Chapter 3
Global Woody Biomass Trade for Energy

Patrick Lamers, Didier Marchal, Jussi Heinimö, and Florian Steierer

Abstract This chapter presents global woody biomass production and trade developments and extracts energy-related trade volumes. It shows that direct, policy-influenced trade for energy has reached over 300 PJ by 2010. The majority of this volume comprises of wood pellets and wood chips aimed for consumption in the European Union (EU). Wood pellets are the largest single commodity stream and have seen a rapid production growth and trade internationalization. This is primarily due to past and expected future EU demand developments in the industrial segment, i.e. large-scale use of wood pellets in co- and mono-firing installations. Belgium, the Netherlands, the United Kingdom, and Denmark in particular are bound to increase consumption, and will remain net pellet importers. Wood pellet production has become a key diversification strategy of many forest companies and other traditional forest sectors, e.g. pulp and paper. Even energy utilities themselves are investing upstream. Wood chip trade for energy is largely limited to wood waste and small volumes of virgin wood chip (including roundwood) trade for energy in the Baltic Sea region and towards Italy. Policy-influenced fuelwood trade is also largest in Europe where it is mainly used in residential heating. Trade is predominantly regional or cross-border, and has been driven by local market price differences, winter condi-

P. Lamers (✉)
Copernicus Institute, Utrecht University, Utrecht, The Netherlands
e-mail: p.lamers@uu.nl; pa.lamers@gmail.com

D. Marchal
Wildlife and Forestry Department, Namur, Belgium
e-mail: Didier.Marchal@spw.wallonie.be

J. Heinimö
Lappeenranta University of Technology, Varkaus, Finland
e-mail: Jussi.Heinimo@lut.fi

F. Steierer
Food and Agriculture Organization of the United Nations (FAO), Rome, Italy
e-mail: wood-energy@fao.org

M. Junginger et al. (eds.), *International Bioenergy Trade: History, status & outlook on securing sustainable bioenergy supply, demand and markets*, Lecture Notes in Energy 17,
DOI 10.1007/978-94-007-6982-3_3,

tions, and regional supply shortages. Market factors and policies have both defined woody biomass trade volumes while policy changes did not have as dramatic effects on trade developments as in the liquid biofuel sector. Economic viability is the key limiting trade factor for woody biomass 'commodities'. Most exporting countries have low feedstock costs and already existing wood processing industries.

3.1 Background, Objective, and Methodology

Woody biomass is the most traditional form of energy use. To the present day, it still makes up about 50 EJ or 10 % of global primary energy supply (Edenhofer et al. 2011). Woody biomass use for heating and cooking dominates end-use and its consumption is still increasing in most developing countries (Johnson et al. 2010). Policies aiming at expanding the use of renewable energy have caused a renaissance of woody biomass use in many industrialized countries over the past decade. With this, two distinct trends have emerged: Formerly rather regional markets are increasingly integrated in global trade portfolios, and new entities, e.g. energy utilities, have become wood fuel producers (and traders). At the centre of these developments stands the European Union (EU) whose internal trade between 2000 and 2010 summed up to two-third of global solid biofuel trade (Lamers et al. 2012a).

The main objective of this chapter is to describe the past developments and the current status of global woody biomass trade for energy (Table 3.1, Fig. 3.1). Agricultural by-products such as palm kernel shells are not covered as they have so far only contributed marginal volumes to global energy related, and policy-driven

Table 3.1 Trade codes of CN/HS chapter 44 'Wood and articles of wood, wood charcoal', typically used in woody biomass for energy trade

CN/HS	CN/HS	Code definition
4401	440110	Fuelwood (logs, billets, twigs, faggots or similar forms)
	440121	Wood in chips or particles (coniferous)
	440122	Wood in chips or particles (non-coniferous)
	440130[a]	Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms
4402	440200	Wood charcoal (including shell or nut charcoal), whether or not agglomerated
4403	440320	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared *coniferous*
	440391	As 440320, for *oak*
	440392	As 440320, for *beech*
	440399	As 440320, for *other (poplar, eucalyptus, birch)*

[a]Replaced by codes HS 440131 Wood pellets and HS 440139 Other as of 2012. The respective EU codes are CN 44013100 Wood pellets, CN 44013910 Sawdust of wood whether or not agglomerated in logs, briquettes, or similar forms (excl. pellets), and CN 44013990 Wood waste whether or not agglomerated in logs, briquettes, or similar forms (excl. sawdust and pellets)

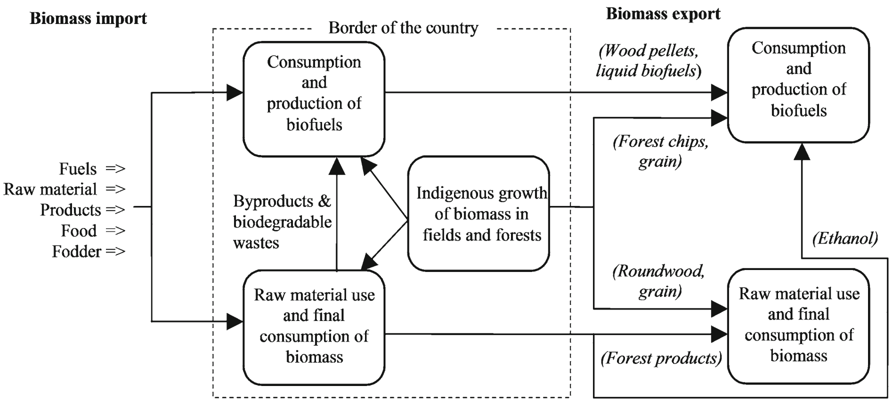

Fig. 3.1 Simplified illustration of biomass trade flows for energy (Source: Heinimö 2008)

trade (Lamers et al. 2012a). Apart from providing quantitative overviews, it also elaborates on the market drivers, and provides a methodological assessment of the respective influencing factors. The analysis is limited to direct trade of commodities for modern bioenergy use in markets where bioenergy support policies are in place. Indirect trade, i.e. volumes not directly related to energy usage, such as wood chips of which a fraction ends up as black liquor and thus energy, are not examined in detail. The chapter however includes an exemplary assessment for the period 2004–2011. Also, woody biomass trade in markets where no bioenergy support policies are in place, e.g. fuelwood or charcoal use across sub-Saharan Africa, is not included since an integral part of the IEA Bioenergy Task 40 work has been the evaluation of policy influences on bioenergy market and trade flow developments.

World production data is derived from (FAOSTAT 2013). Trade data was collected via UN 2013 and EUROSTAT 2013 statistics. Trade codes only refer to the physical appearance of commodities and not their final end-use so that energy related trade streams have remained rather informal. Hence, official data sources needed to be sidelined with anecdotal evidence, e.g. from previous IEA Bioenergy Task 40 work (Bradley et al. 2009; Cocchi et al. 2011; Lamers et al. 2012b; Goh et al. 2013), and scientific methodologies to account for energy related trade only (Heinimö 2008; Heinimö and Junginger 2009; Lamers et al. 2012a) (Fig. 3.1).

The next section provides a global overview of woody biomass production and trade. Global energy related trade developments are inherently part of these trade streams but need to be extracted. This is done in the following section, which also provides exemplary calculations of indirect trade flows. Afterwards, the currently largest trade streams (wood chips and wood pellets) are presented in detail and with specific link to the currently most important market and trade centre: Europe. Wherever applicable, European developments are put into a global perspective. Second to last, a separate section shows which policy and market factors have affected these past developments. The chapter closes with concluding remarks and an outlook on possible future trade developments.

3.2 Global Production and Trade Developments

The total production and relative trade shares per annual production volume of the selected commodities (Table 3.1) are given in Fig. 3.2 (see e.g. FAO 2012 for additional information and commodities). Roundwood is the largest absolute trade stream, followed by fuelwood, wood chips, charcoal, and sawdust and wood waste (Fig. 3.2 top). Traded production shares of the commodities show a heterogeneous picture: While charcoal and fuelwood shares remained stable, wood chip trade shares declined, and sawdust and roundwood shares showed upward trends (Fig. 3.2 bottom).

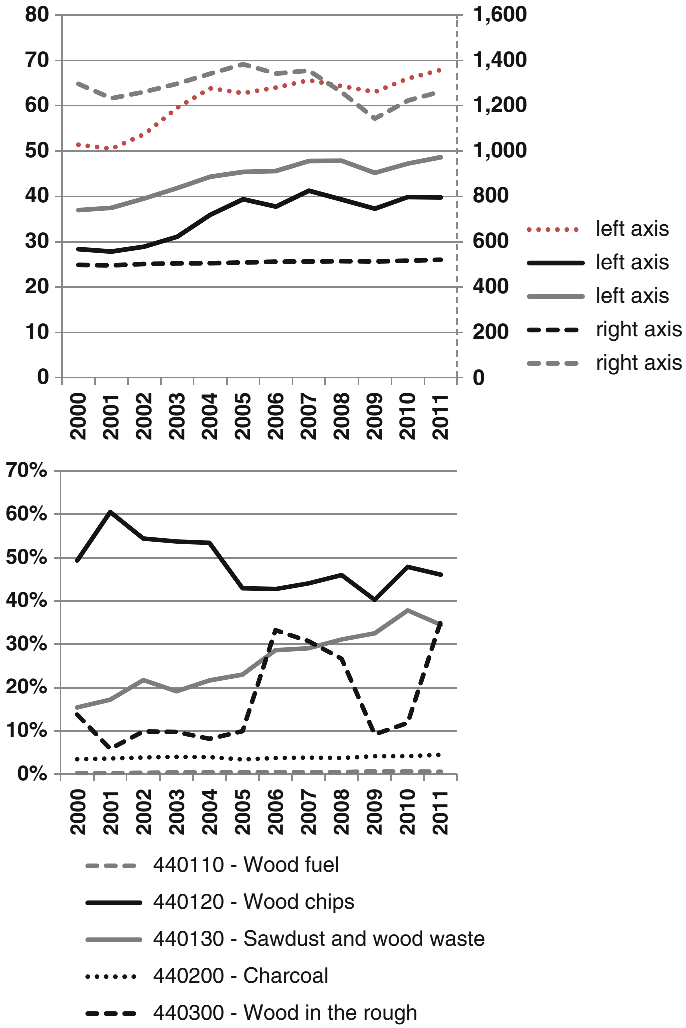

Fig. 3.2 Total global production (*top*) [in Mtonnes] and share of annual production traded (*bottom*) of selected woody biomass commodities (Data: FAOSTAT 2013; UN 2013)

Until 2005, between 10 and 15 % of global industrial roundwood (HS 4403) production was traded annually. Later, trade volumes rose significantly with over 30 % of global production being traded in 2006–2008 (Fig. 3.2). The drop in 2009 is attributed to the introduction of export duties on roundwood in Russia and the global financial crisis. By 2011, trade volumes have risen again to 2006-levels, i.e. 446 Mtonnes (Fig. 3.2), representing 35 % of annual production (Fig. 3.2). This shift in trade shows that roundwood had typically been processed locally; as core forestry nations have also been home to the world's major wood processing industries. More and more however is processed elsewhere, particularly in Asia. The largest absolute production increases have taken place in Brazil, Russia and Indonesia. The largest declines were noted in the USA and Canada. By 2010, five countries produced half of the total world production: USA (20 %), Russia (9 %), Canada (8 %), Brazil (8 %), and China (7 %). While the majority of global roundwood production and trade is not connected to bioenergy, there is a large amount of indirect trade in the form of wood processing residues (Heinimö 2008).

Wood chips (HS 440121, HS 440122) represent the second largest absolute single trade stream (Fig. 3.2), and mainly consists of high quality chips for pulp and paper production. Global wood chip production has grown to 68 Mtonnes by 2011, while the traded annual production volume has declined over time (Fig. 3.2). This may be connected to the general shift of production to economies with low labour costs, predominantly in the Southern hemisphere. The largest production increases over the past years have taken place in China, South Africa, and Brazil. The strongest production decline was noted in the US. By 2010, the key producing nations included Canada (31 %), China (8 %), Australia (7 %), and Sweden (7 %); all major pulp and paper producers. Australia and Canada are also key wood chip exporters – predominantly to Japan and other Asian countries. Trade in wood chips for energy (virgin and/or tertiary waste) is practically limited to Europe, Turkey, and Japan (Lamers et al. 2012a).

Global production of wood residues (as previously covered under HS 440130) has grown from 28 Mtonnes in 2001 to 40 Mtonnes in 2011 (Fig. 3.2). Over the same time, the traded annual production share has increased from 15 to 35 %. The largest part of this volume is made up of harvesting (tops and branches) and processing (sawdust) residues in the form of wood pellets. Wood pellets have become the largest single energy-policy related trade stream. As of 2012, they are tracked under a specific trade code (HS 440131). The remaining fraction, previously listed as 'waste wood and scrap' has now to be filed under HS 440139.

Large scale international shipments of recycled wood for energy purposes are still rare but have been known to occur (Lamers et al. 2012b). Up to now however, the larger share of wood waste is generally landfilled, combusted locally or traded short distances. The key region for international wood waste trade is currently Europe; primarily due to its differences in legal and bioenergy policy frameworks across the individual Member States (Lamers et al. 2012a). Wood waste is generally not chipped but rather crushed to minimize transportation costs.

Fuelwood (HS 440110) and charcoal (HS 440200) represent the lowest annual trade shares. Both can be considered local products, with less than 1 % (fuelwood) or 5 % (charcoal) of their annual production being traded respectively. These numbers however are based on official statistics and are unlikely to include informal cross-border trade, which may be significant given the high share of either fuel in traditional heating and cooking. The same statistics indicate that fuelwood production remained relatively stable over the past decade, while charcoal production continuously increased.

The higher international trade share for charcoal compared to fuelwood (Fig. 3.2) can be explained by the additional uses of charcoal. Apart from heating and cooking (including barbeque in industrial countries), charcoal is applied in the chemical (as active coal) and in the iron and steel industry (as a reducing agent and energy source). The largest producer between 2000 and 2010 was Brazil (13 %), where most charcoal is used in pig iron production. International trade with charcoal has been dominated by Germany (10 %), Japan (9 %), and South Korea (8 %) in terms of imports (Lamers et al. 2012a). Poland is the largest source for charcoal trade to Germany. Japan and South Korea tend to source their charcoal mainly from Indonesia, Malaysia, and China. Total world exports have been led by Somalia over the past 4 years (Economist 2012; FAOSTAT 2013). International charcoal trade generally takes place in bagged form. Up to now there is no direct and large scale trade for modern energy conversion, and current trade for energy purposes is limited to heating, cooking and barbeque.

Fuelwood use for heat generation in high performance boilers and stoves has been heavily driven across the EU over the last years. Its share in global trade increased from 50 % (2000–2004) to over 80 % (2007–2011). Most of this trade takes place cross-border: short- or mid-range in bagged form, conglomerated in nets, or stacked on pallets. Recorded trade streams outside Europe are between South Africa and its neighbouring countries (Swaziland and Namibia), Canada and the USA, and across South East Asia. By 2010, half of the total fuelwood production was centred in India (17 %), China (10 %), Brazil (8 %), Ethiopia (5 %), Congo (4 %), Nigeria (3 %), and Indonesia (3 %) combined.

3.3 Total Energy Related, Policy-Driven International Trade

When defining the amount of policy-influenced woody biomass trade for energy, absolute global trade streams for specific commodities (Fig. 3.2) have to be broken down into their different end-use fractions. Officially reported volumes cover energy related and other streams, e.g. for material purposes in the case of wood chips and roundwood. In addition, one needs to account for potential cross-trading such as re-exports or wholesale activities to avoid double-counting.

Official trade data (e.g. EUROSTAT 2013; FAOSTAT 2013; UN 2013) can thus be seen as a theoretical upper limit of possible energy-related trade. To obtain solely bioenergy related production and trade streams, it is yet indispensable to rely on anecdotal evidence, such as conference presentations, speeches, and interviews of internationally recognized experts from private market parties, industry, academia, or else.

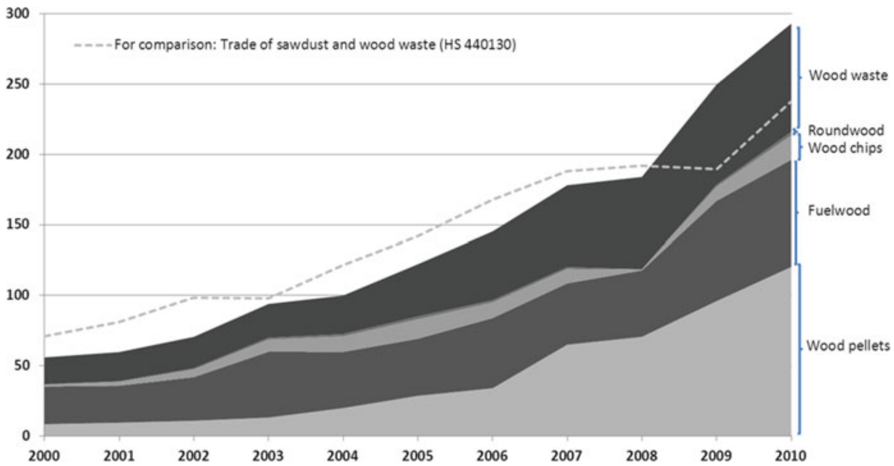

Fig. 3.3 Estimated global net solid biofuel trade [in PJ] (Data: Lamers et al. 2012a)

3.3.1 Net Trade for Energy

The methodology for global net wood pellet trade builds on the central observation (given past developments) that the most lucrative markets from a producer and trader perspective lie in the EU, and to some extent also in the US, Japan, and South Korea due to the policy influenced local market value for woody biomass (Lamers et al. 2012a).

There is practically no risk of double-counting since the markets are yet still separated – apart from the EU-internal distribution of overseas imports. Large-scale shipments also often occur directly from the producer to the end-user. Indirect trade of raw material, e.g. roundwood for wood pellet production has been neglected as the main pellet producing nations are also key roundwood suppliers and do not depend on imports. Furthermore, waste wood and direct roundwood to pellet conversion were only at their initial industry stage in 2009/2010 and the respective facilities all own local forestry plantations.

Given this framework, net woody biomass trade volumes for energy grew sixfold from 56.5 PJ (3.5 Mtonnes) to 300 PJ (18 Mtonnes) between 2000 and 2010 (Fig. 3.3) (Lamers et al. 2012a). Over this period, wood pellets grew strongest and became the dominant commodity on international markets, whereas trade with wood waste, roundwood, and wood chips for energy remained much smaller and practically limited to Europe.

Until 2002, policy-driven woody biomass for energy trade development was largely motivated by legal and technological differences for wood waste combustion in the EU. Trade for residential heating application dominated, and wood pellet trade was limited to intra-EU and intra-North American trade. After 2003, when policy schemes for the promotion of renewable energy and more specifically bioenergy derived electricity production emerged across the EU, trade with wood waste, chips, pellets, and residues started to grow. Incentives for the installation of heat stoves across EU Member States in particular benefited pellet trade whereas trade in wood chips and fuelwood only grew marginally. Regional trade fluctuations mostly adhere to winter conditions and local availability. Post 2005, we see that extra-EU production costs and EU renewable energy support drives EU pellet imports for medium and large-scale power production. Also, there is a growing industry trend towards pellet usage, i.e. away from wood chip combustion. Wood chip trade remains rather regional. This trend continues and is fuelled by rising oil prices until the financial crisis late 2008. In recent years, increases in global policy-influenced woody biomass for energy trade are attributed in principal to a growing US-EU pellet trade, further increases in EU pellet production for intra-EU trade, an oversupply of roundwood from Russia partly traded for energy in the form of wood pellets, wood chips, and fuelwood, and the increase of policy support and trade of pellets across Asia.

3.3.2 Indirect Trade of Raw Materials for Energy

Net trade estimations as shown in Fig. 3.3 do not incorporate indirect trade, i.e. volumes not directly related to energy usage, such as wood chips of which a fraction ends up as black liquor and thus energy. Nevertheless, indirect trade can sum up to substantial amounts.

The wood processing industry procures wood primarily as a raw material. In many cases, wood is imported from other countries. For example, Finland imports large amounts of raw wood (logs, pulp wood, and chips) from, e.g. Russia. In the manufacturing processes of the primary products, a significant amount of the raw wood ends up in energy production or is converted into by-products for energy generation. Biofuel purchase and use of this kind is referred to indirect import of biofuels, and the corresponding export is called indirect export of biofuels. The previously mentioned wood streams jointly constitute indirect trade of biofuels.

On average, 40–60 % of the roundwood can be converted into wood products in the forest industry. The remaining share ends up as a by-product, such as black liquor, bark, sawdust, and chips, with no material use within the specific industry. Using trade volumes for industrial roundwood and wood chips and particles from FAOSTAT 2013, we provide a rough estimate about the potential volume of indirect trade of wood based biofuels (Fig. 3.4). For both roundwood and wood chips, we assume that 45 % is the total trade volume is converted to energy with a calorific value of 9.4 GJ/tonne. Uncertainties in this calculation include, e.g. the conversion efficiency for raw wood, which varies between the production processes of different products, and the level of technology applied and the integration of the production processes which affect conversion efficiency. For a more detailed description of the methodology, we refer to Heinimö 2008 and UNECE/FAO 2010.

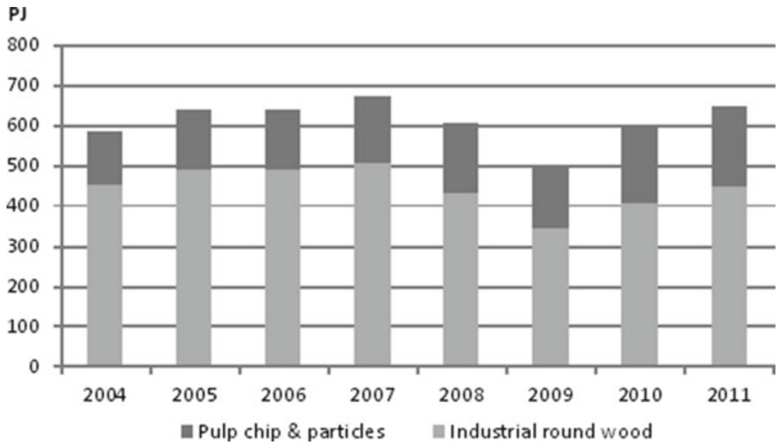

Fig. 3.4 Estimated volume of indirect trade of biomass for energy [PJ]

3.4 Wood Chip and Wood Pellet Market Developments

Industrial roundwood dominates absolute international woody biomass trade volumes. The vast majority of this trade flow however is for non-energy related purposes. Wood fuel and charcoal are traditional energy carriers and typically not traded over long distances, but rather regional or cross-border. Charcoal trade is not considered policy-driven and therefore not further examined. Wood fuel production and consumption increases across the EU have been regarded as policy-influenced, international wood fuel trade however has rather been driven by supply fluctuations and extreme weather conditions, e.g. Swedish imports from Latvia and Russia during harsh winter conditions (Lamers et al. 2012a).

Wood chips, in raw form or as wood waste, and wood pellets are currently the largest absolute energy-related global trade streams (Fig. 3.4) The wood chip trade initially shown in Fig. 3.2 is largely destined for pulp and paper production, with some trade for other uses such as fibre and particle boards. It is estimated that less than 10 % of annually reported trade volumes are energy-related (Lamers et al. 2012b). These cover wood chips made of roundwood, residues, and waste wood. The latter would have been covered under the former HS code 440130. It is noteworthy that this is the only commodity of the selection in Table 3.1 whose production and trade share volumes have continuously grown over the past decade (Fig. 3.2). The reason for this lies in the second component of the trade code: sawdust in the form of pellets.

3.4.1 Wood Chips

The key distinction between wood chips is their source material. High quality chips derived from roundwood are a valuable component in pulp and paper production. Wood chips for energy purposes can either be derived from recovered/waste wood or virgin wood.[1] The latter are typically derived from harvesting residues such as branches, tops, thinnings, or other inferior wood not suitable for material or pulp and paper production, or other processing residues. This implies that bioenergy related trade streams may have fallen under various trade codes including coniferous (HS 440121) or non-coniferous wood chips (HS 440122), or sawdust and waste wood (HS 440130). Technically, wood chips may also be transported as fuelwood (HS 440110) or roundwood (HS 4403) prior to chipping and combustion.

Across Europe, there are two distinct virgin wood chip markets for energy and thus major trade flows. The first encompasses the Baltic Sea bordering states, where Sweden and Denmark (and to some extent also Germany) have been leading importers over the past decade, sourcing largely from Russia and the Baltic states (Junginger et al. 2010). The second market lies in southern Europe, primarily driven by Italian facilities sourcing from neighbouring countries, the Balkan in particular (Fig. 3.5).

Virgin wood chips for the EU residential market are primarily sourced locally. International wood chip trade is exclusively driven by the industrial sector, where chips are combusted in dedicated or converted co- and/or mono-firing installations (primarily fluidized-bed). Respective trade takes place in the form of (virgin) wood chips, crushed (waste) wood, or as roundwood which is chipped at the plant (Lamers et al. 2012a, b). Official statistics indicate that wood waste volumes dominate the EU-related trade.

Between 2000 and 2005, (virgin) wood chips were transported for energy from the US to Europe (primarily Italy); with annual volumes of up to 200 ktonnes (Flynn, 2012, May, Director International Timber at RISI, USA: Global wood chip trade patterns for energy, personal communication). When it became apparent that these streams were in violation of the EU requirements for phytosanitary measures (see Lamers et al. 2012b for details), the trade was stopped. The EU still requires phytosanitary measures for softwood chips from North America. The restrictions have practically eliminated the largest of the softwood chip trade (utilizing Southern Yellow Pine) for both energy and pulp and paper production to Europe (Guizot 2010). As a result, softwood chip streams from North America to countries with less import restrictions have grown, in particular to Turkey and China.

In 2010, there was a substantial increase in demand for wood chips in China. The nation has evolved from being a net exporter of chips 5 years ago, to being a major chip consumer, having quadrupled imports in just 2 years. The country now imports over 28 % of all chips traded in the Pacific Rim and is the world's second largest importer of wood chips after Japan. Trade of wood chips is still the highest in the Pacific Rim, accounting for almost 60 % of the total global trade and over 95 % of water-born trade. So far, little is known about exact volumes entering China for energy purposes. Naturally, Chinese imports could reach very large dimensions in

[1] The EU wood chip quality standard EN 14961–4 defines four classes (FOREST 2011). Class A1 and A2 represent wood chips from virgin wood or chemically untreated wood residues with different ash and moisture contents. Class B1 and B2 extend the source of biomass to chemically treated industrial wood by-products and residues and used wood.

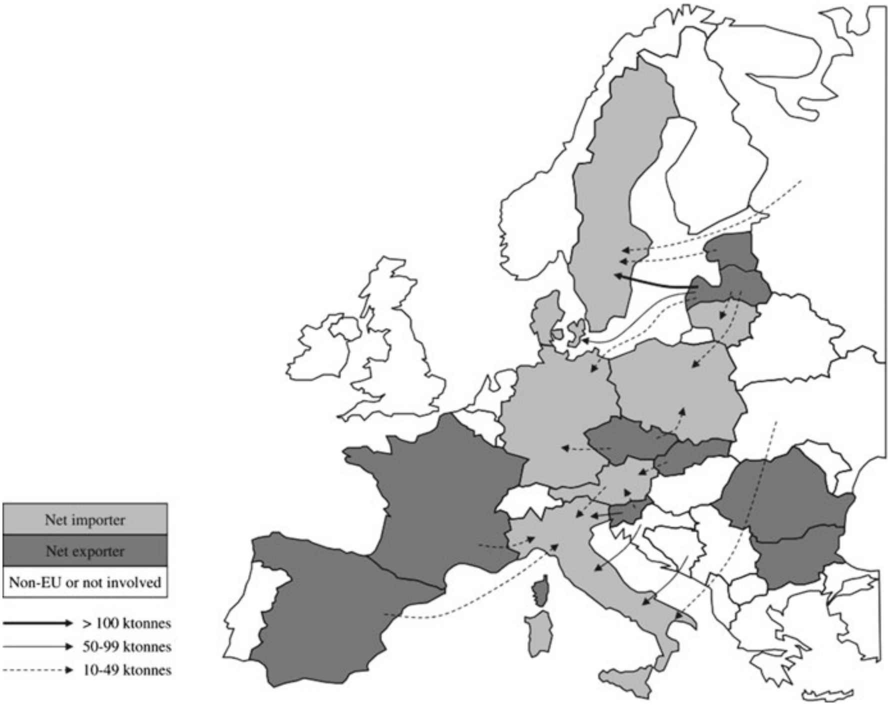

Fig. 3.5 Dimensions of virgin wood chip and roundwood trade for energy (Data: Lamers et al. 2012a, b; EUROSTAT 2013. Note: Trade streams towards Denmark, Germany and Sweden are also indicators for roundwood trade volumes and routes.)

the near future. Apart from North America, trade flows to China originate primarily in Oceania and Asia (including Australia, Vietnam, and Russia).

Japan has also previously sourced (virgin) wood chips from Canada. In 2011, 300 ktonnes wood chips were imported for energy combustion (Goto et al. 2012). Previously it was suggested that wood chips for energy production would be solely derived from domestic demolition wood and that Japanese wood chip imports cover pulp chips exclusively (Goto et al. 2012; Lamers et al. 2012a).

Norway has previously imported mostly hardwood chips from Canada, Brazil and Africa for pellet production (Willumsen 2010). Trade volumes reached around 330 ktonnes per year by 2011 (Willumsen 2010) but came to a halt by 2012 (Flynn, 2012, May, Director International Timber at RISI, USA: Global wood chip trade patterns for energy, personal communication).

For a period of 2–3 years, some of the larger international trade flows to the EU for energy purposes were rubberwood chips from Liberia destined for co- and mono-firing installations of energy utility Vattenfall in Germany and Sweden. The sourcing strategy of the utility has since changed, and, according to official statistics, Liberian trade flows to Europe ceased in 2012.

Generally, wood chips for energy purposes have been transported over shorter distances than wood pellets. Apart from vessel size restrictions in the Baltic Sea region, this is primarily due to the ratio between moisture content, heating value, and bulk density (Alakangas et al. 2007; Junginger et al. 2010).

European combustion facilities have been known to not only import virgin wood chips, i.e. previously unused, woody biomass excluding tertiary residues, but also roundwood for making wood chips. This allows facilities to control chip sizes and quality. There are also storage benefits of roundwood (moisture, heating value). In the Baltic Sea region, wood chip and roundwood trade are closely interwoven. They are often traded on the same vessel (Vikinge 2011) and destined for the same conversion facilities. Winter conditions in Baltic Sea harbours have in the past led to increasing imports from Southern Europe. So far no overseas EU imports of roundwood for energy purposes are known however.

Today, waste wood is typically (co-) combusted across the EU. Differences in renewable energy policy support schemes have driven a strong EU-internal trade of crushed or chipped waste wood (i.e. tertiary wood chips). Historically, Sweden was among the first states to attract large amounts of wood waste. Today, trade to other Member States is far larger. Top importing nations include Germany, Italy, and Belgium. The major exporters are the Netherlands and the UK. The relatively balanced import–export relation of Belgium and Germany is largely related to national policy schemes which favour different streams of waste wood. The German renewable electricity feed-in scheme e.g. has provided strong incentives for the combustion of clean (non-treated) waste wood. Whereas, in the past, more contaminated waste wood had e.g. attracted higher subsidies in the Netherlands (Faber et al. 2006).

3.4.2 Wood Pellets

By 2010, around 60 % of global wood pellet production was concentrated in the EU (Fig. 3.6). Since 2000, EU production, demand, and imports have increased more than tenfold (Lamers et al. 2012a). This trend is clearly policy-influenced. Production and trade patterns have developed in accordance with the respective consumer markets in the individual Member States. Until 2010, most pellets were combusted in residential heating (dominated by Italy, Germany, and Austria), followed by district heating (Sweden and Denmark), and large-scale power production (concentrated in Belgium, Denmark, the Netherlands, and the UK) (Hiegl and Janssen 2009; Sikkema et al. 2011).

We can distinguish between two different pellet types across these markets. Previously, this distinction has been coined high (residential) vs. low (industrial) quality or white (residential) vs. brown (industrial) pellets. These attributes are however relative and not always applicable to the respective trade flows. We suggest differentiating instead merely between end-use, i.e. residential or industrial

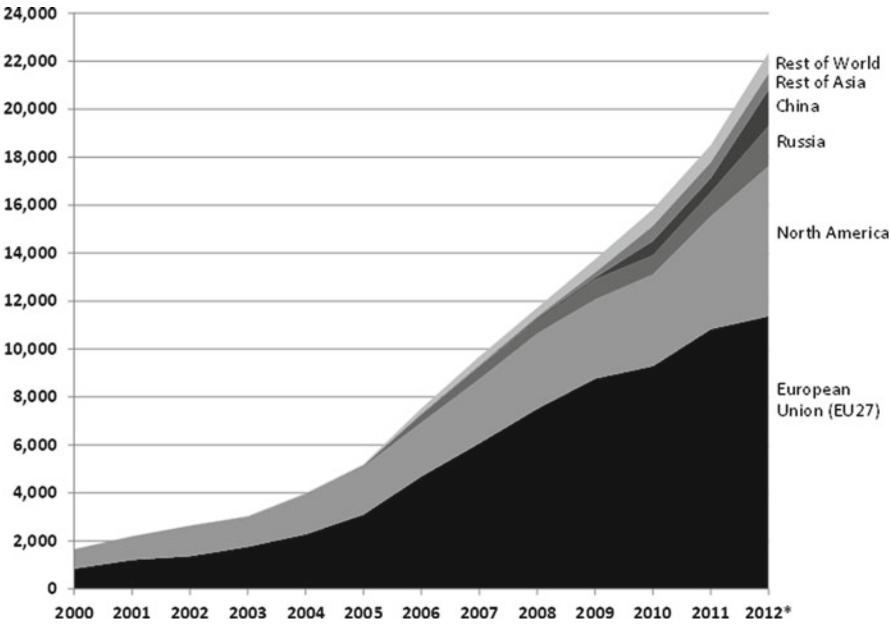

Fig. 3.6 Estimated global wood pellet production [in ktonnes] (Data: Cocchi et al. 2011; Lamers et al. 2012a; REN21 2012; EUROSTAT 2013; Goh et al. 2013)

pellets.[2] Residential pellets generally need to fulfill higher restrictions regarding ash content, ash melting point (slacking), and water content (fouling). Requirements for industrial pellets though have also increased and there are even ambitions to create a uniform certificate (ENplus) for pellets used or traded for the EU heat and power markets, applying to intra-EU trade and extra-EU imports.[3]

Residential pellets have been exclusively sawdust derived. Industrial pellets have also been largely sawdust derived, while the shares of harvesting residues including bark, tops and branches of merchantable trees (for timber) plus whole non-merchantable trees, and pulpwood-quality roundwood have increased.

A key difference between the markets so far has been the logistical aspect and the sourcing range. Residential pellets have largely been supplied in bulk or bagged form via regional retailers and wholesalers. Very little global trade has taken place. Industrial pellets however have been transported globally in large bulk quantities and directly sold and shipped to the power plant/consumer. Very little retailer/wholesaler activity takes place in this segment. It is expected that future trade in the residential sector will also encompass global trade in large bulk quantities. First shipments between Canada and Denmark have already taken place.

While being relatively self-sufficient in the residential pellet market segment, the EU has become heavily import-dependent in the industrial pellet market. This is largely

[2] The EU wood pellet quality standard EN14961-2 differentiates between categories A1, A2, B.

[3] See http://www.enplus-pellets.eu/pellcert/ [January 2013].

Table 3.2 The 15 largest operating pellet mills by 2012

Company	Location	Predominant feedstock	Capacity [tonnes/year]
Vyborgskaya Cellose	Russia	Unmerchantable timber	900,000
Georgia Biomass	GA, USA	Plantation roundwood	750,000
Green Circle (JCE Group)	FL, USA	Plantation roundwood	500,000
Biowood	Averøy, Norway	Wood chips (imported)	450,000
Pinnacle Pellet Inc	BC, Canada	Sawdust, pine-beetle wood	400,000
Enviva, Hertford	NC, USA	Unknown	350,000
Pacific BioEnergy	BC, Canada	Sawdust, pine-beetle wood	350,000
German Pellets	Wismar, Germany	Sawdust	256,000
German Pellets	Herbrechtingen, Germany	Sawdust	256,000
Arkaim	Khabarovsk, Russia	Processing residues	250,000
Plantation Energy	Albany, Australia	Eucalyptus residues	250,000 [closed]
Pinnacle Pellet Meadowbank	BC, Canada	Sawdust, pine-beetle wood	220,000
Ankit Pellets & Briquettes	Bengaluru, India	Unknown	200,000
Houston Pellet Inc	BC, Canada	Sawdust, pine-beetle wood	180,000
Graanul Invest Incukalns	Incukalns, Latvia	Sawdust	180,000

due to the increase in demand (predominantly in the Netherlands and the UK), but also linked to a limited mobilisation and production (within the EU and its border countries), competitive to overseas pellet export prices. Exports from Fennoscandia via the Baltic Sea are limited by ship size and frequently also by ice forming in harbours in winter – the peak demand season for district heating installations, e.g. in Denmark.

In addition, to the increasing number of pellet producers looking to supply into a growing European market, several European energy utilities themselves have started (or are aiming) to expand their activities upstream to secure their supplies of industrial pellets. The strongest absolute production increases in recent years took place in North America, more specifically in the South-East USA (Table 3.2). While also having a strong local consumption, much of the additional US capacity installed since 2010 is aimed at producing industrial pellets for export to the EU (Goh et al. 2013). In 2009, about 1.7 Mtonnes were imported from outside the EU. By 2012 this volume had risen to 4.6 Mtonnes (Fig. 3.7). By 2020, we expect EU wood pellet imports to be in the range of 15–20 Mtonnes (see also Cocchi et al. 2011; Goh et al. 2013). While the majority of this volume will be industrial pellets, wood pellet imports for the domestic market are also expected to increase.

Sourcing of wood pellets from many different world regions creates a challenge for companies and policy makers to ensure that the biomass used is from sustainable sources. The vast majority of wood pellets are still derived from either harvesting or processing residues, largely tops and branches from lumber harvest and sawdust and chips from timber sawmills. The expansion of the sector however, as new investments have shown, will inevitably lead to the use of lower quality roundwood

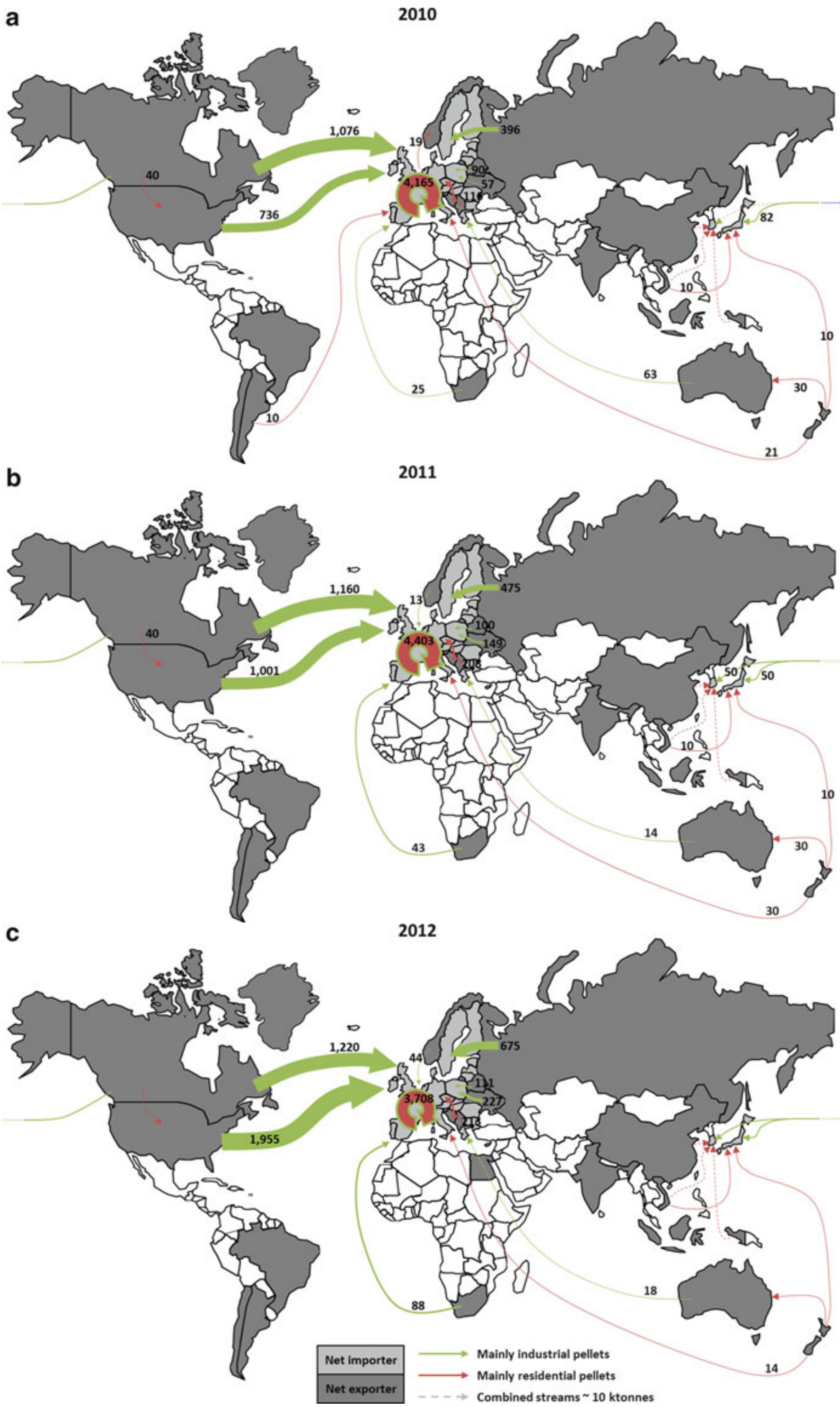

Fig. 3.7 Global wood pellet trade streams in (**a**) 2010, (**b**) 2011, (**c**) 2012 [>10 ktonnes] (Data: Cocchi et al. 2011; Lamers et al. 2012a; EUROSTAT 2013)

fractions (e.g. pulpwood). This feedstock switch may involve new sustainability risks, with potential impacts on forest carbon stocks, biodiversity, and soil productivity being the most pressing (Lamers et al. 2013).

3.4.3 Country Examples: Wood Pellet Markets

Based on Cocchi et al. 2011; Goh et al. 2013 summarized the characteristics, policies/regulatory framework conditions, and trends for the most important wood pellet markets. They distinguished them by consumption pattern and trade profile; Europe and Asia being the key import regions and North America dominating the export focused market side. Table 3.3 provides one country example per specific market category. The European market is differentiated by dominating end-use within the respective Member State.

3.5 Policies and Market Factors Shaping International Woody Biomass for Energy Trade

The different trade pattern developments of the woody biomass commodities imply foremost that they were exposed to different demand, supply, or trade stimuli and show different biofuel or market characteristics (Table 3.4). The dominant producing and exporting nations are clearly those with long-standing, export-oriented forestry, wood processing, and/or pulp and paper industries. The availability of excess residues, the possibility to use existing infrastructure (for processing and transport), and interconnected know-how have turned out to be key drivers and success factors. This is particularly true for regions where domestic policies have triggered national bioenergy markets, as e.g. in Scandinavia or Austria. Countries with little policy support or interest in bioenergy, due e.g. to the abundance of fossil fuel resources (e.g. Russia) show that the existence of aforementioned key factors under absence of strong national interests is not necessarily a guarantee for success. Slow and inconsistent developments in young markets with a high theoretical biomass potential (see e.g. Smeets et al. 2007) further exemplify the need for local experience and continuous domestic interest for market off-taking.

The key defining factor for international solid biofuel trade is economic viability (Lamers et al. 2012a). On the supply side, it is constrained by production and transport costs; in turn mostly influenced by feedstock, vehicle costs, and biofuel characteristics (Olsson et al. 2010). The heating value, correlated to moisture and ash content (Kaltschmitt and Hartmann 2001), bulk density, (homogeneous) form and chemical composition define the monetary value as a biofuel. These factors determine whether a commodity is worth transporting over long distances (via ship), relatively more expensive (short) transport modes (e.g. via truck), or whether it requires further processing (e.g. drying, pelletizing, torrefying; see also Uslu et al. 2008). Low heating

Table 3.3 Country examples for different wood pellet net demand and net supply markets (Goh et al. 2013)

Market characteristics	Policies/Regulatory framework	Market trend
Europe: Residential and district heating: Germany		
No co-firing of wood pellets in power plants – rely on other renewable electricity such as solar, wind and other biomass power	Market incentive program (MAP) – investment subsidy Renewable Energies Heat Act (EEWärmeG) – building regulation	Increased use of wood pellets for residential heating Depletion/Freezing of MAP budget caused uncertainties among the investors leading to a smaller number of pellet heating systems installed in 2010 Reinforced utilization of pellets on the small-scale market The pellets produced for power generation are entirely exported
Europe: Power plants driven market: the UK		
Transparent monitoring of biomass energy use and sustainability certification by Ofgem	Renewable Obligation Electricity Market Reform Feed in Tariff	Increasing use of wood pellets, largely in power plants
Europe: Mixed market: Sweden		
Opportunities: High oil prices, increasing electricity costs, and heavy taxation on fossil fuels Barriers: High raw material prices and intense competition	Electricity certificate system combined with renewable obligations and exemptions from CO2 taxes Indirect effect: Heavy fossil fuels tax	Use of wood pellets in private households has increased by a factor of 20 over a 13 year period Raw material shortage
Other import oriented markets: South Korea		
Large coal power plants	Renewable portfolio standards for power companies (by 2012) Korea Forest Service subsidize the purchase of domestic pellet boilers by 60–70 %	Possibility to co-fire wood pellets with coal Expected that at least 60 % of renewable energy will be from pellets, amounts to 2.25 Mt in 2012 Induce pellets production in Indonesia, Myanmar and New Zealand About 13,600 boilers were installed since 2008
Export oriented markets: the USA		
Many underutilized sources of biomass – mill residues and crop residues	Federal level: Renewable Energy Production Incentive (REPI)	Over 80 % of pellets produced in the US were used domestically; of the remaining, were exported to Europe Production declined when the sawmilling sector retrenched in the 2008–2009 recession

(continued)

Table 3.3 (continued)

Market characteristics	Policies/Regulatory framework	Market trend
Reliance on sawmill residues Increases in the cost of fossil energy Demand and also investment from Europe	State biomass economic drivers	New mills to process chipped roundwood – independence from the sawmill industry has allowed a focus on export Regulations will likely drive existing coal power plants to co-fire with biomass, which will create an increasing market for biomass pellets

Table 3.4 Trade influencing market & policy factors (Lamers et al. 2012a)

	Stimulating (local) solid biofuel production/use	Stimulating international solid biofuel trade
Market		
Market characteristics	Availability of excess residues from existing forestry, pulp and paper, or wood processing industries; also allowing the use of the respective infrastructure, know-how, and political influence Preferential climatic conditions (i.e. potential) Existing businesses with facilities allowing co-/mono-firing; especially fluidized bed technology due to feedstock flexibility	Existing export orientation of the forestry or wood processing industry: big scale bulk infrastructure (railways, harbors), handling equipment (chippers, cranes, terminals etc.), export market/trade know-how High local electricity and heat prices increasing the economic viability for biofuel imports Availability of low cost domestic fossil fuels (e.g. in Russia, North America) allowing/stimulating exports of low cost domestic biofuels Limited large-scale, low cost, domestic feedstock production potential
Solid biofuel characteristics	Local (short-distance) use is typical for biofuels which are either unrefined, cannot be transported in bulk (fuelwood), have a high moisture content, low monetary and/or low heating value (e.g. forestry slash, bark chips) Small margin between supply costs (production and transport) and prices in consumer markets	Refined, homogeneous biofuels with high heating and/or monetary value (e.g. pellets), bulk density, flow-ability (reducing handling costs); low moisture and ash content Large margin between supply costs (production and transport) and prices in consumer markets Similar combustion characteristics to coal increasing the attractiveness for co-firing Flexible end-use (combustion technology and scale)

(continued)

Table 3.4 (continued)

	Stimulating (local) solid biofuel production/use	Stimulating international solid biofuel trade
Policy		
Supply related	Incentives to increase the residue use in the forestry and/or agricultural sector, or the planting of dedicated cellulose crops via investment support, direct subsidies, low-interest loans, grants, or infrastructure projects Mobilization of small forest owners (see e.g. EC 2010 on good practice guidance on the sustainable mobilization of wood in Europe)	Overproduction due to lack of local demand, overstimulation and/or highly competitive production prices compared to other international sources incentivizing exports Differing legal requirements for waste wood combustion between neighbouring countries
Demand related	Renewable electricity and/or heat targets enforced via regulatory or fiscal policies Emission standards Ban on landfilling wood waste Investment support via low-interest loans, grants, or subsidies for equipment	Linking domestic policies with eligibility criteria i.e. limiting the combustion to certain biofuel streams thus increasing respective imports and triggering exports of non-eligible material; the same is true under limited national potential
Trade related	Commodity specific export duties Technical standards e.g. in the form of phytosanitary measures for imports Hypothetically also sustainability criteria (if fulfilled by domestic production and sufficient, cost and GHG efficient biomass available; or criteria hard to fulfil by international imports)	Avoidance of export duties by transforming the respective commodity Technical standards in the form of globally accepted quality standard (e.g. ENplus for wood pellets) Hypothetically also sustainability criteria (if not sufficient, cost or GHG efficient biomass available in export destination and criteria fulfilment in exporting country is possible)

value products (e.g. forestry residues) with a relatively low monetary value are usually used locally or transported cross-border. Refined, homogeneous biofuels with a high heating (low moisture and ash content) and monetary value (e.g. bagged wood pellets for residential heating) are traded globally. A high bulk density is preferable for long or expensive transport and is clearly influenced by processing (e.g. condensing into wood pellets).

On the demand side, the defining economic factors for trade are the margins achievable in the respective end-consumer markets. They are typically influenced by local policies, exchange rates (Olsson et al. 2010), and application scales (Lamers et al. 2012a). Economies of scale allow the trade of low value commodities, in particular those with combustion characteristics similar to those of coal and/or which may be used in different technical installations.

There are multiple design options for renewable energy support schemes (see Mitchell et al. 2011 for a review). They are generally able to influence markets on the supply and demand side, but also trade via tariff policies and regulations. Tariffs have largely been irrelevant as a most-favoured nation (MFN) tariff of 0 % applies between the members of the World Trade Organization (WTO). Trade regulations however did have impacts on trade flows as the EU requirement for phytosanitary measures for wood chips from North America has shown.

Supply side policies predominantly aim at reducing production costs, i.e. costs for feedstock and processing (Alakangas and Keränen 2011). Indirect stimuli via research and development support (e.g. forestry management practices) or direct subsidies for equipment, the collection of unused residues, or planting of dedicated cellulose crops are other examples. As supply side policies have primarily stimulated domestic markets, they yet had marginal effects on trade.

This is different to demand side policies which have significantly stimulated international trade (Lamers et al. 2012a). EU developments illustrate the varying policy effects nicely (see Ragwitz et al. 2007; Held et al. 2010 for a detailed discussion). In the residential heating market, direct and often single fiscal incentives in the form of e.g. low interest grants, loans, or tax rebates have stimulated installments of wood stoves/boilers (e.g. pellets, wood chips). These incentives were especially effective in markets with mature boiler/stove industries and where the respective boiler fuel was price competitive (on a heating value basis) with other heating fuels. Price prognoses in the residential market although are yet practically non-existent or relatively short-term (Sikkema et al. 2011). Hence, short-term feedstock prices and stove/boiler choices connected to fiscal incentives defined local demand patterns. Trade for the residential market is therefore directly linked to feedstock price advantages. Individual investment support in the power and heating market was only relevant for medium-sized, community-owned projects. Rather, the sector has been critically influenced by regulations (quotas, taxes, feed-in schemes) providing long-term framework conditions. The EU is once again a nice illustration were all aforementioned regulation types have proven to be effective (Held et al. 2010). Quota systems, such as those for renewable electricity production in Belgium, Italy, and the UK, primarily led to large-scale co-/mono-firing in existing power/CHP plants (allowing economies of scale), and thus quota achievements at minimal costs. The taxation of fossil fuels (e.g. coal in Denmark, light heating oil in Italy), partly also connected to quota schemes (e.g. in Sweden) has shown similar effects. Trade patterns were exclusively related to the feedstock flexibility of the combustion technology in order to broaden the sourcing portfolio and level out price fluctuations (Lamers et al. 2012a). This observation has also been made for imports under feed-in schemes, e.g. to the Netherlands, unless they included eligibility criteria. Pulverized coal combustion plants in Belgium, the Netherlands, and UK have limited the utilized streams to wood pellets whereas dedicated grate and/or fluidized bed facilities in Sweden, Italy, or Denmark have sourced a much wider feedstock range including palm kernel shells.

3.6 Conclusions and Outlook

In general, the key constraint for international woody biomass trade for energy is economic viability. Margins are primarily influenced by production and transport costs, but also prices in and exchange rates to target markets. As production costs depend heavily on feedstock prices, it is not surprising that key producing and exporting regions have a long tradition in export oriented forestry, wood processing, and/or pulp and paper industries, and benefit from the availability of low/no cost feedstock and/or residues, infrastructure, and experience.

EU markets are expected to remain the largest driver for international, policy-influenced, woody biomass for energy trade in the near future. In this, the EU will remain a net importer and North America a net exporter of wood pellets, despite the significant domestic consumption of wood pellets in the USA. East Asia is predicted to be-come the second-largest consumer of wood pellets after the EU. The development in Latin America regarding wood pellets is still unclear. Local demand is expected to remain marginal but the region is regarded to have significant production potential (van Vuuren et al. 2009; Beringer et al. 2011; Schueler et al. 2013). Previous investment strategies by Brazilian Suzano Energia Renovavel (subsidiary of paper giant Suzano) alone would see a rise in wood pellet production capacity of 3 Mtonnes by the end of 2015. The pellets are aimed for consumption in Europe. It is yet to be seen however whether such investments take place as wood for pellet production competes with the production of fibre for pulp and paper. Also, Brazilian production would need to qualify under potential future requirements for the sustainability of woody biomass in the importing countries.

Global wood chip trade for energy to the EU is unlikely to increase significantly in the short-term. North American imports underlie phytosanitary measures (due to pine beetle and nematode infection) which increase end prices and limits their use to the higher priced markets such as pulp and paper production. South America, Brazil in particular, and Asia are increasing their pulp and paper production capacities. Previously traded woody biomass, such as chips, will continuously be used within these regions. Africa has slowly increased wood chip production for energy in recent years. Developments are however primarily driven by European companies, and end-use markets will remain off-shore. It is also expected that wood chips are eventually converted to pellets prior to transport.

We know that policy related international trade has risen sharply over the past years. Sophisticated analysis of exact trade volumes however is inherently dependent on robust data and trade codes are still not used consistently on an international scale. Comparisons between officially reported volumes, market data and anecdotal evidence suggest that EUROSTAT statistics provide a good starting basis (especially regarding international wood pellet trade).

References

Alakangas, E., & Keränen, J. (2011). *Report on policy instruments affecting on the forest industry sector and wood availability, survey result report*. Jyväskylä: VTT. Available at: http://www.eubionet.net/GetItem.asp?item=digistorefile;292990;1770&params=open;gallery. Accessed 4 July 2011.

Alakangas, E., Heikkinen, A., Lensu, T., & Vesterinen, P. (2007). *Biomass fuel trade in Europe* (ed Eubionet2). Jyväskylä: VTT. Available at: http://eubionet2.ohoi.net/ACFiles/Download.asp?recID=4705. Accessed 5 Apr 2011.

Beringer, T. I. M., Lucht, W., & Schaphoff, S. (2011). Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. *GCB Bioenergy, 3*, 299–312.

Bradley, D., Kranzl, L., Diesenreiter, F., Nelson, R., & Hess, J. (2009). *Bio-trade & bioenergy success stories* (IEA bioenergy task 40). Available at: http://www.bioenergytrade.org/downloads/bioenergysuccessstoriesmar92009.pdf. Accessed 12 Jan 2011.

Cocchi, M., et al. (2011). *Global wood pellet industry and market study* (IEA bioenergy task 40). Available at: http://www.bioenergytrade.org/downloads/t40-global-wood-pellet-market-study_final.pdf. Accessed Jan 2012.

EC. (2010). *Good practice guidance on the sustainable mobilisation of wood in Europe*. Available at: http://ec.europa.eu/agriculture/fore/publi/forest_brochure_en.pdf. Accessed Jan 2013.

Economist. (2012, November 17). It mustn't be business as usual. *Economist*, New York/London/San Francisco.

Edenhofer, O., et al. (Eds.). (2011). *IPCC special report on renewable energy sources and climate change mitigation*. Cambridge/New York: Cambridge University Press.

EUROSTAT. (2013). *Data explorer – EU27 trade since 1995 by CN8*. Brussels, Belgium, Eurostat. Retrieved Jan 2013. Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

Faber, J., Bergsma, G., & Vroonhof, J. (2006). *Bio-energy in Europe 2005 – Policy trends and issues*. Delft: CE Delft.

FAO. (2012). *2011 Global forest products facts and figures*. Available at: http://www.fao.org/fileadmin/user_upload/newsroom/docs/2011%20GFP%20Facts%20and%20Figures.pdf. Accessed Feb 2013.

FAOSTAT. (2013). *ForesSTAT*. Rome, Italy, Food and Agriculture Organization of the United Nations. Retrieved Jan 2013. Available at: http://faostat.fao.org/site/626/default.aspx#ancor.

FOREST. (2011). *A guide to biomass heating standards*. Rome, Italy: Comitato Termotecnico Italiano Energia e Ambiente. Available at: http://www.forestprogramme.com/files/2011/05/FOREST-Standard-Guide_V04_UK.pdf. Accessed Jan 2013.

Goh, C. S., et al. (2013). Wood pellet market and trade: A global perspective. *Biofuels, Bioproducts and Biorefining, 7*, 24–42.

Goto, S., Oguma, M., Iwasaki, Y., & Hayashi, Y. (2012). *Japan country report 2011* (IEA bioenergy task 40). Available at: http://bioenergytrade.org/downloads/iea-task-40-country-report-2011-japan.pdf. Accessed May 2012.

Guizot, M. (2010). The prospects of wood chips and pellets production and trade. In *Proceedings of the 2nd biomass for heat and power conference,* Brussels.

Heinimö, J. (2008). Methodological aspects on international biofuels trade: International streams and trade of solid and liquid biofuels in Finland. *Biomass and Bioenergy, 32*, 702–716.

Heinimö, J., & Junginger, M. (2009). Production and trading of biomass for energy – An overview of the global status. *Biomass and Bioenergy, 33*, 1310–1321.

Held, A., Ragwitz, M., Merkel, E., Rathmann, M., & Klessmann, C. (2010). *Indicators assessing the performance of renewable energy support policies in 27 Member States*. Available at: http://www.reshaping-res-policy.eu/downloads/RE-Shaping%20D5D6_Report_final.pdf. Accessed Feb 2011.

Hiegl, W., & Janssen, R. (2009). Pellet market overview report – Europe. In *Pellets@las*. Available at: www.pelletsatlas.info. Accessed Feb 2011.

Johnson, F., Tella, P., Israilava, A., Takama, T., Diaz-Chavez, R., & Rosillo-Calle, F. (2010). *What woodfuels can do to mitigate climate change* (FAO Forestry Paper). Available at: http://www.fao.org/docrep/013/i1756e/i1756e00.pdf. Accessed Mar 2011.
Junginger, M., van Dam, J., Alakangas, E., Virkkunen, M., Vesterinen, P., & Veijonen, K. (2010). Solutions to overcome barriers in bioenergy markets in Europe. In *EUBIONET3*. Available at: http://www.eubionet.net/GetItem.asp?item=digistorefile;144551;1087&params=open;gallery. Accessed Jan 2011.
Kaltschmitt, M., & Hartmann, H. (2001). *Energie aus Biomasse: Grundlagen, Techniken und Verfahren*. Berlin: Springer.
Lamers, P., Junginger, M., Hamelinck, C., & Faaij, A. (2012a). Developments in international solid biofuel trade – An analysis of volumes, policies, and market factors. *Renewable and Sustainable Energy Reviews, 16*, 3176–3199.
Lamers, P., Marchal, D., Schouwenberg, P. P., Cocchi, M., & Junginger, M. (2012b). *Global wood chip trade for energy* (IEA bioenergy task on 40 Sustainable International Bioenergy Trade). Available at: http://www.bioenergytrade.org/downloads/t40-global-wood-chips-study_final.pdf. Accessed June 2012.
Lamers, P., Thiffault, E., Paré, D., & Junginger, H. M. (2013). Feedstock specific environmental risk levels related to biomass extraction for energy from boreal and temperate forests. *Biomass and Bioenergy, 55*(8), 212–226.
Mitchell, C., et al. (2011). Policy, financing and implementation. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, & C. V. Stechow (Eds.), *IPCC special report on renewable energy sources and climate change mitigation*. Cambridge/New York: Cambridge University Press.
Olsson, O., Vinterbäck, J., Dahlberg, A., & Porsö, C. (2010). *Price mechanisms for wood fuels*. Available at: http://www.eubionet.net/GetItem.asp?item=digistorefile;178383;1087&params=open;gallery. Accessed June 2011.
Ragwitz, M. et al. (2007). OPTRES – *Assessment and optimisation of renewable energy support measures in the European electricity market*. Intelligent Energy for Europe – Programme (Contract No. EIE/04/073/S07.38567). Available at: http://www.optres.fhg.de/OPTRES_FINAL_REPORT.pdf. Accessed Feb 2011.
REN21. (2012). *Renewables global status report*. Renewable Policy Network for the 21st century. Paris: REN21. Available at: http://www.ren21.net/default.aspx?tabid=5434. Accessed Jan 2013.
Schueler, V., Weddige, U., Beringer, T., Gamba, L., & Lamers, P. (2013). Global biomass potentials under sustainability restrictions defined by the European Renewable Energy Directive 2009/28/EC. *GCB Bioenergy*, online early view, doi:10.1111/gcbb.12036.
Sikkema, R., Steiner, M., Junginger, M., Hiegl, W., Hansen, M., & Faaij, A. (2011). The European wood pellet markets: Current status and prospects for 2020. *Biofuels, Bioproducts and Biorefining, 5*, 250–278.
Smeets, E., Faaij, A., & Lewandowski, I. M. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science, 33*, 56–107.
UN. (2013). *Commodity Trade Statistics Database (COMTRADE)*. New York, Geneva, United Nations. Retrieved Jan 2013. Available at: http://comtrade.un.org/db/default.aspx.
UNECE/FAO. (2010). *Forest product conversion factors for the UNECE region*(Geneva Timber and Forest Discussion Paper 49). Geneva: United Nations Economic Commission for Europe, Food and Agriculture Organization of the United Nations. Available at: http://www.unece.org/fileadmin/DAM/timber/publications/DP-49.pdf. Accessed Feb 2013.
Uslu, A., Faaij, A., & Bergman, P. (2008). Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. *Energy, 33*, 1206–1223.
van Vuuren, D., van Vliet, J., & Stehfest, E. (2009). Future bio-energy potential under various natural constraints. *Energy Policy, 37*, 4220–4230.
Vikinge, B. (2011). Trading of wood chips in the Baltic Sea region. In *EUBIONETIII workshop: Biomass trade – focus on solid biofuels*, Espoo.
Willumsen, K. (2010). Import of wood-chips from non-European countries – need for a common PRA? In *Nordic-Baltic plant health meeting*, Finland.