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The European wood pellet markets: current status and prospects for 2020

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Abstract: The wood pellet market is booming in Europe. The EU 2020 policy targets for renewable energy sources and greenhouse gas (GHG) emissions reduction are among the main drivers. The aim of this analysis is to map current European national wood pellet demand and supplies, to provide a comprehensive overview of major market types and prices, and to discuss the future outlook in light of raw material supply. Approximately 650 pellet plants produced more than 10 million tonnes of pellets in 2009 in Europe. Total European consumption was about 9.8 million tonnes, of which some 9.2 million tonnes is within the EU-27, representing a modest 0.2% of Gross Energy Consumption (75 EJ level in 2008). The prices of most pellet types are increasing. While most markets of non-industrial pellets are largely self-sufficient, industrial pellet markets depend on the import of wood pellets from outside the EU-27. Industrial pellet markets are relatively mature, compared to non-industrial ones, because of their advanced storage facilities and long-term price-setting. However, industrial pellet markets are unstable, depending mainly on the establishment or the abolishment of public support schemes.

Following our scenarios, additional 2020 demand for woody biomass varies from 105 million tonnes, based on market forecasts for pellets in the energy sector and a reference growth of the forest sector, to 305 million tonnes, based on maximum demand in energy and transport sectors and a rapid growth of the forest sector. Additional supply of woody biomass may vary from 45 million tonnes from increased harvest levels to 400 million tonnes after the recovery of slash via altered forest management, the recovery of waste wood via recycling, and the establishment of woody energy plantations in the future. Any short-term shortages within the EU-27 may be bridged via imports from nearby regions such as north west Russia or overseas. © 2011 Society of Chemical Industry and John Wiley & Sons, Ltd

Supporting information may be found in the online version of this article.

Keywords: EU-27; Renewable Energy Directive; wood pellet; international trade; NREAP 2020; forest sector

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Introduction

Today, wood pellets are one of the largest internationally traded solid biomass commodities used specifically for energy purposes. In terms of traded volume – about 4 million tonnes – they can be compared to biodiesel or bioethanol.[1] While the handling of wood pellets requires care, the advantages over other types of solid biomass such as wood chips or agricultural residues are their storability and relative easy handling. Wood pellets also have a low moisture content and relatively high energy density (about 17.5 GJ_{LHV}/tonne), interesting properties for long-distance transport. It is economically more feasible to transport wood pellets instead of wood chips above 5000 nautic miles[2] (9300 km). The first truly long-distance transport of wood pellets was in 1998 from Canada to Sweden.[3] Ever since, the international trade in wood pellets by truck and boat and, to a lesser extent, by train, has been growing rapidly. The overall rationale behind long-distance trade is an abundant availability of cheap feedstock in some world regions, high demand in other, resource-scarce regions, and the presence of cost- and energy-efficient logistics.

In January 2007, the European Commission launched a plan for a more ambitious and integrated policy for Europe in order to tackle the issues of climate change and energy supply. New objectives were embedded in a legislative Directive for Renewable Energy Sources (RES),[4] which would ensure the equitable participation of all EU member states.[5] A first objective concerns the share of energy from renewable sources in gross final consumption of energy in 2020, set at 20%. For comparison: the 2008 share of renewables sources is 8.4%, of which 3.9% is from wood and wood waste materials,[6] including wood pellets (0.2%).

The EU Directive defines three options to reach the '20% renewable goal' in 2020:

1. The use of renewable electricity.
2. The use of renewable energy for heating and cooling.
3. The use of renewable transportation fuels (e.g. liquid biofuels).

Wood pellets can contribute to the first two goals (electricity and heating). In the (near) future wood pellets could, in principle, also be used as a lignocellulose feedstock for the production of second-generation biofuels. The use of wood pellets (replacing fossil fuels) also leads to the reduction of greenhouse gas (GHG) emissions and therefore contributes to another objective of the EU Directive: 20% of reduction in GHG emissions. Sikkema *et al.*[7] showed that the use of pellets in the Netherlands, Sweden, and Italy, respectively can result in significant avoided GHG emissions. An estimated 12.6 million tonnes of CO_2 eq emissions were avoided in 2008 in EU-27 countries plus Norway and Switzerland, based on a consumption of 8.2 million tonnes of wood pellets and the substitution of coal and heating oil.

Despite the rapid growth of wood pellets production and consumption, and the high GHG emission reduction potential, a comprehensive market analysis has so far been lacking. The aim of this analysis is to map major European wood pellet flows (production, trade, and consumption), to provide the main drivers for dedicated pellet markets for heating and power production (trading prices, national policy support), and to discuss future projections. The focus of this analysis is on EU-27 markets for pellet production and use in 2009, but the analysis also includes trade flows from non-EU-27 countries, a major source of supply for the EU-27. Main questions for our future projections are: how much can wood pellets contribute to the EU's 20% RES policy in 2020 and what is the self supply of raw material needed for the expected 2020 consumption levels of pellets and other woody biomass?

Following this introduction, we briefly present the methodology used for data collection, followed by a description of the input of country data and volumes. We continue with a discussion of wood pellet price developments and an outlook of future consumption of pellets and raw material availability. Methodological constraints and actual market developments are reviewed in the Discussion section. We end with conclusions and recommendations.

Methodology

Three main sources are used to map the European pellet flows. First of all, figures for the 27 EU countries, plus Norway and Switzerland are extracted from the European Pellets@las-project.[8] These Pelletsatlas data are used as a main source for tables and graphs. Second, Rakitova and Ovsyanko[9] inventoried pellet markets in Russia, Belarus, and Ukraine. Third, data lacking from the Balkan countries

have been derived from a workshop, organized by the United Nations Economic Commission for Europe (UNECE) Timber Section.[10] The pellet markets in Europe for production, international trade, and consumption flows are evaluated as follows:

1. Production: Volume data was collected once a year for the previous year via national pellets associations, the Internet or direct contact with pellet manufacturing companies. In the exceptional case of incomplete country figures, alternative data were derived from a survey by Bioenergy International (BI)[11, 12] on individual production plant capacities and realized production for pellet-producing countries in 2008 and 2009. Unlike our own inventory, the BI survey did not include all small pellet plants (<10,000 tonne). The BI survey also lacked real production data for some, larger, pellet plants. Where possible, additional production data was estimated via an average utilization rate of the other (aggregated) production capacities in a country. Two different methods exist for specifying the production capacity. While some producers name the 'technical production capacity' (calculated out of possible tonnes per hour for the whole year), others name the 'real production capacity' (which takes into account reduced working hours, repair times, and raw material supply).
2. Trade: Since January 1, 2009, export and import figures on pellets are published by Eurostat[13] using a new product code (44.01.3020), defined as 'sawdust and wood waste and scrap, agglomerated in pellets'. Before that time, only global estimations could be made based on expert opinions and more generic statistics for sawdust (old code 44.01.3010) or wood waste and scrap (old code 44.01.3090), both codes stating 'whether or not agglomerated in pellets'. For export, the trading partner is in principle the country (or member state) which is the final destination of the goods. For imports (external EU trade) the trading partner is the country of origin of the goods. For arrivals (intra-EU trade), the trading partner is the member state that consigns the goods.[14] Further embedding of the specified pellet code in the Harmonised System nomenclature of the World Customs Organisation will take place no earlier than 2012,[15] thus the pellet trade is not yet officially monitored outside the EU-27.
3. Consumption: Before doing an inventory of pellet consumption by all types of final consumers, the 'apparent consumption' was determined per country, using formula A. Note that minor amounts of wood pellets may also be used as stable bedding for horses, cattle, etc. We assumed that those volumes were negligible and thus 100% of wood pellet production and trade was used for energy purposes.

(formula A)

Apparent consumption = Production + import +/– stock changes – export

For a detailed analysis of trade flows, both domestic destinations and export are investigated. The breakdown of data for apparent national pellet consumption for separate markets was collected via national pellet associations, the Internet or direct contact with pellet consumers. Based on our inventories, the following markets are distinguished in Europe:

- *Industrial bulk pellets for large-scale users.* Public data on pellet consumption by power utilities is not yet available. IEA, Eurostat, and UNECE will start distributing a joint questionnaire for collecting new data on renewable energy via the national statistical offices in 2010.[16] So far, Dutch pellet consumption, for example, had to be estimated from annual reports of power companies, phone enquiries of power companies or other available sources (e.g. environmental reports of public authorities). The following variables are useful: capacity of the power companies (MW), annual full-load hours of dedicated biomass cofiring units, amount of electricity annually produced (GWh), average efficiency rates of cofiring and the specific shares of pellets in total fuel feedstock.[17] In case utilities use other types of biomass, like wood chips, dairy waste, and liquid palm oil, these are excluded from our inventories.
- *Industrial bulk pellets for medium-scale users*. Market studies of district heating and other medium-scale users provide direct inventories of pellet use. For example, in Denmark the consumption is surveyed every second year by the wood pellet survey from the Danish Energy Agency. The survey is based on mandatory annual registration from all energy producers in combination with other questionnaires to all pellet producers and traders.[18]

- *Bulk pellets and bagged pellets for small-scale users.* As quantitative data for this market segment are not available, the consumption was estimated via general trend analyses, such as the amount of heating appliances, average temperature, amount of winter days, etc. In Austria, for example, the previous year's sales of pellet boilers and stoves, including heating capacities, are surveyed each year by a representative farmers' organization.[19] The number of boilers (bulk pellets) have been surveyed in Austria since 1996, and the number of pellets stoves (bagged pellets) since 2006.
- In addition to the national market types, there are also a number of countries that display a relatively low domestic demand for wood pellets in the period 2007–2009, and mainly produced wood pellets for export. Corresponding export volumes for 2009 have been extracted from Eurostat.[13]

As a second part of the market analysis, an overview was compiled of price developments in recent years, based on the major market types per country. Price developments were collected from producers, traders, retailers, and large-scale consumers (see Box 1 for definitions). Since wholesale prices of pellets depend largely on individual agreements between two companies, the focus of the price data inventory was on end-consumer prices. Three different categories exist:

Box 1: List of acronyms and main conversation factors.

ARA. Amsterdam, Rotterdam, and Antwerp, the major harbors in Europe for international pellet transhipments.

CIF. Cost, insurance, and freight. Title and risk pass to the buyer when delivered on board the ship by the seller who pays transportation and insurance cost to destination port. Used for sea or inland waterway transportation[35] and focusing on import harbors. VAT is not applicable at this stage.

Exchange rates. The amount of foreign currency in € (euro). Currency rates are derived both from www.oanda.com[56] and from www.ecb.int.[111]

FOB. Free on board. Title and risk pass to buyer including payment of all transportation and insurance cost once delivered on board the ship by the seller. Used for sea or inland waterway transportation[35] and focusing on export harbors. The FOB price plus costs for insurance freight results into CIF prices. Freight costs are are calculated by means of charter rates, bunker fuel prices and unloading costs.[112] VAT is not applicable at this stage.

GEC. Gross Energy Consumption. In 2008, the GEC in the EU-27 was about 75 EJ or 1800 million tonne of oil equivalents (MTOE). 1 MTOE = 2.38 million tonnes of pellets.

GJ_{th}: Gigajoules. 1 GJ_{th} = 0,067 tonne of bagged pellets (efficiency $\eta = 0.85$) for residential heating or 0,062 tonne of bulk pellets ($\acute{\eta} = 0.92$) for district heating.

$GJ_{(p)}$: Primary GJ. 1 primary GJ = 278 $kWh_{(p)}$.

Retailers. A retail merchant or retailer sells pellets to end-consumers (including businesses). A shop owner is a retail merchant. If a producer sells to end consumers, he is also a retailer.

Tonne pellet equivalent (TPE). One TPE has a solid volume[113] of 2 m^3, a moisture content of about 10 to 20% and a primary energy content of 17.6 GJ per tonne. Solid m^3 industrial roundwood is excluding bark (underbark). One m^3 sawdust = 0.35 TPE. One metric tonne is 1.10 short dry ton (US unit).

Traders. A wholesale merchant or trader operates in the chain between producer and retail merchant. Some wholesale merchants only organize the movement of goods rather than move the goods themselves. If a producer is selling to traders or retailers, he is also considered to be a trader.

Transportation fuel. Average conversion efficiency of woody biomass into liquid biofuels is about 50%.

$TWh_{(p)}$. Terra Watt hours primary. 1 $TWh_{(p)}$ = 0.205 million tonnes of pellets (moisture content 10%), based on a primary energy content of 17.6 GJ per tonne pellet. 1 $MWh_{(p)}$ = 0.205 tonne of pellet.

$TWh_{(e)}$. Terra Watt hours electric. 1 $TWh_{(e)}$ = 0.51 million tonnes of pellets (moisture content 10%), based on a primary energy content of 17.6 GJ per tonne pellet and an efficiency rate (η) of 40.1% for Dutch electricity production based on 10% wood pellet cofiring (η = 41% for 100% coal).[7]

1. A purchase of a maximum of 1 tonne of non-industrial, bagged pellets (15 to 25 kg bags) at retailer shops by residential users (in € per tonne, including VAT). Transport costs between retailer and households are therefore not included.
2. A delivery of about 5 tonnes of non-industrial bulk pellets for residential markets (in € per tonne, including VAT) and a single maximum transport distance of 50 km to households.
3. Sales of industrial bulk pellets to large-scale consumers (in € per tonne), when delivered and unloaded at the harbor of destination (CIF ARA, excluding VAT). Delivered volumes had to be at least 5000 tonnes. CIF ARA means wood pellets delivered to the Rotterdam, Amsterdam, or Antwerp area, and costs, insurance and (sea) freight are paid by the (overseas) seller of wood pellets. Inland transport by road or river ways and power plant handling are excluded.

Four times a year, we collected either quarterly or monthly pellet prices, depending on responses and data availability. From the first quarter of 2007 to the third quarter of 2009, we collected pellet prices for 25 European countries plus Norway and Switzerland either on a monthly or quarterly basis, depending on responses and data availability.[20] For each of the three price categories outlined, the preferred method was to calculate a weighted average price, based on the individual respondent's volumes, according to formula B. However, respondents and volumes could be double-counted, when more than one actor is involved in a tonne of pellets. For example, a producer sells to a trader, who then re-sells to another buyer.

(formula B)

$$\textit{Average price} = \frac{\textit{Price\_actor1}^{*}\textit{Volume1} + \textit{Price\_actor2}^{*}\textit{Volume2} + \ldots + \textit{price\_Actori}^{*}\textit{Volumei}}{\sum \textit{Volume}}$$

The introduction of non-industrial pellet enquiries differed from country to country. Whereas some countries already had existing price statistics, like Austria,[21] Germany,[22] and Ireland,[23] other countries had to start from scratch. In that case, we started to collect prices ourselves, or waited for external price surveys to be developed. For example, Sweden[24] and Switzerland[25] started in July 2007, Belgium[26] and Finland[27] started in 2008. In France, an index of pellet prices exists since 2006, with all indexes related to pellet price in first quarter of 2008.[28] Consequently, the continuity of prices may vary because the response rate in most countries was quite low in the beginning. For some countries (Czech Republic, Latvia, Lithuania, Slovakia, Slovenia, and Portugal) it was more or less impossible to collect price data, due to the limited number of actors or the lack of cooperation. Figure 1 shows the responses of actors involved in non-industrial pellets for heating. The external surveyed countries are generally based on non-weighted average prices (*arithmetic mean*), i.e. dividing the sum of all prices by the total number of respondents. In that case, only respondents are shown.

The survey of industrial consumers started in the Amsterdam, Rotterdam and Antwerp (ARA) area, commonly used for coal transportation. Pellets are mostly traded via the main hub of Rotterdam harbor, after which pellets are transhipped (redistributed to smaller vessels) to other destinations, such as the United Kingdom. Between 2007 and 2009, only one large trader and two to three small traders participated in the Dutch price surveys. Their aggregated trading volume was between 350 and 400 Ktonne. From November 2008 onwards, the average weighted prices for these bulk pellets (CIF ARA) were replaced by index prices published by APXEndex.[29] The Endex pellet prices are compiled by an expert panel of about 10 pellet actors (producers, traders, and consumers) and are calculated by the sum of all prices divided by the number of experts. Two prices (the maximum and minimum price submitted) are left out of the Endex price settlements. By the end of each month (since November 2008), we extracted Endex's short-term prices, one month ahead of delivery. These prices came closest to the collected prices in Pelletsatlas. However, daily prices from the real spot markets (in time delivery) do not realy reflect purchases by large-scale power plants, because the spot market cannot immediately deliver the large volumes needed (see Discussion). During our surveys in Sweden and Denmark, the share of bulk pellets for medium-scale users got larger than those for residential heating. Therefore, we incorporated new price statistics for industrial bulk pellets for medium-scale district heating and for (larger) combined heat power (CHP) plants. Based on real invoiced pellet deliveries, FOEX[30] publishes monthly average weighted pellet

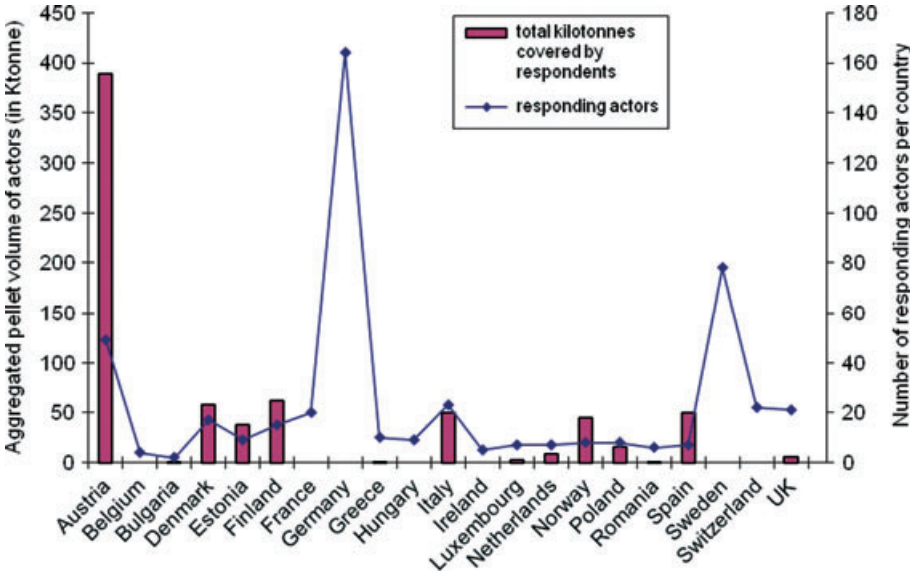

Figure 1. Responding actors (non industrial pellets) by the 3rd Quarter of 2009.

prices for the Nordic market, derived from about 10 to 20 Scandinavian pellet actors (with an aggregated volume of about 600 Ktonne of pellets). The lowest and highest prices (20% of submitted data) are omitted from their average weighted price overview.

The price section is completed with data for major pellet export harbors in Latvia, Russia, the USA, and Canada, derived from expert resources and commercial bulletins.[31–34] These prices are generally registered free alongside ship (FAS) without the costs of loading or free on board (FOB) with loading costs. In our analysis, we used FOB prices for dry bulk ships in export harbors, connected either by sea or inland rivers. Under FOB conditions, title and risk passes to the buyer once the freight is loaded on board the seller's or international trader's ship[35] (Box 1).

Major pellet markets and characteristics

Based on formula A, this section is divided into production, trade, and apparent consumption. Possible effects of stock changes are incorporated in the consumption section. Figure 2 shows the demand (below the x-axis) and supply (above the x-axis) situation in the major European pellet markets in 2009. Only markets larger than 500 000 tonnes are illustrated. In the case of Russia,*) the export is limited to the total recorded imports from Russia by all EU-27 member states.

Aggregated European production

Approximately 670 pellet plants in Europe produced about 10.1 million tonnes of pellets (Appendix A), an increase of about 1.8 million tonnes compared to an earlier study of production in 2008.[20] A large number of these plants, 28%, are small production plants with capacity of less than 10 000 tonnes per annum. Bioenergy International[11,12] listed about 480 large pellet plants in Europe. The EU-27 produced about 8.75 million tonnes. The largest ones are Sweden and Germany, both producing about 1.6 million tonnes. Most of the feedstock needed is purchased from external sawmills. Italy on the other hand, Europe's third largest pellet producer (0.77 million tonnes), has a lot of integrated pellet plants. Integrated pellet plants are built within or nearby sawmills. This way the feedstock is fully sourced within a short distance.

After Europe, North America has the largest pellet production facilities.[11] North American production capacity has grown from 1.1 million tonnes in 2003 to 4.2 million tonnes in 2008[36] and 6.2 million tonnes in 2009.[37] In 2009, a number of new plants were built in the United States to process chipped roundwood for bulk pellets designated for export. Those plants have 3 to 4 times the production capacity of the older plants, which are limited to 100 000 tonnes or less.[36] As of June 2009, about 110 US and Canadian wood pellet plants were in operation or were about to become

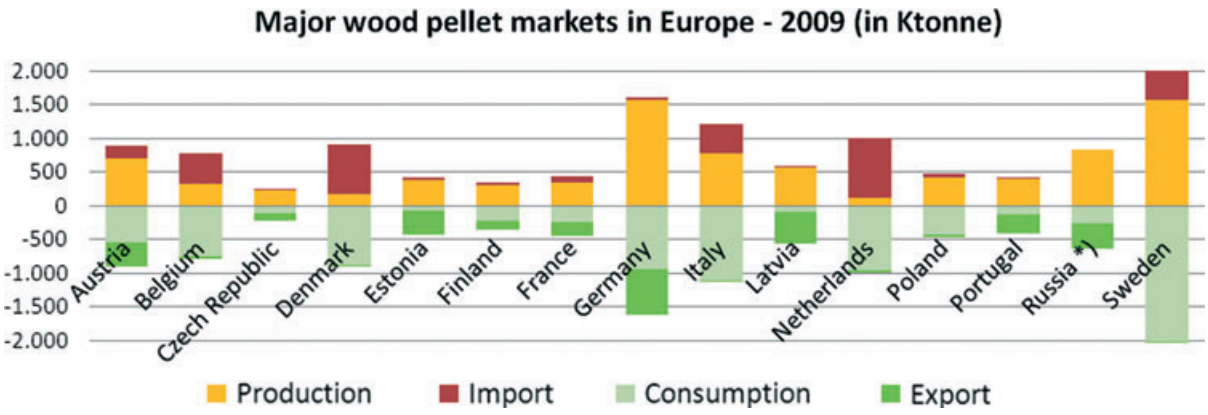

Figure 2. Balance of pellet volumes for the major European country markets in 2009.

operational. Wood pellet production in the United States in 2008 amounted to 1.8 million tonnes, which was 66% of capacity. In Canada, the estimated production was 1.4 million tonnes, about 81% of capacity. The lower capacity utilization in the United States is a result of the more recent start-up of the plants. In both countries limitations on feedstock availability occurred because the economic crisis constrained sawmill operations and reduced the output of sawdust and shavings in 2008.[36]

The utilization rates of pellet plants of Europe's largest producers Sweden, Germany, and Italy in 2008 were 64%, 56%, and 87%, respectively. In other words, if the capacity in these three countries was fully utilized, production could hypothetically rise by almost 2 million tonnes. Also, other European countries have not fully utilized their production capacities: the average Europe utilization rate of pellet production capacity in 2008 was about 54%.[20]

European trade volumes

While some markets such as Germany or Austria are largely self-sufficient, other markets, such as the Netherlands, Belgium, Denmark and Italy, depend to a very large extent on the import of wood pellets. On the other hand, in many producing countries (Canada being the prime example, but also other areas such as the Baltic countries and north west Russia), the pellet production sector largely depends on export opportunities. A rather new actor in the market is the USA, which has started in 2008/2009 to export wood pellets by train to and by ship from south-east US harbors. These pellets originate from pellet producers using sawmill residues and chipped trees from softwood plantations.[38] Hintz[37] estimated about 500 000 tonnes of pellet export from the USA to Europe in 2009, which is twice the 2008 exports.[39]

For 2009, about 3.3 million tonnes of pellet export was registered,[13] of which 98% was traded within the EU. The EU import was about 3.8 million tonnes, of which about 53% was covered by intra-trade. The biggest trade volumes are recorded by the Netherlands, Belgium, and Sweden; see Table 1 for export or import volumes about or above 100 000 tonnes per annum. The main trade routes are from North America to the Netherlands and Belgium with average overseas (Panamax) shipments of 20 000 to 30 000 tonnes per freight, and from the Baltic States and Russia to Scandinavia by coast liners with average loads from 4000 to 6000 tonnes.[40] Another important route is by truck from Austria to Italy, with average loads of 24 tonnes.[7]

According to Eurostat statistics,[13] total EU intra-export is not equal to total EU intra-import volumes – the export of pellets is about 1.2 million tonnes more than import. Bilateral comparisons have revealed persistent discrepancies[15] in various member states on intra trade statistics, called asymmetries. Main deficiencies occur:

- *Within the new pellet code (44.01.3020).* Most commonly, the export is registered first, followed by a registration of the import. Countries are obliged to report their intra-EU export and import flows within 10 weeks.

Table 1. Overview of major pellet trade flows in 2009, about or above 100 Ktonnes.[13]

	Country of origin (extra-EU trade) or country of consignment (intra-EU trade)	Destination of export (both intra- and extra-EU trade)	Trade volumes (Ktonne)	
			Volumes recorded by exporting country	Volumes recorded by importing country
Extra EU		Total volumes	64	1769
	Canada	Netherlands	No official custom records available	413
	USA	Netherlands		313
	USA	Belgium		185
	Russia	Sweden		163
	Canada	Belgium		87
	Russia	Denmark		87
	EU-27	Switzerland	46	No records available
Intra EU		Total volumes	3313	2135
	Austria	Italy	292	142
	Estonia	Denmark	256	215
	Lithuania	Denmark	167	36
	Germany	Spain	167	1
	Latvia	Denmark	152	71
	Latvia	Sweden	137	74
	Germany	Denmark	98	30
	Latvia	Estonia	95	40
	Portugal	Netherlands	86	70

For trade with non-EU countries, the administration must happen within 6 weeks. According to Eurostat,[14] there should be no time lag between the date or registration of a transaction in one member state and the date on which the same transaction is recorded as an arrival in another. In practice, the administration occurs in the reference month, in which the goods are exchanged or otherwise the following month. Delays in data processing can have a non-negligible impact on monthly statistics but are more or less negligible for the annual statistics. In case of non-response, the pellet trade is not registered, but the National Offices will make adjustments on a Chapter level, in our case Chapter 44 Wood Products.

- *Within the total category of 'pellet, sawdust and other residues'.* As shown in Table 1, recorded exports (on a country level) are usually larger than recorded imports. Misapplication of the rules may occur due to the implementation of the new pellet code by Eurostat. Discrepancies may occur by registering the exports as pellets, but the import either like sawdust (new code 44.01.3040) or like 'wood waste and scrap' (new code 44.01.3080).
- *Within the total wood products trade section (Chapter 44).* The system of thresholds for small actors makes it possible to exempt a number of pellet actors from statistical formalities. For a given transaction, a large trader company may be required to provide statistical information about export in one member state, whereas the receiving smaller customers in another member state may be exempted. According to Eurostat,[14] the principle of full coverage has been in force since January 2005. The principle implies that member states should estimate undeclared trade, including trade below threshold at least at Chapter level and by partner country.

In the Discussion section, we take more discrepancies on a country level into consideration, like Lithuania and Luxembourg with a negative apparent consumption.

Apparent consumption, storage facilities, and other market characteristics.

The apparent consumption in Europe is estimated at about 9.8 million tonnes in 2009, of which 9.2 million tonnes is within EU-27 member states. Sweden is by far the largest user of pellets (2.0 million tonnes), followed by Italy (1.1 million tonnes), the Netherlands (0.95 million tonnes), Germany (0.94 million tonnes), and Denmark (0.89 million tonnes). For comparison, about 80% of US-produced pellets (1.5 million tonne) are put in small bags and consumed domestically for residential heating.[41] By contrast, most Canadian pellets (90%) are transported as bulk and shipped overseas for power production in Europe.[36] Asia could also become an important consumer as the first large-scale industrial project to cofire coal with (Canadian) wood pellets took place in Japan by the end 2008.[39] The wood pellet association of Canada[42] estimated that Japan imported around 110 000 tonnes of wood pellets in 2009.

On the basis of final pellet consumption, the European countries are further classified by their major markets (Fig. 3), as defined in the section on Methodology.

Markets in Belgium and the Netherlands are dominated by the utilization of pellets in large-scale power plants. The UK[43] and Poland[8] are also classified as large-scale industrial pellets markets, based on their 2009 consumption and plans for further wood pellet replacement at coal-fired plants. According to BAPE,[8] Poland promotes the use of agricultural biomass, including pellets made from agro residues (mixed biomass pellets). Medium-scale consumers using bulk wood pellets for district heating and also for (larger) CHP plants are found in Sweden, Denmark, and Norway. Alongside the industrial pellets users, the Scandinavian countries make considerable use of bulk pellets for households. Whereas the first (industrial) pellet market partly relies on imported pellets, the second (non-industrial) market gets its supplies solely from domestic resources. In Austria and Germany, pellets are predominantly delivered in bulk and used in small-scale private residential and industrial boilers for heating. Another group of countries exists of small-scale consumers that use bagged wood pellets in stoves. Such residential markets are found in Italy, France, Bulgaria, and Hungary. Finally, major export markets are found in Finland, Portugal, Spain, Russia, the Baltic States, and most other East European countries.

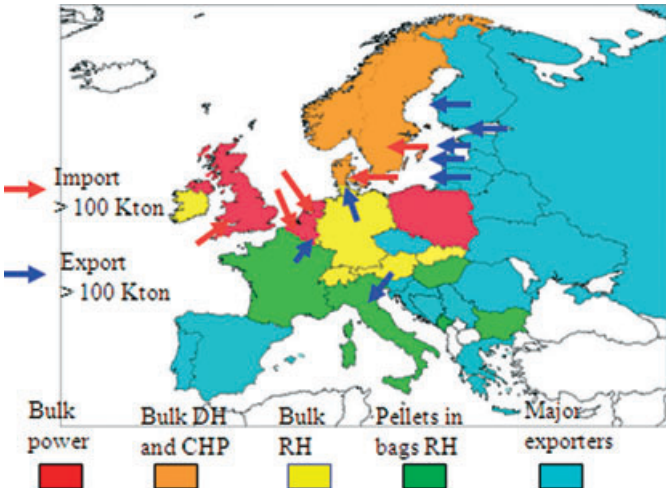

Figure 3. Overview of European pellet market and main market types per country in 2009.

From available data in Austria, Germany, and Italy (Table 2) we learn that the average storage capacity at pellet production plants varies from 2300 to 3700 tonnes. For comparison, Hoglund[44] indicated average stored volumes in 2007 of between 3100 and 4300 for Swedish pellet plants, and an average storage capacity of 14 000 tonnes per plant. By multiplying the storage capacity per plant and the number of pellet plants, the total storage capacity on a country level is estimated. In Austria, even an official strategic stock on a country level was proposed but not introduced.[45] Large pellet producers have more storage facilities compared to small ones, due to a higher fluctuation in their real production volumes. The average storage time is probably no more than one week's production for large pellet plants. Storage times at harbors could be even higher. The storage of pellets is not without risk, due to the moulding of pellets. Damp pellets can swell up and are no longer usable. Even worse, dust explosion may occur during storage. Consequently, intermediate harbor companies (stevedores) have restrictions when storing industrial pellets. In Canadian harbor silos, the moisture content is limited to 8% and the weight fraction of fines to 5% (Verkerk B, 2010, pers. comm.), whereas in

Table 2. Stored volumes of pellets in Austria, Germany, and Italy in 2008 (in tonnes).

	Total capacity on country level	Real production on country level (Appendix A)	Number of pellet plants responding to storage facilities	Average storage capacity per plant	Corresponding storage capacity on country level
Austria	1 006 000	626 000	25	2600	65 000
Germany	2 400 000	1 460 000	46	3700	168 000
Italy	750 000	650 000	75	2270	170 000

Dutch silos, the moisture content is limited to 5% for white pellets or 9% for bark pellets, and 2% for fines. The temperature is also limited to a range between 40°C and 50°C.[46] Pellet actors may also incorporate the new European standards: EN 14961-1 for industrial (a framework with flexible requirements) and EN 14961-2 for non industrial pellets[47] (more or less replacing country-specific standards). One of the differences between both EN-categories is related to the kind of feedstock (Table 3). Whereas the feedstock of non-industrial pellets is limited to woody biomass (from forests, plantations, industrial residues, or waste wood), feedstock of industrial pellets may also be sourced from herbaceous and fruit biomass or from blends and mixtures. Non-industrial pellets are further split into subcategories: A1, A2, and B, each having detailed specifications for feedstock but also for others. One distinctive element is the allowed ash content: 0.7%, 1.5%, and 3.0% (weight fraction) for respectively A1, A2, and B.

Since 2008, power companies in the Netherlands no longer purchase their pellets on a single-utility basis. Instead they have moved their trading activities to dedicated European head trading offices for strategic reasons and they have created a well-developed market. Most large-scale consumers have long-term contracts with their suppliers, but in case of low prices, they are eager to buy from short-term delivery markets. For that reason they have created strategic storage facilities at the harbors. The individual power units use these stored pellets for cofiring or the central trade office will re-trade them to other users within or outside the country. Whereas the storage facilities at production and at conversion sites (power plants) are mostly dependent on the season (high in summer at production; high in winter at conversion), the storage at intermediate distribution stages (harbors) shows market dependent fluctuations (low storage at high price level; high storage at low price level). From the few responses from large-scale consumers, it is known that their storage volumes may be quite large. The intermediate storage in Rotterdam harbor reached about 200 000 tonnes in 2007, whereas the storage at the individual power utilities could reach about 20 000 tonnes. Bulk pellets used for district heating also rely on intermediate storage facilities. For example, Pelletsindustrins Riksförbund (PiR) coordinates about 80% of Swedish pellet purchases toward district heating and therefore has accumulated storage facilities in Swedish harbors up to 10 000 tonnes.[33] Non-industrial pellets have almost no intermediate storage facilities in the supply chain, but boilers are relative large and have extra space for pellet feed-in.[48]

Price developments

Industrial pellet prices (CIF)

The pellet prices for Dutch power plants are volatile,[52,53] because the ARA market has a limited amount of actors, up to five large power companies and three international traders. The pellet prices have increased from around €115 per tonne in July 2007 to €140 per tonne at the beginning of 2009. Since then, prices have steadily been declining towards €125 per tonne at the end of 2010 (Fig. 4). Between 2003 and 2006, the Dutch government granted long-term subsidies for cofiring biomass of up to €0.06 and €0.07 per kWhe, a scheme ending between 2012 and 2015. This is equal to about €120–135 per tonne of pellets and has given an enormous boost to the cofiring of pellets in coal power plants. This feed-in tariff is meant for bridging the gap between total production costs (fuel, operation and maintenance, capital) of pellets and coal.[7] Another pellet price index for north-west Europe was created in May 2009,[31,32] based on submissions from about 15 pellet actors in UK harbors as well as in Dutch and Belgium harbors for deliveries within 90 days.

Table 3. Characteristics of Europe's major pellet market types.

	Large-scale users (bulk)	Medium-scale users (bulk)	Small-scale users (bulk)	Small-scale users (small bags)
Suppliers	International pellet production plants.	European pellet production plants.	Domestic production plants.	Domestic production plants.
Storage at pellet plants	Average 2500 to 5000 tonnes of actual storage per pellet production plant.			
Intermediate companies	International operating traders (with one main European office)	Predominantly domestic traders	Domestic traders	Retailers
Typical way of transport	(Inter-) continental shipping (in Panamax or Handymax vessels, freights: 10 000 to 100 000 tonnes).	European short sea shipping (average 5000 tonne) or lorry transport (max volumes 40 tonnes).	Lorry transport (delivery of 1 to 6 tonnes per household per year).	Both lorry transport to retailers and private cars to households.
Contracts	Both long-term contracts (up to 3 years) and purchase from short-term markets, e.g. within one month deliveries.	Predominantly long-term contracts (up to 3 years), plus short-term delivery from daily spot markets.	Annual deliveries upon request.	Infrequent purchase at retailers (15 to 25 kg bags).
Number of demand players per country	Few, internationally operating utilities. For example, in 2009, the Netherlands had four power companies that cofired wood pellets in six existing units.	For example, Sweden has about 100 district heating plants, using pellet boilers. In Denmark larger CHP plants use pellets, too.	Used in pellet boilers, both in households and in small industry. For example, between 1997 and 2009, about 71 000 boilers were sold in Austria.[19]	Dedicated stoves, mainly in households. A range of pellet stoves is cited. In Italy the range is estimated between 525 000[49] and 801 000.[50]
Actual storage at end users	Both at harbor (up to 200 000 tonnes) and on-site (up to 10 000 tonnes per plant). Annual stock changes at a country level may be considerable.	Storage in harbors could be large, up to 10 000 tonnes (like in Sweden). On site less stock volumes needed: up to 500 tonnes.	Average use for boilers in Austria & Germany about 6.5 tonnes per year; storage capacity from 1.5 to 15 tonnes.[51] Proposed national strategic Austrian pellet stock is not honoured.[45]	Low, due to the small size of the bags (15 to 25 kg) and ad hoc purchase of these bags.
Quality requirements	Company-specific criteria, like in harbors.[46] Implementation of a flexible, pan European EN 14961-1 standard for industrial pellets[47] since April 2010. Feedstock may exist of woody biomass, herbaceous biomass, fruit biomass or blends and mixtures.		Predominantly country specific standards. Implementation of pan European standard EN 14961-2 for non industrial pellets[47] from 2011. Three subcategories A1, A2, and B, each consisting of detailed specifications for woody biomass feedstock, ash content and others.	

Sweden has a major market for bulk pellets for medium-scale consumers and (larger) CHP plants. The price of industrial pellets in Scandinavia increased since January 2007 to about €138 per tonne in October 2010. Remarkably, pellet prices in Scandinavia are moving in the opposite direction, compared to those in the Netherlands, probably due to a different methodology of price setting (see Discussion). Also, in the current Swedish tax system, heat generation and power production from fossil fuels is taxed (about €10 per GJth) for CO_2 and sulfur emissions.[7] The Swedish tax is equal to about €160 per tonne of pellets. Obviously, the Swedish subsidy for pellet use allows district heating plants to pay higher prices for wood pellets, compared to power utilities in the Netherlands. Next to feed-in tariffs and taxation measures, an extra incentive is applicable for all industrial pellet markets via revenues from CO_2 emission rights. The price of CO_2 rights were between €10 and €20 in the period 2007 to 2009,[54] or on average €0.012 per kWh_e.[7] This is equal to about €24 per tonne of pellets (Box 1).

Residential pellet prices

According to another European study,[49] a surge in sales of solid fuel appliances (boilers for bulk and stoves for bagged pellets) in Europe has occurred since the mid- 2000s after a long period of declining solid fuel appliance sales during

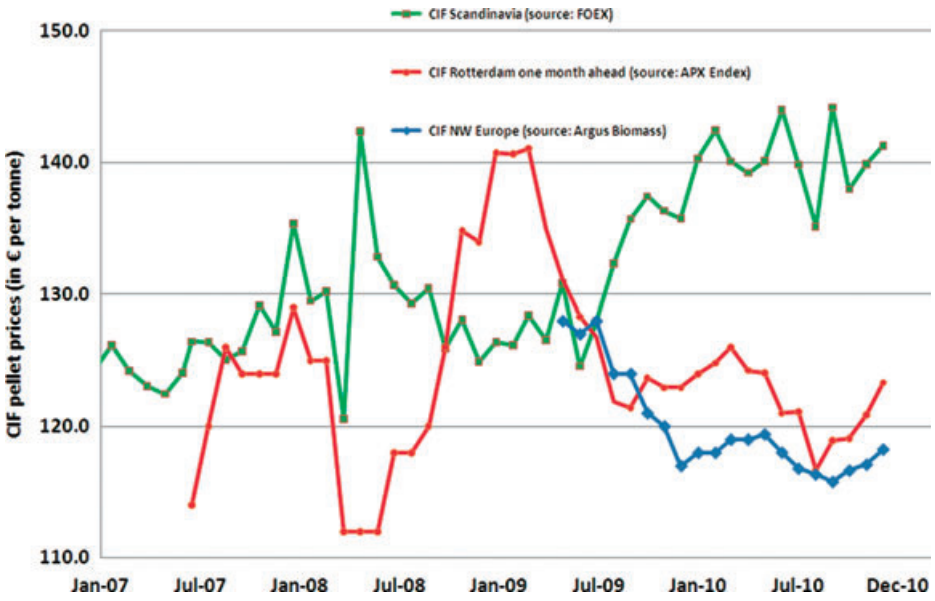

Figure 4. CIF prices of bulk pellets for large scale power production in the Netherlands, United Kingdom and for medium scale district heating & CHP in Scandinavia.[8,31–34]

the 1990s. The increase accelerated in 2005, notably in Austria, the Czech Republic, France, Germany, Poland, and Scandinavia. The growth can be explained by three key elements: the image of high-performing, environmentally friendly heating appliances; increasing prices of natural gas and heating oil; and government subsidies for pellet boiler investments.

Non-industrial pellets for households are generally more expensive than their industrial counterparts. The former include VAT both for bulk and bagged pellets. They also have higher quality standards (ash content, dust, etc). The extremely high pellet prices in Austria and Germany, early in 2007, were exceptional and were mainly caused by a fast increase in Italian pellet demand and a cold winter the year before. German and Austrian seasonal developments are very similar. They have both their market structures in raw material supply, and pellet distribution in common. Until now, they have been more or less self-sufficient. The non-industrial pellets price in Northern Europe does not seem to follow any seasonal pattern. Rising prices in Finland are due to the rising price of the raw material. Swedish prices used to be quite stable. Due to a changing rate of the Swedish krona against the euro, market prices in euro went up on average after October 2008 (Fig. 5). Note that Danish and Norwegian inventories had a low response rate and are therefore not incorporated. Like the Swedish krona, the Swiss franc has gone up in value against the euro, resulting in higher pellet prices in euro. Obviously, Switzerland started to import relatively cheap pellets from its 'euro neighbors'. Switzerland imported one-third of its apparent consumption from France, Germany, and Austria.[13]

The market price for pellet in bags (at retailer's shops) were quite varied during 2007 and 2008, but they tended to stabilize between €200 and €220 per tonne in 2009 (Fig. 6). Neighboring countries Italy and France show a similar price development. Bulgaria and Hungary have only recently started pellet production and are largely exporting, due to a lack of domestic demand. Pellets for the marginal domestic demand are usually sold 'explant', due to a missing pellets distribution system, and are thus relatively cheap. Whereas Bulgaria has a fixed exchange rate against the uuro, Hungarian changing rate led to increasing pellet prices in euro.

Transport costs

Distribution costs are a key factor in total costs.[7] The main means of transport within Europe is road transport. The global road transport prices for wood pellets varied between

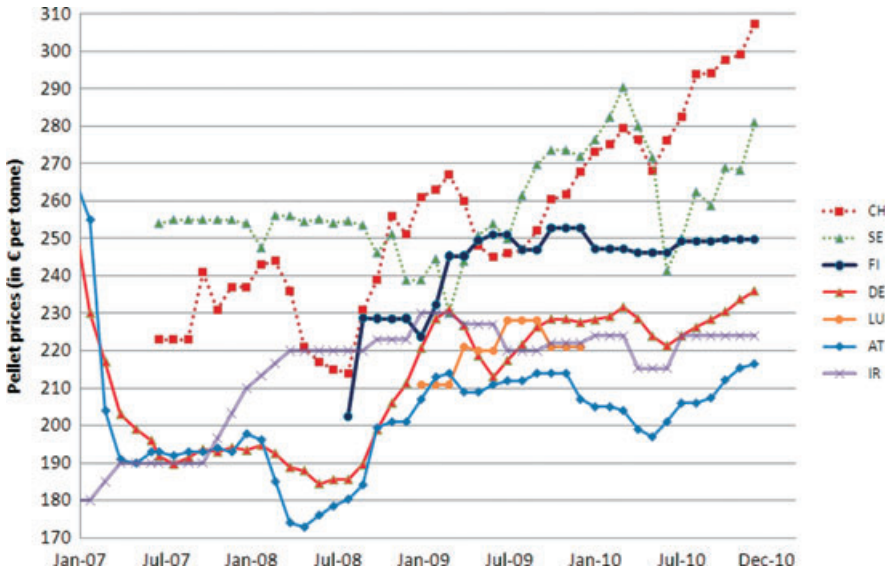

Figure 5. Prices of bulk pellets for residential heating in Europe (including delivery and VAT).

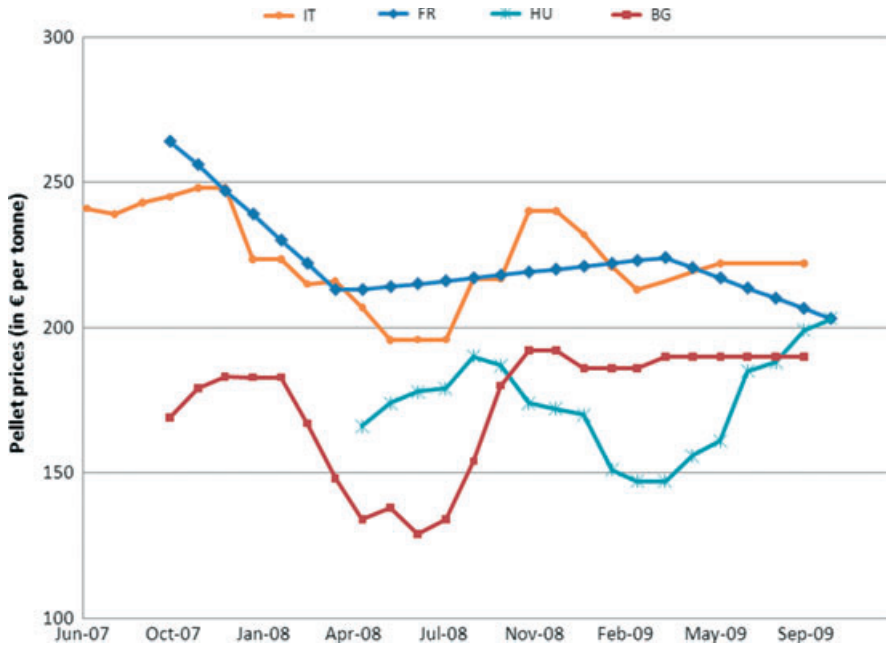

Figure 6. Prices of pellets in small bags (<25 kg) for residential heating (at retailer's shops, including VAT).

€12 per tonne and €18 per tonne in 2009, depending on distance and truck load. For comparison, a large pellet trader[55] cited €16 per tonne for a 25-tonne pellet truck and a distance of 200 km. However, in the case of pellet transportation from the Baltic States and Russia, pellet traders prefer short sea shipping (with freights from 4000 to 5000 tonnes), which are equipped with on board cranes and can unload themselves.[33] The main means of transport used for dry bulk freights from North America are Panamax ocean vessels (60 000 to 80 000 tonnes).

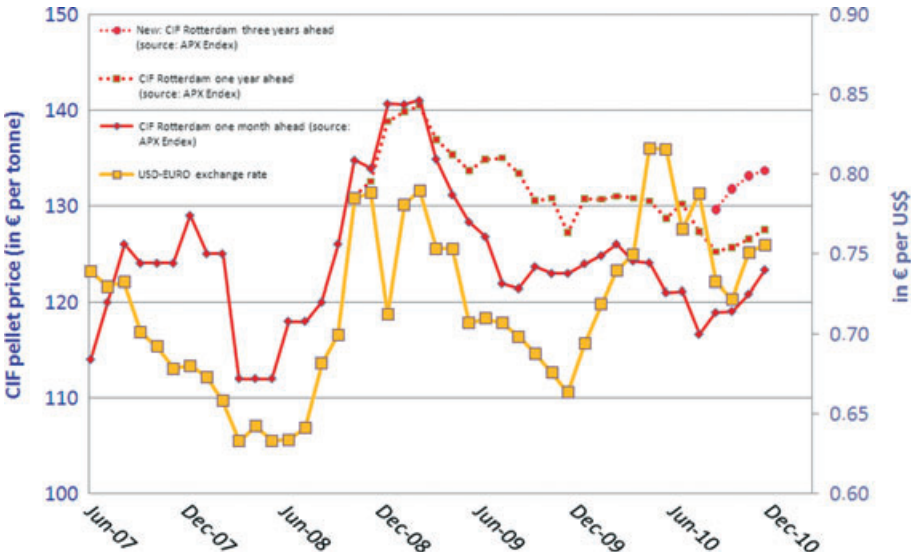

Figure 7. US Dollar exchange rate versus CIF ARA pellet prices.[8,29,56]

The industrial bulk pellet price is closely linked to the size and the length of a contract. Next to short-term contracts, both APX Endex[29] and Argus Biomass[31] started to publish longer-term contracts (for deliveries up to three years ahead) in the fourth quarter of 2010. The latter could be more than €10 per tonne pellet more expensive, because buyers pay a premium to secure their feedstock supplies. According to the Forest Energy Monitor,[52,53] most wood pellets are shipped under long-term contracts, made in dollars. The exchange rate of the dollar against the euro is thus a key factor for European customers. Figure 7 shows the possible correlation of the dollar exchange rate with CIF ARA prices for wood pellets from one month to three years ahead ahead of delivery.

Another relevant factor is the cost for freight. Figure 8 shows the ocean freight costs since 2002 between North America and Europe ranging from €27 to €69 per tonne of pellets.[57–59] The dry bulk market, which was high since 2003, collapsed in 2008 as a result of decreased trading activity and overcapacity of dry bulk ships in this sector[60] and costs went back to the level they were before the price peak. Price differences also occur between European destinations.[52] Long-term contracts for shipping, signed early 2009, settled at below US$25 per tonne for Rotterdam, and were US$28 to US$29 for the UK and US$42 for Scandinavia. For comparison, a Canadian pellet study[61] assumed that sea transport to Sweden is on average US$7 per tonne more than shipping to the Netherlands.

Pellet export prices (FOB)

The USA and Canada are the largest exporters of wood pellets to Europe.[13] The major export harbors in North America are located in the south-east USA (Mobile in Alabama; Panama City in Florida) and Vancouver in west Canada (Verkerk B, 2010, pers. comm.).[38] The wood pellet prices for export (FOB)[31,32] rose from €85 in July 2009 to €112 per tonne of pellets by November 2010 in south-east USA and in the same period from €78 to €112 per tonne in west Canada (Figure 9). The tightness of feedstock supplies pushed up pellet production costs in North America and Europe in 2009.[52]

The major export flows from Eastern Europe originate from Russia and the Baltic States. Most pellets are delivered to Europe through St Petersburg harbor in north-west Russia and via Riga harbor in Latvia. The remainder are transported by truck. The prices of pellets exported from St Petersburg to Scandinavia and Western European countries were early 2010 at a level between €105 and €115 per tonne FOB.[9,34] Average export prices in Riga have gone up on an annual basis to about €119 per tonne by the end of 2009. Continuous supply has been difficult in both Riga and St Petersburg harbors. Most of the suppliers are relatively small – in terms of production less than 25 000 tonnes per annum – so it takes

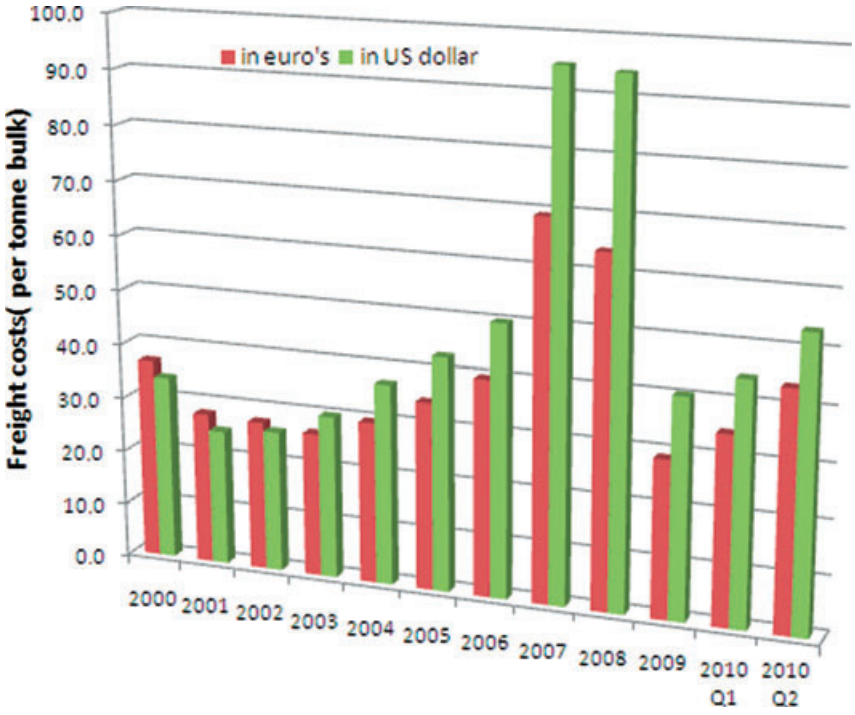

Figure 8. Historic ocean freight costs between North America and Europe.[57–59]

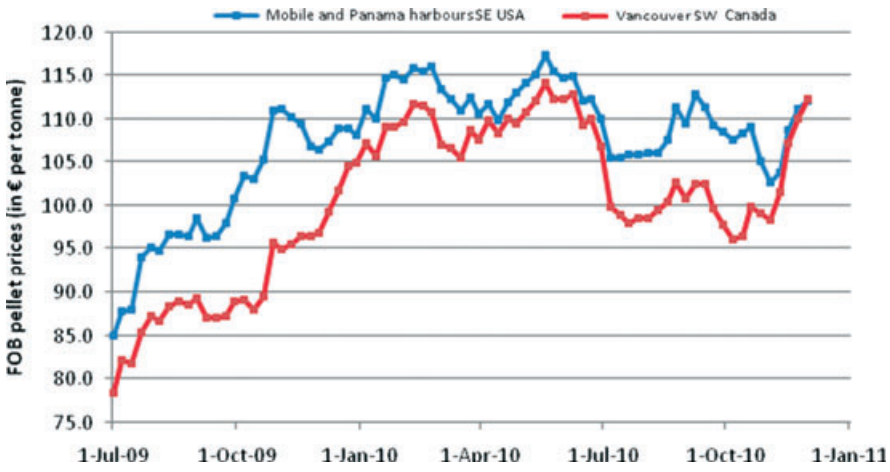

Figure 9. FOB pellet prices in North American harbors.[31,32]

time for them to supply a full vessel. To have reliable delivery and uniform quality, Scandinavian customers are willing to pay a premium on top of daily pellet spot prices.[33] By the end of 2009, the average shipping costs from Riga to Denmark, as estimated by involved pellet actors,[33,59] were about €20 per tonne and about €25 per tonne for loads from both St Petersburg harbors. The latter have higher costs due to a longer period of ice coverage around the harbors and waterways, which leads to additional costs for icebreakers.

Main pellet market trends

Table 4 summarizes the price developments for the major pellet market types as described in the previous sections. The pellet market is quite dynamic due to economic developments and recently released government biomass support plans. Public support is needed to cover the additional costs of capital investment, operation and maintenance of renewable energy equipment, and pellet fuel feedstock, in comparison with their fossil fuel alternatives.[7] From the market

Table 4. Major trends & proposals in Europe's major pellet markets. Possible effects on pellet prices are converted to € per tonne pellet (Box 1).

All impacts in € per tonne pellet	Large-scale users (bulk)	Medium-scale users (bulk)	Small-scale users (bulk)	Small-scale users (small bags)
Feedstock costs	Topic W. USA: upward price in 2010 for delivered sawdust: €45/tonne pellet. Proposal USA: BCAP programme subsidy for feedstock (equal to €13 per tonne[62]).	Topic Latvia: Since 2008: low quality logs (and chips) are also used.[33] Higher feedstock costs and primary energy input.[7]	Topic Germany: upward prices for sawdust: price 2009: €85 per tonne delivered.[72] Remarkably: next to a basic increase of ex mill prices, sawdust transport is increasing (fuel costs; distance).	Topic Italy: relatively high share of integrated sawmills and small pellet plants. External share of feedstocks low, thus limited transport of sawdust, etc.
Pelletization costs	Topic Canada: larger-scale plants are constructed for lower costs per tonne of pellets.[61]	Topic Sweden: higher costs for power consumption per tonne of pellet produced[7]	Topic Austria: Higher pellet drying costs.[71] Topic Switzerland: extra import from €-countries, due to relatively low price.	Topic Hungary and Bulgarian: bagged pellets have lower prices, with sales at the pellet plant (rather than from the retailer) due to a lacking distribution system.[8]
FOB prices	Topic USA & Canada: upward prices in 2010: level €110-115 per tonne.[31]	Topic Russia & Latvia: upward prices 2009 between €105–115 tonne.[34]	Not applicable	Not applicable
International pellet transport	Ocean shipping prices are fluctuating: between €30 and €70 per tonne in 2007–2010.[57–59]	Short sea shipping: in 2009 about €20 per tonne from Riga and €25 from St Petersburg.[33,59]	Truck transport between €16 and €18 per tonne in 2008-2010 for pellet transport.[7,55]	
	Some future options. First a CO_2 levy on international shipping fuels:[65] a levy of €15 per tonne CO_2 results in €4 per tonne pellet extra costs, based on 16 500 km distance and 15.9 g CO_2 emissions per tonnekm.[66] Second, torrefied wood pellets (TWP) are developed for long distance shipping. TWP are assumed to have 40% lower transportation costs per unit.[61]			
CIF prices	Topic Netherlands: Fluctuating APX-Endex prices, currently above €130 per tonne.[29]	Topic Sweden: upward 2010 Foex price level of about €135 per tonne pellet.[30]	Not applicable	Not applicable
	Note: Long-term (instead of short-term) contracts are most common, with purchases up to 3 years ahead of delivery.	Note: reported FOB prices Russia,[9,34] plus sea freight and handling[33,59] are just below CIF prices.[30]		
Final use (energy conversion) of wood pellets	Topic Netherlands: Public supported feed-in tariffs, €0.05 to €0.07 per kWh_e (€120 to135), will gradually disappear after 2012.	Topic Sweden: €10 per GJ_{th} tax on CO_2 and sulphur emissions, equal to about €160 per tonne.[7]	Topic EU-27: new certification standards (EN 14.961-2) for non industrial use. Possible certificates are DIN+, EN+, etc. Example: basic certification costs for EN+ (excl. surveillance visits) are €0.06 to 0.13 per tonne pellet. EN+ partly relies on existing certificates for sustainable forest resources.[70]	
Government subsidies	Topic Netherlands: new options proposed (e.g. min. biomass share cofiring).[67]	Topic Poland: share of agro residues of 100% in 2015 for >5 MW plants.[8]	Topic Germany: MAP subsidies (€36 per kW) for purchase of boilers for households are continued again, after a temporary stop.[73]	Topic France: incentives for pellet stoves and boilers leads to replacement of old log boilers.[74]
	Topic UK: reduced ROC subsidies for cofiring, down to £45 per MWh_e,[31,68] equal to €100 per tonne pellet.	Topic UK: RHI for dedicated biomass use in heating plants. Tariff for large plants (>0.5 MW) are £16 to £25 per MW_{th}, equal to €85-€135 per tonne pellet.[69]		Topic Italy: support of local biomass for energy plants is delayed by administrative procedures.[32,75]

types incorporated in the summary, we have seen the following trends occurring in recent years:

- *Large-scale bulk for power production.* One topic from the start of the pellet supply chain is the BCAP programme in the USA. The US government announced financial support for all kinds feedstock for bioenergy:[62] US$17.5 per tonne, possibly lowering pellet production costs by about €13 per tonne. In order to prevent unwanted shifts from the forest industry to the energy sector, the BCAP focuses on forest residues (low-quality logs) rather than sawmill residues (chips, sawdust). In Canada, as another example, newly constructed pellet plants are larger[61] to comply with the growing needs of the European power plants. CIF market prices for pellets are increasing; the dollar rate has a major stake in this trend. Remarkably FOB prices in North America[31] plus the reported freight[57–59] seems to overtake the CIF prices (in case of short-term delivery time) by 2010. Concluding, published short-term CIF prices[29,31] do not reflect the real market, because pellets are more and more frequently purchased on longer-term contracts up to three years.[63,64] A near future impact for sea transport is a possible implementation of a carbon levy on shipping fuels after 2012.[65] To illustrate the relatively low impact: a tax of €15 per tonne CO_2 is equal to €4 per tonne of pellets.* A larger effect may be expected from a future introduction of torrified wood pellets. Transport costs are expected[61] to decrease by 40% due to a higher energy density per m^3. At the other end of the pellet supply chain, public support is much stronger on the European continent; public support by Dutch feed-in tariffs (€120 to €135 per tonne) will be gradually phased out after 2012 and maybe replaced by another regulation, like for example an obligatory proportion of biomass cofiring.[67] For comparison, the Renewable Obligation Certificates system[68] in United Kingdom supports the use of biomass with about €100 per tonne of pellets (derived from £45 per MWh_e for large-scale power production).
- *Medium-scale bulk for district heating and CHP.* Pellets for medium-scale heating in Scandinavia show an increased price trend, through the increased cost of domestic pellet production. The number of pellet plants is increasing: traditional forest industries are investing in pellet plants resulting in extra feedstock competition.[53] On the other hand, the prices of imported pellets also went up. Latvian pellets, for example, increased from €95 to almost €120 per tonne FOB Riga. Amongst others, Latvian prices have increased by introducing new feedstocks such as low quality pulpwood, which is more expensive than traditional sawdust (Fig. 10). The distribution of pellets, by means of short sea shipping remains quite stable: between €20 and €25 per tonne. At the end of the supply chain, Swedish consumers of industrial pellets generally pay higher pellet prices, due to a high tax system for CO_2 and sulfur emissions of competing fossil fuels: €10 per GJth. This tax, equal to €160 per tonne of pellets has the largest impact of all trends. A minimum obligation is already in place in Poland, where for larger (>5 MW) energy plants a share of 100% is valid for biomass from agricultural resources (like mixed biomass pellets) in 2015.[8] The UK focuses on the heating market in its renewable action plan. The UK public subsidies are designed for the use of all kinds of biomass, including pellets. The proposed subsidies (Renewable Heat Incentive) range between €85 and €135 per tonne pellet, converted from a tariff of £16–25 per MWh_{th} for (district heating) plants larger than 0.5 MW.[53,69]
- *Small-scale bulk and bagged pellets for residential heating.* Where bulk pellets for residential heating are delivered at home, bagged pellets have to be purchased from retail shops, or in case a distribution network is lacking (as in Hungary and Bulgaria), from pellet production plants. Italy has the largest bagged-pellet market and most of its production integrated in small sawmills. In France, the support for pellet stoves has led to the replacement of older log boilers and fire places.[74] A particular trend break for pellets occurred in Germany: public subsidies on the purchase of residential boilers were set on hold and later decreased to €36 per kW installed kW.[73] Bagged pellets and bulk

*Average CO_2 emissions of international shipping are about 15.9 g CO_2 per tonne km[66] and the shipping distance between Vancouver, Canada and Rotterdam, the Netherlands is 16 500 km[7].

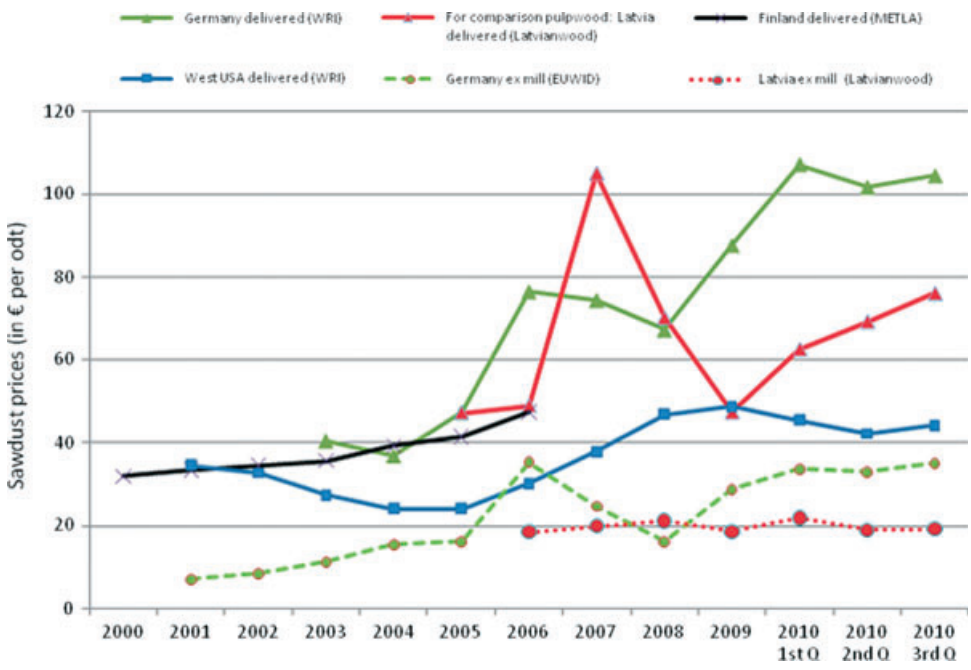

Figure 10. Historic prices of sawdust ex sawmill and delivered[62,72,76,77] and of pulpwood delivered[76] (in € per tonne).

pellets for households have most characteristics in common: their supplies have become more expensive, due to larger production costs[71] and slightly increasing prices for sawdust.[72] Bulk and bagged pellets for households are also going to face one pan-European standard in 2011 (Table 3). The accompanying costs for optional 'EN-14961' certification are assumed to be relative low. According to DEPI,[70] the certification costs are about €0.10 per tonne, excluding any additional costs for regulatory audits. The certification will partly rely on existing certification systems for sustainable forest resources (FSC; PEFC). Finally, both market types show a predominant use of domestic pellets instead of imported ones. However, this market situation seems to change soon. Related to the attractive euro exchange rate, European countries with another currency, like Switzerland, may wish to import a larger part of their domestic needs from 'cheap neighbouring euro countries'. Accross Europe, the distribution of residential pellets relies on truck transport, which costs vary from €16 to €18 per tonne of pellets.[7,55]

Current and future feedstock supplies

To which extent can pellet plants get enough raw material supply now and in the near future? In our scenarios, forest industries and the growing bioenergy sector compete for traditional feedstocks, like sawdust, shavings, logs, and sawmill chips, and also newer feedstocks, like forest slash and forest chips. Biomass needed for drying during wood and pellet production processes is taken into account in our Discussion section.

Current supplies

The feedstock supply for the pellet sector used to be quite specific: until 2008 the sector used largely leftover feedstocks like wet sawdust (mainly produced during the processing of logs) and shavings (processing of sawn wood). In addition to the pellet industry, sawdust and shavings are used by forest industries for the production of wood-based panels. Worldwide, there is little market information available on sawdust and shavings. Only WRI,[62] EUWID,[72] Latvianwood,[76] and Metla[77] regularly publish prices on sawdust. Figure 10 shows the historic developments, fluctuating, but also slightly increasing since 2001 in selected regions,

western USA, Germany, Latvia, and Finland. Remarkably, German prices for sawdust delivered to consumers increased relatively more than for sawdust produced at the saw mill (ex-mill). The increase is probably caused by increasing transport costs, and higher local demand. Sawn-timber production decreased across North America and Europe in 2008/2009[39] and led to less available feedstock for the growing needs of the pellet sector. At the same time, the pulp and paper sector, and also the panelboard sector (especially oriented strand board) cut their needs, leading to alternative feedstock for the pellet sector from low-quality logs (pulpwood) and sawmill chips. According to RISI,[78] the downturn in demand for pulpwood was partially compensated for by the growing needs of the pellet sector. Information about pulpwood and chip prices is abundantly available.[79,80] However, they show a large variety by including different wood species. To illustrate one trend, we have added an average price for Latvian pulpwood (assuming equal shares of pine, spruce, birch, and aspen),[76] which are used for Latvian pellet production since 2008.[33]

In the near future, forest chips and whole branches and tops (forest slash) from existing forests and new energy plantations will become technically feasible. They can be pelletized alongside traditional feedstocks such as sawdust, shavings, and pulpwood chips. New production steps prior to drying will then have to be integrated into the process of pelletization. The bark must be removed from the green chips or slash, which is then reduced to chips. These chips are further pulverized prior to drying, by wet milling instead of dry milling.[81] Bark and other rejects can be used for the drying process.

Future demand

The EU's gross final energy consumption is increasing.[6,82] Simultaneously, the demand from the energy sector (heating, cooling, power production) and from the transport sector (biofuel), related to the input of biomass and waste, has gone up from 150 million tonnes to 250 million tonnes (Fig. 11; Box 1). The EU 2020 policy target, 20% renewable energy sources in gross energy consumption (GEC), is a predominant driver for future biomass and waste demand. Based on the World Energy Outlook (WEO),[83] the future trends for consumption of biomass and waste for energy are derived for the EU-27. The WEO reference scenario includes EU-27 goals for achieving a 20% share from renewable energy sources and 20% GHG emission reduction. The WEO '450 scenario' is aiming for a long-term limitation of greenhouse gases in the atmosphere (concentration of 450 ppm), via more stringent measures, like 37% emission reduction goals in power production and transport.[83]

Wood and wood waste have a major share in the category 'biomass and waste'. According to Eurostat,[6] the gross energy consumption of wood and wood waste has increased from 125 million tonnes in 2000 (83% of total biomass and waste consumption) to 175 million tonnes (67%) in 2009. Wood and waste wood is primarily used by the energy sector (heating, cooling, electricity).[6] The current use of woody biomass by the transport sector (transportation fuels) is limited. Actually, mainly non-woody first-generation biomass, such as cereals and corn, is used for the production of transportation fuels. In near future also second-generation biomass (woody or herbaceous feedstocks) is likely to be used for transportation fuels.[84,85]

The EU's forest sector is also a major player in the woody biomass arena with an industrial round wood (logs) consumption of 324 million m^3, equal to about 160 million (air dry) tonnes.[86,87] The sector expected an industrial log consumption in the EU-27 in 2020[†] of between 481 and 576 million m^3, starting from 366 million m^3 in 2000.[88] Compared to the lower 2009 level, the future increase is between 160 and 250 million m^3, equal to between 80 and 125 million tonnes. The lowest increase occurs in UNECE's reference scenario; the highest increase is supposed to occur via a quick integration of new EU member states after 2004 (UNECE's rapid growth scenario).

The expected growing needs for wood and wood waste (including pellets), by the transport, energy and forest sectors, are shown in Fig. 11. In the following sections, we have elaborated some considerations for future feedstock availability of woody biomass, in relation with the magnitude of future pellet markets.

To explore the future needs of woody feedstock for forest, energy and transportation sectors between 2010 and 2020, we compiled two scenarios:

[†]EU-27 has an average share of 73% in total 2020 European industrial wood use, based on 2000–2009 data.[86,87]

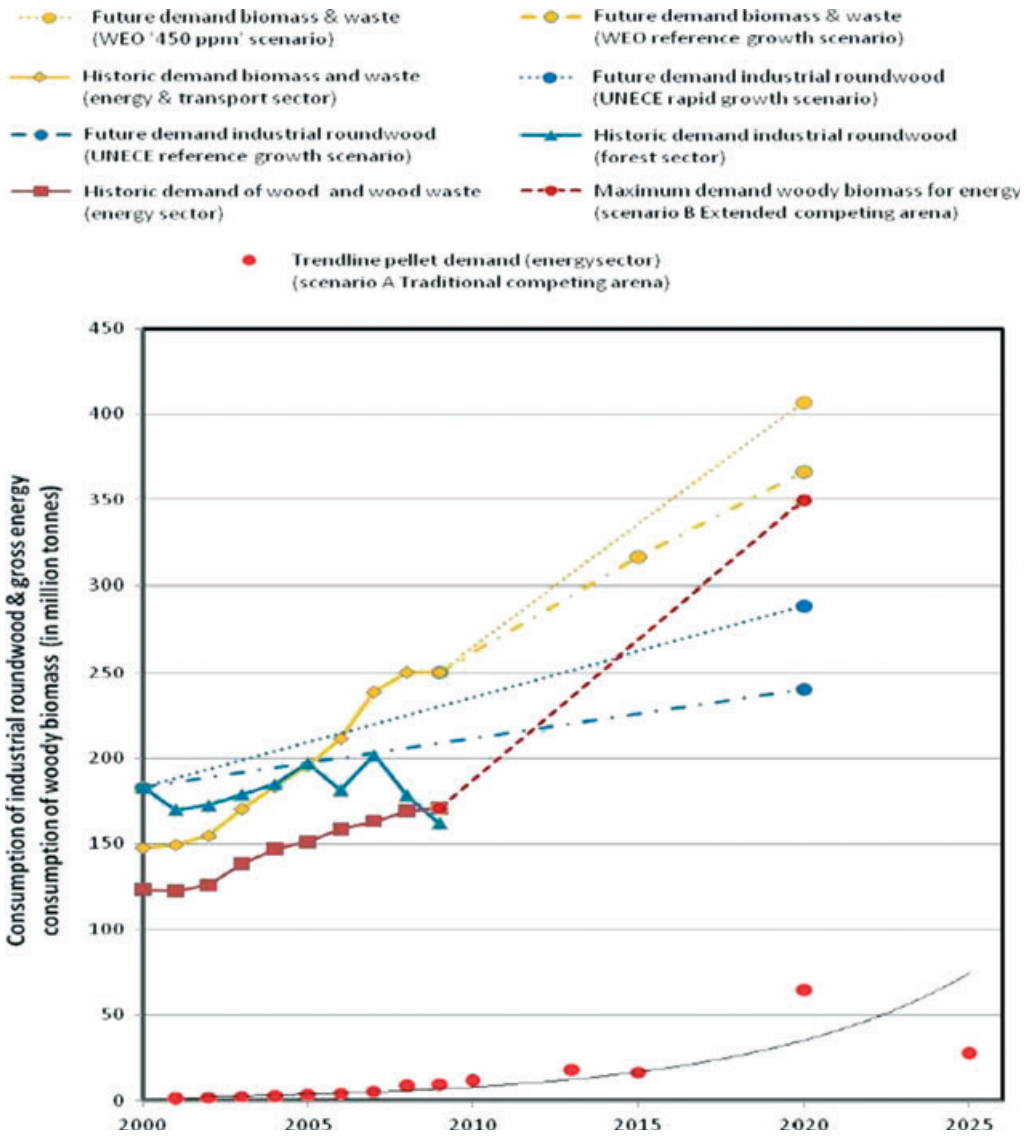

Figure 11. Consumption patterns of industrial round wood in the EU-27 and primary energy demand of wood and other biomass sources in EU-27 (in million air dry tonnes).[33,82,83,86–92]

(A) *Traditional competing arena with tight supplies.* Scenario A does reflect the current competition between forest sector and the energy sector (assuming a growth pattern limited to wood pellet markets) and their respective growing demands for existing feedstocks like sawdust, shavings, pulpwood, and chips.

(B) *Extended competing arena with a maximum demand for woody biomass and broad supplies.* Scenario B reflects an extended competition arena, in which again both the forest sector and the energy sector take part plus the entrance of the transport sector. They are now using all kinds of wood and wood waste (including pellets). The future feedstock supply is enlarged with new energy plantations and with the recovery of slash in EU-27 forests from altered forest management and of waste wood from post-consumer waste disposal.

Scenario A: Traditional competing arena

The growth in demand for feedstocks after 2009 is about 105 million tonnes of pellet equivalents (Fig. 12; Box 1), consisting of logs (80 million tonnes) for a reference growth of forest industries[88] and extra future feedstock needs (25 million tonnes) for pellet consumption by the energy sector.

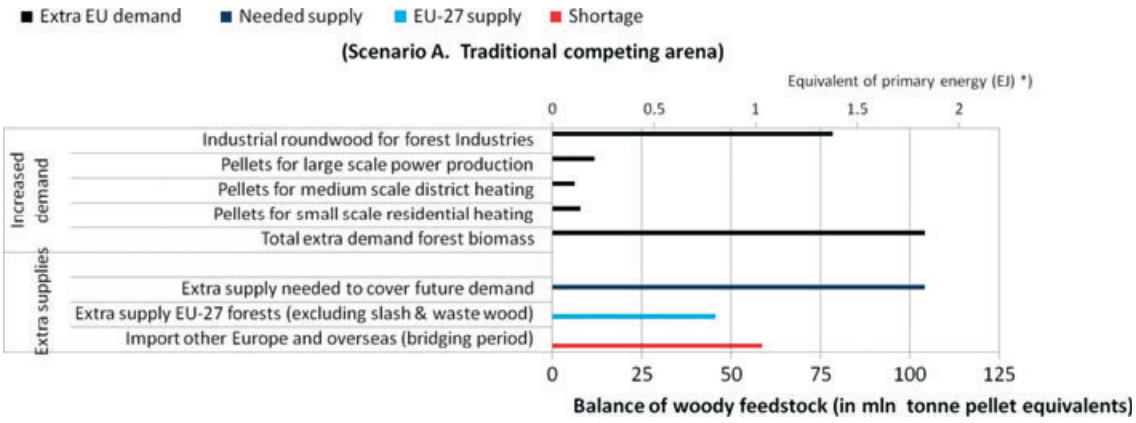

Figure 12. Additional annual forest feedstock supplies in 2020.[33,87–93]

The future pellet consumption trend is derived from our historic 2001–2009 Pelletsatlas data and four future projections: Jaakko Poyry,[89] Ekman & Co.,[33] AEBIOM,[90,91] and New Energy Finance.[92] All projections are based on Europe,[‡] but estimated for different years. Ekman reckons on 18 million tonnes in 2013; Pöyry estimates 16.5 million tonnes in 2015; AEBIOM expects between 50 and 80 million tonnes in 2020; and New Energy Finance expects about 28 million tonnes in 2025. Most projections foresee the largest growth in the electricity sector, ranging from a modest 3% share for cofiring of pellets[92] to even 20% cofiring[90] shares in some utilities. After an exponential fit (Fig. 11), a consumption level just lower than 35 million tonne could be reached in 2020, starting from 9.2 million tonnes in 2009. Information on specific shares for the major pellet market types (as defined in our Methodology section) is extremely scarce. To distinguish between pellet use for small-scale residential heating (bulk and bags), medium-scale district heating and for large-scale power production (including CHP), we assumed the following shares for the EU-27: 40%, 20%, and 40% in 2009 respectively 33%, 22%, and 44% in 2020.[33]

The EU-27 forest supply is derived from the good practice guidance for sustainable wood mobilization by UNECE and FAO,[93,94] more specifically from the 'socio-economic potential'. This potential exists of additional tree fellings for forest maintenance, and unused wood residues from forest industry. The UNECE options 'forest expansion' (plantation chips), 'forest slash' (branches and tops including bark, left after current and future harvests) and 'waste wood' (post-consumer recovered wood) are not regarded like traditional feedstock, but are included in scenario B. The UNECE option 'fibers from agricultural residues' is not applicable for our analysis, because we focus on woody feedstocks.

Resuming: The total extra demand for pellets and industrial round wood in the EU-27 can only be partially (45%) supplied by EU-27 forests, leaving a shortage of 60 million tonnes. Any shortage must be 'bridged' via imports from other European countries and overseas. A main source just outside the EU-27 is additional fellings from north-west Russian forests. According to recent studies,[95,96] between 17.5 million and 50 million tonnes of forest residues can be sustainability harvested in this region. Finally, the potential of pellets as a renewable energy source could increase from 0.2% to 0.8%, based on a gross final energy consumption in the EU-27 in 2008 (75 EJ).

Scenario B: Extended competing arena

The maximum needs are compiled for three sectors as follows. First, the rapid growth scenario (125 million tonnes) of the forest industry[88] is incorporated. Secondly, we have anticipated the additional need of 30 million tonne of second-generation biomass for the expected output of transportation fuels in 2020.[85] Therefore, we used an efficiency factor of about 50% to 52% for extracting liquid

[‡]The EU-27 share in total European pellet consumption was 94% in 2009 and is expected to reach 99% in 2020.[33]

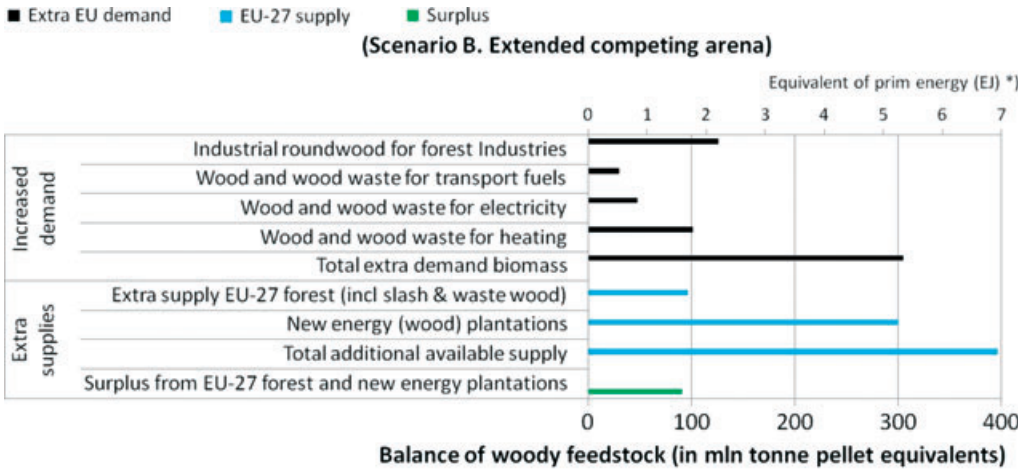

Figure 13. Additional annual biomass feedstock supplies in 2020.[84,85,87,88,93,99,100]

fuels (biodiesel) from short rotation crops.[97,98] Thirdly, we considered a maximum use of woody biomass by the energy sector (Appendix B), which is built of two parts: biomass for heating (growth of about 100 million tonnes) and for electricity production (50 million tonnes). The increased demand for heating is based on a substitution of 50% of the most recent (2004) data for heating oil consumption.[99] When assuming an average lifetime of 20 years for heating boilers in general, about 50% of heating oil boilers could be replaced by biomass boilers between 2010 and 2020. The maximum future demand for biomass cofiring (based on an EU-wide average cofiring rate of 10% biomass and 90% coal or lignite) in EU-27 power plants is estimated at about 50 million tonnes. Data are derived from Hansson *et al.*,[100] more specifically the substitution case for power plants up to 40 years old. The current input of biomass for cofiring (4 million tonnes of wood pellets) is subtracted from the 2020 potential, leaving the increase in annual biomass demand until 2020.

About 400 million tonnes of woody biomass is available in scenario B (Fig. 13). First, substantial areas can be released through sustainable gains in yield in the food and feed sectors.[84] According to this analysis of future land use and biomass supply in the EU-27^{+} (REFUEL project), second-generation biomass will be largely grown on available cultivated land in Eastern Europe. The possible future supply from second- generation woody energy plantations (with *Salix, Populus,* and *Eucalyptus* species) is estimated at about 300 million tonnes in the EU-27. Secondly, altered forest management may lead to a sustainable recovery of forest slash (30 million tonnes). Thirdly, about 20 million tonnes of additional waste wood can be recovered after waste collection.

Resuming: the maximum demand of woody biomass in the extended scenario (305 million tonnes in 2020) can be met, provided that these three additional sources are used in the near future, next to the existing EU-27 forest potential in scenario A (45 million tonnes). The use of wood and wood waste as a renewable energy source could more than double from 3.9% in 2008 to 8.2% in 2020, both based on GEC level of 75 EJ.

Discussion

Our forecasts for the growth of industrial round wood (80 to 125 million tonnes) are based on older estimations by UNECE[88] in 2005 and will be updated by UNECE in 2008–2013. Meanwhile, a preparatory study[101] shows that the expected increase of demand in the EU-27 (with a 73% share in total European consumption) between 2010 and 2020 will be lower: 19 to 31 million tonnes. Our other forecasts for the use of woody biomass for energy and transport purposes, range from a minimum growth of 25 million tonnes of pellets in our traditional competing arena (scenario A), to a maximum growth of 180 million tonnes of wood and wood waste in our extended competing arena (scenario B). For comparison we have checked the National Renewable

Energy Action Plans (NREAP's) of the EU-27. Per December 2010, all member states[§] have submitted their biomass needs for a renewable energy production in 2020: total 136 MTOE.[102] This means that the use of biomass needed for the final production of electricity, heating & cooling and transportation fuels (plus the respective conversion losses according to Appendix B and Box 1) will grow by about 220 million tonnes pellet equivalents, compared with the 2010 use of biomass for renewable energy production.[82]

Our forecasts exclude feedstock for drying of final products, like sawn wood, wood-based panels, and pellets. Note that here are large potential GHG savings possible when drying processes with fossil fuels are replaced with bark or other woody residues. In case of pellet production, about 0.33 to 0.66 tonnes of wet feedstock per tonne pellet is needed for separate (kiln) drying processes[7] and 0.33 to 0.73 tonne per tonne sawn wood, respectively wood-based panel (OSB).[103] All calculations are based on an average primary energy value of 7.5 GJ per tonne of low-quality drying feedstock (with a range between 6 and 9 GJ per tonne[104,105]). Assuming a 100% pellet share in the woody biomass growth of the energy sector, 100% production of sawn wood from industrial round wood in scenario A and 100% OSB production in scenario B, the need for drying feedstock could vary between 20 million tonnes and 140 million tonnes for separate (kiln) drying systems. New developments are heading toward more integrated systems, in which residual heat of CHPs is used for the drying processes and in that case, less woody feedstock for drying is needed.

Future pellet markets for energy

Concluding from our detailed overview in Appendix B, the EU member states with the most potential for additional wood and wood waste use for heating and electricity production are: Germany (43 million tonnes), France (19 million tonnes), UK (14 million tonnes), Spain (13 million tonnes), Poland (7 million tonnes), Belgium (7 million tonnes), Greece (6 million tonnes) and Italy (6 million tonnes). It is uncertain to what extent the demand for woody biomass will be covered by wood pellets. National subsidy schemes for biomass use will be determining for the use of wood pellets or other types of biomass. In Poland for example, the use of residues from agriculture and agro industry is supported.[8] In the UK, the feed-in subsidies for biomass for energy production are more favorable for medium-scale heating plants than for large-scale cofiring units.[53,69] In order to meet the forecasted increasing biomass demands, it is most likely that in the near term, the current import from outside the EU-27 and overseas will increase, next to more supplies from the EU-27 forest sector. January through June 2010 showed[53] an increased volume of imports from outside the EU-27: 1.1 million tonnes (same period 2009: 0.85 million tonnes). In the long term, the possible establishment of new woody plantations for energy may relieve further pressure, not only in EU-27 (a potential of 300 million tonnes is included in our extended scenario), but also in Ukraine. The potential extra supply of woody biomass from Ukraine is estimated at about 135 million tones.[84]

Technological changes are also relevant for the EU's future pellet markets, especially those for coal power plants. For our future demands, we assumed a relative conservative pellet cofiring share between 3% and 20%. Nowadays, shares of up to 35% are already possible [106,107] or above 50% in the future with more advanced systems.[108] With regard to future supply, torrified wood pellets and other torrified biomass are being developed for cofiring, next to traditional wood pellets. When ready for commercial production, their characteristics of high energy density and weather durability, will facilitate long-distance transport and storage, and be comparable with those of coal.

Methodological constraints

In two small pellet European markets (Luxembourg and Lithuania), the apparent consumption turned out to be negative in 2009, while net export was larger than domestic production (formula A). When compiling the apparent consumption for all European countries, the applied data for real production, trade, respectively stock changes, show serious deficiencies. According to the widely used pellet production data of Bioenergy International (BI),[11,12] less than 500 plants in Europe are listed with capacities between 10 000 and 250 000 tonne. BI does not include smaller plants (<10 000 tonnes), and therefore BI's total pellet production is underestimated. The number of smaller pellet plants is about 190[20]. In return, an overestimation of pellet production occurs when full utilization (100%) of capacity is assumed

[§]Data for renewable energy production processes in Hungary are separately covered via the Hungarian NREAP.

by BI, where real production figures per plant are lacking. In 2008, the capacity utilization was on average 54% for all European pellet plants[20]. Secondly, officially registered pellet import and export flows by Eurostat[13] show a large discrepancy in total EU intra-trade levels and also at individual EU member state level. On the EU-27 level, the difference is about 1.2 million tonnes, compared to a consumption of about 9.2 million tonnes in the EU-27. On a bilateral level, the highest discrepancy was between Germany and Spain: German export of wood pellets to Spain was reported to be about 167 000 tonnes, whereas registered Spanish imports from Germany only amounted to 1000 tonnes. Thirdly, we assumed the stock changes of pellets to be negligible. However, stock changes (within one year) may be considerable, especially those for industrial pellet stocks. The storage capacity in Rotterdam harbor was reported by one utility to reach 200 000 tonnes in 2009, which is large compared to Dutch annual consumption (950 000 tonnes).

Representation of pellet price surveys

With regard to pellet price surveys, the number of responding pellet actors and their corresponding volumes are rather low compared to the total number of actors. In the case of markets with a few large consumers, prices are volatile and even the risk of price setting exists. An extra check has to be incorporated to prevent the idea of price setting. For example, FOEX has its index approved by the European Commission and audited by an independent body.[109] Where FOEX incorporates historic prices (from a certain date) in its index, APX Endex uses a forecasting method (from one month up to three years ahead of delivery). The respective price curves are different, although a similar pattern of fluctuations occurs. Apparently, FOEX seems to follow the future price trend such as that set by APX Endex.

Conclusions

The EU is aiming at a 20% contribution of renewable sources in 2020 to the gross final energy consumption (GEC). Pellets and other types of woody biomass could significantly contribute to this goal. Current EU pellet consumption for energy is about 10 million tonnes (0.2% of GEC) and total wood and wood waste consumption (including pellets) is at about 170 million tonnes (3.9%). Market volumes of pellets and other woody biomass for energy are expected to increase further. Energy market experts expect the wood pellet market to grow by about 25 million tonnes in 2020, equal to an increasing share of 0.6% toward our current GEC (shown in scenario A). In scenario B, a maximum growth of 180 million tonnes of wood and wood waste for energy consumption is compiled (8.2% of GEC), i.e. doubling the current share.

After including the growing demand by the forest sector, additional 2020 demand for woody biomass varies from 105 million tonnes, in scenario A (including reference growth of the forest sector), to 305 million tonnes, in scenario B (rapid growth of the forest sector). Additional supply of woody biomass may vary from 45 million tonnes from increased harvest levels to 400 million tonnes after the recovery of slash via altered forest management, the recovery of waste wood via recycling, and the establishment of woody plantations (with *Salix, Populus* and *Eucalyptus* species) in future. Any short-term shortages within the EU-27 may be bridged via imports from nearby regions like north-west Russia or overseas. Next to the EU-27 potential of wood energy plantations, Ukrainian woody plantations may be interesting from a long-term perspective, too.

Current prices of pellets are under pressure. The prices of most pellet markets have steadily increased in the EU-27 since 2007. Pellet demand is growing across Europe, whereas pellet production capacities are still largely unused. Industrial pellets are also sourced from regions outside the EU, mainly from North America and north-west Russia, and their volumes have steadily grown. Nevertheless, future demand is highly uncertain, while the EU-27 markets are subsidy-driven. From all trends, the impact of public support for energy conversion is the largest. The two largest markets for industrial pellets, the Netherlands and Sweden, mainly rely on feed-in tariffs (equivalent to about €120–135 per tonne of pellets), and on combined carbon-sulfur taxes (equivalent to about €160 per tonne of pellets), respectivelty, but both systems may not last until 2020. Apart from fossil fuel price developments, new renewable energy obligations[4] will determine future pellet markets, in combination with the abolishment of existing public support schemes and/or the establishment of new ones. New global production capacities are still being constructed around the world, both the number of plants and the average plant size will grow, and the respective pellet producers are obviously counteracting further future growth of pellet demand.

Recommendations

The data quality of pellet surveys can be further improved. The methodology of apparent consumption shows serious deficiencies through incomplete production data, inconsistent trade data, and the lack of inventories for national pellet stocks. Real production data should include small pellet plants, too. To get consistent trade data, it would certainly help if Eurostat introduced a double-entry bookkeeping system for intra-European trade import and exports. When exporting one tonne of pellets from country A to country B, country A should register this volume as an exported commodity on behalf of country A, and have the same volume automatically registered as an imported commodity on behalf of country B. Finally, we recommend the monitoring of national pellet stocks by the end of each year and a crosscheck of the resulting apparent national consumption through enquiries with final pellet users in the case of industrial pellets, or advanced estimation methods, in case of non-industrial pellets.

Pellet price indexes need further development. So far, most mature pellet markets have introduced price indexes, like that for small-scale users of bulk pellets in Austria[21] and Germany,[22] medium-scale in Scandinavia,[30] and large-scale in the Netherlands[29] and the UK.[31] In the case of forecasted price indexes for industrial pellets, long-term prices better reflect market conditions than short-term prices, due to general contract conditions with deliveries up to three years in advance. In the case of non-industrial pellets in small bags, there is currently no real price indication for major markets in Europe. Preferably, a collection of prices for bagged pellets needs to re-established after a trial period in the Pelletsatlas project (2007–2009).[8]

An early impact analysis of feedstock competition between different sectors is recommended. More attention is needed for the complex relationship between feedstock use for the bioenergy sectors (heating, cooling, electricity, and transport fuels) on the one hand, and for forest industries, like the panelboard industry and pulp mills, on the other. More historic price data on common shared feedstock, such as sawdust and pulpwood, should be published to make the mutual relationship more understandable. Beyond immediate issues related to market effects of subsidies, the question was raised as to how traditional forest industries will fare over the long term with increased worldwide competition for the same raw materials. As a first step, UNECE and FAO have introduced a good practice guidance on sustainable wood mobilization.[94]

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References

1. Heinimö J and Junginger HM, Production and trading of biomass for energy - an overview of the global status. *Biomass Bioenerg* **33**(9):1310–20 (2009).
2. Röder H, *Pellets or Wood Chips - Where is the Trend Headed for Large Power Plants*? Pöyry Consultants Oy. International Pellet Forum, Stutgart (2010).
3. Obernberger I and Thek G, *The Pellet Handbook: the Production and Thermal Utilization of Biomass Pellets*. EarthScan, London (2010).
4. European Parliament and EU Council, Directive 2009/28/EC (23 April 2009) on the Promotion of the Use of Energy from Renewable Sources. *Official Journal of the European Union* **L 140** (EN): 16–62 (2009).
5. Eurostat, *Panorama of Energy; Energy Statistics to Support EU Policies and Solutions*. Eurostat Statistical Books, Luxembourg (2009).
6. Eurostat, *Energy statistics; Supply, tranformation, consumption (1990–2008)*. [Online]. Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database [September 2, 2010].
7. Sikkema R, Junginger HM, Pichler W, Hayes S and Faaij APC, The international logistics of wood pellets for heating and power production in Europe. *Biofuel Bioprod Bioref* **4**:132–53 (2010).
8. Pellets@las, *Country reports EU 27, Norway and Switzerland and Web Based Data per Country about Volumes and Prices*. [Online]. Available at: http://www.pelletsatlas.info [December 4, 2010].
9. Rakitova O and Ovsyyanko A, *Wood Pellets Production and Trade in Russia, Belarus and Ukraine* (deliverable 6-1). [Online]. Utrecht University, the Netherlands (2009). Available at: http://www.pelletsatlas.info [April 12, 2010].
10. Glavonjic B, *Wood Energy: Definition, Objectives and Challenges in South East Europe*. UNECE. Workshop Policy options for wood energy, Dubrovnik (2009).

11. Ljungblom L, The Pelletsmap 2009–2010. *Bioenerg Int* **41**(7):1–52 (2009).
12. Ljungblom L, The Pelletsmap 2008–2009. *Bioenerg Int* **35**(6):1–52 (2008).
13. Eurostat, *EU 27 Trade since 1995 by CN 8. Product 4401.3020 Sawdust and Wood Waste and Scrap, Agglomerated in Pellets*. [Online]. Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/external_trade/data/database [October 30, 2010].
14. Eurostat, *Statistics on the Trading of Goods - User Guide*. Office for the Official Publications of the European Communities, Luxembourg (2006).
15. Ala Kihnia J, General explanations on European trade statistics, in *Proceedings of the Workshop on Development of Meaningful Statistics for Sustainable Bioenergy Trade*. IEA, Paris (25 February, 2008).
16. Roubanis N, *Development of renewable energy statistics*. Dinner debate on renewable energy in EU energy statistics. EHPA, Brussels, (13 April, 2010).
17. Junginger HM, de Wit M, Sikkema R and Faaij APC, International bioenergy trade in the Netherlands. *Biomass Bioenerg* **32**:672–87 (2008).
18. FORCE, *The Danish Wood Pellet Market 2008*. (Energistyrelsen) DEA, Copenhagen (2009).
19. Fürtner K and Haneder H, *Biomasse - Heizungserhebung 2009.* Landwirtschaftskammer Niederösterreich, St Polten (2010).
20. Sikkema R, Steiner M, Junginger HM and Hiegl W, *Final Report on Producers, Traders and Consumers of Wood Pellets (2009)*. [Online]. Available at: http://www.pelletsatlas.info [December 15, 2009].
21. Propellets Austria, *Pelletpreis bei Bestellung von 6 t.* [Online]. Available at: http://www.propellets.at [Period January 2007, December 2010].
22. Carmen, *Holzpelletpreise in Euro pro ton; Lieferung von 5 Tonnen im Umkreis von 50 km*. [Online]. Centrales Agrar-Rohstoff Marketing und Entwicklungs Netzwerk e.V. Available at: http://www.carmen-ev.de/dt/energie/pellets/pelletpreise.html [period January 2007, December 2010].
23. SEIA, *Domestic Fuels; Comparison of Energy Costs.* [Online]. Sustainable Energy Authority of Ireland. Available at: http://www.seia.ie [October 24, 2010].
24. Pelletspris Medelpris Bulk*, All Priser Anges i Kronor per ton Inklusive Moms*. [Online]. Available at: http://www.pelletspris.com/pellets_af_b.php?m=3 [period July 2007, December 2010].
25. Pelletpreis, *Preise (je Tonne inkl. MwSt. und Lieferung) Entwicklung*. [Online]. Available at: http://www.pelletpreis.ch/ [period July 2007, December 2010].
26. Pieret N, *Evolution du Prix des Pellets*. [Online]. Valbiom (2010). Available at: http://www.valbiom.be/files/gallery/prixpellets [October 1, 2010].
27. Statistics Finland, *Energy Supply, Consumption and Prices*. [Online]. Appendix table 06 Consumer prices of domestic fuels in heat production. Available at: http://www.stat.fi/til/ehkh/2010/02/index_en.html [December 16, 2010].
28. ProPellet France, *Site Officiel du Chauffage au Granulé de Bois Pellet*. [Online]. Available at: http://www.propellet.fr/choix-economique.html [September 30, 2010].
29. APX Endex, *Industrial Wood Pellet Price Index*. [Online]. Rotterdam, the Netherlands. Available at: http://www.apxendex.com [period November 2008, December 2010].
30. FOEX, *Pix Pellet Nordic Index*. [Online]. Helsinki, Finland. Available at: http://www.foex.fi [period June 2007, January 2011].
31. Argusmedia, Weekly biomass markets, news and analysis. Methodology and specifications guide (November 2010). *Argus Biomass Markets* (all issues from January - December 2010).
32. Argusmedia, Weekly biomass markets, news and analysis. Methodology and specifications guide (November 2009). *Argus Biomass Markets* (all issues from May - December 2009).
33. Dale A, *Update of European Pellet Markets 2009-2010.* Personal communication. Ekman & Co AB, Gothenburg, Sweden (2010).
34. Stern T and Rakitova O, *Price Developments in the Russian Bioenergy Market*. Eubionet 3. World Bioenergy, Jönköping, Sweden (2010).
35. Freightplus. *Incoterms (2009)*. [Online]. Available at: www.freightplus.eu/incoterms-2000.html [June 6, 2009].
36. Spelter H and Toth D, *North America's Wood Pellet Sector*. Research Paper FPL-RP-656. Laboratory UFP, Madison, USA (2009).
37. Hintz N, *An Update on the US Biomass Market.* Argus Biomass Trading Conference, Brussels (15 April, 2010).
38. Kotrba R, Closing the energy circle. *Biomass Power and Thermal,* **November** (2007).
39. UNECE, Forest Products Annual Market Review 2008-2009. *Timber and Forest Study Paper* **24** (2009).
40. Selkimäki M, Mola-Yudego B, Röser D, Prinz R and Sikanen L, Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland. *Renew Sust Energ Rev* **14**(9):3068–75 (2010).
41. Strauss W, *An Analysis of the Expected Demand for Wood Pellet Fuelled Residential Boilers*. Future Metrics, USA (21 July, 2009).
42. Swaan J, *European Wood Pellet Import Market; the Canadian Influence*. Pellet Fuels Institute. PFI Annual Conference, Hilton Head, USA (2008).
43. John Clegg Consulting Ltd, *Wood Fibre Availability and Demand in Britain 2007 to 2025.* Confor, UKFPA and WPIF, Edinburgh, United Kingdom (2010).
44. Höglund J, *The Swedish Fuel Pellets Industry: Production, Market and Standardization*. *SLU Examensarbeten* **14**:1–70 (2008).
45. Rakos C, *Current Development of the Austria Pellet Market.* ProPellets Austria. International Pellet Forum, Stutgart, Germany (7 September, 2010).
46. EBS, *Milieu Instructie EBS 2006; Stappenplan Op- en Overslag Houtpellets* (including an update 2010). Rotterdam, the Netherlands (2010).
47. Alakangas E, *New European Pelet Standards (November 2010)*. [Online]. Eubionet III. Available at: http://www.eubionet.net [December 2, 2010].
48. Hilgers C, Large heating (Grosses Heißen). *Sonne Wind und Wärme* **9**:76–81 (2008).
49. Mudgal S, Turbé A and Roy N, *Lot 15 Solid Fuel Small Combustion Installations.* [Online]. Bio-intelligence Service SAS Task 2: Economic and market analysis. Available at: http://www.ecosolidfuel.org [June 29, 2009].
50. Hilgers C, Pellettrading goes international. *Sun and Wind Energy* **3**:220–223 (2008).
51. Sénéchal S and Grassi G, *Logistic Management of Wood Pellets; Data Collection on Transportation, Storage & Delivery Management.* [Online]. Eubia (2009). Available at: http://www.pelletsatlas.info [October 6, 2009]
52. Hawkins Wright, Biomass & Pellets - markets - investments - legislation. *Forest Energ Monit* **1**(1–4) (2009).
53. Hawkins Wright, Biomass & Pellets - markets - investments - legislation. *Forest Enery Monit* **2**(5–10) (2010).
54. EEX, *EU Emission Allowances January - December 2009.* [Online]. Available at: http://www.eex.com/en [January 5, 2010].
55. Resink R, *The Choice Between Wood Pellets and Wood Chips for Large Scale Users.* GF Energy. Argus Biomass Trading conference, Brussels, Belgium (15 April, 2010).

56. OANDA, *Average Daily Exchange Rate*s. [Online]. Available at: http://www.oanda.com/currency/average [August 8, 2010].
57. Murray G, *Development of the Canadian pellet market.* International Pellet Forum, Stuttgart (8 September, 2010).
58. Swaan J and Melin S, *Wood Pellet Export: History, Opportunities and Challenges.* Wood Pellet Association of Canada. Smallwood Conference (13 May, 2008).
59. Rotterdam Harbor, 2009-2010 market update from main pellet actors Personal communication. Port of Rotterdam, EBS, Dutch Shipbrokers Society and Peterson International, Rotterdam (2010).
60. UNCTAD, Trade and freight markets, in *Review of Maritime Transport*. United Nations, New York & Geneva (2009).
61. Peng JH, Bi HT, Sokhansanj S, Lim JC and Melin S, An economical and market analysis of Canadian wood pellets. *Int J Green Energ* **7**:128–42 (2010).
62. Ekström H, Wood Resources International. *North American Wood Fiber Review* March 2010:1–24 (2010).
63. Energeia, APXEndex en havenbedrijf Rotterdam zetten plan voor houtpelletbeurs door. [Online]. Available at: http://www.energiekeuze.nl/nieuws.aspx?id=385 [November 26, 2010].
64. Romijn P, Update 2009-2010 pellet markets. Personal communication. RWE Essent, Den Bosch (2010).
65. WWF, *International Shipping in a Post 2012 Climate Deal*. WWF Global Climate Policy, United Kingdom (2008).
66. Faber J and Rensma K, *Left on the High Seas; Global Climate Policies for International Transport*. CE, Delft (2008).
67. Bergsma G, Kampman B and Croezen H, *Goed Gebruik van Biomassa*. CE, Delft (2010).
68. eROC, A*uction of Renewable Obligation Certificates.* [Online]. Available at: http://www.eroc.co.uk/trackrecord.htm [April 13, 2010].
69. Bingham J, *UK's Renewable Heat Incentive and its Implications for the Pellets Market*. Hawkins Wright (Forest Energy Monitor). International Pellet Forum, Stutgart, Germany (8 September, 2010).
70. DEPI, ENplus Zertifiziering von Pellets fur den Endkundenmarkt; Handbuch fur Deutschland und Österreich. prEN 14961; Teil 2 (Stand 26.05.2010), Deutsches Pelletinstitut (2010).
71. Thek G and Obernberger I, *Wood Pellet Production Costs under Austrian Framework Conditions*. ETA Florence. 17th European Biomass Conference, Hamburg (1 July, 2009).
72. EUWID, Price watch: sawmill residues Germany. *Wood Products and Panels* **84** (8,30,42) (2010).
73. Schmidt B, *Current Development of the German Pellet Market*. DEPV. International Pellet Forum, Stutgart (8 September, 2010).
74. Mangel AC, *Development of the French Pellet Market.* ProPellet France. International Pellet Forum, Stutgart, Germany (8 September, 2010).
75. Bubholz M and Nowakowski R, *Mapping of Subsidy Systems and Future Consumption of Biomass*. Svensk Fjärrvärme, Stockholm (2010).
76. Latvian wood, *Sawdust Prices in Kurzem and Vidzem and Pulpwood Prices for Pine, Spruce, Aspen and Birch*. [Online]. Elaborated by A Nikolajeva, Meza Funds SIA, Latvia. Available at: http://www.latvianwood.com [November 29, 2010].
77. Heinimo J and Alakangas E. *Market of Biomass Fuels in Finland*. Research Report 3. LUT Energy, Lapppeenranta, Finland (2009).
78. RISI, Biomass development stays strong for 2009, but will it last? *Wood Biomass Market Report* **3**(01):1–7 (2010).
79. RISI. A quarterly update of global timber prices. *World Timber Price Quarterly* May:2–20 (2010).
80. Karlsson S, *Table*: average prices of pulpwood (pine, spruce and birch). [Online]. Skogsstyrelsen, Jönköping, Sweden. Available at: http://www.svo.se/minskog/Templates/EPFileListing.asp?id=16709 [October 30, 2010].
81. Ertmer K, The right hardware. *Sun and Wind Energy* **6**:179–81 (2010).
82. Keenan R, Statistiscal aspects of the energy economy in 2009 (Eurostat). *Statistics in Focus* **43**:1–12 (2010).
83. OECD and IEA, *World Energy Outlook 2009*. International Energy Agency, Paris (2009).
84. de Wit M and Faaij APC, European biomass resource potential and costs. *Biomass Bioenerg* **34**:188–202 (2010).
85. Londo M, Lensink S, Wakker S, Fischer G, Prieler S *et al.* The REFUEL EU road map for biofuels in transport. *Biomass Bioenerg* **34**:244–55 (2010).
86. UNECE, Forest products 2000-2004. *Timber Bulletin* Volume LVIII (2005).
87. UNECE, Forest products statistics 2005-2009. *Timber Bulletin* **63**(2): provisional (2010).
88. UNECE, European forest sector outlook study. *Geneva Timber and Forest Study Paper* 20:main report (2005).
89. Pöyry Forestry Industry Consulting, *Wood Pellets - The Bioenergy Feedstock Solution*? Global market, players and trade to 2015. Investments AB Kinnevik; Cheam, United Kingdom (2009).
90. Aebiom, *A Pellet Road Map for Europe*. Aebiom, Brussels (2008).
91. Rechberger P, *Overview of Pellets for Bioenergy in Europe*. AEBIOM. Gesbois Annual Meeting, Brussels (2010).
92. Herold I, *Biomass and Waste to Energy Investment Trends*. New Energy Finance. 17th European Biomass Conference, Hamburg (2009).
93. Hetsch S, *Potential Sustainable Wood Supply in Europe*. Discussion Paper 53, Geneva (2008).
94. Forest Europe, *Good Practice Guidance on the Sustainable Mobilization of Wood in Europe*. Forest Europe Liaison Unit Oslo; DG Agriculture and Rural Development and UNECE FAO Timber Section, Aas, Norway (2010).
95. Sikkema R, Faaij APC, Ranta T, Gerasimov YY, Asikainen A, Heinimo J and Nabuurs GJ, Mobilisation of bioenergy sources from boreal forests in Finland and Russia under present SFM certification and new EU Directives on Renewable Energy Sources. *Forestry* in press (2011).
96. Petrov V and Orlov A, *Energetic Utilisation of Wood in Northwest Russia*. St. Petersburg State Forest Technical Academy. EFI 2010 Annual Conference, Dresden, Germany (16 September, 2010).
97. Van Vliet O, Faaij APC and Turkenburg WC, Fischer-Tropsch diesel production in a well-to-wheel perspective: a carbon, energy flow and cost analysis. Energ Convers Manage **50**(4):855–76 (2009).
98. Fischer G, Hizsnyik E, Prieler S, and van Velthuizen H*, Assessment of Biomass Potentials for Biofuel Feedstock in Europe: Methodology and Results*. Refuel project, Workpackage 2, Laxenburg, Austria (2007).
99. Eurofuel, *Consumption of Heating Oil (thousands of tons) in 2004*. [Online]. Available at: http://www.eurofuel.eu/eng/facts.asp [July 23, 2009].
100. Hansson J, Berndes G, Johnsson F and Kjärstad J, Co-firing biomass with coal for electricity generation - an assessment of the potential in EU 27. *Energ Policy* **37**:1444–55 (2009).
101. Mantau U, Saal U, Prins K, Steierer F, Lindner M, Verkerk H *et al., Real Potential for Changes in Growth and Use of EU Forests*. EU Wood, Hamburg, Germany (2010).

102. Beurskens LWM and Hekkenberg M, *Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States (update 26 countries)*. [Online]. Available at: http://www.ecn.nl/publications/default.aspx?nr=ECN-E--10-069 [January 6, 2011].
103. Scharai-Rad M and Welling J, *Biomass for Greenhouse Gas emission Reduction; Sawn Timber and Wood Based Based Products as Building Materials*. Bundesforschungsanstalt für Forst- und Holzwirtschaft (BFH), Hamburg, Germany (1999).
104. Alakangas E and Virkunen M, *Biomass Fuel Supply Chains for Solid Biofuels* (Eubionet 2). VTT, Jyvaskyla, Finland (2007).
105. Hakkila P, *Developing Technology for Large Scale Production of Forest Chips* (TP report 6). TEKES, Helsinki, Finland (2004).
106. Denis N, *Biomass Demand and Supply Dynamics in EU-27*. McKinsey & Company. AEBIOM European Bioenergy Conference, Brussels, Belgium (June 30, 2010).
107. Kang S, *Essent's Vision on Renewable Growth*. Essent. Biomasss Conference 4/5 November 2009, Geertruidenberg (2009).
108. Kiel J, Biomass Cofiring Symposium. Vergroening van kolencentrales; technische mogelijkheden & uitdagingen. [Online]. ECN & KEMA (2010). Available at: http://www.biomasscofiring.nl/symposium [May 27, 2010].
109. Sihvonen M, Price indices for wood pellets, in *Foex Indexes Ltd*. WSED / European Pellet Conference, Wels, Austria (March 3, 2010).
110. Republic of Latvia, *Forecast Document on Attaining the Target Share of RES in Gross Final Consumption by 2020*. Ministry of Economic Affairs, Department of Energy. Pursuant to Article 4(3) of Directive 2009/28/EC: 1–5 (2009).
111. ECB, *Monthly, Quarterly and Annual Exchange Rates of Euro with Other Currencies*. [Online]. Available at: http://www.ecb.int/stats/exchange/eurofxref/html/index.en.html [November 17, 2010]
112. Bradley D, Diesenreiter F, Wild M and Trømborg E, *World Biofuel Maritime Shipping Study*. IEA Bioenergy Task 40 (2009).
113. Hagauer D, *Empfohlene Umrechnungsfaktoren für Energieholzsortimente bei Holz- bzw*. Energiebilanzberechnungen. KlimaAktiv, Vienna (2009).

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