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Production and trading of biomass for energy – An overview of the global status

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ABSTRACT

The markets for industrially used biomass for energy purposes are developing rapidly toward being international commodity markets. Determining international traded biomass volumes for energy purposes is difficult, for several reasons, such as challenges regarding the compilation of statistics on the topic. While for some markets (pellets and ethanol) separate overviews exist, no comprehensive statistics and summaries aggregating separate biomass streams are available. The aim of this paper is to summarise trade volumes for various biomasses used for energy and to review the challenges related to measurement of internationally traded volumes of biofuels. International trade of solid and liquid biofuels was estimated to be about 0.9 EJ for 2006. Indirect trade of biofuels thorough trading of industrial roundwood and material byproducts comprises the largest proportion of trading, having a share of about 0.6 EJ. The remaining amount consisted of products that are traded directly for energy purposes, with ethanol, wood pellets, and palm oil being the most important commodities. In 2004–2006, the direct trade of biofuels increased 60%, whereas indirect trade has been almost constant. When compared to current global energy use of biomass (about 50 EJ yr^{-1}) and to the long-term theoretical trading potential between the major regions of the world (80–150 EJ yr^{-1}), the development of international trade of biomass for energy purposes is in its initial stage, but it is expected to continue to grow rapidly.

1. Introduction

Commitments to decreasing greenhouse gas emission, desire to secure and diversify the supply of energy and uncertainties related to oil price are rendering various biomass types more interesting fuels in industrialised countries, and the modern use of biomass is increasing rapidly in many parts of the world. To meet the growing demand, biomass has to be transported longer distances, even from other continents. This trade is in its initial phases, with wood pellets, ethanol, and palm oil being typical examples. However, good statistics on the global international trade in biofuels are not available. While for some markets (e.g., wood fuels, ethanol and vegetable oils) separate overviews exist (see e.g., [1–6]), no comprehensive overview is available for global biomass trade. Yet, such an overview is highly relevant for market actors and policy-makers.

In an optimal case, figures on international biofuels trade are available directly from the international statistics, but in practise this is often not the case, despite a multitude of international authorities, agencies, institutions, and enterprises compiling and publishing biomass and biomass product statistics. Determining international trade volumes for solid and liquid biofuels are difficult for several reasons.

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First, many biomass streams are traded for material purposes but ultimately end up in energy production. Second, biomass streams can have several final applications, among them are palm oil (feedstock for biodiesel or for food applications) and ethanol (transportation fuel or as feedstock for the chemical industry). Third, some biomass fuels, such as wood pellets and bio-ETBE, are recorded in aggregate form by foreign trade statistics. For example, wood pellets are recorded under the same code as wood waste in the EU's trade statistics, thus making it difficult to assess the exact volume.

The main aim of this paper is to summarise the current status of international biofuels trade as illuminated by several separate sources. Sections 2 and 3 review the present role and long-term opportunities of biomass in the global energy supply. The scale of international biofuels trade is identified by biofuel type, in Section 4. Next, in Section 5, the global trade streams of the most important biofuels are highlighted, and then a summary and conclusions are presented.

2. The contribution of biomass to the world's energy supply

Fossil fuels – oil, coal, and natural gas – dominate the world energy economy, covering more than 80% of the total primary energy supply of 479 EJ (see Table 1). Renewable energy sources accounted for 12% (59 EJ) of the world's total primary energy demand in 2005 [7]. Because of its widespread non-commercial use in developing countries, biomass is by far the greatest source of renewable energy (48 EJ). Approximately two-thirds of biomass is used for cooking and heating in developing countries [8]. The remaining energy use of biomass takes place in industrialised countries where biomass is utilised both in industrial applications within the heat, power, and road transportation sectors and for heating purposes in the private sector.

Generally, biomass has been a marginal source of energy in industry and district heating. However, in countries such as Sweden, Finland, and Austria, which have a large forestry sector, forest-based biomass has a remarkable importance. For example, in Finland, renewable energy sources account for 24% of the total primary energy consumption, and 85% of renewable energy is was derived from wood [9].

Table 1 – Proportions of various energy sources in the world's total primary energy supply in 2005 [7].

Source of energy	Energy (EJ)	Share
Coal	121	25.3%
Oil	168	35.0%
Natural gas	99	20.7%
Nuclear	30	6.3%
Hydropower	11	2.2%
Combustible renewables and waste	48	10.0%
Others	2	0.5%
Total	479	100%

Biomass fuels approximately 1% of global electricity production and it is often used in combined heat and power production. The global biomass power generation capacity is approximately 36 GW. Global consumption of liquid biofuels in transportation was 0.8 EJ in 2004, of which the United States accounted for 44%, Brazil for 41%, and Europe for 13%. The share of biofuels in total global transport consumption was about 1%. [8]

International climate agreements are the ultimate determining factor for continuing ongoing positive development of bioenergy. Most industrialised countries have committed themselves to a significant decrease in greenhouse gas emissions via the Kyoto Protocol. An important means of attaining this goal is increasing the share of renewable energy sources in the total energy supply. The EU, for example, aims to double the use of biomass from the 2003 level by 2010 [10].

3. Long-term biomass production potential for energy purposes

Despite the current minor contribution of modern bioenergy to the global energy mix, biomass has, in the long run, potential to contribute much more significantly to the global energy supply. Numerous studies have been carried out to estimate the potential to harvest energy from biomass. A review of the 17 studies carried out by Berndes et al. in 2002 revealed greatly differing estimates of the contribution of biomass to the global energy supply, from below 100 EJ yr^{-1} to above 400 EJ yr^{-1} in 2050 (see Fig. 1) [11]. Nevertheless, it was clarified that the largest biomass production potential will lie in large-scale energy plantations in areas with a favourable climate for maximising the production of biomass. The major reason for the differences between the results of the various studies is that the most crucial parameters – land availability and yield levels in energy crop production – are very uncertain and thus subject to widely varying opinions and assumptions for underlying scenarios.

Later, several new studies tackled the issue see, e.g., sources [12–14]. In the most optimistic scenarios, biomass meets more than the current global energy demand, without competing with wood production, forest production, and biodiversity. Table 2 gives a summary of biomass production potential in the light of the latest studies, by biomass category, and shows the main assumptions made in the determination of these figures. In total, the expected contribution to the world's primary energy supply could be in the range of 250–500 EJ [15]. A recent literature review by Dornburg et al. investigated how factors such as food supplies, water use, biodiversity, energy demands, and agro-economics affect these potentials [16]. Their main conclusion was that, even in applying strict criteria, excluding areas with water stress or high biodiversity value, a minimum of 250 EJ is likely available. Latin America, Sub-Saharan Africa, and Eastern Europe, along with Oceania and East and North-East-Asia, have the most promise to become important biomass producers in the long term, while the main demand is in the OECD countries and South-East-Asia. Therefore, international bioenergy trade will play a pivotal role in developing this potential.

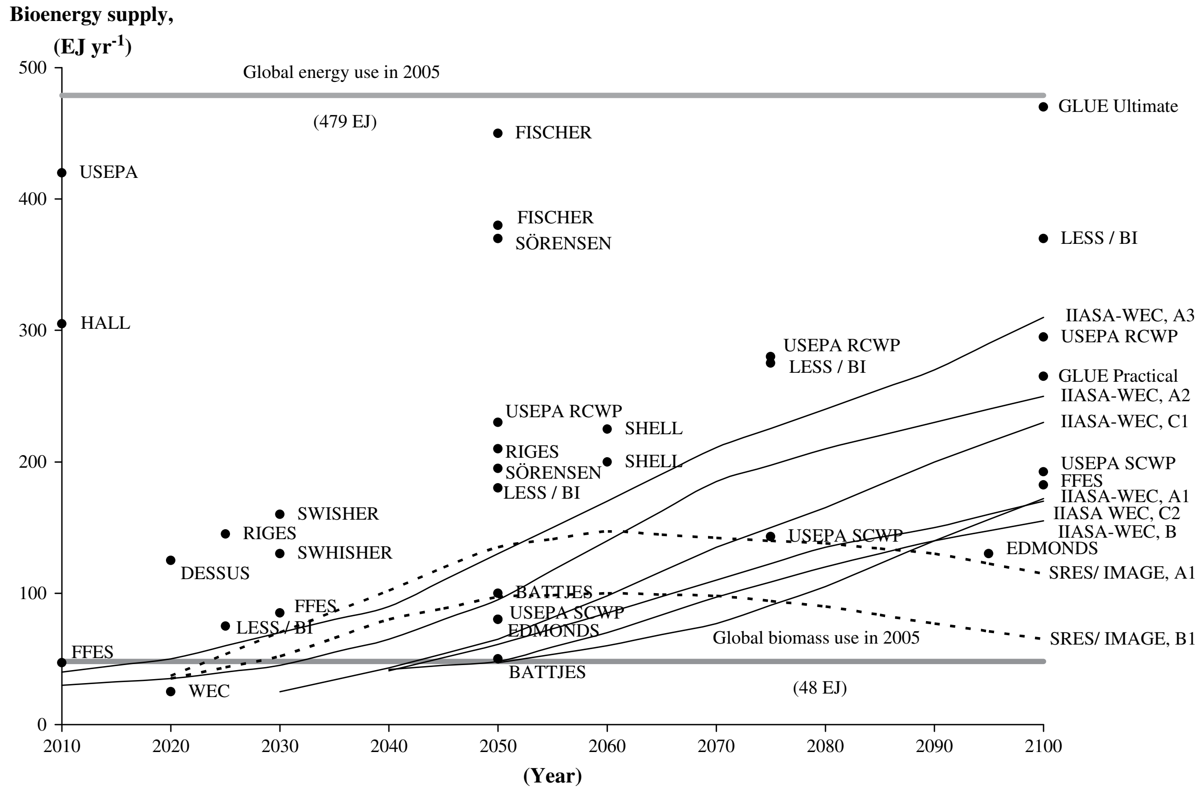

Fig. 1 – Results from 17 studies that have evaluated the potential to harvest energy from biomass up to 2100. Small circles and lines indicate results from various studies. Note that global primary energy consumption was projected to increase from the current level over the coming decades, but the upper grey line indicates the present consumption. Data obtained from Refs. [7,11].

4. International trade of biomass for energy purposes

4.1. *Interconnection between trade streams of biomass and biofuels*

A significant number of cross-border streams that include biomass in diverse forms can be found. These streams of biomass – raw, processed, or within products – together with their various end-use purposes constitute a complex field that is outlined simply in Fig. 2.

Imported biomass or a product that includes biomass can be processed in the import country into more refined final products, which are then consumed in the country or exported onward. Foreign biomass that has entered the country can be used as fuel, e.g., wood pellets. Nevertheless, some products, such as ethanol or some forest–industry byproducts, can be used for both energy and raw material purposes, making it necessary to know where the products are consumed. Biomass is also traded for biofuels production – e.g., palm oil for biodiesel – and this will be a more common trend when large bio-refineries produce liquid biofuels for road transport. Eventually, most of the products that include biomass end up in recycling and energy production.

4.2. *International trading of biomass*

Ethanol, vegetable oils, fuel wood, charcoal, and wood pellets are the most important products that currently are internationally traded for energy purposes. Nevertheless, the international trade of these products is much less than the international trade of biomass for other purposes. Table 3 depicts the volumes of global production and international trade of various biomass products in 2004–2006. Most of the biomass products reviewed are mainly consumed locally in the countries of production, but in the case of products such as sawn timber, paper and paperboard, palm oil, and wood pellets, a considerable proportion of the total production is exported.

4.3. *Indirect trade of biofuels*

When the definition of biofuel is considered, biomass becomes biofuel when it is purchased for energy use or, in some cases, when it is consumed in energy production. The examination of international biofuels trade becomes complicated if all biomass streams, including forest products, agricultural products, and biodegradable wastes, are counted. It is rather easy to determine the calorific values of the above-mentioned products in the state in which they cross a national border. However, determining to what extent the bioenergy production of a country is based on imported forest products, food, fodder, and municipal waste is troublesome for several reasons. (1) The streams of these products, until the carbon they include is oxidised into CO_2, are complex and difficult to observe. Fibres of paper are often recycled and exported several times during their lifetime. For example, exported paper or cardboard can return to the country within packaged products and later be utilised in energy production as recovered fuel or biogas. Organic

Table 2 – Overview of the global potential of bioenergy supply on the long term for a number of categories and the main conditions and assumptions determining these potentials [15].[a]

Biomass category	Main assumptions and remarks	Potential bioenergy supply up to 2050 (EJ yr^{-1})[b]
Energy farming on current agricultural land	Potential land surplus: 0–4 Gha (most scenarios find 1–2 Gha on average). A large surplus requires structural adaptation of intensive agricultural production systems (i.e., modernisation of all aspects). When this is not feasible, the bioenergy potential could be reduced to zero. On average, higher yields are likely because of better soil quality: 8–12 dry ton ha^{-1} yr^{-1} is assumed.[c]	0–700 (100–300)
Biomass production on marginal lands	On a global scale, a maximum of 1.7 Gha could be involved, with low productivity of 2–5 dry ton ha^{-1} yr^{-1}.[c] The supply could be low or zero on account of poor economics or competition with food production.	0–150 (60–150)
Residues from agriculture	Potential depends on yield/product ratios and the total agricultural land area as well as the type of production system. Extensive production systems require reuse of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15–70
Forest residues	The (sustainable) energy potential of the world's forests is unclear. Some is natural forest (reserves). The range is based on data in the literature. The low-value figure is for sustainable forest management, while the high value represents technical potential. Figures include processing of residues.	0–150 (30–150)
Dung	For use of dried dung, the low estimate is based on current global use, while the high estimate indicates technical potential. Longer-term utilisation collection) is uncertain.[d]	(0) 5–55 EJ
Organic wastes	The estimate is based on values in the literature and strongly dependent on economic development, consumption, and the use of bio-materials. Figures include the organic fraction of MSW and waste wood. Higher values are possible through more intensive use of bio-materials.	5–50 +[e]
Total	Most pessimistic scenario: no land available for energy farming; only utilisation of residues. Most optimistic scenario: intensive agriculture concentrated on better-quality soils. (In brackets: average potential in a world aiming for large-scale use of bioenergy.)	40–1100 (250–500 EJ)

a The overview is based on a review of 17 studies and on Refs. [11,12,14]. The range of the land area required to meet the potential additional global demand for bio-materials (such as bio-plastics or construction materials) is not included here. Increased use of bio-materials would, however, also raise volumes of organic waste.

b Where two ranges are given, the numbers in brackets give the range of average potential in a world aiming for large-scale utilisation of biomass. A lower limit of zero implies that potential availability could be zero, e.g., if we fail to modernise agriculture and thus more land is needed to feed the world.

c Calorific value: 19 GJ per ton of dry matter.

d Note that traditional use of dung as fuel should be discouraged. The dung potentials shown here mainly relate to intensive agriculture, which offers opportunities for fermentation and production of biogas.

e The energy supply of bio-materials ending up as waste can vary between 20 and 55 EJ (or 1100 and 2900 Mt of dry matter) per year. This range excludes cascading and does not take into account the time delay between production of the material and 'release' as (organic) waste.

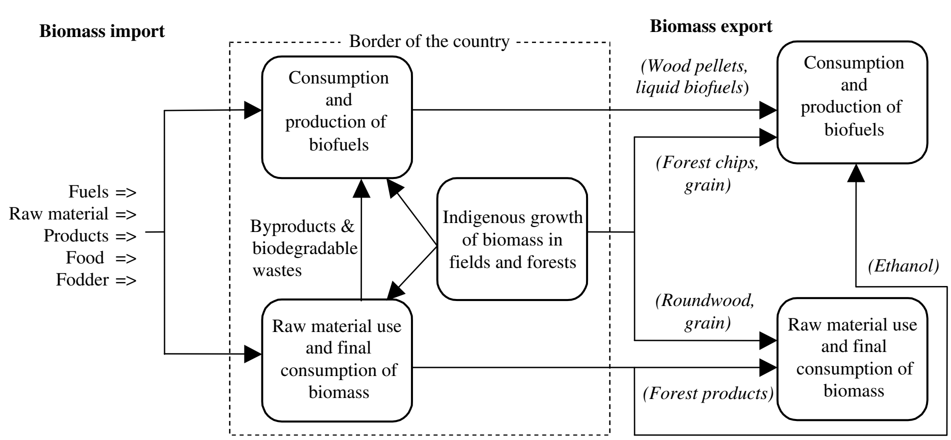

Fig. 2 – An illustration of biomass streams within a country and between countries. Products presented in brackets represent examples of products [17].

Table 3 – An overview of world production and trade volumes of selected agricultural and forestry commodities with potential energy application in 2004–2006.

Product/year	Unit	World production			International trade volumes		
		2004	2005	2006	2004	2005	2006
Industrial wood and forest products:[a]							
Industrial roundwood	Mm^3	1656	1709	1684	121	131	129
Wood chips and particles	Mm^3	215	222	232	39	43	44
Sawn timber	Mm^3	421	426	427	133	134	133
Pulp for paper production	Mt	190	189	190	42	42	43
Paper and paperboard	Mt	355	354	354	111	113	114
Agricultural products:[a]							
Maize	Mt	727	713	695	83	90	95
Wheat	Mt	633	629	606	118	121	125
Barley	Mt	154	141	139	22	25	24
Oats	Mt	26	24	23	3	3	3
Rye	Mt	18	15	13	2	2	2
Rice	Mt	607	632	635	2	2	2
Palm oil	Mt	31	34	37	23	26	29
Rapeseed	Mt	46	50	49	9	8	11
Rapeseed oil	Mt	15	16	17	2.6	3.1	4.1
Solid and liquid biofuels:							
Ethanol[b]	Mm^3	40.8	46.0	51.1	2.7	3.0	4.3
Biodiesel[c]	Mt	2.3	3.6 (2.7–3.8)	5.3	n.a.	0.2	0.4
Fuel wood[a]	Mm^3	1771	1824	1827	4	4	4
Charcoal[a]	Mt	46	43	43	1.1	1.3	1.4
Wood pellets[d]	Mt	4.0 (3.7–4.8)	5.5 (4.6–6.5)	7.8 (7.1–8.4)	1.5 (1.2–1.7)	2.4	3.6

a Source [18].
b These numbers cover total ethanol trade – i.e., trade for all end uses. Sources [19–21].
c The main numbers of biodiesel production are the best estimates of the authors, with lower and upper estimates in brackets. Data from sources [22–25]. Figures of biodiesel trade are from source [2] and are net trade. I.e. if a country imports 1 million and exports 2 million tonnes biodiesel, they will only report 1 million 'net export'.
d International trade volumes should be seen as rough estimates. The values presented are estimated averages, with lower and upper estimates in brackets, based on published production capacity and/or production volumes. Sources [26–29].

waste includes fractions that have grown outside the country, and it is difficult to determine the exact amount of foreign-based matter in this fraction. (2) The lifetimes of these products vary a great deal, and only a part of the products end up in energy in the same year they have been imported. For example, the lifetime of wood used in building materials is typically decades. (3) Only a part of these products finally end up in energy production; the rest is oxidised without energy recovery. The utilisation rate varies between waste fractions and depends also on the waste management and recycling systems applied in the country concerned.

The forest industry procures wood primarily to be used as raw material. In many cases, the wood is imported from other countries. For example, Finland imports large amounts of raw wood (logs, pulpwood, and chips) from, amongst others, Russia. In the manufacturing processes of the primary products, a significant amount of the raw wood ends up in energy production or is converted into byproducts utilised in energy production. Biofuel purchase and use of this kind is referred to in this study as indirect import of biofuels, and the corresponding export is called indirect export of biofuels. The previously mentioned wood streams jointly constitute indirect trade of biofuels.

On average, 40–60% of roundwood can be converted into forest products in the forest industry. The rest remains as byproducts such as black liquor, bark, sawdust, and chips, that have no feasible raw material use within the forest industry. The conversion efficiency for raw wood varies between the production processes of different products, and the level of technology applied and the integration of the production processes affect conversion efficiency as well. For instance, mechanical wood processing can convert wooden raw material into products more efficiently than chemical pulp-making.

4.4. *Overview of the international biofuels trade*

Three different biomass categories are included in the overview in this study:

- Biofuels (products traded for energy production, such as fuel ethanol, wood pellets, and firewood)
- Raw materials that are traded for manufacturing of biofuels (e.g., sawdust and pulpwood that is used in pellet production or pre-processed biomass that is used in the production of liquid biofuels)
- Raw wood (wood matter that is used in the manufacturing of forest products)

Table 4 gives an estimate of the scope of international trade of biomass for energy purposes in 2004–2006. The trade volumes used in the calculations were derived from Table 3. In the case of ethanol and palm oil, the final use is not always clear, and some assumptions must be made as to how much of the total trade is earmarked for fuel use. Currently, indirect trade of biofuels through trading of industrial roundwood and material byproducts composes the largest share of the trade. The trading represents approximately 5% of the total use of biofuels in industrialised countries.

4.5. *Prospects*

In many areas, regionally and nationally, biomass production potential cannot meet the demand. Typical examples are industrialised countries such as EU members, the USA, and Japan. On the other hand, there are areas where biomass production potential exceeds local demand, such as many parts of Sub-Saharan Africa and Latin America. However, local use of biomass is often more reasonable than exporting, especially when fossil fuels can be replaced by local biomass fuels, and for this reason imported biomass will account for only a limited proportion of the global energy use of biomass.

Taking the local production and usage potentials into account, Hansson and Berndes have estimated the global potential for biofuels trade flow between different world regions to be 80–150 EJ in favourable conditions in 2050 [32], which can be seen as a theoretical upper limit for international biofuels trade. Compared to the long-term potential, the development of international trade of biomass for energy purposes is in its early stages (see Table 4). The next section discusses three major biomass trade streams: industrial roundwood, ethanol, and wood pellets.

Table 4 – An estimate by the authors of the scope of international trade of biofuels in 2004–2006, (PJ); tall oil, ETBE, and wastes are excluded.

Year/product	2004	2005	2006
Indirect trade:	580	640	630
• Industrial roundwood[a]	450	490	480
• Wood chips and particles[b]	130	150	150
Direct trade:	190	230	300
• Ethanol[c]	70	80	120
• Biodiesel[d]	2	7	15
• Fuel wood[e]	40	40	40
• Charcoal[f]	20	20	20
• Wood pellets[g]	30	40	60
• Palm oil[h]	30	40	40
Total	770	870	930

a Roundwood in FAO's statistics [18] is without bark, so 10% bark was added. Other assumptions: average density of 0.8 ton m^{-3}, 45% average conversion into biofuels, and calorific value of 9.4 GJ t^{-1}.
b Assumptions: average density of 0.8 ton m^{-3}, 45% average conversion into biofuels, and 9.4 GJ t^{-1} calorific value.
c Assumed calorific value: 27 GJ m^{-3}.
d Authors' estimate based on sources [2,23]. Assumed calorific value: 37 GJ t^{-1}.
e Assumed density and calorific value of 0.7 t m^{-3} and 13 GJ t^{-1}.
f Assumed calorific value: 22 GJ t^{-1}.
g Assumed calorific value: 17.5 GJ t^{-1}.
h According to Ref. [30], the EU-25 and China have by far the greatest industrial consumption of palm oil among the countries that have no palm oil production of their own. The assumptions made for the estimation were that in 2004–2006 the EU was the only significant user of palm oil for energy among the countries with no palm oil production and that in the EU the oleo chemical industry's use of palm oil has been 0.3 Mt yr^{-1} and the rest was used for energy purposes. These assumptions and data from source [31] gave for the trade volume of palm oil for energy 0.7 Mt in 2004, 1.0 Mt in 2005 and 1.1 Mt in 2006. The calorific value of palm oil was assumed to be 37 GJ t^{-1}.

5. Main global trade streams

5.1. *Industrial roundwood*

Forest biomass is the major raw material of the forest industry and has an important role as a source of bioenergy. Forest covers 30% of the earth's land area, of which about 96% are natural forests and 4% are plantations [33,34]. The worldwide average woody biomass is 109 ton per hectare of forest land. Brazil (101 000 Mt), Russia (64 000 Mt), and the USA (38 000 Mt) have the largest biomass resources in their forests [34].

The current rate of utilisation of forest resources varies between the various regions of the world. Deforestation, poor forest management, and overuse of wood resources are serious problems in several areas, but, on the other hand, in many parts of the world the sustainable utilisation of forest resources can be increased. Some FAO estimates show that the global production of industrial roundwood and wood fuel reached a total of 3510 Mm^3 in 2006 [18]. As much as 52% of this was fuel wood, and about 90% of fuel wood is currently produced and consumed in developing countries for cooking and heating [18]. In 2006, the total production of industrial roundwood was 1684 Mm^3, with the USA (428 Mm^3), Canada (203 Mm^3), Russia (145 Mm^3), Brazil (118 Mm^3), and China (95 Mm^3) being the largest producers [18].

Industrial roundwood is a rather local product. More than 90% of the industrial roundwood produced is consumed locally in the countries in which it is produced. However, industrial roundwood is one of the most important biomass products in world trade, and unprocessed wood has been shipped increasingly to markets further from where it is harvested (see Table 3). The wood import regions are East-Asia (mainly China and Japan) and the Nordic countries. Russia, Eastern Europe, Oceania, and North America are the main sources of exports (see Fig. 3).

Since the collapse of the Soviet Union, Russia has become the largest wood exporter in the world, currently accounting for about 40% of global roundwood trade. The transition to a market economy in the early 1990s bled the Russian forest industry badly, resulting in collapse of both demand in Russian internal markets and production volumes, as well as stagnation of investments in the industry. The decline in wood demand has increased wood supply for export in Russia. Despite the positive development of the Russian forest industry in recent years, the commercial utilisation of the forest resources in Russia is still modest. In 2006, wood export from Russia totalled 51 Mm^3, about 35% of the country's roundwood production. East-Asia and Europe are the major importers of Russian roundwood. Russia aims strongly to increase the local processing of its wood resources and has launched a programme to raise export duties of roundwood in 2007–2011. By

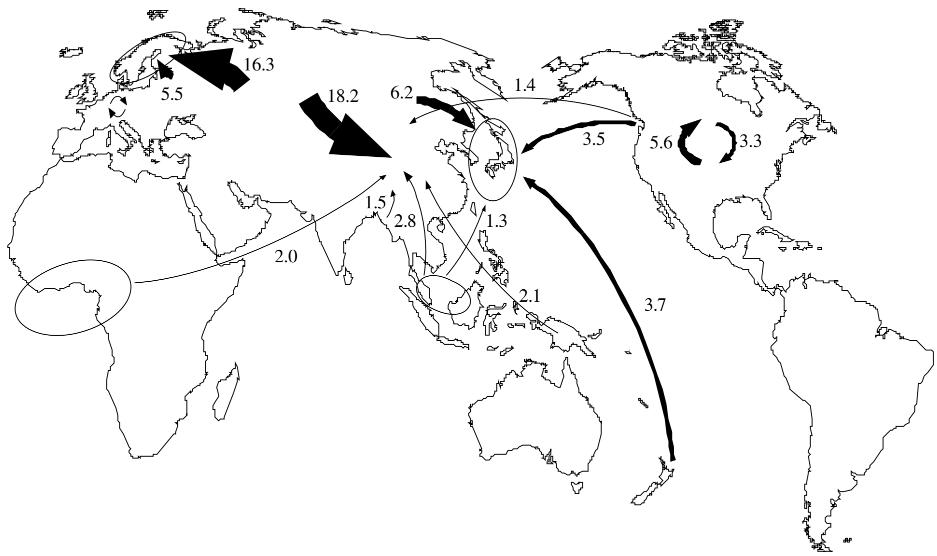

Fig. 3 – Main global trade streams of industrial roundwood (Mm^3 without bark). In 2006, the total trade volume of industrial roundwood was 129 Mm^3. Figures are without bark and include wood chips. Information was obtained from Ref. [18].

2011, the export duties will have been raised gradually by 80%, meaning an increase of approximately €50 (solid m^3)$^{-1}$ in the price of exported roundwood, which will probably decrease export of Russian wood in the coming years [35].

In 2006, China (33.2 Mm^3), Finland (14.7 Mm^3), and Japan (10.7 Mm^3) were the world's largest importers of industrial roundwood. The rapid development of the local economy has increased demand for raw materials in China. China's own forests meet only part of the growing roundwood demand. Since 2004, China has been the world's largest importer of roundwood. In 2006, approximately a fourth of the total roundwood consumption in the country was imported. [18]

5.2. *Wood pellets*

The production and international flow of wood pellets is possibly one of the most successfully traded biomass commodities. Wood pellets offer a number of advantages over other solid biomass fuels: they generally have a low moisture content and a relatively high calorific value (about 17 MJ kg^{-1}), which allows long-distance transport by ship without affecting the energy balance. Handling during transport is relatively easy, and they can be stored over long periods without significant loss of dry matter. These attractive properties have caused the demand for wood pellets to soar in the last few years. Applications of wood pellets range from small-scale residential heating to large-scale co-firing in coal power plants. In 2006, the majority of global wood pellet production (and consumption) took place in Europe. On the basis of a survey conducted by Bioenergy International [26], we estimated that in 2006 upto 6.4 Mt of wood pellets may have been produced in Europe, compared to about 1.2 Mt in Canada and 0.8 Mt in the USA (see also Table 5). The data in Table 5 should be considered as rough estimates (especially estimated total production), yet they give a good picture of production in the different regions.

Estimating global pellet trade is challenging, as there are no official statistics for wood pellets, and the market is immature and developing rapidly. In a recent publication of EUBIONET [1], total import to a number of EU countries of wood pellets (including refined wood fuels and briquettes) amounted to about 30 PJ (approximately 1.7 Mt) in 2004. The authors estimate that about 35% of all wood pellets produced in Europe (including Eastern European countries such as Ukraine and Russia) are traded across a border. From this assumption and imports from the USA and Canada, we estimate that international trade in wood pellets may have reached more than 3.6 Mt (60 PJ) in 2006 – i.e., doubled within two years. The main trade streams of wood pellets are depicted in Fig. 4.

In more detail, currently, the most important wood pellet exporting country in the world is Canada. Manufacture and export of wood pellets in Canada has grown exponentially for the past several years, primarily exports from Canada's west coast (British Columbia) to Europe. Increasing from about 400 kilotonnes in 2004, this export reached about 625 kilotonnes in 2006 [36], making Canada by far the largest wood pellet exporter in the world. Other important pellet exporting countries are the Baltic States, Finland, and other Eastern European states. Sweden is probably still the most important country of import. Pellets are imported mainly from Canada to the Baltic States, and Finland [38]. As rising import countries, Belgium, Denmark, the Netherlands, Sweden, the UK, and (most recently) Italy are all major players. Especially in Italy, sales of residential pellet stoves increased strongly in 2005–2006, and huge demand was expected, reportedly leading to large volumes of wood pellets being imported (also from Austria) to Italy. After a very mild winter and consequent lower demand than expected, it is now reported that Italy is exporting pellets again. More structural is the demand in countries such as Belgium, The Netherlands, and The UK, where the pellets are used for large-scale co-firing in coal-fired power plants. The demand is created by governmental support measures (e.g., feed-in tariffs). These countries have reported structural imports of several hundred kilotonnes in 2004–2005 (see Refs. [39–41]).

Table 5 – Estimated global wood pellet production in 2006 [26,36].

	Reported capacity (k ton y^{-1}) [a]	Reported production (k ton)[b]	Estimated production (k ton)[c]
Sweden	1144	1128	1297
Canada	–	1200	1200
US	–	800	800
Austria	970	290	756
Russia	862	–	647
Germany	843	342	640
Denmark	667	40	480
Latvia	540	380	451
Poland	365	256	450
Finland	556	259 [d]	259 [d]
Estonia	380	240	338
Italy	244	–	183
France	–	146	146
Lithuania	120	70	108
Other Europe	639	211	471
Total	7330	5362	8226

a Capacity reported per individual plant. In some cases capacity was not given.
b Production reported per individual plant. In some cases production volumes were not given.
c In many cases, pellet mills reported capacity but not actual production. The average production load factor of all plants that reported both capacity and production, when averaged overall countries, was about 0.75. With this load factor, a production volume was estimated for all plants that reported only their capacity.
d Source [9].

Regarding future development in wood pellet trade, Canada probably has excellent opportunities to increase its pellet exports further. However, also Eastern European countries such as Poland, Belarus, and Russia have huge resource potential, which must be developed. Import developments depend to a large extent on the development of governmental support measures but in the short term also on meteorological conditions, as illustrated above. Overall, it can be expected

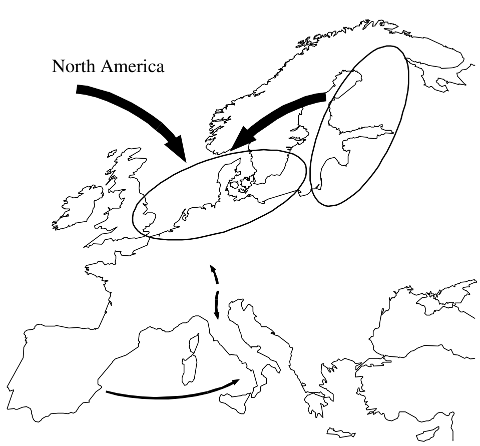

Fig. 4 – Major international trade streams of wood pellets in 2004–2006. The estimated total trade volume increase ranges from 1.2 to 1.7 Mt in 2004 to up to 3.6 Mt in 2006. Data obtained from Ref. [37] and the authors' estimates.

Table 6 – Estimated global ethanol production in 2004–2006 by country [44–46].

Country/region	Production, in Gl		
Year	2004	2005	2006
Brazil	15.1	16.0	17.0
USA	13.4	16.1	18.4
China	3.6	3.8	3.9
India	1.7	1.7	1.9
Rest of the world	7.0	8.4	9.9
Total	40.8	46.0	51.1

that demand for wood pellets will remain to grow greatly in (Western) Europe.

Given the differing availability and demand for wood pellets, different costs of feedstock, and the immature nature of the wood pellet market, production costs and price levels may cover a wide range globally. These price differences are, of course, the major driver behind the developing international pellet trade. Prices may vary with the country and season, and they are generally higher for small-scale end consumers than for large industrial consumers. End-consumer prices in five European countries were €7–13 GJ^{-1} (incl. VAT) in 2005 and €8–18 GJ^{-1} in 2006 [1].

5.3. *Bio-ethanol*

Ethanol is a commodity that – whether produced from biomass or fossil feedstocks – has been produced and traded globally in large volumes for decades. The (bio-) ethanol market is well-developed, as is the logistical infrastructure in many countries (see, e.g., Ref. [42]).

In 2005, about 60% of ethanol production was based on sugar crops, 30% from grains, 7% corresponding to synthetic ethanol, and 3% from other raw materials [6]. For decades, Brazil was the world's largest producer and consumer of ethanol, but it was surpassed by the USA in 2005 (see Table 6). Worldwide, Brazil is the largest producer of sugarcane. It was estimated that production in the 2005–2006 harvest season reached 410 Mt [43]. Sugarcane production has risen by, on average, 9.7% per year during the years 2001–2006. Besides the increase in domestic demand for bio-ethanol, other factors are pushing the growth of the sugarcane industry in Brazil, such as: (1) high demand for sugar in the domestic and international market, (2) the rise of bio-ethanol exports, and (3) continuous improvements in productivity. In 2006, Brazil had around 320 combined sugar mills and bio-ethanol distilleries, with a further 51 under construction, including new plants and expansion of existing ones. The bio-ethanol production capacity was estimated at 18 Gl yr^{-1} [43].

The USA and Brazil are dominating ethanol market producing 70% of the world's ethanol. In the USA, ethanol is produced 97% from corn [47]. In the end of 2006, the USA had around 100 sugar mills [20]. The United States is expected to continue as the world's largest ethanol producer. The Energy Policy Act of 2005 established the renewable fuels standard (RFS), which prescribes production volumes of renewable fuels of upto 28 Gl in 2012 [6].

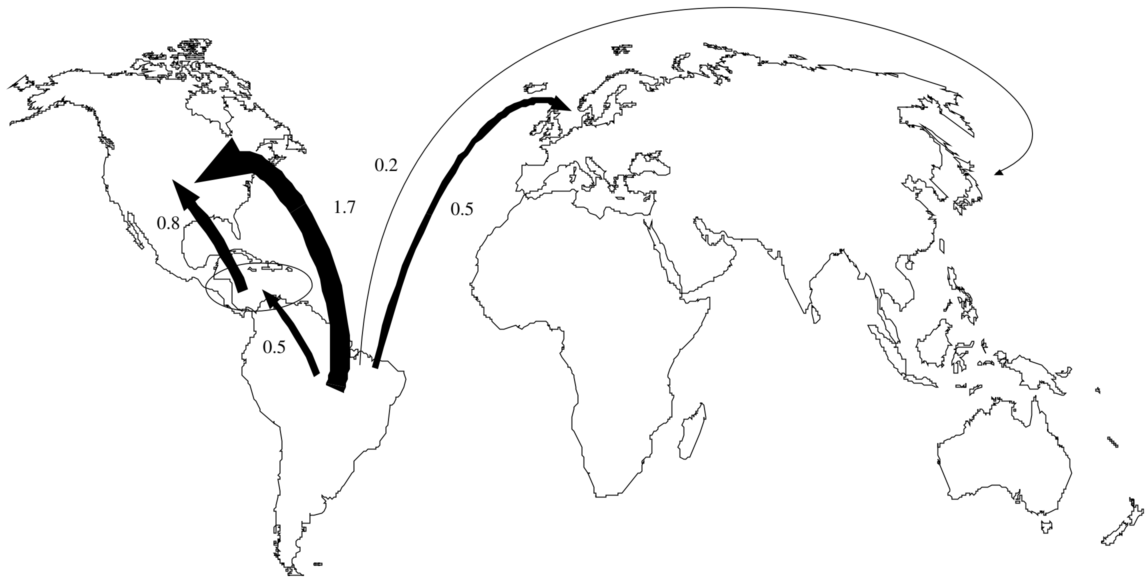

Fig. 5 – Major ethanol trade streams in 2006, in Gl. The total volume of the trade was approximately 4.3 Gl (120 PJ) in 2006 [21,46].

Data related to fuel ethanol trade are imprecise on account of the various potential uses of ethanol (fuel, industrial use, and beverage use) and also because of the lack of proper codes for biofuels in the Harmonized System Commodity Description and Coding System (HS) [48]. Fuel ethanol is traded under HS code 2207, covering denatured and un-denatured alcohol. Both can be used as fuel ethanol, but denatured ethanol is often used as a solvent [48]: a material is added to the ethanol to make it undrinkable [42].

In ethanol trading, Brazil is the largest exporter, with the USA and the EU being, correspondingly, the largest importers (see Fig. 5). In 2006, the total trade of ethanol was estimated to be 4.3 Gl, with Brazil (3.5 Gl) as the main exporter, and the USA, Japan and the EU as the main importers [19–21].

Fig. 6 shows Brazil's bio-ethanol trade since 1980. Market opportunities and constraints have determined exports and imports. A Significant amount of alcohol was imported in the 1990s, first during the supply shortage of bio-ethanol (1990–1991) and later when international sugar markets were favourable for exports (1993–1997). Traditionally, Brazilian exports of bio-ethanol have been oriented to beverage production and industrial purposes, but trade for fuel purposes has grown recently. As can be seen in Fig. 6, since 2000 Brazilian exports of bio-ethanol have risen steadily. In 2006, the exports reached 3 Gl. [47]

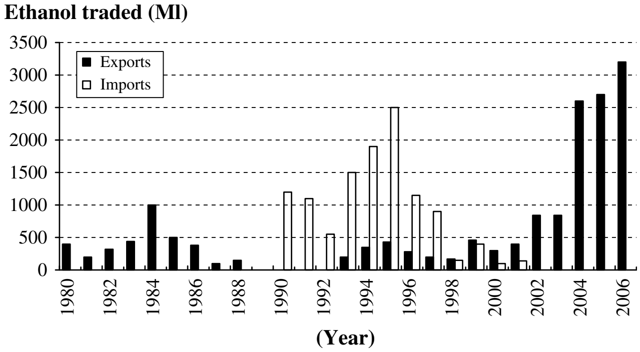

Fig. 6 – Trade in bio-ethanol in Brazil in 1980–2006 [47].

In 2002–2005, the USA imported fuel ethanol from Central America and Caribbean countries, but the volumes traded have been low (0.2–0.5 Gly^{-1}) [20]. However, in 2006 the amount imported to the USA had increased to 2.5 Gl and represented about 5% of US domestic consumption. The majority (1.7 Gl) of imported ethanol came from Brazil. The second largest import stream (0.6 Gl) came form Jamaica, Costa Rica, El Salvador, and Trinidad and Tobago [20], of which about 0.5 Gl was originally from Brazil [6].

In the EU, in 2006 net import of ethanol was estimated at 0.5 Gl The Netherlands and Sweden being the largest importers [21]. For Europe, the main port for ethanol trade is Rotterdam. The harbour of Rotterdam reported that overall traded (i.e., the sum of import and export) ethanol volume had grown from 0.25 Gl in 2002 to 1.1 Gl in 2005 and 2006, climbing over 2 Gl in 2007 [23]. The greatest proportion of the increase was determined to have been used in biofuel for transportation. In 2007, 40% of all ethanol imported came from Brazil, France being second with 10% of imports. In 2007, also Latin American countries such as Argentina, Costa Rica, Peru, and Guatemala exported ethanol to Rotterdam. On the export side, 40% of all exports were destined for Sweden, and another 15% for the UK. In comparison, the European bioethanol Fuel Association estimated that approximately 0.2 Gl of ethanol for fuel purposes was imported in 2006, compared to 0.8 Gl in 2007 [49].

6. Summary and conclusions

Direct trade of solid and liquid biofuels is growing rapidly. In the past, the volume of indirectly traded biofuels was significantly higher – e.g., three times greater than the direct streams in 2004. This is a remarkable result, which has gained little attention so far. Methodological issues related to indirect trading of biofuels have to be explored in more detail in order to allow better insights into global biomass carbon flows. Yet it is clear that the amount of directly traded solid and liquid biofuels is increasing strongly, in some cases even exponentially in recent years. This holds especially for liquid biofuels (ethanol and biodiesel), for which demand has grown tremendously in recent years in the EU and the USA, and which has triggered the export of ethanol (mainly from Brazil), vegetable oil (e.g., palm oil and soybean oil), and biodiesel from South-East Asia and Latin America. Also, pellet exports from Canada to the EU (next to large-scale intra-European trade) show strong growth rates. It is expected that direct trade volumes will overtake indirect trade within a few years.

With an estimated total volume of internationally traded biofuels of approximately 0.9 EJ in 2006, biomass trade is still a long way from its estimated long-term maximum of 80–150 EJ y^{-1}. However, given the current policy developments to stimulate the use of biofuels in, e.g., the EU and US and the current high fossil oil prices, a continuing increase in trade can be expected in the near future. Policy will affect international bioenergy trade in other ways also; examples include development of sustainability criteria for biofuels (such as the recently proposed revision to the RES directive [50]) and the changing trade tariffs for commodities such as ethanol.

In the work on this paper, it has become clear that high-quality statistics on global bioenergy trade are often unavailable, and figures had to be indirectly estimated or based on expert opinions. As recently discussed at a workshop for IEA Bioenergy Task 40 [51], the main reasons for this are:

- The indirect trade flows, which cannot be assessed (directly) via trade statistics and whose examination requires details on biomass flows and conversion patterns
- The fact that in many cases (e.g., for ethanol and vegetable oil) the final end use (energy, feedstock for the chemical industry, or food) is not known when the commodity is traded
- The lack of proper CN/HS codes to distinguish dedicated biofuels – for wood pellets and biodiesel, this has been addressed recently, but for advanced refined biofuels (e.g., torrefied pellets, pyrolysis oil, and second-generation Fischer–Tropsch diesel), it may be relevant in the future

As bioenergy trade is expected to increase strongly, reliable bioenergy trade figures are of use for industry actors, policy-makers, and scientists alike, and, on account of its expected pivotal role in developing biomass production potential in the future, it is recommended to increase efforts to collect and publish coherent bioenergy trade statistics.

REFERENCES

[1] Alakangas E, Heikkinen A, Lensu T, Vesterinen P. Biomass fuel trade in Europe summary report. VTT. Eubionet II project. VTT-R-03508–07. Jyväskylä, Finland; 2007. 55 p.

[2] Carrquiry M, Dong F, Elobeid A, Fabiosa J, Hart C, et al. U.S and world agricultural outlook. Food and Agricultural Policy Research Institute. Iowa State University and the University of Missouri-Columbia; 2008. FAPRI Staff Report 08-FSR 1. ISSN 1534-4533. 395 p.

[3] Ericsson K, Nillsson LJ. International biofuel trade – a study of the Swedish import. Biomass and Bioenergy 2004;26(3): 205–20.

[4] Hillring B. World trade in forest products and wood fuel. Biomass and Bioenergy 2006;30(10):815–25.

[5] Kaltschmitt M, Weber M. Markets for solid biofuels within the EU-15. Biomass and Bioenergy 2006;30(11):897–907.

[6] Walter A, Rosillo-Calle F, Dolzan P, Piacente E, Borges da Cunha K. Perspectives on fuel ethanol consumption and trade. Biomass and Bioenergy 2008;32(8):730–48.

[7] IEA. Key world energy statistics. Paris. Available at: http://www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf; 2007. pp 78.

[8] IEA. World energy outlook 2006; 2006. pp. 596. ISBN 92-64-10989-7-2006.

[9] Statistics Finland. Energy statistics. Yearbook 2007. Helsinki; 2007. ISBN 978-952-467-776-9.

[10] Commission of the European Communities. Biomass action plan, communication from the commission. Brussels; 7 December 2005. 47 p.

[11] Berndes G, Hoogwijk M, van den Broek R. The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy 2003;25(1):1–28.

[12] Hoogwijk M. On the global and regional potential of renewable energy sources. Doctoral dissertation, Copernicus Institute, Utrecht University. 2004. pp. 256. ISBN 90-393-3640-7.

[13] Hoogwijk M, Faaij A, Eickhout B, de Vries B, Turkenburg W. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 2005;29(4): 225–57.

[14] Smeets E, Faaij A, Lewandowski I. A quickscan of global bio-energy potentials to 2050. An analysis of the regional availability of biomass resources for export in relation to the underlying factors. Copernicus institute – Utrecht University, ISBN 90-393-3909-0; 2004. 121 p.

[15] Junginger M, Faaij A, Rosillo-Calle F, Woods J. The growing role of biofuels – Opportunities, challenges and pitfalls. International Sugar Journal 2006;108(1295):618–29.

[16] Dornburg V, Faaij A, Verweij P, Langeveld H, van de Ven, G, et al. Biomass assessment: global biomass potentials and their links to food, water, biodiversity, energy demand and economy. Climate change scientific assessment and policy analysis (WAB) programme. 2008. 98 p.

[17] Heinimö J. Methodological aspects on international biofuels trade: international streams and trade of solid and liquid biofuels in Finland. Biomass and Bioenergy 2008;32(8): 702–16.

[18] FAOSTAT data. From: http://faostat.fao.org/ [accessed 30.03.09].

[19] Beghin J, Dong F, Elobeid A, Fabiosa J, Fuller F, et al. U.S and world agricultural outlook. Food and Agricultural Policy Research Institute. Iowa State University and University of Missouri-Columbia; 2007. FAPRI Staff Report 07-FSR 1. ISSN 1534-4533. 395 p.

[20] Renewable Fuels Association. Ethanol industry statistics. From: http://www.ethanolrfa.org/industry/statistics/#E; [accessed 29.03.09]

[21] Sugarcane Industry Association Brazil. Ethanol exports by country. From: http://english.unica.com.br/dadosCotacao/estatistica/ [accessed 22.02.09].

[22] EurObserv'ER. Biofuels barometer: 5.38 Mtoe consumed in 2006 in the EU. Available at: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro179_b.pdf; 2007. May.

[23] Port of Rotterdam. Verdubbeling Rotterdamse Overslag Biobrandstoffen Doubling of liquid biofuels trade in

Rotterdam harbour. From: http://www.portofrotterdam.com/nl/nieuws/persberichten/2008/20080229_01.jsp; 2008 [accessed 29.02].
[24] REN21. Renewables 2007-Global status report. Renewable Energy Policy Network for the 21st century (REN21 Secretariat). Available at: Paris and Washington, DC: Worldwatch Institute, http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf; 2008. 54 p.
[25] Wikipedia. Biodiesel. From: http://en.wikipedia.org/wiki/Biodiesel [accessed 21.03.08].
[26] Bioenergy International. The PelletsMap 2006/07. No 6 December 2006. p. 7–15.
[27] Bioenergy International. The Pellets map 2005/06. No 6 December 2005. p. 3–13.
[28] Bioenergy International. The Pellet Map 2004. No 11 December 2004. p. 1–7.
[29] Peksa-Blanchard G, Dolzan P, Grassi A, Heinimö J, Junginger M, et al. Global wood pellets markets and industry: policy drivers, market status and raw material potential. IEA Bioenergy Task 40. Available at: http://www.bioenergytrade.org/downloads/ieatask40pelletandrawmaterialstudynov2007final.pdf 2007; 120 p.
[30] Indexmundi. Oil; palm – production, consumption, exports, and imports statistics. From: http://www.indexmundi.com/en/commodities/agricultural/oil-palm/ [accessed 18.12.07].
[31] United States Department of Agriculture. Production, supply and distribution online. from: http://www.fas.usda.gov/psdonline/ [accessed 29.03.09].
[32] Hansson J, Berndes G. The prospects for large-scale import of biomass and biofuels into Sweden – a review of critical issues. Energy for Sustainable Development 2006;X(1):82–94.
[33] FAO. Global forest resource assessment – progress towards sustainable forest management; 2006. 320 p. ISBN 92-5-105481-9.
[34] FAO. State of the World's forests 2007. ISBN 978-92-5-105586-1. 2007. 144 p.
[35] Kivelä H. Venäjän puuntuonnin tulevaisuus. (The future of round wood import from Russia). Presentation at the Metsäpäivät 2007 seminar. Helsinki; 20 March 2007.
[36] Swaan J. North American wood pellet industry update. presentation at bioenergy days. Linköping, Sweden. Available at: http://www.bioenergydays.com/pdf_file/lecturer_eng/am_Session_Bioenergy/J_Swaan_WoodPellets_America_2006.pdf; 24 August 2006.
[37] Dahl J, Broechner-Andersen M, Hanh B, Winterbäck J, Erkkilä A, et al. Wood pellets – a growing market in Europe. In: 14th European Biomass Conference, 17–21 October 2005 p. 1975–8. Paris, France.
[38] Hektor B., Ling E. Country Report, Sweden. Country report for IEA Bioenergy Task 40. 2006. August. 10 p.
[39] Junginger M, de Wit M, Sikkema R. International bioenergy trade in the Netherlands. Biomass and Bioenergy 2006;32(8):672–87.
[40] Marchal D, Ryckmans Y. Country report of Belgium. draft. Available at: http://www.bioenergytrade.org/downloads/belgiumcountryreport060906.pdf; 4 September 2006. 48 p.
[41] Rosillo-Calle F, Perry M. Country report for United Kingdom. Country report for IEA bioenergy Task 40. Available at: http://www.bioenergytrade.org/downloads/ukcountryreport180906.pdf; 2006 September. 44 p.
[42] Rosillo-Calle F, Walter A. Global market for bioethanol: historical trends and future prospects. Energy for Sustainable Development 2006;X(1):20–32.
[43] Walter A, Dolzan P, Piacente E. Biomass energy and bioenergy trade: historic developments in Brazil and current opportunities – country report for IEA Bioenergy Task 40. Unicamp. Campinas, Brazil. Available at: http://www.bioenergytrade.org/downloads/brazilcountryreport.pdf; 2006. 35 p.
[44] Renewable Fuels Association. Homegrown for the homeland – ethanol industry outlook 2005. Washington, DC. Available at: http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2005.pdf; 2005. 15 p.
[45] Renewable Fuels Association. From Niche to Nation – Ethanol Industry Outlook 2006. Washington, DC. Available at: http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2006.pdf; 2006. 24 p.
[46] Renewable Fuels Association. Building new horizins – ethanol industry outlook 2007. Washington, DC. Available at: http://www.ethanolrfa.org/objects/pdf/outlook/RFA_Outlook_2007.pdf; 2007. 19 p.
[47] Walter A, Rosillo-Calle F, Dolzan P, Piacente E, Borges da Cunha K. Market evaluation: fuel ethanol. Task 40 Sustainable bio-energy trade; securing supply and demand, Deliverable 8. Unicamp. Campinas, Brazil. Available at: http://www.bioenergytrade.org/downloads/finalreportethanolmarkets.pdf; 2007. 75 p.
[48] Zarilli S. The emerging biofuels market: regulatory, trade and development implications. United Nations Conference on Trade and Development. Geneva, Switzerland. Available at: http://www.unctad.org/en/docs/ditcted20064_en.pdf; 2006. 52 p.
[49] Vierhout R. European bioethanol fuel association. The EU bioethanol fuel market -state of play and the challenges ahead. In: Presentation at the World Biofuels Markets Congress. Brussels, Belgium; 13–14 March 2008.
[50] European Commission. Proposal for a directive of the European parliament and of the council on the promotion of the use of energy from renewable sources. Brussels, Belgium; 23 January 2008. 61 p.
[51] Sikkema R, Junginger M, Faaij A. Proceedings of the workshop on Development of meaningful statistics for sustainable bioenergy trade, organized by IEA Bioenergy Task 40 on Sustainable International Bio-energy Trade. 25 February. Paris, France. 9 p. Available at: http://www.bioenergytrade.org/downloads/parisproceedingsworkshopmeaningfulbioenergytra.pdf; 2008.