TECHNOLOGY-ANALYSIS:

Biomass -

Availability as a Renewable Energy Source

(Summary)

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Summary

1. Biomass as a renewable energy source in European Union

Energy security and climate change mitigation are the core elements in the current European Union (EU) Energy policy. In 2008, the EU established the so-called "20/20/20 in 2020" goals, which state that by 2020, the EU shall reduce its greenhouse gas emissions by 20%, reach a share of 20% renewable energy in the energy mix and increase energy efficiency by 20% (Council of the European Union, 2008). Annexes to Directive 2009/28/EC specify i) the national overall targets for the share of energy from renewable sources for the year 2020 and a reference value for the year 2005 (Annex I; *Figure 1*), and ii) indicative trajectory for each Member State, that must be attained or exceeded in the reference years specified. Moreover, European Council has presented a long term target of 80-95% cuts in greenhouse gases emissions (GHGs) by 2050.

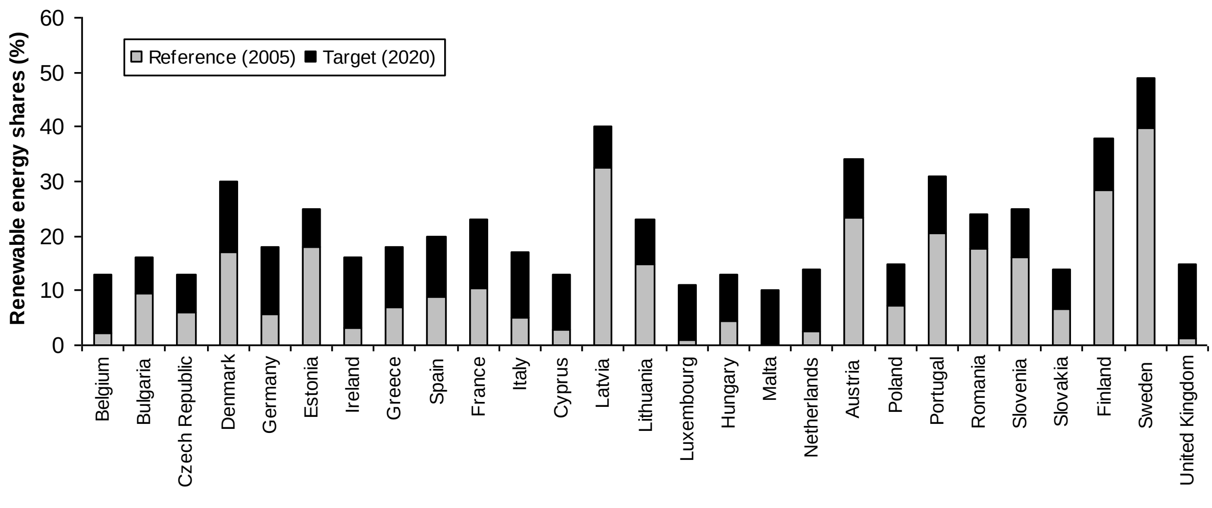
According to EU renewable projections, biomass is estimated to account for 51% of the total renewable energy supply in EU-27 by 2020 (Beurskens et al., 2011). In particular, if only renewable energy production for heating and cooling is considered, biomass represents 81% of the total.

Bio-energy designates energy derived from three main categories of feedstock (agriculture, forestry and waste) for three main uses (transport, heat and electricity). Wood energy, in particular, is derived from wood fuels, which includes all biofuels derived from woody biomass (CEN, 2004).

The two main sources of biomass are the purpose-grown energy crops and wastes. In this short report, we focus on solid wood fuels and agricultural crop residues, which make up the majority of solid bio-fuels.

Agricultural crop residues can be defined as aboveground plant material which is left on the ground after crop harvest. Wood fuels can be distinguished in: i) refined wood fuels, which include

Figure 1 - Renewable energy shares from Annex I of the Directive 2009/28/EC.



material that have gone through industrial processes to achieve certain specific fuel properties, and ii) unrefined wood fuels, which are converted into energy from a form that is not changed significantly from its forest origin other than through reduction in size (e.g. through chipping or crushing). The first category include, for example, wood pellets and wood briquettes which are dried and compressed in order to increase energy density. In fact, wood pellets contain twice the amount of energy per weight unit compared to wood chips, which has important consequences for logistics and trade. The most important fuel characteristics are granulometry, density, heating power, humidity, ash content, chlorine, content and fusibility ash temperature (for more details about feedstock characteristics, see Saidur et al., 2011).

2. Biomass conversion to energy

Biomass can be converted to fuel by means of numerous processes. The actual choice of a process will depend on the type and quantity of available biomass feedstock, the desired energy carrier (end-use), environmental standards, economic conditions and other factors.

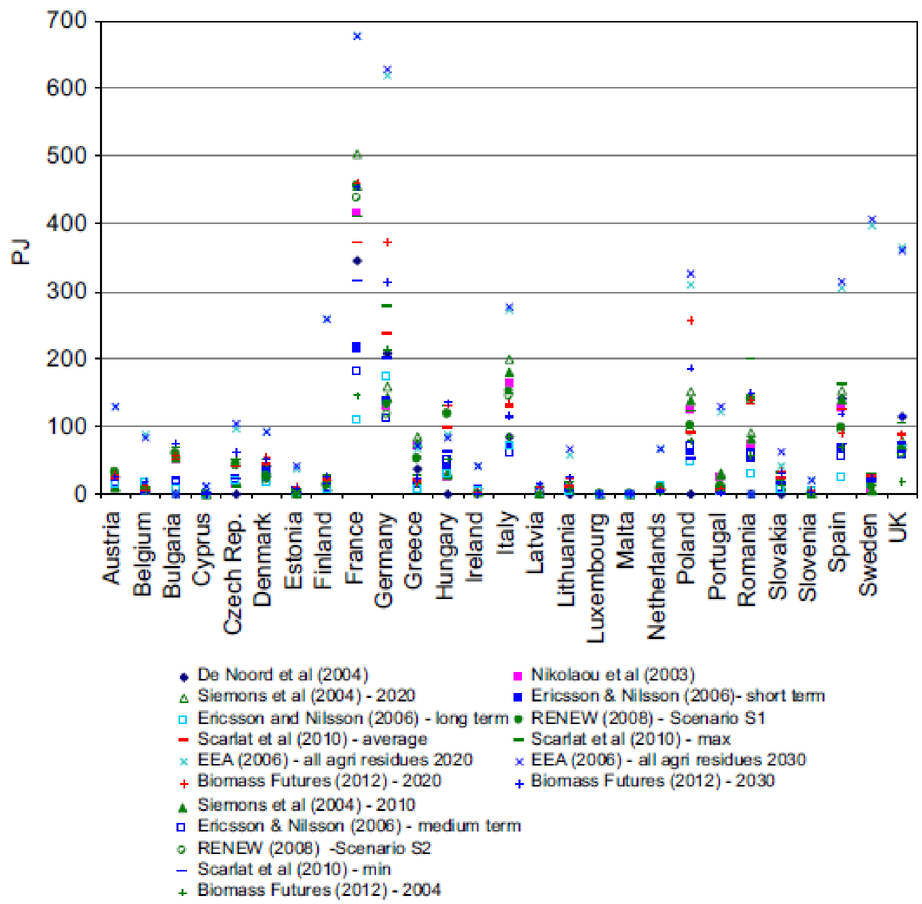
There are several available methods to convert biomass into useable form of energy:

- direct combustion. The chemical energy bound in wood fuels and other biomass is converted into useful energy – e.g. heat or electricity – by means of combustion. In such a case, biomass can be burned directly in waste-to-energy plants without any chemicals processing to produce steam for making electricity. However, direct combustion is substantial pollution source;
- pyrolysis. It consists in thermal decomposition of organic matters in absence of oxygen. It is a relatively slow chemical reaction occurring at low temperatures to convert biomass to a more useful fuel such as hydrocarbon rich gas mixture and a carbon rich solid residue. The main products of biomass pyrolysis depend on the temperature, heating rate, particle size and catalyst used;
- gasification. It consists in thermo-chemical conversion of biomass into gaseous fuels by means of partial oxidation of the biomass at high temperatures. The composition of syngas is affected by gasification conditions (temperature, equivalent ratio and pressure). A complete review on available gasification technologies can be found in Graciosa Pereira et al. (2012);
- fermentation. It is the process by which ethanol fuel can be produced. The two most commonly used processes involve using yeast to ferment the starch in the plant to produce ethanol which can be used as a fuel in the transportation sector;

- anaerobic digestion. It is the biochemical conversion of organic material to biogas. This conversion is done by bacteria in absence of oxygen;
- chemical conversion. Biomass can be converted into gas or liquid fuels by using chemicals or heat.

On the demand side, markets are diverse and range from single-household wood pellet stoves to combustion facilities of several hundred MWe. Concerning with heat production from biomass, European biomass heat industry is highly diversified as it covers residential services and institutional and industrial markets. Moreover, as each biomass is different from a chemical and physical point of view, boilers must be designed specifically for each biomass type. Generally, the required investment for a biomass boiler is higher than for a fossil fuel boiler, but the fuel is clearly cheaper.

Figure 2 – Different assessments for crop residue potential and availability in the EU (Monforti et al., 2013).



As far as available technologies (stove and boilers) are concerned, Minguez et al. (2012), in their exhaustive review covering 186 companies and 995 boiler models, identified six main available devices-feedstock combinations: boiler with wood pellets, boiler with wood chips, boiler with wood logs, boiler with chips and pellets (pellet and-chip boiler), multi-fire or multi-fuel boilers and, finally, pellet stoves. Nearly all pellet stoves and wood log boilers use a fixed grate even though, concerning with chip and pellet boilers, the use of moving grates becomes more frequent as the boiler power increases. In 56% of pellet boilers and 66.9% of pellet stoves an automatic ignition system is used, whereas in 66.3% and 83.7% boilers which burn chips and pellets and chips, respectively, the hot-air automatic system is used. Feeding from above (gravitational) is the most common technique in low power boilers (<15 kW), while horizontal feeding is more common in boilers with a power higher than 40 kW. Most of boilers have an automatic control system with different control parameters.

3. Agricultural crop residues availability as energy source in Europe

A large number of studies aimed to estimate the potential of different biomass residues available for energy use in Europe have been published in the last 20 years (Figure 2). However, the uncertainty in such assessments is still very high (Monforti et al., 2013) because of the differences in the adopted statistical and methodological approaches. Moreover, this uncertainty is also related to different definitions of available biomass (i.e. total production, sustainable harvest from a environmental point of view, technically feasible).

Recently, Monforti et al. (2013) quantified a total crop availability for energy use using a GIS approach applied at NUTS2 level for all over EU-27. In particular, they based their estimates on crop yields, harvested areas and specific residue-to-product ratios. According to their estimate, a total amount of 283,890 kt of residues have been produced in the period 2000-2009 at EU-27 scale.

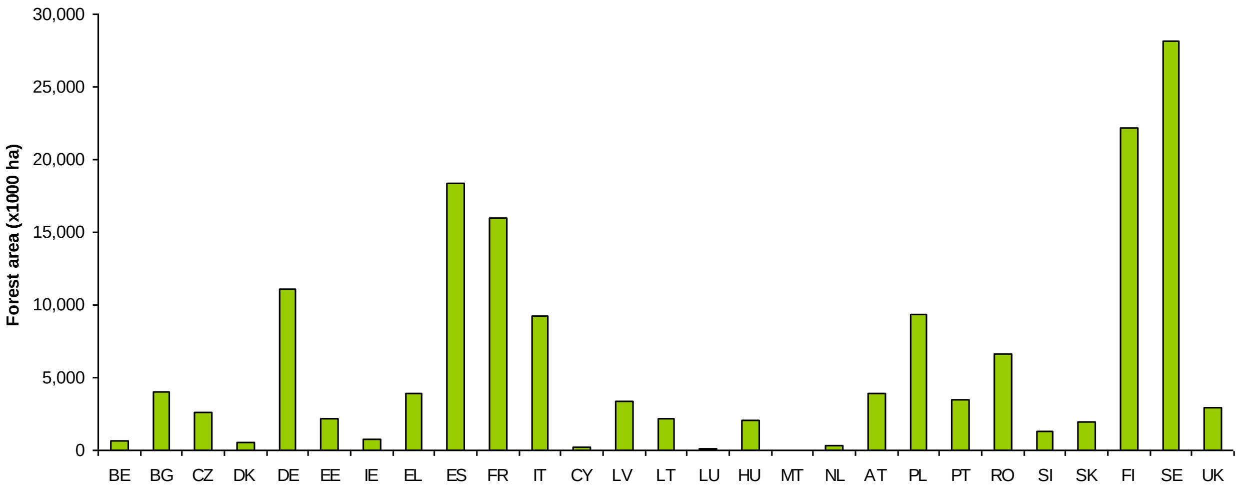
Only part of these residues are available for energy use (35%) as not all residues are collected and part of the collected residues are used for animal bedding. In fact, removal rates must be suitable in order to maintain soil fertility (usually, 40%) and the use of residues for animal bedding can be significant in some countries (i.e. Ireland).

In the same study, the authors estimated the total number of power plants which could use this available biomass. A typical power plant was defined as a plant with a capacity of 50 MW of thermal input (100 kt $year^{-1}$ of was material) and was considered suitable if the necessary biomass could be found in a radius of 50 km (maximum travel distance of 70 km). According to these assumption, the authors estimated a number of plants ranging from 837 to 852 with an optimized or randomized distribution, respectively, and overall energy production between 1510 and 1540 PJ.

4. Forest biomass as an energy source in Europe

There are 1.02 billion hectares of forest in Europe (FAOSTAT, 2012), which amount to 25% of the world total. In particular, the EU-27 countries have experienced a steady increase in forest area over the last 50 years. This increase in forest area has been related to trends in economic globalizations which have promoted agriculture intensification, industrialization and migration of population from the rural areas. As a consequence, areas of marginal agriculture have been abandoned leading to secondary successions. On the other hand, EU has promoted the conversion of agricultural land to forest plantations (both short term for biomass production and medium/long term for high quality wood production or for natural purposes). Actually (2011), forests cover more than 157 10^6 ha in EU-27 corresponding to 36% of the total land area (FAOSTAT, 2012)(Figure 3).

Figure 3 – Forest area in EU-27 in 2011 (from: FAOSTAT, 2012).



In terms of standing biomass and growth, there is abundant evidence that forest growth (net primary production, NPP) has been increasing in Europe over the last century: using national inventory, timber harvest statistics, allometric relationship and appropriate turnover rate for leaves and fine roots, Ciais et al. (2008) reported that Europe has, on average, multiplied the biomass standing stocks per hectare of forest by 1.75 and the NPP. The highest NPP and stock increments were calculated in the period 1970-1990 when no significant changes in forest area occurred, indicating that area variation alone cannot explain the observed increases in NPP. Changes in the age structure of the forests, different management and harvest strategies, the combined effects of increased atmospheric deposition of nitrogen and reduced sulphur emissions, and increasing CO_2 atmospheric concentration were considered among the most likely causes of increasing NPP.

Forest are considered an important resource to meet EU renewable energy targets as: i) wood and wood waste represent currently about 50% of all the renewable energy production (EUROSTAT, 2010), ii) forests are arguably not managed to their full extent as fellings are generally well below the annual increment (MCPFE, 2007). However, it is still unclear how much wood or biomass EU forests can efficiently supply to satisfy the demand for material and energy use.

At present, forest biomass is mainly used to support material demand, but in the future energy purposes may take over as the major demand. In fact, if the energy demand develops approximately according to the policy targets – and assuming energy efficiency (+20%) and that biomass accounts for “only” 40% of renewable energy, – then, the demand for energy wood will more than double by 2020 (Mantau et al., 2010). In 2010, the total supply of all woody resources in the EU-27 was about one billion cubic meters whereof almost 70% come from forest and 30% come from woody biomass from outside the forest.

Table 1 - Characteristics of different studies that assessed the forest energy potential in Europe. From: Rettenmaier et al. (2010).

Reference	Type of potential	Approach	Biomass sources	Geographical coverage	Time frame
Alakangas et al. 2007	Technical, economic	Demand-driven	Stemwood, logging residues, stumps, early thinnings	EU20	2001-2004, 2010, 2020
Asikainen et al. 2008	Technical, economic	Resource-focused	Stemwood, logging residues, stumps	EU27	2005
De Wit and Faaij 2010	Technical (economic)	Demand-driven	Stemwood, logging residues	EU27 + Ukraine	2000-2030
EEA 2007	Sustainable	Resource-focused	Stemwood, logging residues	EU25	2010, 2020, 2030
Ericsson and Nilsson 2006	Technical	Resource-focused	Logging residues	EU25 + Belarus + Ukraine	Short term (10-20y), medium term (20-40y), long term (>40)
Panoutsou et al. 2009	Technical	Resource-focused	Stemwood, logging residues	EU27	2000, 2010, 2020
Thrän et al. 2006	Technical, economic	Demand-driven	Stemwood, logging residues	Germany, EU15, EU27 + Turkey	2000, 2010, 2020

In oven dry tonnes this is about half a billion oven dry tonnes and equals about 8,500 PJ. While the demand for energy wood more than doubles, the wood consumption for material uses would rise by only 35%, from 458 M m^3 to 620 M m^3. The energy demand would exceed the material demand at some point between 2015 and 2020. Moreover, energy demands is usually underestimated as energy consumption has always been higher than the reported "fuelwood" because consumption is often partly recorded in official statistics and "fuelwood" only refers to wood from forest sources.

Wood potential supply for energy purposes can be defined as the theoretical supply under technical and environmental constraints and some socio-economic constraints. The volume of the potential supply will only be available on the market when it is economically affordable to mobilise this potential. This is especially relevant for forest residues where the price of mobilisation is under current circumstances often higher than the energy value.

Several studies (

Table 1) have attempted to estimate the potential for energy use from forests in Europe and they reported different estimates because of the different adopted constrains. None of the studies included social factors, whereas they are considered an important constraint to wood mobilisation (e.g., Straka et al., 1984).

The study by Thran et al. (2006) provides the largest estimate of current biomass potential in EU-27 (2.82 EJ yr^{-1}) while the lowest current potential was reported by Siemons et al. (2004) (0.47 EJ yr^{-1}). Assuming a conversion factor of 6.3 GJ m^{-3} (assumption: 1 m^3 = 1.7 MWh = 6.3 GJ), these two estimates correspond to 447 $x10^6$ and $74x10^6$ m^3 yr^{-1}, respectively.

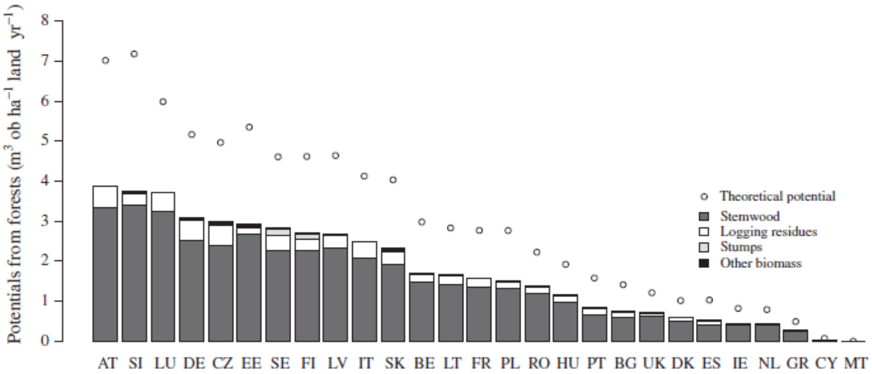
All the other studies lie in between these two extremes. Similarly, also the projections of potentials of stem-wood and primary forest residues are very different.

One of the most recent assessment was published by Verkerk et al. (2011). The authors estimates potential wood supply for energy purposes for the period 2010-2030 according to three scenarios:

- high scenario (HI): strong focus on the use of wood for producing energy and for other uses. Effective implementation of current recommendations on wood mobilisation. In such a scenario, strong mechanisation is taking place across Europe and existing technologies are effectively shared between countries through improved information exchange. Biomass harvesting guidelines become less restricting. Application of fertilizer is permitted to limit detrimental effects of logging residue and stump extraction on the soil;
- medium scenario (ME): existing recommendations are not all fully implemented or do not have the desired effect. New forest owner associations or co-operations are established throughout Europe, but this does not lead to significant changes in the availability of wood from private forest owners. Biomass harvesting guidelines that have been developed in several countries are considered adequate and similar guidelines are implemented in other countries. Mechanisation of harvesting is taking place, leading to a further shift of motor–manual harvesting to mechanised harvesting. Application of fertilizer is permitted to limited extent;
- Low scenario (LO): strong environmental concerns against the intensified use of wood and forest owners are more reluctant to harvest. Application of fertilizer to limit detrimental effects of logging residue and stump extraction on the soil is not permitted. Forests are set aside to protect biodiversity with strong limitations on harvest possibilities in these areas. Furthermore, forest owners have a negative attitude towards intensifying the use of their

forests. Mechanisation of harvesting is taking place, leading to a shift of motor–manual harvesting to mechanised harvesting.

Figure 4 - Distribution of the average, realisable forest biomass potential per hectare of land across EU member states in 2010. Source: Verkerk et al. (2011).



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The maximum theoretical biomass potential from EU-27 forests in 2010 was estimated to be equal to at 1277x10^{6} m^{3} yr^{-1} over bark. This overall potential was projected to decrease by 1.8% in 2030.

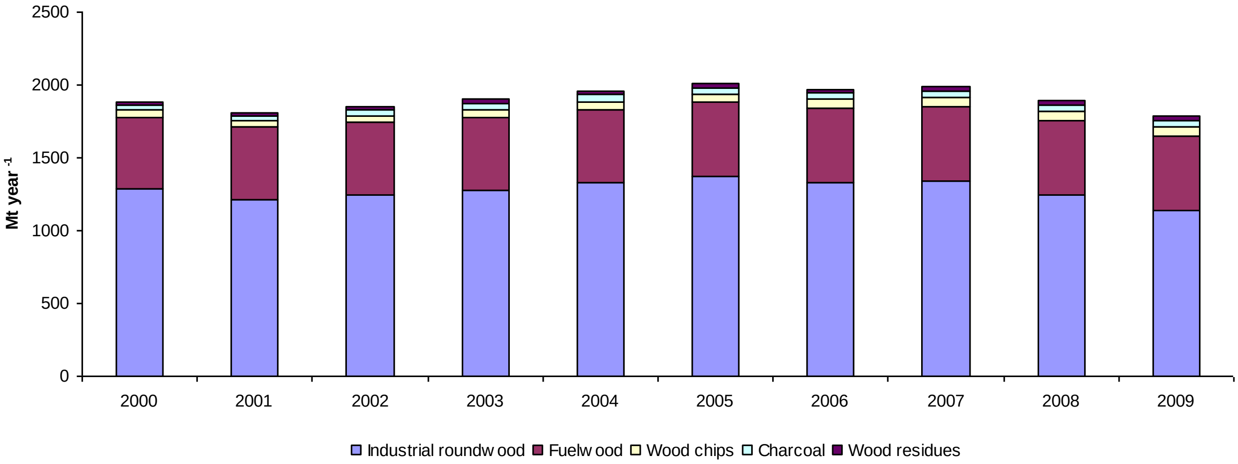
Most of this maximum potential is in stems (52%), while residues and stumps represent 26% and 21%, respectively. Other biomass represented only 1% of the total theoretical potential. According to the applied environmental, technical and social constrains, Verkerk et al. (2011) estimated a current realisable biomass potential from forests of 744x10^{6} m^{3} yr^{-1} overbark in 2010 (58% of the maximum theoretical potential). Adopting a HI scenario, the realisable biomass potential would raise to 895x10^{6} m^{3} yr^{-1} in 2030 (71% of theoretical potential), while adopting a LO scenario, the potential would be 623x10^{6} m^{3} yr^{-1} (50% of theoretical potential). In any case, the realisable biomass potentials are not equally distributed between EU member state. Most of the biomass potential is concentrated in Sweden, Germany, France, Finland and Italy (58% of total EU forest biomass potential and 58% of the available forest area for wood supply).

According to the sensitivity analysis performed within the study, the main factors influencing the biomass potential are represented by constraints related to harvesting activities by private forest owners, as well as constraints related to forest protection. In fact, while changes in forest growth may have a reduced impact on biomass potential (+1.6 or - 3.9% in case of forest growth increase or decrease, respectively), constrains related to harvesting activities may increase or decrease potentials by more than 20%.

5. International trade in fuel-wood products

International trade in wood biomass for energy use include fuel-wood, wood chips, wood residues and charcoal. Solid bio-fuel trade developments of the past decade show a highly heterogeneous picture: wood pellet, wood chip, wood waste, fuel-wood and residue trade streams have been driven by various market and policy factors on the supply and demand side.

Figure 5 - World production of wood and wood-derived biomass types in Mt based on FAOSTAT (2011)



Fuel-wood accounts for roughly two thirds of global bio-energy use (around 33.5 EJ), primarily in the form of traditional heating and cooking (IEA, 2010; Edenhofer et al., 2011). Global fuel-wood production has grown from 497 Mt in 2000 to 509 Mt in 2009 (FAOSTAT, Figure 5). Major increases have taken place in India, Ethiopia, and Congo; the largest reduction has been observed in China, Indonesia, and Russia.

Traditionally, wood fuels have predominantly been a local fuel: less than 1% of its production is traded annually according to official statistics (Lamers et al., 2012; Olsson and Hillring, 2012). This is likely to change as a result of growing demand for wood fuels in countries without substantial domestic wood fuel resources. In particular, EU-27 has been the key driver and importer (

Figure 6): it has been covering over 50% of global trade between 2000 and 2004 and more than 80% between 2005 and 2009. The majority of EU fuel-wood trade is for residential heating.

Figure 6 - EU fuel-wood trade streams (>50 kt) in 2010. Numbers are maximum annual volumes, i.e. may be based on import or export data. Exports may include re-exports. From: Lamers et al. (2012).

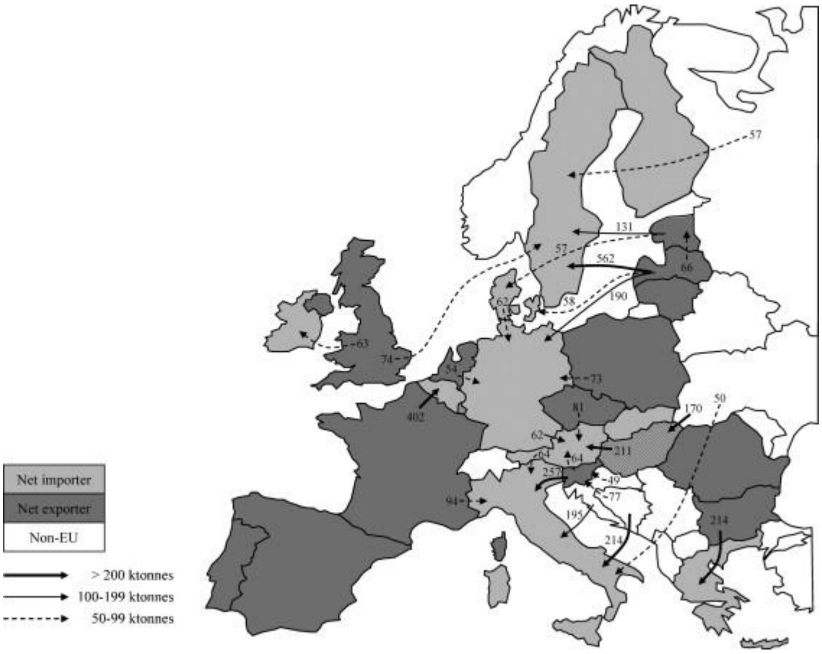


Figure 7 - Estimated world pellet production from 2000 to 2010 in kt (from: Lamers et al., 2012).

Wood chips are by far the most traded commodity relative to their total global production volume. They mainly derive from harvesting or processing forest residues (branches, tree tops, thinnings, bark, etc.). The main producers of wood chips across the past decade have been Canada (37%), Australia (8%), Sweden (7%), Russia (6%), and China/Finland (5% each). The EU has been a net importer of wood chips, sourcing (i.e. extra-EU) largely from Russia, Uruguay, Brazil, Canada, Congo, Belarus, and the Ukraine (Eurostat, 2011).

Wood residues mainly include sawdust and wood waste and scrap. This material can be directly used for combustion or can be converted to pellets. Wood pellets have become an increasingly internationally traded commodity. In 2010, global wood pellet production was estimated to be about 15 million tonnes, out of which approximately 6.6 million tonnes, or 44%, were traded between countries (Lamers et al., 2012; Figure 7).

Pellet industry has grown from small scale production units with capacities below 50 kt and relying on surplus sawmill residues to large scale plants whose individual capacities reach almost 1 Mt. EU production, demand, and imports have increased more than tenfold since 2000. Currently, EU is a net importer of wood pellets despite the high transport costs.

Finally, world charcoal production has grown from 36.7 Mt in 2000 to around 47 Mt in 2009. Wood charcoal for heating and cooking, but also finds application in the chemical and in the iron and steel industry. International trade has been dominated by Germany (10%), Japan (9%), and South Korea (8%) in terms of imports.