of international biomass trade streams and imports and/or exports of major countries were accessed from literature such as country reports and statistics as well as in consultation with industry experts. This study utilizes data from different statistical sources,[16,17] but these are based on a few common primary sources such Comtrade. Yearly trade data are mainly based on UN Comtrade, which is the world's largest database of trade statistics and is maintained by the United Nations Statistics Division (UNSD). For countries that do not report their national trade statistics to UN Comtrade, trade is reconstructed on the basis of data reported by partner countries and missing information is complemented by national and regional sources.

With regard to the global trade figures, trade streams for the EU present approximate evaluations of the trade within the EU. In this work, the biomass trade streams are presented in the figures as net trade flows due to the difficulty of estimation of re-imports and re-exports. Net trade is calculated as the difference between imports and exports. In reality, actual physical flows may be larger in both directions between two countries, for example Austria and Germany (wood pellets), the Netherlands and Belgium (bioethanol and biodiesel), the United States, and Canada (biodiesel). The EU is the leading importer of most of the studied product. For wood pellets, biodiesel, and bioethanol, the additional figures show the trade streams within the EU and exclude trade streams outside of the EU. However, trade streams within the EU are sometimes related to imports from outside the EU. For example, the Netherlands imports biofuels from oversees and then re-exports to other EU countries. A report of the port of Rotterdam, which is the main port for ethanol trades, suggests a throughput of 3.8 Mt of biofuels including 1 Mt of ethanol in 2014.[18]

For more reliable and comprehensive data, the study uses different sources for different products (Table 1). Where the sources give inconsistent data, volumes of studied products were calculated as averages. As each feedstock varies in data quality, data availability, amount used for energy end-use or other purposes, the methodological approach requires slight adjustment for each biomass type.

Table 1. List of data sources used for the products studied.

Studied product	Main data sources
Wood pellets	'Global wood pellet industry – market and trade study 2017' by IEA Task 4015[19]; Trade Map[17]; FAOSTAT statistics.[16]
Bioethanol	OECD-FAO agricultural outlook 2015–2024, FAOSTAT;[20] Trade Map;[17] USDA reports;[21,22] Biofuel Policy Watch;[23] RFA;[24] EIA.[25]
Biodiesel	OECD-FAO agricultural outlook 2015–2024, FAOSTAT;[20] Trade Map;[17] USDA report;[21] AgMRC;[26] USDA.[27]
Palm oil	Trade Map;[17] indexmundi;[28] transport and environment;[29] WWF;[30] Oil World.[31]
Charcoal	FAOSTAT;[16] TradeMap;[17] personal communication with experts.
Industrial roundwood	FAOSTAT.[16]

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For *wood pellets,* data are taken from 'Global wood pellet industry – market and trade study 2017' by IEA Bioenergy Task 40,[19] which presents data collected by experts from different countries mostly based on local database sources. Data from this study are compared with FAOSTAT statistics[16] and data from Trade Map (product code 440131).[17]

For *ethanol*, trade streams are derived from Trade Map[17] based on product code 2207 'Undenatured ethyl alcohol of an alcoholic strength of >= 80%; ethyl alcohol and other spirits, denatured, of any strength.' Product code 2207 does not include spirits, liqueurs, and other spirituous beverages for human consumption, which are classified as product code 2208. Export of ethanol from the United States is estimated based on UN Comtrade statistics compiled by UNSD (Quantity and Weight Data in UN Comtrade).

Ethanol trade statistics do not differentiate between imported ethanol used for biofuels and for other purposes. To improve the reliability of the international ethanol trade flow analysis, the study therefore attempted to determine the share of ethanol that is used for energy in the importing country. By doing so, it is possible to quantify the share of the total traded volumes that is used for energy. The values presented should, however, be seen as an estimation due to the differences in trade flows and consumption reported by different available sources. From FAOSTAT statistics,[20] the consumption of ethanol for biofuels use is taken as the difference between 'total consumption' (for fuel) minus estimates for 'for other uses.' For Brazilian ethanol,[21] the initial stocks for ethanol consumption for 'all uses' are based on information from the Ministry of Agriculture, Livestock and Supply (MAPA); this information was consistent with previous ATO/Sao Paulo GAIN reports. Initial stocks for ethanol 'for fuel only' are estimated based on historical average use of bioethanol for fuel/other uses. The total ethanol consumption was calculated based on the difference between total supply and demand (consumption and exports). A USDA report about ethanol in the EU[22] presents volumes of ethanol used for fuel and other industrial chemicals excluding 'synthetic' ethanol made from petroleum fuels, which has a very small market in the EU. The USDA data were compiled based on European Commission, Eurostat, Global Trade Atlas, ePURE, and EU FAS posts. Data are compared also with other sources (for bioethanol[23,24,25] and biodiesel[26,27]).

For *palm oil*, trade streams data, which are taken from Trade Map,[17] include crude and refined palm oil and their derivatives but exclude chemically modified palm-oil products (code 1511). Production, consumption, and trade streams are also cross-checked with IndexMundi.[28] The use of palm oil for energy applications (transport fuel, electricity and heat) for the EU-28 is based on data from Transport and Environment,[29] which in turn uses data from a publication of WWF[30] and Oil World,[31] and their estimates on usage by different industries. For earlier data, Transport and Environment[29] used data from Fediol, which is the industry association representing the vegetable oil and protein meal industry in Europe. In most cases, national imports are first considered and then linked to an evaluation of where the oil is consumed by national industries. The national consumption of all member states is then summed. The consumption of palm oil is presented by industry rather than end users. Palm oil consumption is thus presented as an estimation.

To the best of our knowledge, this study is a first attempt to map and quantify trade streams for *charcoal*. Charcoal trade streams include shell or nut charcoal, whether or not agglomerated, and exclude wood charcoal used as a medicament, charcoal mixed with incense, activated charcoal, and charcoal in the form of crayons (product code 440200).[17] It is difficult to judge to what extent this data is complete. For example, informal charcoal trade between African countries may not be recorded in general global statistics due to a lack of documented data about such trade flows. Furthermore, such trade often occurs illegally, and it is thus hard to obtain accurate data or even estimates.

Trade flow data for *industrial roundwood* were taken from FAOSTAT,[16] where industrial roundwood is defined as saw logs, pulpwood, and other roundwood. Industrial roundwood data in this work refer to indirect trade in energy biomass – that is, the fraction of a biomass traded primarily for material purposes (e.g. roundwood to be processed into sawn wood in the destination country) that ultimately ends up in energy through usage of process residues (e.g. sawdust).[3,4] The primary use of roundwood is for material applications, e.g. building construction, rather than for bioenergy. After product manufacture, some by-products such as residues and woody wastes are used as fuel for energy. Approximately 30–45% of by-products from roundwood usage can end up being used for energy purposes. Estimation of roundwood residue usage for energy purposes is rather complex and more detailed discussion of this topic is found in another paper in this issue, 'Global biomass trade for energy: Part 1–Statistical and methodological considerations.'[15]

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Results

Wood pellets

The wood pellet market is one of the most dynamically developing solid biofuel markets in the energy sector.[32–35] The leading wood pellet producers (Table 2) are the United States, Canada, and the EU-28, which produced over 14 Mt of wood pellets in 2015. The consumption of wood pellets was about 20 Mt in the EU.[19]

In 2015, according to the statistics, the total world import and export of wood pellets was 15.6 Mt and 16.0 Mt respectively. The difference is caused by statistical error (the volume recorded by exporting countries versus the volumes recorded by the importing countries). In an ideal situation, world imports are equal to world exports. However, there are numerous reasons for these discrepancies. For example, some trade deals could have been canceled and there could also be categorization difference. Time lags can occur when, for example, exports are registered in one year and the corresponding imports in the following year.[15]

In the United States, exports of wood pellets increased from 1.9 Mt (2012) to 4 Mt (2014).[16] In 2015, the biggest wood pellet export destinations of the United States were the United Kingdom, Belgium, and Italy.[36] Recently, industrial wood pellet use has increased in South Korea and Japan (Figure 1), mainly to substitute coal in coal power plants.[37] South Korea increased imports of wood pellets from 0.12 million tons in 2012 to 1.85 million tons in 2014,[38] and in 2016 became globally the third largest importer of wood pellets after Denmark and the United Kingdom.[39] In EU-28, total wood pellets imports were 13.4 Mt (Figure 2). The biggest importers of wood pellets in the EU in 2015 were the United Kingdom (6.5 Mt), Denmark (2 Mt), and Italy (1.6 Mt).[17,19] Italy uses wood pellets mostly for residential heating, whereas in the United Kingdom and Denmark, wood pellets are used almost exclusively for large-scale industrial operations, i.e. electricity and heat production.

In 2015, the Baltic countries – Estonia, Latvia, and Lithuania – accounted for 35% of all European wood pellet exports with a total pellet production of 2.7 Mt and total exports of 2.8 Mt,[19] which can explained changes in storages and slight import of wood pellets to the Baltic countries. Baltic countries have excellent potential for future wood-pellet industry development because they have abundant forests and low costs, and are in close proximity to naval ports.[36] Portugal also has potential for further development of wood pellet exports due to abundant forest resources, relatively low production costs (e.g. 30% less than in Germany), and limited local consumption.[19] In recent years, however, wood pellet market development has been relatively slow, and oversupply occurred in European markets between 2012 and 2015, mainly due to a series of mild winters. In addition, global oil prices have decreased, causing demand for residential wood pellets to slow.[40]

Liquid biofuels

The United States and Brazil are leaders in the ethanol market with 75% of the world's ethanol production (Table 3); 97% of ethanol produced in the United States

Table 2. Global wood pellet production between 2010–2015 (in ktons).[16,17,19]

Country/years	2010	2011	2012	2013	2014	2015
United States	3 000	4 000	4 500	4 900	6 900	7 500
Germany	1 700	1 800	2 200	2 350	2 080	2 000
Canada	1 300	1 400	1 500	1 750	1 900	1 900
Sweden	1 700	1 400	1 400	1 300	1 500	1 600
Latvia	615	725	1 050	1 105	1 380	1 380
Russia	750	850	880	810	890	1 050
France	450	520	680	900	1 030	1 030
Austria	820	920	850	950	945	1 000
Estonia	425	365	500	580	995	890
Poland	430	600	600	600	620	870
Rest of the world	3 010	4 420	6 140	7 755	8 610	8 780
World total	14 200	17 000	34 300	23 000	26 850	28 000

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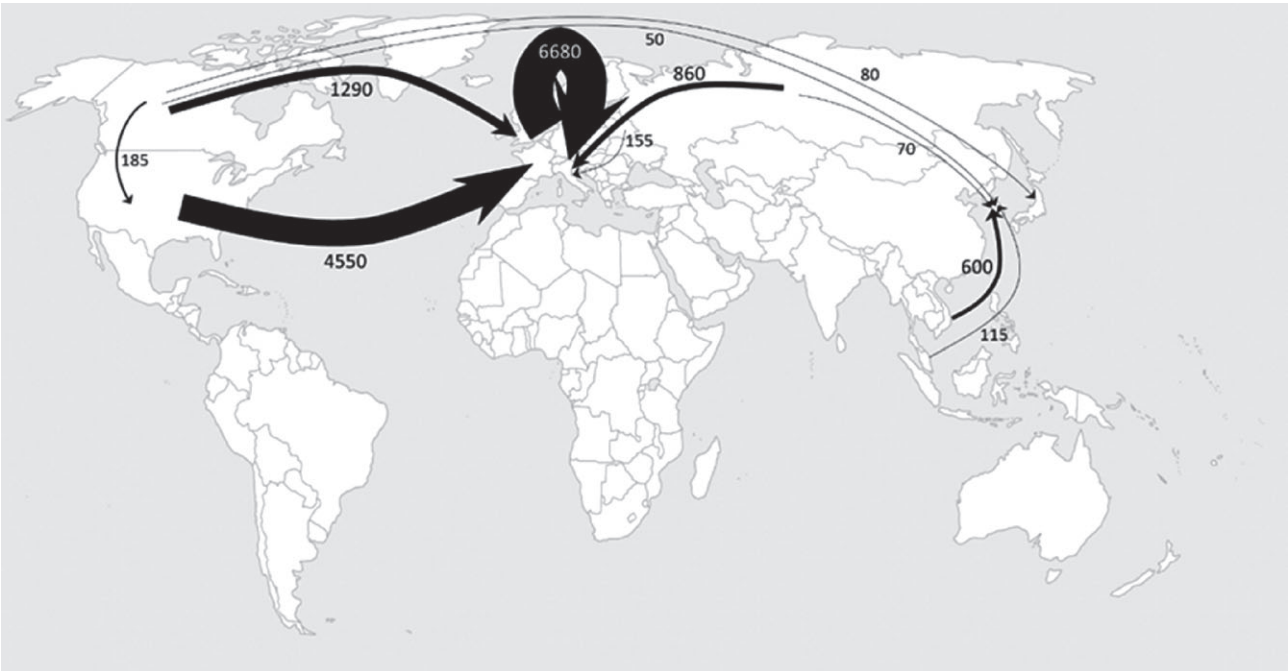

Figure 1. Major net wood pellets streams (≥30 ktons) (in ktons) in 2015. Data were obtained from.[16,17,19]

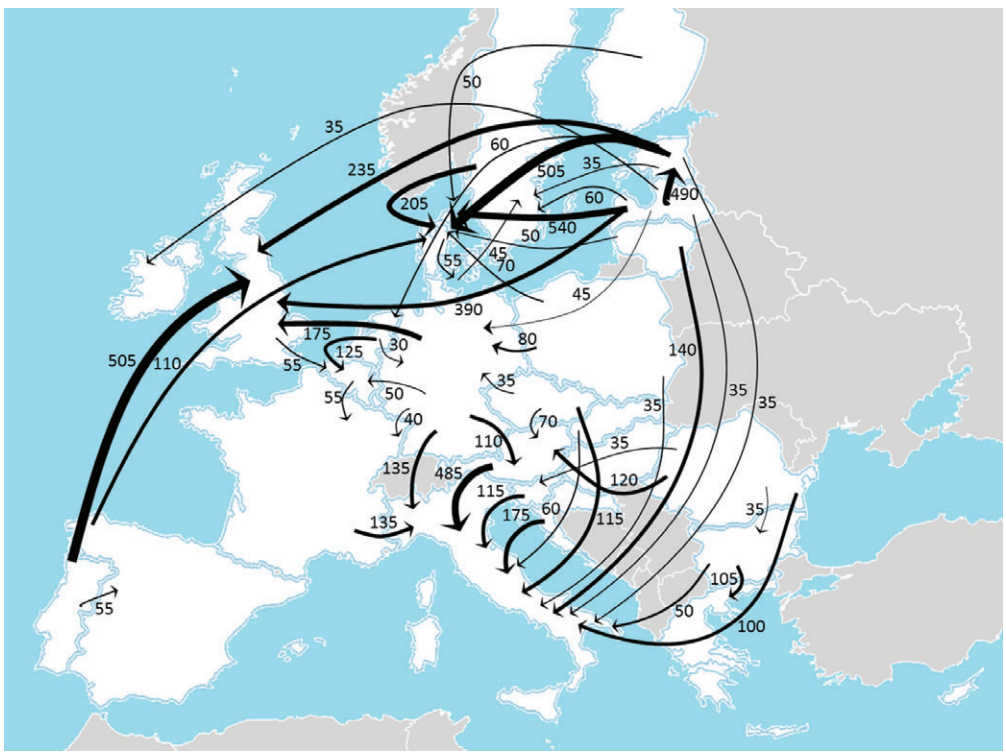

Figure 2. Net wood pellets trade streams within the EU-28 (≥30 ktons) (in ktons) in 2015. Data were obtained from.[16,17,19] For imports from outside the EU (United States, Canada, Russia), see Figure 1.

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Table 3. Global ethanol production between 2006-2015 (in ktons). Data were obtained from.[20,22-24] Density of 785.06 kg/m^3 is assumed.

Country/years	2006	2010	2011	2012	2013	2014	2015
United States	15 070	41 090	43 035	40 850	41 320	44 920	44 585
Brazil	14 070	21 645	17 850	18 450	21 955	22 160	23 660
China	4 935	6 500	6 740	7 005	6 090	5 895	6 010
EU-28	2 700	4 940	5 215	5 205	5 500	5 535	5 900
India	1 220	1 265	1 570	1 515	1 600	1 785	1 780
Rest of the world	4 280	6 195	6 725	7 690	8 325	9 030	9 565
World total	42 275	81 635	81 135	80 715	84 790	89 325	91 500

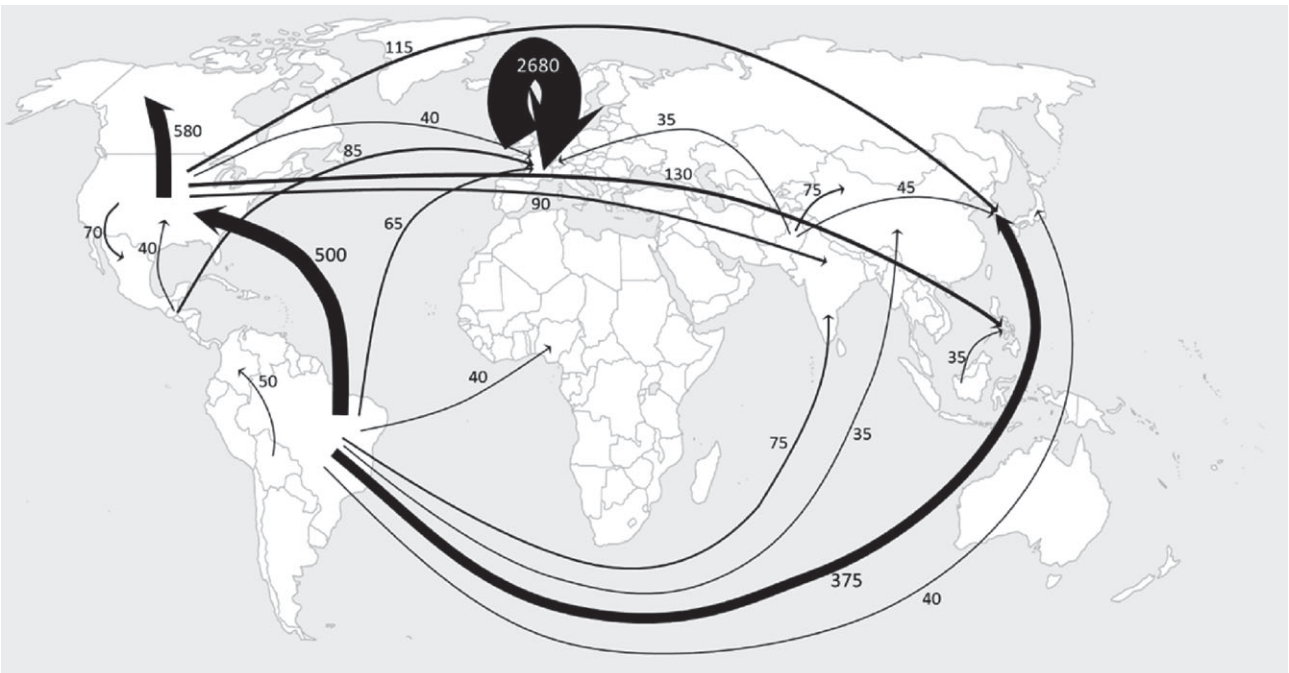

Figure 3. Major net ethanol trade streams (≥35 ktons) used for all end uses (in ktons) in 2015. Data were obtained from.[12,17,21,22,25]

is derived from corn, and 38% of all corn production in the country is used for ethanol production.[41] In 2015, the primary exporters of ethanol were the United States (1.7 Mt) and Brazil (1.5 Mt) (Figure 3).[17] Ethanol has become an important commodity for US markets thanks to strong policy support.[23] The industry has matured in terms of corn processing, which suggests that the United States will remain the leading player in ethanol markets for many years to come.[42] Following the increase in local ethanol production, US imports have fallen dramatically.[24] When considering intra-EU trade, the Netherlands is the biggest recipient of ethanol exports in the EU-28 (Figure 4).

The United States, the Caribbean countries, and Sweden mainly import ethanol from Brazil for fuel usage, whereas Japan, South Korea and several other importing countries, including countries in the EU, import Brazilian ethanol for industrial and other uses.[21] Overall, more than 90% of the global ethanol consumption is used as biofuel. Figure 5 presents an estimation of how much of total ethanol consumption is for transport fuel use, based on combining different statistics for main ethanol consumers. For ethanol use as fuel in the United States, the data from EIA[25] differs slightly from that published by FAOSTAT[20] (e.g. 41.45 ktons instead 42.16 ktons in 2015). For Brazil, FAOSTAT[20] and USDA[21] reported slightly different volumes for ethanol consumption and its use as biofuel for 2011–2015. Overall, it is clear that ethanol consumption for technical and other purposes has remained relatively

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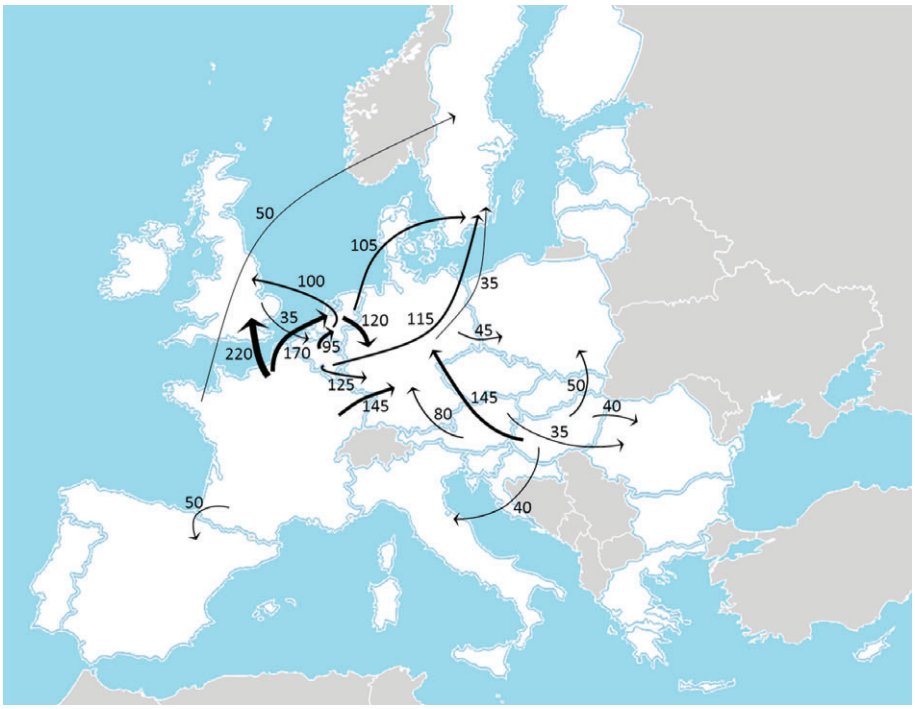

Figure 4. Net ethanol trade streams within the EU-28 (≥30 ktons), (in ktons) 2015. Data were obtained from.[17,21] For imports from outside the EU (United States, Brazil, Guatemala and Pakistan), see Figure 3.

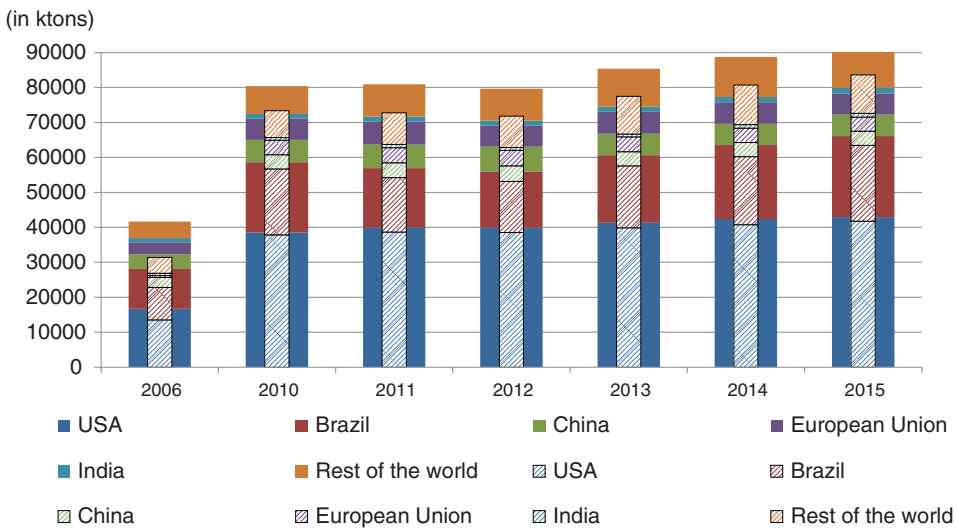

Figure 5. Consumption of ethanol for biofuel use (narrow bars) and total ethanol consumption (wide bars) (in ktons)[20] for Brazil[20,21], for the EU-28,[20,22] for USA.[20,25] Density of 785.06 kg/m^3 is assumed.

stable and the increase in consumption is mainly due to its use as transport fuel.

Like bioethanol production, global biodiesel production has increased significantly over the last ten years (Table 4).[20] In the United States, a peak of biodiesel production occurred in 2013 due to increased consumption, which can be explained by factors such as the need to satisfy total renewable fuel standards, biodiesel tax credits, growing access to foreign biodiesel, mostly from Argentina, and favorable blending economics.[26] In

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Table 4. Global biodiesel production for 2006–2015 (in ktons). Data were obtained from.[20,22,26] Density of 885.00 kg/m^3 is assumed.

Country/years	2006	2010	2011	2012	2013	2014	2015
EU-28	4 870	9 580	9 120	9 725	10 380	10 645	12 000
United States	840	1 150	3 250	3 390	5 150	5 130	4 005
Brazil	60	2 110	2 365	2 405	2 580	3 290	3 990
Indonesia	55	655	1 345	1 595	1 800	2 035	3 020
Argentina	0	2 415	2 440	2 470	2 010	2 335	2 350
Rest of the world	485	1 860	2 230	2 715	2 895	3 325	3 135
World total	6 310	17 770	20 750	22 300	24 815	26 760	28 500

Figure 6. Major net biodiesel trade streams (≥10 ktons) (in ktons) in 2015. Data were obtained from.[17,26,27]

the EU-28, production of biodiesel is mainly based on imports. In 2015, the EU imported about 53% of feedstocks (vegetable oils mainly from rapeseed, palm and soya) used to produce crop biodiesel in EU installations.[43] The EU-28 consumed about 12.9 Mt of biodiesel in 2015.[22]

The United States was a net exporter of biodiesel from 2007 to 2012 and then became a net importer from 2013 to 2015.[26] Export of biodiesel from many non-European countries to the EU is relatively small (Figure 6) due to EU anti-dumping policy.[44] Extra-EU imports of biodiesel decreased from about 2.8 Mt (2012) to about 0.8 Mt (2014).[45] Nevertheless, in 2015, the main importers of biodiesel from Malaysia were Spain, Switzerland, and the Netherlands with 65%, 19%, and 11% of total exports from Malaysia respectively. Spain and the Netherlands re-exported the largest part to other EU member states (Figure 7). Malaysia increased exports of biodiesel from about 330 ktons in 2014 to 615 ktons in 2015.[27]

Palm oil can be used for biofuel production using a wide range of different technical approaches.[46] In 2015, the main global producers of palm oil were Indonesia (33.4 Mt), Malaysia (29.9 Mt), and Thailand (1.8 Mt).[47] The main importers of palm oil were India, the EU-28, and China (Figure 8).[17] In India, imports of palm oil have risen strongly over the last decade. In 2014, India imported about 8.8 Mt of palm oil, while domestic production was about 0.05 Mt. Approximately 90% of imported palm oil is used for edible products (mostly as cooking oil), and the remaining 10% goes toward non-food-based usage such as cosmetics and detergents.[48] The share of palm oil used in India for

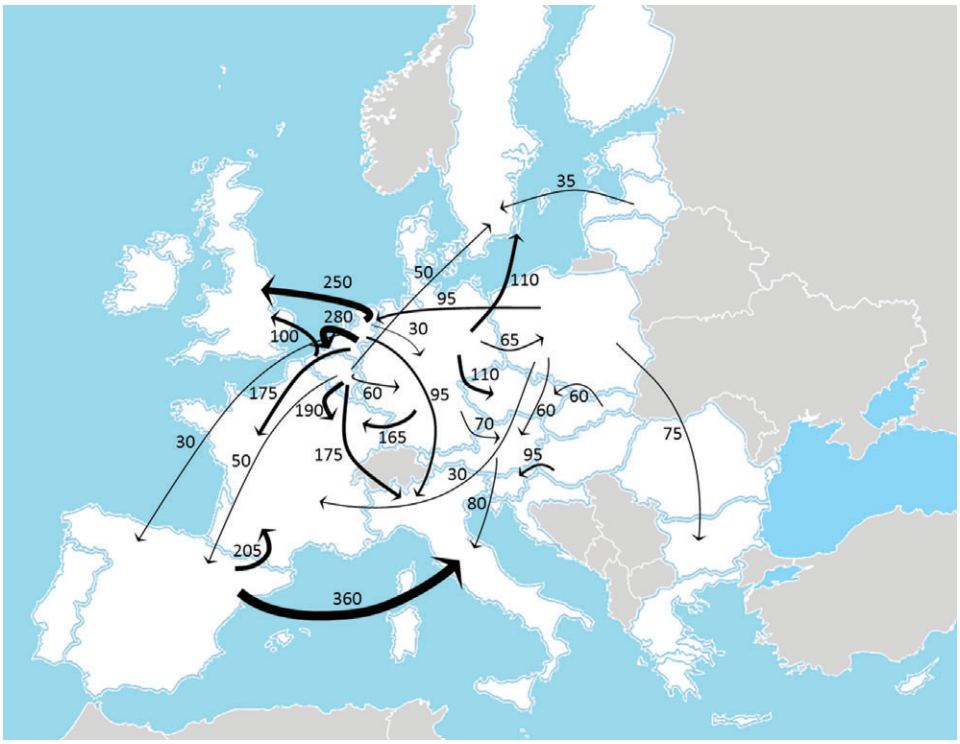

Figure 7. Net biodiesel trade steams within the EU-28 (≥30 ktons) (in ktons) in 2015. Data were obtained from.[17,22] For imports from outside the EU (Malaysia and Indonesia), see Figure 6.

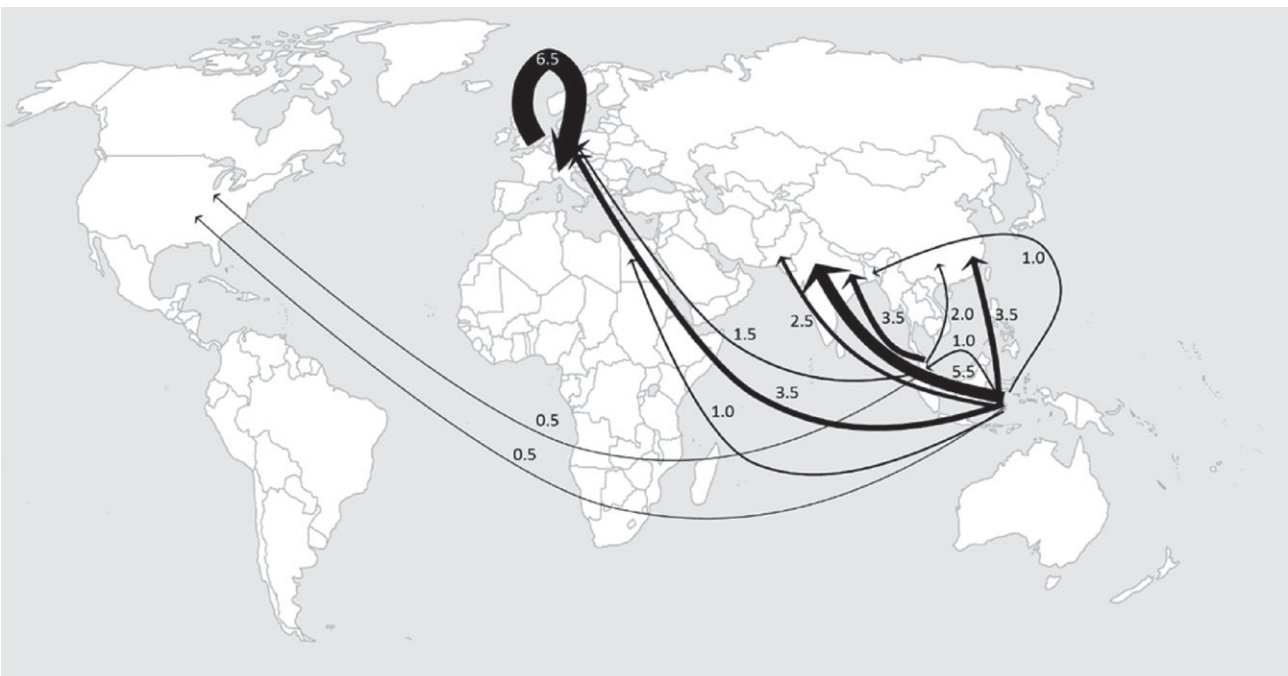

Figure 8. Major palm oil streams (≥500 ktons), (in Mtons) in 2015. Data were obtained from.[17,28,31]

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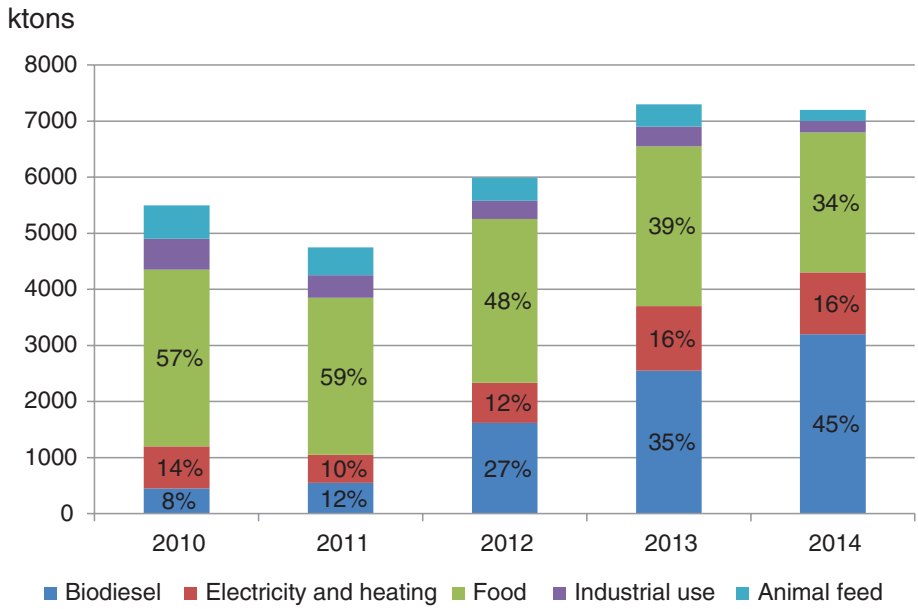

Figure 9. Palm oil consumption in the EU. Data were obtained from.[29,43]

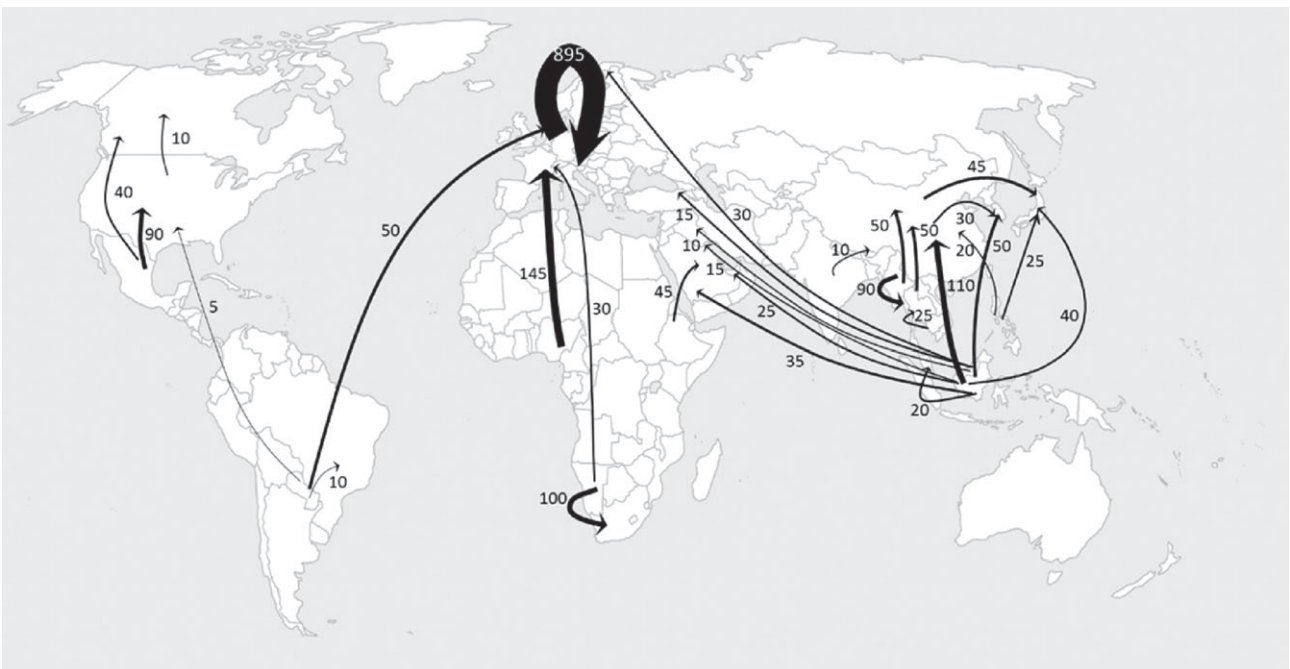

Figure 10. Major charcoal trade streams (≥5 ktons), (in ktons) in 2015. Data were obtained from.[16,17]

biodiesel is negligible. China also uses palm oil mainly for food (70%), with the remaining oil mostly being used in the chemical industry.[30]

In the EU-28, after rapeseed oil, the dominant feedstock for biodiesel production is palm oil. Imported palm oil used for the production of biodiesel increased between 2010–2014 (Figure 9).[29,43] In the EU-28, the leaders in palm oil consumption are the Netherlands, Germany, and Italy. In 2015, the Netherlands imported about 130 ktons of palm oil for biodiesel production, of which 85.4% and 14.6% were from Malaysia and Indonesia respectively.[49] Germany used 128 ktons of palm oil for biodiesel production (fatty acid methyl esters, FAME) and 164 ktons for renewable diesel fuel (hydrotreated vegetable oil, HVO) in 2015.[50]

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Table 5. Global roundwood production for 2006–2015 (in Mm^3). Data were obtained from.[16]

Country/years	2006	2010	2011	2012	2013	2014	2015
United States	410	335	355	350	355	355	370
Russia	175	160	175	175	180	190	190
Canada	180	140	145	145	150	150	150
China	95	160	160	160	170	160	165
EU-28	340	340	340	330	335	345	350
Rest of the world	535	570	595	605	610	620	650
World	1735	1705	1770	1765	1800	1820	1875

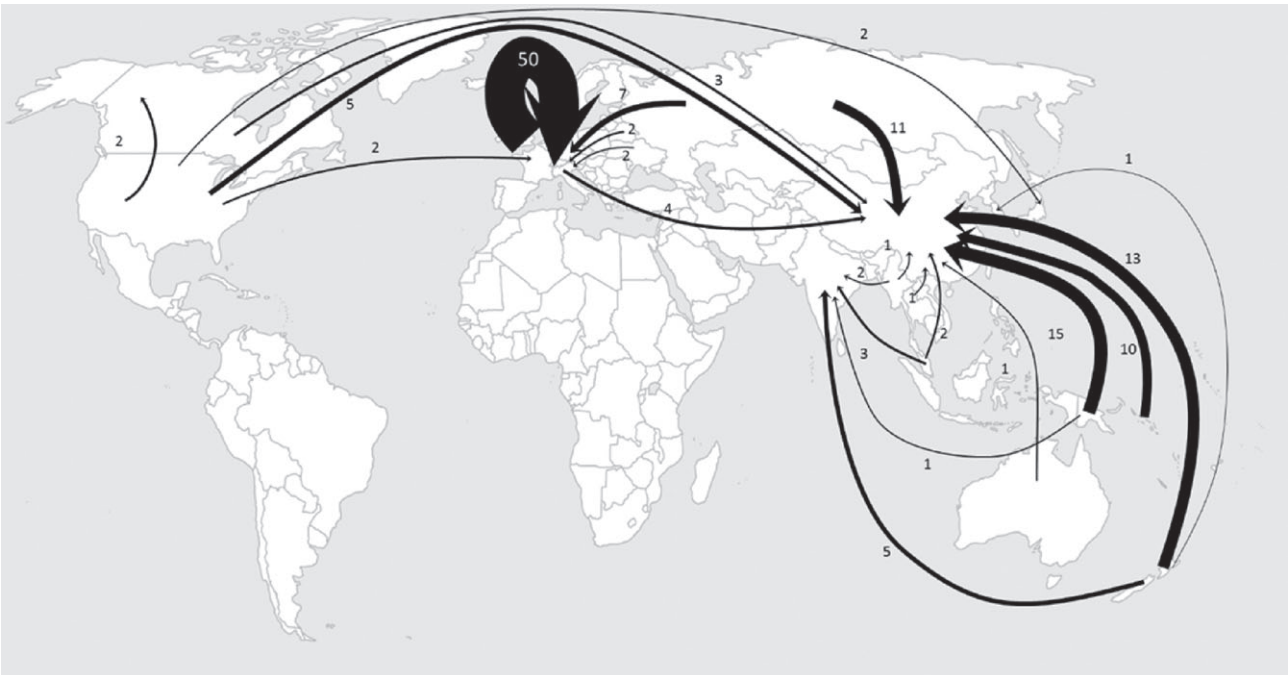

Figure 11. Major net trade streams of industrial roundwood (≥ 1 Mm^3), (in Mm^3) in 2014. Data were obtained from.[16]

Charcoal

In 2015, formally recorded world production of charcoal was around 52 Mt and documented export of charcoal slightly more than 2 Mt.[16] The charcoal trade doubled between 2008 and 2015, which can be partly explained by increasing charcoal use for cooking in Africa, the Middle East and Asia. Figure 10 presents preliminary estimates of major charcoal trade streams.

Industrial roundwood

The leading industrial roundwood producers are the United States, the EU-28 and Russia (Table 5). The largest importers of industrial roundwood are China and the EU (Figure 11). In the EU, the main markets of industrial roundwood are located in Denmark, Finland, Sweden, Germany, Estonia, Latvia, Lithuania, and Poland. The large amount of roundwood imported into China may be explained by the fact that China is a major exporter of wood-based panel products. In the past few years, the country has become the largest global importer of wood products due to growth in domestic consumption and export-oriented manufacturing activities.[51]

Review of emerging biomass for energy streams

In the long term, new trade streams of biomass for energy can emerge. For example, torrefied biomass is very attractive as a biofuel product for long-distance transportation. Torrefied biomass has a greater density and heating value than raw wood, which makes transportation easier and

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more economic.[52,53] According to IEA Task 40,[52] global torrefied biomass demand in industrial applications could theoretically reach more than 7 Mt by 2025. Different scenarios indicate that total torrefied biomass demand might reach 10–18 Mt by 2030.[53] However, the market for torrefied biomass is not yet well developed and global production capacity is currently far below 1 Mt per year.

Another emerging commodity traded for energy is used cooking oil (UCO), which is uniquely used for biodiesel as a replacement for mineral diesel (in the form of used cooking oil methylester (UCOME) and hydro treated vegetable oil (HVO)) and for bio-kerosene. From the technical point of view, biodiesel production from UCO uses similar methods to conventional transesterification processes.[54] Used cooking oil is collected all over the world. In the last few years, traded volumes of UCO have increased.[55] Due to double counting of biofuels produced from UCO under the Renewable Energy Directive (RED), and because the EU imports UCO from all over the world, evaluation of the level of trade for the EU-28 is difficult. In the EU, about 1 Mt of UCO per year was used for biodiesel production in past years.[49,55] Used cooking oil is collected in several EU countries such as Germany, the Netherland, and Italy. For example, in the Netherlands, collection of UCO from restaurants is nearly 100%. Approximately 60 ktons of UCO were collected in the Netherlands and even more was imported from other EU Member States and third countries.[55] Use of UCO can decrease biodiesel production costs. If shortages of UCO in the EU occur, imports may increase, and the cost of obtaining the raw material may be higher. Generally, in EU countries, the biodiesel production chain from UCO has essential economic and environmental benefits.[54] The traded volumes of charcoal are comparable with traded volumes of used cooking oil (UCO). However, the trade streams for UCO are not shown due to the limited information available (documentation of UCO trade is a new subject).

Aviation biofuel (biomass-derived jet fuel) could also become a new biomass commodity. At present, however, there is no large-scale aviation biofuel production, and thus also no international trade. The European Advanced Biofuels Flightpath has set a target to ensure the commercialization and consumption of 2 Mt of sustainably produced paraffinic biofuels in the aviation sector by 2020 (for more details see the study by Kousoulidou and Lonza).[56] Despite such efforts, in the coming years, the demand and production of aviation biofuel are expected to remain negligible compared to conventional fossil jet fuel.[57]

Last but not least, another example of a bio-product that in future years could be traded for energy purposes is biochar, which is a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. In Europe, the total consumption of biochar was 22.6 tons in 2015, while in 2011 it was about 12 tons. Europe uses biochar mostly for soil amendment as soil conditioner (47.5%) and fertilizer (33.8%). Energy applications account for about 18.7% of total biochar use. The use of biochar for energy increased from 2.4 tons in 2011 to 4.2 tons in 2015. The price of biochar is high for energy applications. European imports of biochar were 2.2 tons in 2015, and 1.1 tons in 2011.[58]

Discussion

The current study found that wood pellet markets have significantly developed during the last five years. The large trade in wood pellets can be explained by increased demand in the heating and industrial sectors. In both sectors, global wood pellet markets have increased significantly in the past decade. In the EU, the high wood-pellet consumption and significant imports can be explained by historical reasons – the use of wood pellets started in Sweden – by renewable energy development trends, and by policy support and environmental issues. Different scenarios suggest that European wood pellet markets will grow still further.[19,59]

It seems that Asian wood pellet markets will continue development thanks to policy support and the global trend of wood-pellet market development. In South Korea, widespread interest in wood pellets started from a renewable portfolio standard that became effective in 2012 and had the goal of reaching 10% energy generation from renewable resources in the 2022 to 2027 timeframe.[38] Japan is also expected to increase wood pellet imports quite substantially over the next five years.[57] The abundance of primary forest feedstock and by-products from forest products manufacture, as well as relatively low production costs, make Vietnam a very promising country for wood-pellet market development.[38] Malaysia, Indonesia, and Thailand also have potential for further development. Indonesia almost doubled production and export during 2013–2014. Thailand increased wood pellet production from 20 000 tons in 2013 to 115 000 tons in 2015.[38]

The relatively low levels of ethanol exports from the United States to Europe can be explained by an anti-dumping duty on bioethanol imports from the United States imposed by the European Commission. At the beginning of 2013, the duty was set at €49.20 per 1000 L (0.785 tons) for the following five years, on top of an existing import tariff of €102 per 1000 L. In the medium

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term, it is questionable whether corn-based ethanol will be exported to the EU, as the minimum greenhouse gas savings criteria is being increased to 50–60% from the current 35% threshold.[22]

In Brazil, the stagnation of ethanol production between 2009 and 2014 had multiple causes. The economic crisis of 2008 delayed sugar cane replanting for 2009,[60] and combined with unfavorable weather conditions the crisis had a highly negative impact on ethanol production.[12] Lastly, in 2009–2014, ethanol became less competitive due to the government's reduced support for ethanol production and the introduction of price freezes, which favored fossil fuels.[61] This unfavorable business environment led to the closure of some ethanol production facilities and fewer facilities being built. Brazil has a large potential of biomass resources and is well placed to continue to be a dominant player in exporting resources for global trade in the future.[62]

Although palm oil is globally the most important vegetable oil used for human consumption, it is increasingly also being used for biodiesel production. Some sources believe that palm oil biodiesel, produced from refined palm oil, will become one of this century's most important commodities.[63] However, the negative environmental impacts associated with palm oil production, the 7% cap on food-based biofuels, and the increasing greenhouses gases threshold in the EU are plausible reasons to believe that the use of palm oil as a fuel will actually decrease. In Indonesia and Malaysia palm oil exports bring considerable profits for the economies of these countries. However, the processes of direct and indirect land-use change have caused deforestation and the conversion of carbon-rich peatlands into palm-tree plantations.[64] For these environmentally related reasons, some European countries, such as the United Kingdom, are disinclined to use palm oil for biodiesel production or other energy production purposes.

For the production of 1 ton of wood-based charcoal, 5–12 tons of wood are required.[65] Due to poor post-harvest management, charcoal production, especially in countries such as Indonesia, the Philippines, and Nigeria, contributes to forest degradation. It should also be noted that there is much illegal charcoal trade in many African countries.[66] The Nigerian National Council on the Environment has called for the cessation of the production and export of charcoal from Nigeria. Thus far, this demand has been ignored by local authorities.[65] Exports of charcoal from countries such as Nigeria, but also Indonesia and Myanmar, should be questioned in terms of sustainability given the ongoing deforestation in these countries.

Conclusion

This study shows the main trade streams of industrial roundwood, wood pellets, ethanol, and biodiesel. It considers the trade in palm oil and charcoal and, more briefly, some emerging bioenergy trade flows that have been identified. The research extends knowledge of international biomass trade streams, and the overview presented can be of value for creating scenarios for the further development of biomass trade markets.

On the whole, all solid and liquid biofuels show a steady increase in production and reach a maximum in 2015, the last year studied. The conclusion can be drawn that trade stream volumes have potential to continue their growth. Interestingly, use of palm oil for energy has increased in the EU despite concerns about related environmental issues. Perspectives for the palm oil trade for energy seem unclear due to sustainability issues, which have been the subject of considerable debate. In the long term, additional bioenergy trade flows, both as regards the products traded and the trading routes used, can be expected to emerge and establish their own niche in international biomass trade in biomass for energy.

Our findings show that the biomass trade for energy covers many different countries and many different products. In recent years, Asian markets have developed considerably; for example, Malaysia and Indonesia (palm oil), and Thailand, Vietnam, South Korea, and Japan (wood pellets). Further increasing demand on Asian markets will play an increasingly important role in the global wood pellet trade, which can be expected to change current global trade streams. In Europe, the Baltic countries Estonia, Latvia, and Lithuania have made much progress in the export of wood pellets. The EU is the main leader in biomass utilization and the main importer of most biomass products. Divergent policy regulation and large price differentials have led to complex wood pellet trade streams within the EU.

Many different factors influence current biomass trade streams, such as historical bioenergy development, availability of biomass resources, policy regulations, and sustainability certification. Future scenarios of trade streams of biomass for energy and detailed investigation of the interplay of the various factors influencing the biomass trade could be interesting topics for future research. Future research could also consider the role of agricultural products (such as oil seeds, but also other agricultural products) and indirect trade of these for energy; and the potential role in international markets of currently non-traded bioenergy products such as municipal and biomass waste.

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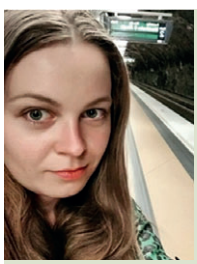
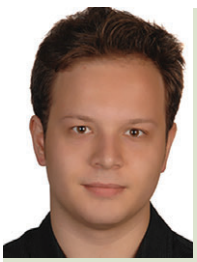


Svetlana Proskurina
Svetlana Proskurina is a junior researcher at the Lappeenranta University of Technology. Her research interests include biomass trade and logistics. Her work includes wood pellets and other solid biofuels, their markets, transportation, and applications, as well as sustainability and certification aspects.

Prof Dr Martin Junginger
Martin Junginger holds the Bio-Based Economy Chair at the Copernicus Institute, Utrecht University. He leads a research group of 20 researchers working on sustainable biomass production, supply chains, conversion, and end use for energy and materials. He also leads IEA Bioenergy Task 40 on sustainable biomass markets and international trade to support the biobased economy.

Dr Jussi Heinimö
Jussi Heinimö has nearly 20 years of experience in applied research and development projects in the field of energy technology. He holds a DSc (Tech) degree in energy technology from Lappeenranta University of Technology (LUT). Currently, he works as program director at Mikkeli Development Miksei Ltd. Since 2004, he has also been a member of IEA Bioenergy Task 40 on sustainable biomass markets and international trade to support the biobased economy.



Beysin Tekinel
Beysin Tekinel has worked as a Junior Researcher at Lappeenranta University of Technology. His research interests include sustainability, municipal solid waste management, waste to energy, and bioenergy.

Prof Dr Esa Vakkilainen
Esa Vakkilainen currently works at Lappeenranta University of Technology as professor of sustainable energy systems. His professional career started in the 1980s as assistant professor of power plants. His main interests have been fouling of heat transfer surfaces, fuel delivery, air distribution, and combustion. He teaches and researches furnace heat transfer, optimization of power plant cycles, district heating, and combustion of biofuels.

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