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Coordination of biomass resource availability import strategies and demand

DIA-CORE
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Abbreviations

a	annum (year)
ARA	Antwerp, Rotterdam and Amsterdam region
bbl	Oil barrel (159 L)
BIT-UU	Biomass Intermodal Transportation model - Utrecht University
BU	Bottom-Up
CCL	Climate Change Levy
CH_4	Methane
CHP	Combined Heat and Power
CIF	Cost, Insurance and Freight
CO_2	Carbon dioxide
DC	Dia-Core extra-EU supply scenario of solid biomass
DECC	Department of Energy & Climate Change (UK)
dLUC	direct land use change
EC	European Commission
EJ	Exa joule (1 x $10^{\wedge 18}$ joule)
EPR	EmployRES-II extra-EU supply scenario of solid biomass
EU	European Union (EU28)
FAME	Fatty Acid Methyl Ester
FOB	Free on Board
GHG	Greenhouse gas
GIS	Geographic Information System
GJ	Giga joule (1 x $10^{\wedge 9}$ joule)
iLUC	indirect land use change
kt	kilotonne (1 x $10^{\wedge 6}$ kg)
LHV	Lower Heating Value
MJ	Mega joule (1 x $10^{\wedge 6}$ joule)
Mt	Million tonne (1 x $10^{\wedge 9}$ kg)
Mtoe	million tonne of oil equivalent (41.868 PJ)
N_2O	Nitrous oxide
NG	Natural Gas
NGO	Non-governmental organization
NREAP	National Renewable Action Plans
NUTS2	Nomenclature of Territorial Units for Statistics
PJ	Peta joule (1 x $10^{\wedge 15}$ joule)
PV	Photovoltaics
QUO	Scenario using quota systems
RE	Renewable Energy
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RES-E	renewable electricity
RES-H	renewable heat
RES-T	renewable transport
SNP	Strengthened National Policies
t	metric tonne (1000 kg)
toe	tonne of oil equivalent (41.868 GJ)
UK	United Kingdom
US	United States
wpe	wood pellet equivalent (17.6 MJ/kg)

1 Introduction

1.1 Dia-Core

With Directive 2009/28/EC the European Parliament and Council have laid the grounds for the policy framework for renewable energy sources (RES) until 2020. The aim of this project is to ensure a continuous assessment of the existing policy mechanisms and to establish an active stakeholder dialogue on future policy needs for renewable electricity (RES-E), heating & cooling (RES-H), and transport (RES-T). Future consequences of policy choices will be analysed in detail using the Green-X model, highlighting possible additional policy needs for 2020 target achievement and contributing to upcoming 2030-related discussions.

1.2 Background information

As a result of increasing efforts to reduce fossil energy consumption and mitigate greenhouse gas (GHG) emissions, the use of biomass for energy purposes has grown rapidly. Especially in the European Union (EU), where member states have agreed on legally binding renewable energy targets of 20 % in 2020. These developments have already changed biomass markets from a local source of fuel for heating and cooking to modern uses of biomass including increasing amounts of internationally traded biomass. Modern uses of biomass, including large scale electricity generation, but also small scale applications such as efficient pellet stoves and boilers, will play a key role in meeting the renewable energy targets in 2020. Over 50 % expected to be generated from biomass in 2020 according to the national renewable action plans. However, the supply of biomass and shares of domestic and imported biomass remains uncertain. Furthermore, beyond 2020, when low-value sources of biomass might become exploited, efficient use of biomass as well as intra-EU and extra-EU trade might become increasingly relevant to meet renewable energy targets.

To facilitate and coordinate an efficient and sustainable deployment of biomass for bioenergy to 2020 and to 2030, insight is required in the prospective supply and demand markets, intra- and extra-EU trade of biomass as well as current and future feedstock requirements by different end-users. To this purpose, this study will assess different scenarios of renewable energy deployment in the EU in time steps to 2030 whilst taking into account competition and possible interaction with alternative sources of renewable energy (for example wind or PV).

1.3 Objectives

This task analyses the impact on the global biomass markets on the EU RES supply until 2030. Options for coordination of optimized solid biomass utilization and joint biomass import strategies will be elaborated. The quantitative outcome of this study includes realistic scenarios for solid biomass imports from outside the EU up until 2030 and a set of scenarios on how demand for large-scale co-firing and small-scale combustion of solid biomass may develop up until 2030 as well as deployment pathways of bioenergy using the energy system model Green-X.

2 Method

2.1 Modeling approach

This study presents the result of an up-to-date model based assessment of bioenergy deployment in the EU to meet the renewable energy targets in 2020 and perspectives to 2030 under different scenarios. With scenarios, key uncertainties in biomass supply, competing demand and future policy support are assessed. The results will identify future hotspots of demand and trade of biomass in the EU taking import from current and future export regions outside the EU into account.

To this purpose, this study builds on an established modeling framework developed for the IEE Re-Shaping project to assess scenarios of renewable energy deployment in the EU using the energy system model Green-X[1]. Green-X is a partial equilibrium model of the European energy sector developed by the Energy Economics Group of Vienna University of Technology. It includes an in-depth representation of energy policies and is extended with an international biomass trade module.

The modeling framework used in this study was originally developed for the Re-Shaping project[2] and IEA Bioenergy Task 40[3] as described in detail in Hoefnagels et al. (2014) and summarized in Figure 1. Next to the scenario information, input data and assumptions used in the Green-X model (a), the biomass cost-supply database at member state level is combined with cost and GHG emission data for tradable biomass sources and each possible route and period (b). These origin-to-destination specific cost and GHG emissions are calculated with the geographic explicit Biomass Intermodal Transport tool (BIT-UU) and based on country specific input data such as labor cost, fuel prices (e) and actual network data and locations of biomass supply at NUTS2 level (f). A detailed description of the scenario input developed for this study is described in the next section.

Projections of final energy demand, the conventional (fossil) generation mix and related primary fossil energy demand and CO_2 emissions are exogenously applied to the Green-X model and taken from the PRIMES Reference scenario (2012) (EC, 2013). Green-X includes a rich set of renewable energy technologies for heat, electricity and transport fuels as well as their current and future techno-economic performance. Future cost and performance are addressed endogenously in Green-X based on technology diffusion, following S-shaped curves and technological learning, based on capacity growth. An overview of Green-X inputs and endogenous variables are provided in Table 1.

[1] A detailed description of the Green-X model is available online: www.green-x.at
[2] IEE Re-Shaping: http://www.reshaping-res-policy.eu/
[3] IEA Bioenergy Task 40: http://www.bioenergytrade.org/

Table 1 General assumptions

Based on PRIMES*	Defined for this study
Energy demand by sector	RES policy framework
Primary energy prices	Reference electricity price
Conventional supply portfolio and conversion efficiencies	RES cost (Green-X database, incl. biomass)
CO_2 intensities	RES potential (Green-X database)
Carbon price	Biomass trade specification
	Technology diffusion
	Learning rates

*) PRIMES Reference scenario as of 2012, see EC (2013)

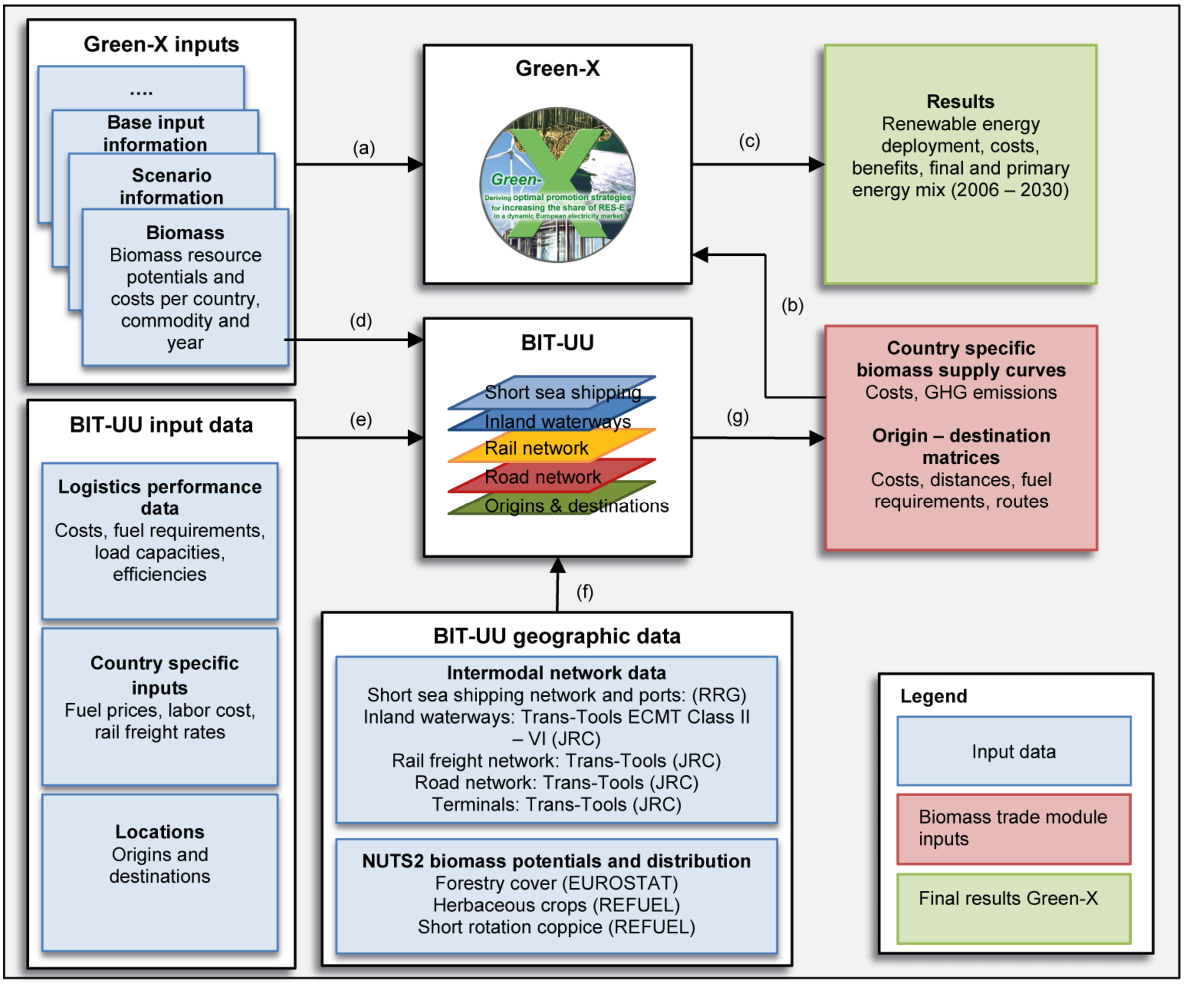


Figure 1 Overview of the modeling approach (Hoefnagels *et al.*, 2014).

2.2 Scenarios

Table 2 summarizes the scenarios and main variables used in this report. The underlying assumptions are discussed in the following sections.

Table 2 Overview of scenarios

Scenario	Extra-EU solid biomass supply	RES Policy framework	RES targets
Baseline (DC)	Dia-Core	Continuation of current support, phased out beyond 2020	None
Baseline (EPR)	EmployRES-II		
SNP-27 (DC)	Dia-Core	Strengthened National policies	2020: 20% (10% transport) 2030: 27% (10% transport)
SNP-27 (EPR)	EmployRES-II		
QUO-27 (DC)	Dia-Core	Harmonized policy concept with EU-wide quotas	2020: 20% (10% transport) 2030: 27% (10% transport)
QUO-27 (EPR)	EmployRES-II		
QUO-27 noBF (DC)	Dia-Core	Harmonized policy concept with EU-wide quotas	Same as above, but phasing out of biofuel support beyond 2020
QUO-27 noBF (EPR)	EmployRES-II		

2.2.1 Extra-EU supply potential of solid biomass

Scenarios of extra-EU supply of solid biomass have been developed for the Re-Shaping project and revised and extended to 2050 for the EmployRES-II study (Duscha *et al.*, 2014). In the EmployRES-II study, two scenarios of extra-EU supply of solid biomass have been developed: a Conservative scenario and an Optimistic scenario. The Conservative scenario assumes a delayed development of energy plantations in South America as well as stagnation of sustainable expansion due to direct land use change in South America. Furthermore, the domestic demand in existing export regions including Canada and the US is assumed to increase beyond 2020 resulting in a decreased potential for export (Duscha *et al.*, 2014). The total potential of extra-EU supply of solid biomass is estimated to increase to between 73 Mt wpe[4] (31 Mtoe) in the Conservative scenario and 137 Mt wpe (58 Mtoe) in the Optimistic scenario in 2030.

Recent trends have shown that the total demand for wood pellets has slowed down. After years of rapid growth of wood pellet export in the US Southeast, from practically zero to 4.1 Mt in 2014, export figures for 2015 show to be similar to 2015 (RISI 2015). As a result of reduced demand in the EU28, Forisk estimates that there might be an overcapacity of wood pellet plants in the US Southeast. This will likely result in a delayed opening of announced capacities and stop to new announcements (Lang, 2015). These recent developments in wood pellet trade indicate that the Conservative scenario of the EmployRES-II study might be still too optimistic, at least for the midterm to 2030. To assess the impact of reduced extra-EU solid biomass supply, a revised scenario is developed and compared to the EmployRES-II Conservative scenario. The EmployRES-II supply scenario will be referred to as **EPR** scenario in this report. The revised scenario will be referred to as Dia-Core scenario (**DC**).

[4] wpe: wood pellet equivalent, 17.6 MJ/kg (LHV)

For the **DC** supply scenario, an up-to-date literature review is conducted combined with market announcements and information from conferences and workshops. For this scenario, we assumed a continuation of developments of current wood pellet supply in key exporting regions and driven by demand, mainly for heating and electricity markets to meet the 2020 targets (Lechner & Carlsson, 2014; Walker, 2014a).

2.2.2 RES policy framework

The RES policy scenarios used in this study include three main scenarios and a sensitivity case. The scenarios are summarized below and explained in more detail in Resch et al. (2014).

Baseline

- The Baseline scenario assumes a continuation of current RES support to 2020. Beyond 2020, RES support will be phased out. A carbon price will remain however (based on the PRIMES Refence scenario).

SNP-27

- The SNP-27 (Strengthened National policies) scenario assumes that the target of at least 27% renewable energy share in gross final energy consumption by 2030 will be met as agreed on by EU leaders in the framework for climate and energy policies at the EU level. The scenario follows a national approach by improving existing national support policies and mitigation of non-economic barriers. Note that efficiency target (27% increases in energy efficiency) and greenhouse gas reduction target (40% reduction compared with 1990) are not taken into account in these scenarios.

QUO-27

- The QUO-27 scenario has the same ambition levels to the SNP-27 scenario, but follows a more harmonized policy concept with EU-wide quotas (QUO) to meet the renewable energy target of 27% by 2030.

QUO-27 noBF

- The QUO-27 noBF is a sensitivity scenario to the QUO-27 scenario. In this scenario, it is assumed support for biofuels used in transport will be provided to meet the 2020 target (10% biofuels), but will be phased out beyond 2020.

2.2.3 Sustainability criteria

The RED sets specific sustainability criteria for biofuel and bioliquids with respect to the GHG saving performance and land use, but these binding criteria do not apply to solid and gaseous biomass. The Green-X modeling framework has the option assess possible minimum GHG savings for solid biomass. However, the criteria set for liquid biofuels in the RED can in most cases easily be met by solid biomass. These minimum GHG saving requirements are 35% today and increasing to 50% in 2017 and 60% for new installations in 2018. In general, GHG savings for heaty and electricity are well above 60% and could exceed 70% if efficient conversion systems are used such as CHP plants or co-firing in modern coal fired power plants (Sikkema *et al.*, 2010; Giuntoli *et al.*, 2015). The impact of possible on the extra-EU supply potential of temporal imbalances in carbon and the resulting carbon debt as well as required sustainable forest management (SFM) principles are difficult to quantify (Galik & Abt, 2015). The assessment of more strict GHG criteria (over 60% saving requirement) and other sustainability criteria is outside the scope of this study.

3 Bioenergy: state of play and market expectations

3.1 Bioenergy

Total gross inland consumption[5] of renewables almost doubled from 97 Mtoe in 2000 to 187 Mtoe in 2012 and increased with 5% to 197 Mtoe in 2013 (EUROSTAT, 2015a). Biomass remains the dominant source of renewable energy; almost 2/3rd of renewable energy consumption was from biomass in 2013 with 46% supplied from wood and others solid biomass, 7% from liquid biofuels and 7% from biogas. Furthermore, half of biogas production in the EU28 in 2013 was produced and consumed in Germany. Wood and other solid biomass was mainly consumed in forestry rich countries. However, also in countries that import solid biomass for electricity generation (Belgium, Denmark, Netherlands, UK), solid biomass adds substantially to gross inland consumption of renewable energy. Almost 9% of gross inland consumption of wood and other solid biofuels was derived from wood pellets in 2013.

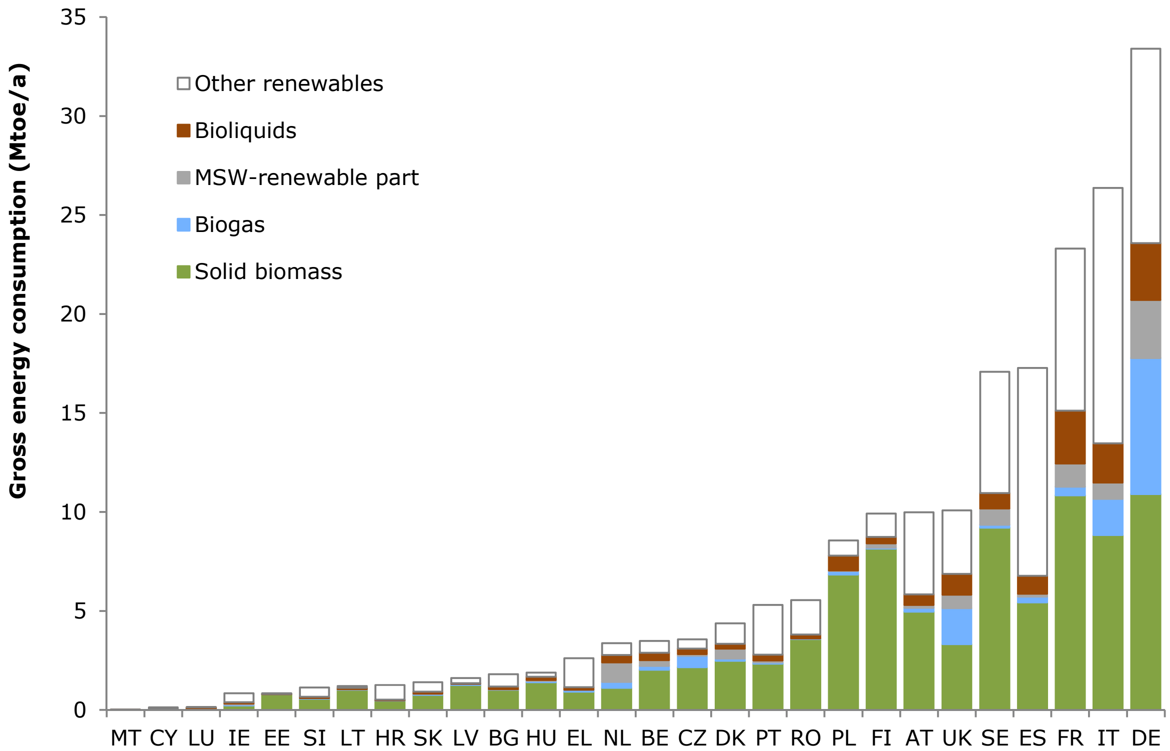


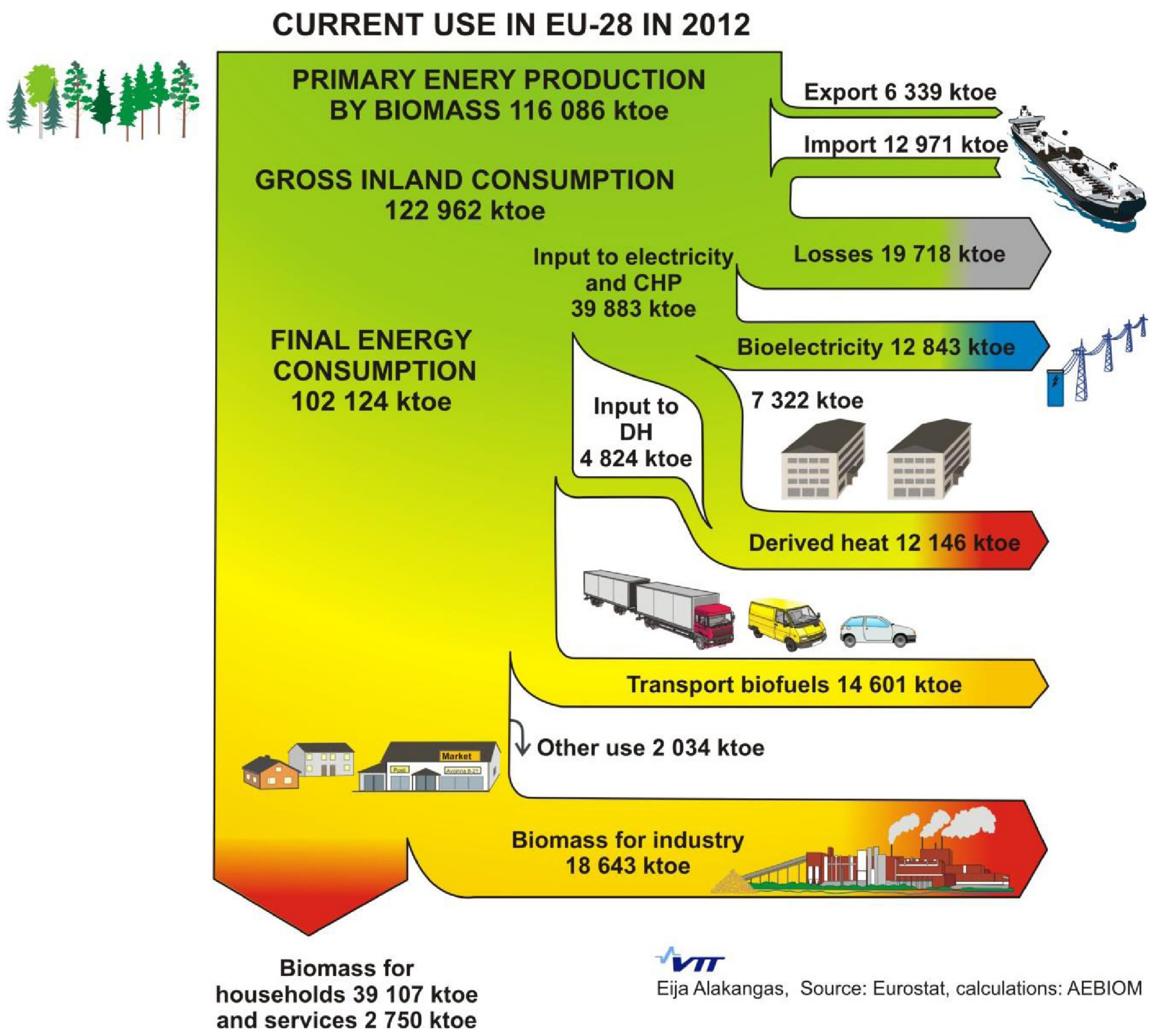
Figure 2 Gross energy consumption of renewable energy in European Member States in 2013 (EUROSTAT, 2015a)**, adapted from Pelkmans** (2015)

Figure 3 shows the energy balance of bioenergy in the EU28 in 2013. The net imports of bioenergy were 6.6 Mtoe in 2012 including liquid biofuels, but also solid biomass (mainly wood pellets). Analysis of trade flows of liquid and solid biomass for energy purposes

[5] Primary production + net imports

have proven to be difficult because energy and non-energy uses of feedstock are not reported. For example, vegetable oils are used for biodiesel production, but also for food markets and materials such as cosmetics (Lamers *et al.*, 2011, 2012). Wood pellets are almost solely used for bioenergy purposes and are therefore relatively easy to trace (Lamers *et al.*, 2012). A detailed description of wood pellet consumption and trade is provided in Section 3.2.

In 2012, the final energy consumption from biomass was 102.1 Mtoe of which the largest amount (73%) was used as heat in the residential sector, service sector and industry. Electricity (13%) and biofuels for transport (14%) make up the remaining uses of bioenergy. The main driver for increasing demand of bioenergy is the EU Renewable Energy Directive (EC, 2009) and included binding targets of renewable energy to increase the total share of renewable energy in gross final energy consumption to 20% in 2020 and at least 10% in the transport sector. According to the National Renewable Action plans (NREAPs), EU Member States expect that the total final supply of bioenergy will increase with 35% compared to 2012 to 138 Mtoe in 2020 (AEBIOM, 2014). Heat is projected to increase with 20%, electricity with 98% and transport fuels with 35% (AEBIOM, 2014). However, given the draft law to cap biofuel production from crops grown on agricultural land to 7%, as voted for by the European Parliament (EP, 2015), might reduce the total final consumption of liquid biofuels in 2020 compared to the NREAPs. Note that these recent changes have not been incorporated in the scenario projections included in this report (Section 5).



Note: Exports and Imports include also intra-EU trade.
Source: Eurostat and AEBIOM calculations. Graph done by Eija Alakangas, VTT

Figure 3 Bioenergy balance in 2012 (AEBIOM, 2014)

3.2 Wood pellets

3.2.1 Total consumption and international trade

Since 2005, wood pellet trade has started to grow rapidly driven by renewable energy support and increased demand in medium and large scale power generation in EU member states. In 2013, actual production in the EU28 increased to 12.1 Mt/a, whereas global production increased to 21.7 Mt (Figure 5). Figure 4 shows the development of global wood pellet consumption and trade between 2008 and 2014.

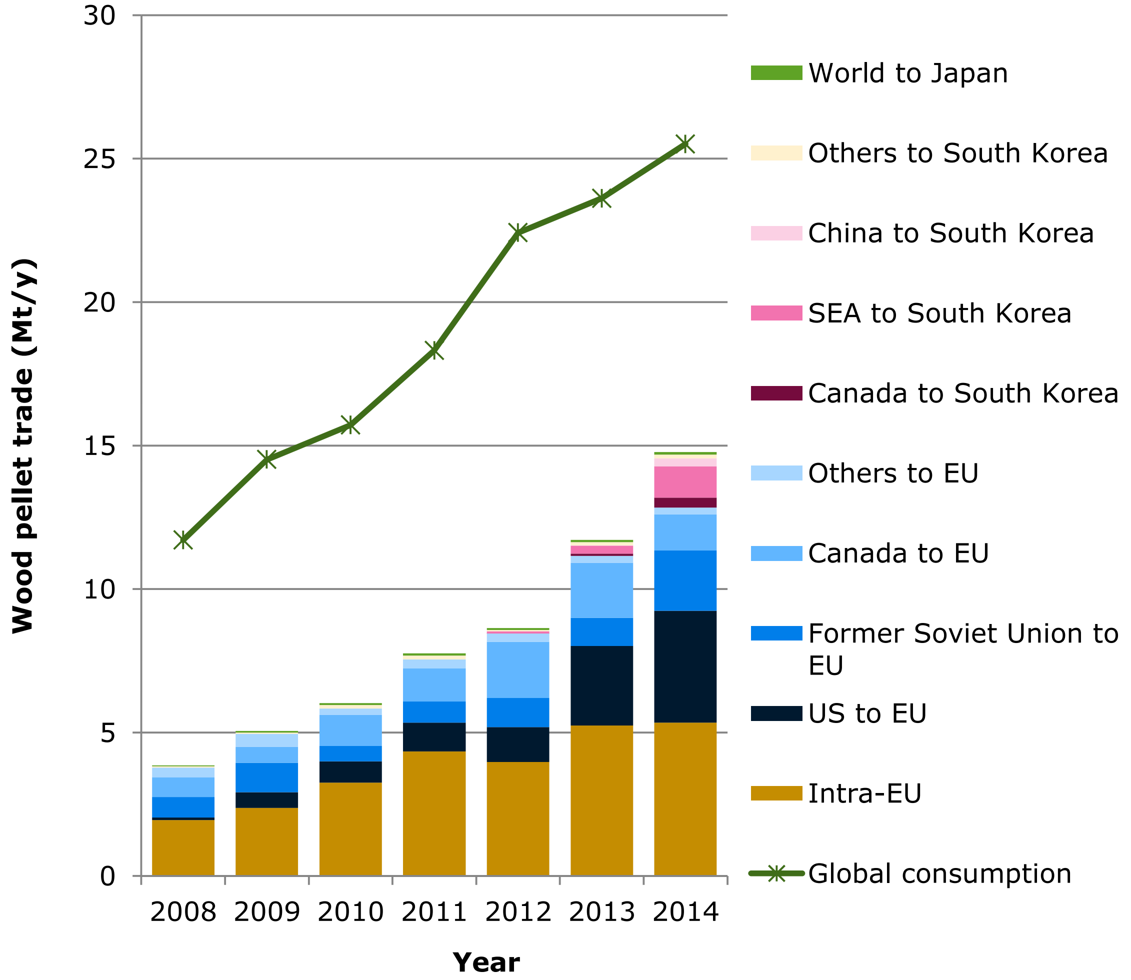


Figure 4 Global wood pellet trade and consumption 2008 – 2014 (Lamers *et al.*, 2012; EUROSTAT, 2015b; Goetzl, 2015; Junginger *et al.*, 2015)

Gross inland consumption of wood pellets in the EU28 has grown exponentially in the last decade to about 19 Mt in 2013 (8.0 Mtoe), which is about 80% of global wood pellet consumption (Figure 4). There are two distinct end use markets for wood pellets: residential pellets and industrial pellets. Residential pellets often need to meet higher quality specifications compared to industrial pellets, mainly regarding ash levels, ash melting point and moisture content (Lamers *et al.*, 2014a). In the past, the EU has been rather self-sufficient to meet wood pellet demand for the residential sector, but in recent years, industrial and residential pellet trade markets have started to converge. As an example, Italy has become the second largest importing countries of wood pellets used solely for heating purposes (Figure 6). To meet the demand for residential markets, some Italian ports are now equipped with bagging facilities (Napoli, Livorno, Savona, Ravenna) (Rebiere, 2014).

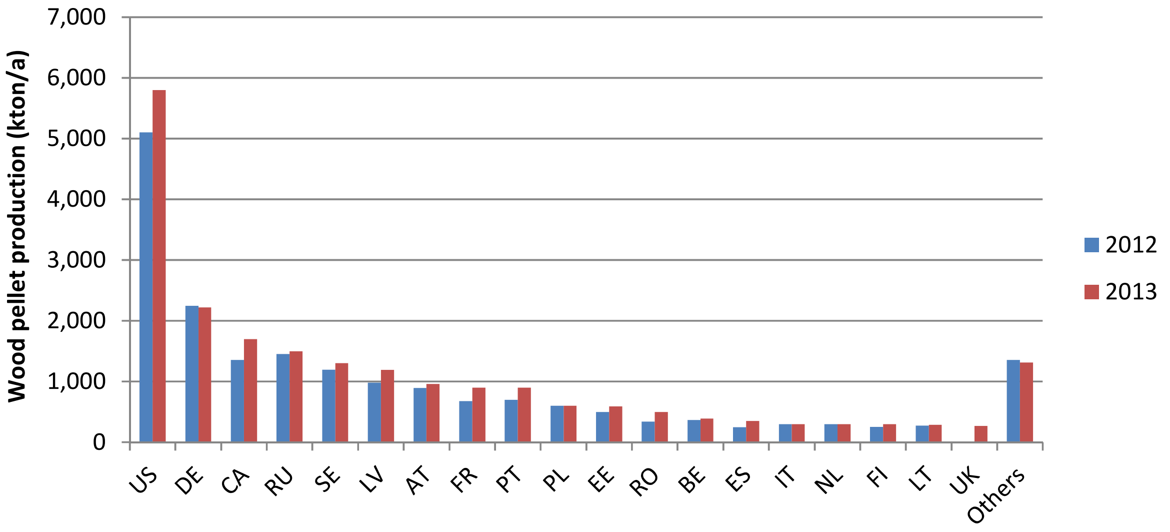
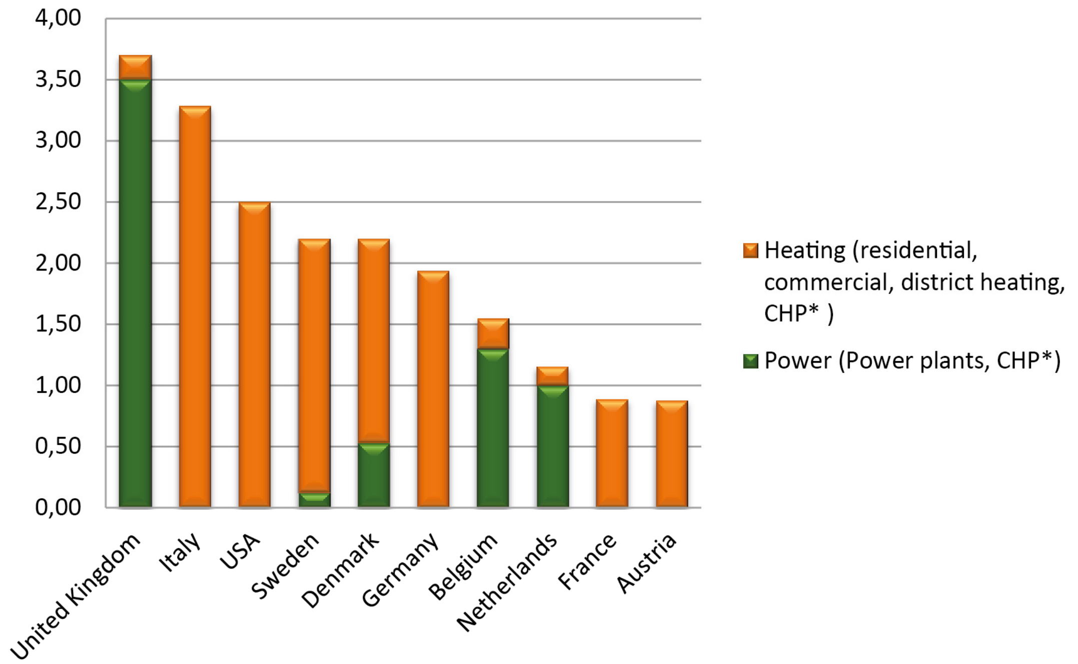


Figure 5 Global wood pellet production (AEBIOM, 2014)



Source: Hawkins Wright, EPC Survey

*2/3 of the global CHP Pellet consumption is attributed to heating. 1/3 of the global CHP Pellet consumption is attributed to power.

Figure 6 Pellet demand for heating and power plants in 2013 (AEBIOM, 2014)

3.2.2 Power (power plants, CHP)

Co-firing and dedicated power generation in converted coal power plants is mainly concentrated in Northwest Europe, including Belgium, Denmark, the Netherlands and the UK (Figure 6) and it is expected that industrial pellet markets will develop further in these countries given their current reliance on coal and support for bioenergy (quota, Feed-in Tariff and CO_2 tax). Figure 7 provides an overview of coal fired power plants that have or consider co-firing of biomass and have or consider full conversion from coal to biomass in Northwest Europe. In general, these countries lack large domestic biomass resources and are therefore likely continue to be dependent on imported solid biomass.

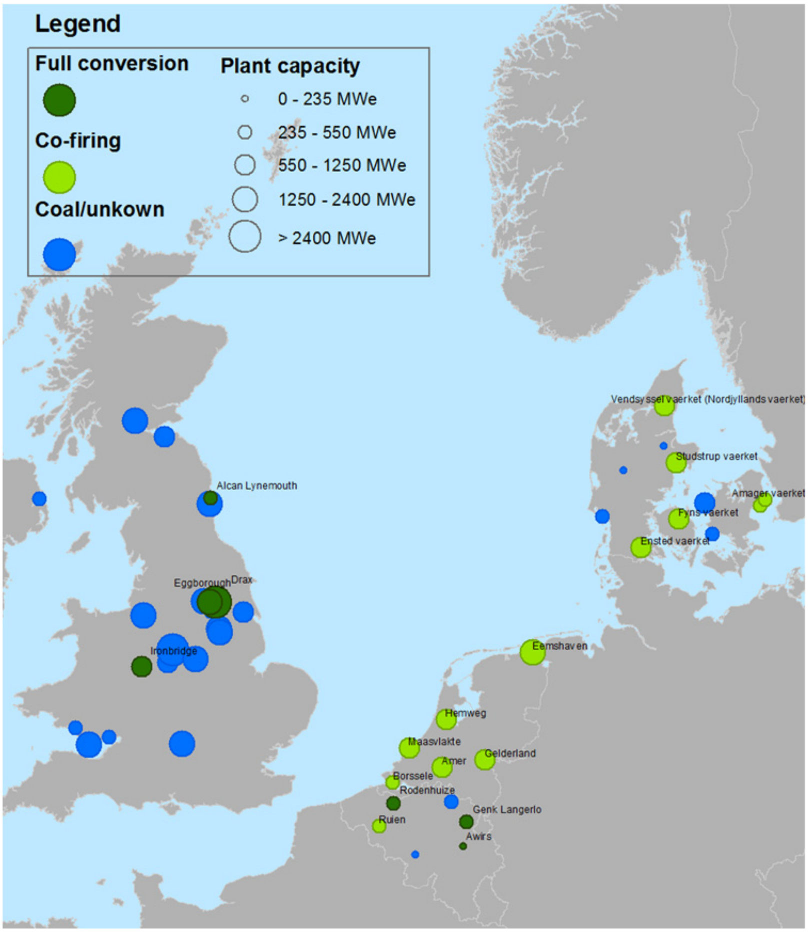


Figure 7 Power plants with co-firing and fully converted power plants. Plant locations (Davis, 2012)

UK

With an overall RES share of 4.2% in final energy consumption 2012, total RES generation has to more than triple in 2020 to meet the target set for the UK (15% in 2020). Stand-alone electricity generation from biomass is one of the key sources of renewable energy generation, 10.8% of electricity generation is from renewable sources of which 46% is generated from solid biomass in dedicated electricity plants. CHP is hardly used in the UK (Pelkmans *et al.*, 2014a). Despite the closure of RWE Tilbury (750 MWe), which was fully converted to biomass, wood pellet demand has continued to increase in the UK mainly due to the demand for Drax Power. Drax Power has already converted two out of its six units (6x660 MWe) to biomass and will convert its third unit in 2016/2017. With each of these units burning 2.3 to 2.5 Mt wood pellets per year, total annual wood pellet demand is expected to be about 7.5 Mt. Conversion of the fourth unit is also under consideration, but highly uncertain. Other plans that are under consideration include Eggborough (2 GWe, 6 Mt pellet demand) and RWE Lynemouth (420 MWe, 1.5 Mt pellet demand). The total estimated demand for solid biomass in these power stations will be around 15 Mt in 2020 depending if these projects will come online.

Plans to convert the Rugeley power station (GDF Suez) have are already been cancelled (Argus Media, 2013). Furthermore, the Lynemouth conversion project, and its support under the Contract for Difference (CfD), has been subject to investigation if the proposed payments are in line with State Aid rules set by the European Commission (Voegele, 2015). The recently announced ending of the Climate Change Levy (CCL) exemption for renewable energy (HM R&C, 2015), a tax to energy use of businesses, might also negatively affect the economic feasibility of bioenergy projects in the UK.

The Netherlands

In the Energy Agreement for Sustainable Growth in the Netherlands (SER)[6] sets out the actions needed to meet the Dutch national target of the RED of 14% renewable energy by 2020 and a new target of 16% renewable energy by 2023. The agreement is based on a consensus between different stakeholders including amongst others energy companies, NGOs and trade unions. Given that the Netherlands is still far off from its target (RES share in 2013 was 4.5%), a set of measures is required including substantial growth of onshore and offshore wind as well as energy savings. For bioenergy, it was agreed on that co-firing in coal fired power plants will be capped at 25 PJ final energy, or about 3.5 Mt wood pellets. Furthermore, all coal power plants that were built before 1990 will need to be decommissioned. The total electricity generation capacity that will be decommissioned is 2.7 GW. These include (ACM, 2013):

1. RWE/Essent: Amer 8 (645MW), to be closed down on 1-1-2016;
2. Delta: Borssele (406 MW), to be closed down on 1-1-2016;
3. E.on: Maasvlakte I & II (2 x 520 MW), to be closed down on 1-7-2017;
4. GdF SUEZ: Gelderland-13 (602 MW), to be closed down on 1-1-2016.

Given the constraint supply of 25 PJ final energy from co-firing and the remaining coal fired capacity (4.7 GW), the average share of biomass co-firing will be 20%. It is expected that utilities in the Netherlands will ramp up biomass use by 2017-2018.

[6] http://www.government.nl/issues/energy-policy/energy-agreement-for-sustainable-growth

In the Netherlands, NGOs and industries recently (March 2015) agreed on sustainability criteria for solid biomass used for electricity generation including measures to mitigate risks of high carbon debts, no conversion of (semi-natural) forests after 2008, avoid competition with material markets and GHG saving requirements (70% reduction against the EU fossil reference). One of the main goals is to achieve 100% FSC or equivalent certified wood consumption for electricity generation by 2023. A fund will be created to support the certification process (Rijksoverheid, 2015).

Belgium

With a current RES share of 6.8%, a doubling of renewable energy generation is needed to meet the RES target set for Belgium (13% in 2020). Biomass makes up over 85% of renewable energy generation today with around 73% of renewable electricity generated from biomass (Pelkmans *et al.*, 2014b). Renewable electricity generation in Belgium is mainly promoted via a quota system of Green Certificates. There are however different systems and standards in place in Flanders, Wallonia and Brussels-Capital region. In the Flemish region, certificates are granted depending on the avoided fossil energy whereas in Wallonia, the CO_2 avoidance performance is used as an indicator to allocate Green Certificates.

The current demand for solid biomass mainly comes from Electrabel's Rodenhuize power station (roughly 1 Mt/a). However there are several new plans for conversion of existing plants and greenfield projects from Electrabel in Ghent and Liege, E.on in Antwerp and Genk, Bee Power in Ghent. The total consumption is estimated to increase to 3.0 Mt/a by 2020 (Piddington, 2015).

Denmark

The share of renewable energy in Denmark gas grown rapidly in the last decade increasing from 14.5% in 2004 to 26% in 2012 and therefore already close to the target of 30% in 2020 (AEBIOM, 2014). Denmark has set the ambition to replace all fossil energy by renewable energy by 2050. Furthermore, Denmark aims to cease coal fired generation in Copenhagen in 2025 and the rest of Denmark in 2030. The future demand of wood pellets in Denmark in 2020 is expected to be similar to the Netherlands (3.5 Mt/a). The main consumers are expected to be Dong and Vattenfall (Walker, 2014b; Piddington, 2015).

3.2.3 Heat

Both wood pellet stoves, that are used most often in combination with a central heating system and wood pellet boilers, that can provide all heating services and therefore substitute central heating are being deployed. The latter is interesting as it can be used in regions that lack a natural gas network and replace expensive heating fuels such as heating oil and LPG (Thomson & Liddell, 2015).

Between 2008 and 2015, heating pellet demand doubled in the EU28 with 6 member states making up almost 90% of the market in 2014. These include Italy (2.7 Mt), Germany (2.0 Mt), Sweden (1.5 Mt, Austria (0.95 Mt), France (0.87 Mt), Denmark (0.62 Mt). Other EU member states consumed 1.2 Mt in 2014 (Walker, 2014b). Although pellet heating is supported in some EU member states, for example via investment subsidies for pellet boilers and VAT tax reductions on wood pellets, pellet heating is considered a self-sustaining commercial activity driven by high prices of alternative fuels (Hawkins Wright, 2014). Figure 8 shows a projection of the heating market development in the EU28 according to Hawkins Wright. The biggest markets for pellet heating are expected to remain in Italy and Germany, but also substantial growth in France is expected. Pellet heating in the EU28 is projected to increase from 9.8 Mt in 2014 to 17 Mt in 2024 (Figure 9).

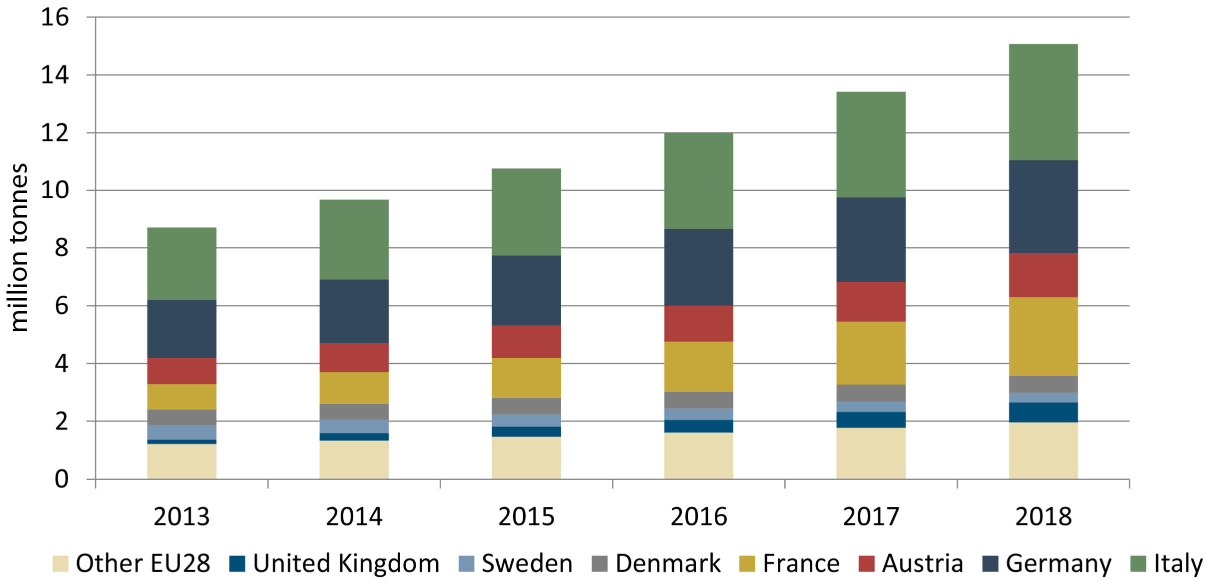


Figure 8 Current and projected pellet demand for heating in the EU28 (2013 – 2018) (Hawkins Wright, 2014)

3.2.4 Projected overall wood pellet demand

Based on development in industrial and residential pellet markets in Europe, North America and Asia, RISI projects that global wood pellet demand will increase from 23 Mt/a in 2014 to 50 Mt/a in 2024 as depicted in Figure 9 (Walker, 2014b). The demand in Europe is expected to increase from 18 Mt (10 Mt heat, 8 Mt industrial) to 37 Mt in 2024 (17 Mt heat, 20 Mt industrial). In relative terms, the EU share of wood pellet demand is expected to decrease from 80% in 2014 to 75% in 2024, mainly due to growth of industrial wood pellet demand in Asia (Japan and Korea). If we extrapolate the trend to 2030 assuming linear growth between 2020 and 2030, total global wood pellet demand will grow to 59 Mt in 2030 of which 42 Mt will be consumed in Europe.

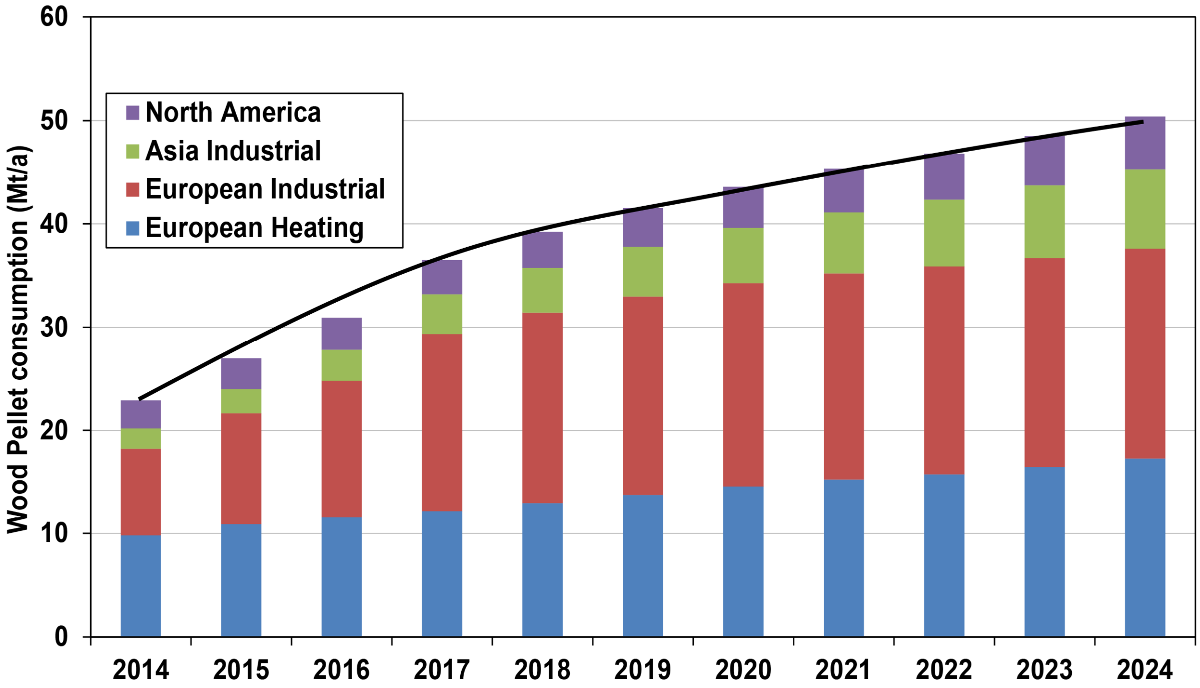


Figure 9 Projected total global wood pellet demand to 2024 by RISI (Walker, 2014b)

3.2.5 Wood pellet prices

With wood pellets supplied to industrial and residential sectors, there is a substantial price difference between these markets. This can be partly explained by the logistic cost difference and complexity of the supply chains (Sikkema *et al.*, 2010) and the required quality of wood pellets with respect to ash levels and moisture content (Lamers *et al.*, 2014a). Figure 10 depicts CIF ARA spot prices of industrial wood pellets both in US-dollars and euros. The US is the largest supplier of industrial wood pellets in the EU28. Furthermore, fossil fuel prices and bulk freight rates are paid in US-dollars. The US dollar to euro exchange rate variations therefore has a large impact on CIF-ARA market prices of industrial pellets (Ehrig *et al.*, 2015). Despite the recent decline in spot prices of industrial pellets in US$, CIF ARA prices of industrial wood pellets have increased as a result of the weakening euro against the US dollar. Between 2009 and May 2015, CIF-ARA prices of wood pellets were on average 129 €/t compared to 66 €/t for coal. In May 2015, pellet prices were on average 150 €/t compared to 52 €/t. The combination of the weak euro, low CO_2 price and low coal price results in high cost of co-firing biomass.

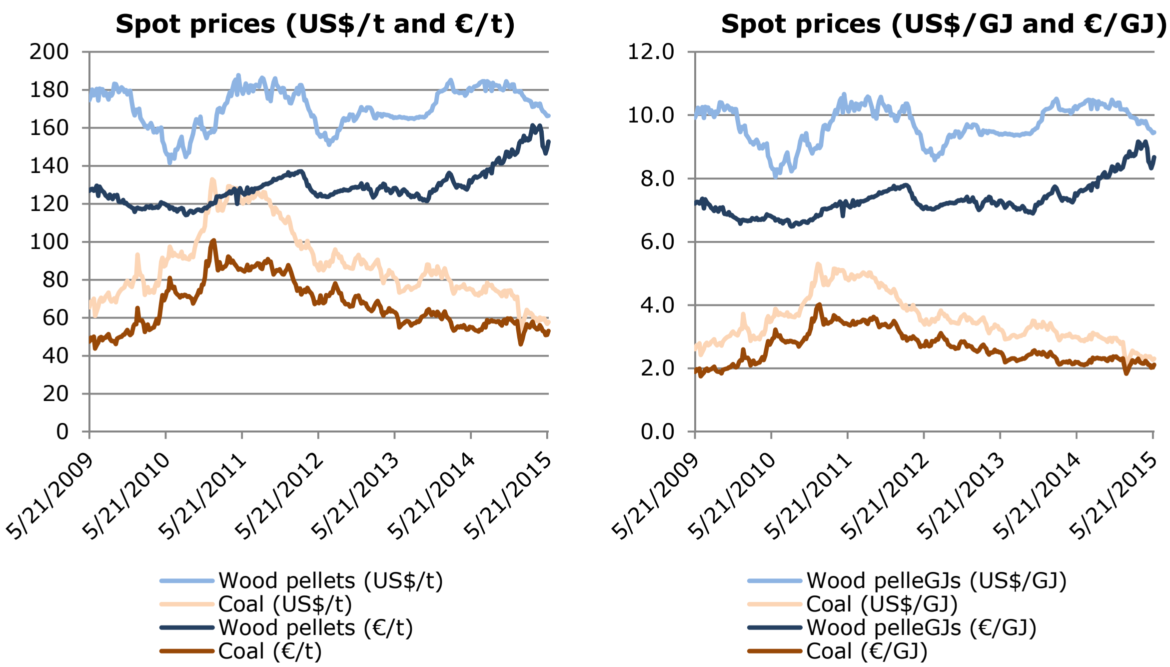


Figure 10 CIF ARA spot prices of coal (API 2, net calorific value 25.1 MJ/kg) and wood pellets (net calorific value 17.6 MJ/kg) (Argus, 2015)**. EURO/US dollar exchange rate: XE** (2105)**.**

Figure 11 shows the variation in wood pellet prices for heating markets. Prices vary substantially between countries, but the seasonal variation amongst these countries has been more consistent. One of the reasons for the price difference between countries is the variation in VAT rates and possible VAT reduction for wood pellets in some countries. VAT rates for wood pellets in Europe ranges between 5% in the UK (20% general VAT) and 27% in Hungary (general rate) (AEBIOM, 2014). Nonetheless, wood pellet prices in Italy have been one of the highest in Europe despite the reduced VAT rate (10%). A possible explanation is that Italy is heavily dependent on imports of wood pellets (Rebiere, 2014).

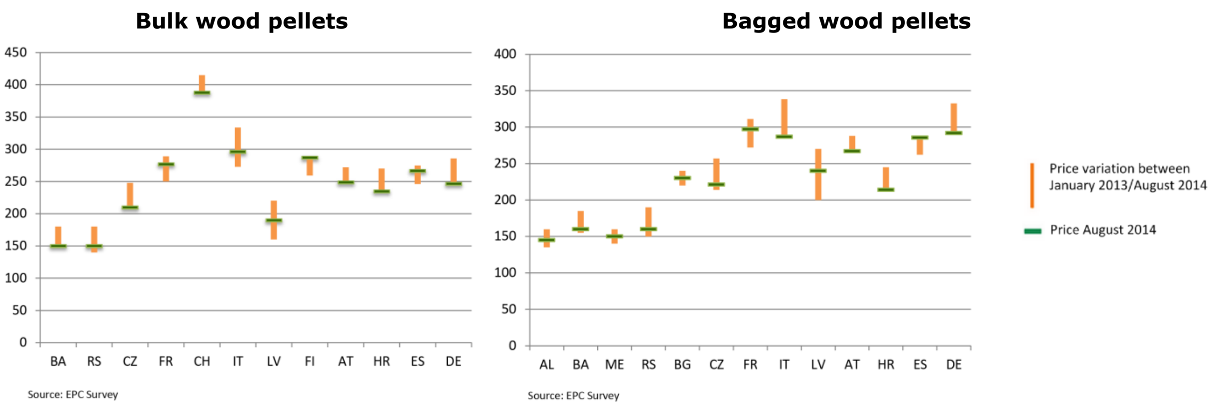


Figure 11 Variation in bulk (6t delivered, 100 km) and bagged (retailer price, 1 pallet) wood pellet prices in €/t pellets including VAT in Europe between January 2013 and August 2014 (AEBIOM, 2014)**. Note that the charts have different scales.**

4 Scenarios for solid biomass imports from outside the EU up until 2030

This section covers scenarios for solid biomass imports[7] from outside the EU28 up until 2030. These scenarios include a revised scenario, the **DC** scenario, are based on available literature, monitoring of ongoing market developments, policy developments in (potential) export regions and expert interviews. The **DC** scenario is compared to the existing EmployRES-II supply scenario (**EPR**).

4.1 Biomass supply per region

4.1.1 Selection of key supply regions

The selected global supply and demand regions are depicted in Figure 12. The regions in this study include existing and future potential large sourcing areas of surplus biomass for bioenergy purposes outside the EU28 to 2030. For illustration, also major competing import regions are shown that could affect the export supply potential available for the EU28.

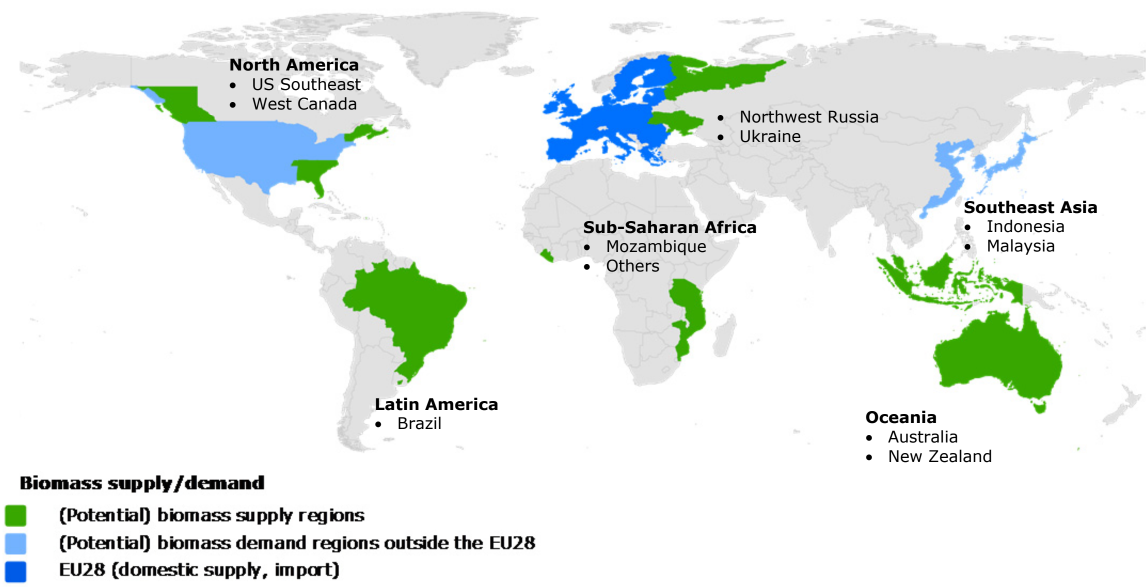


Figure 12 Selection of supply regions of export to the EU28 and competing import regions.

4.1.2 US Southeast

Short-term potential to 2020

[7] All solid biomass that is imported from extra-EU resources, is assumed to be processed first into pellets, the main traded commodity of solid biomass.

According to the Wood Pellet Plants map of the Southern Environmental Law Center (SELC) (Sackett, 2015), 25 plants are currently in operation (5.4 Mt/a) and 27 plants are planned, proposed (10.2 Mt/a) or on hold (840 kt/a). Near term (to 2020) potential wood pellet supply in the US Southeast in this study is largely based on this current and planned pellet production capacity. A success rate of 50% for these planned and proposed projects as assumed by Lamers et al. (2014b) has proven to be too conservative. Therefore, planned capacities are assumed to come online before 2020 with a success rate of 75%. New capacity is assumed to be delayed by one year, as a result of overcapacity (Lang, 2015).

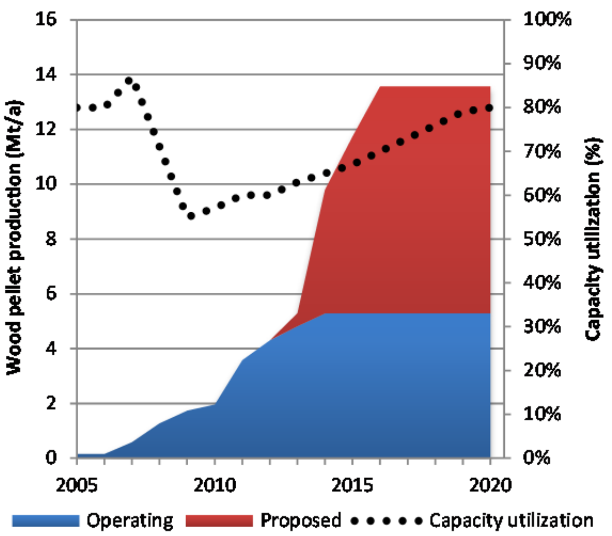


Figure 13 Wood pellet production capacity (Sackett, 2015) and capacity utilization based on Walker (2014)

The average capacity utilization of pellet production facilities in the US has dropped significantly to under 60% in 2009 (Cocchi *et al.*, 2011; Walker, 2014a). According to RISI (Walker, 2014a), capacity utilization of wood pellets for residential markets is expected to increase again to 80% by 2018. We assume a similar development for pellet plants that produce industrial pellets.

In contrast to pellet production in the Northeast and Western US, the US Southeast mainly produces wood pellets for export markets with a relatively small share produced for domestic heat markets. The near term trend in production for domestic markets is based on RISI (Walker, 2014a) and extrapolated to 2030 assuming a linear growth with 45 kt/a to 1.0 Mt in 2020 and 1.4 Mt in 2030.

Beyond 2020 and comparison with other studies

The midterm (2030) export potential of wood pellets from the US Southeast in this study is based on Fritsche et al. (2014) and Abt et al. (2014).

Figure 14 shows the resulting estimated export potential of wood pellets (black dotted line) in comparison to estimated potentials and ranges by other recent studies for the US Southeast. In 2020, many studies have used similar assumptions and therefore determined almost similar wood pellet export potentials. These include (Goh *et al.*, 2013; Duscha *et al.*, 2014; Fritsche & Iriarte, 2014; Lamers *et al.*, 2014b). The export potential as presented in Figure 14 for Abt et al. (2014)[8] is a demand driven potential based on expected wood pellet demand in the EU28. Potentially, Abt et al. have overestimated the demand for wood pellet from the US Southeast as they did not take into account other exporting regions, for example Western Canada. Nevertheless, the projection is in line with the demand driven projection from Pöyry (20 Mt wood pellets in 2025) and estimated potential of the EmployRES-II study (27.6 Mt wood pellets in 2030) (Duscha *et al.*, 2014). For the short-term to 2020, the revised export potential in the DC scenario is consistent with RISI[9].

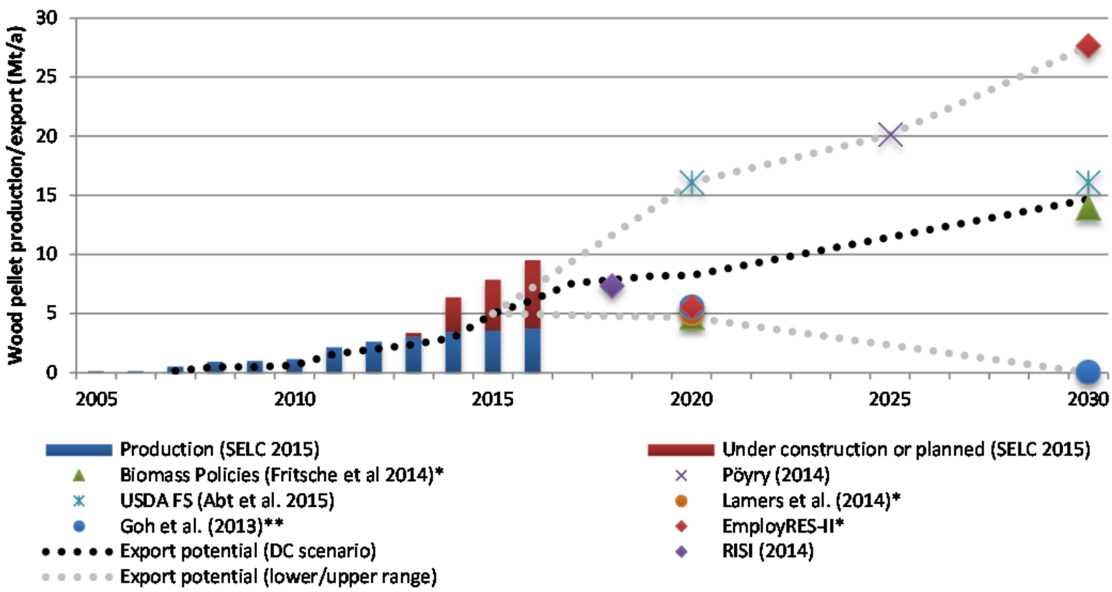


Figure 14 Wood pellet production and (*) export potential in the US Southeast

4.1.3 Canada

As shown in Figure 4 and Figure 5, Canada is the third largest producer of wood pellets and second largest supplier of wood pellets to the EU. Most of the supply is currently exported from Western Canada (British Columbia), but also Eastern Canada could become an exporting region of wood pellets. Given the shorter distance between Eastern Canada and the EU, Eastern Canada could have a competitive advantage over Western Canada due to reduced shipping costs. There are currently 19 wood pellet plants in operation in Eastern Canada with a total capacity of 1 Mt/a producing 270 kt/a wood pellets of which 120 kt is exported to the EU28 (Bradley *et al.*, 2014). The recent growth in timber industries might improve the availability of sawdust for wood pellet production,

[8] The wood pellet supply is not presented, but derived from the projected demand for bioenergy (20 Mt odt in 2020 and 2030), the amount of wood used for non-pellets bioenergy (5 Mt odt) and a net calorific value of 19.58 MJ/kg odt.
[9] RISI (Walker, 2014a) shows the total growth of wood pellet industry in the US. We assumed that all industrial pellets are exported and produced in the US Southeast (7.3 Mt in 2018).

one of the main issues the Eastern Canadian pellet industry is facing today. Furthermore, supply chains are improving. According to Fritsche et al. (2014), the sustainable potential of wood pellet export from Eastern Canada could increase to 38 Mt wpe in 2020 and 28 Mt wpe in 2030. In this study, Eastern Canada is not included which might imply an underestimation of the Canadian wood pellet export potential. Supply growth from Western Canada in the DC scenario is based on Pöyry. According to Pöyry (Lechner & Carlsson, 2014), wood pellet production will increase moderately from 1.9 Mt/a today to 3.8 Mt in 2025. To 2025, Pöyry does not expect major exports from Eastern Canada.

4.1.4 South America (Brazil)

There are 12 wood pellet production facilities in Brazil with the majority located in the South of Brazil and a total capacity of 60 kt/a (Coelho & Escobar, 2013). At these scales, varying from 3 kt/a to 37.5 kt/a, wood pellet production is mostly oriented towards domestic, residential markets. Nevertheless, Brazil has a large potential for solid biomass export if substantial investments would be made and could become a large exporting region of solid biomass. So far however, developments in dedicated energy crops or forestry plantations for bioenergy purposes are lacking (Lamers *et al.*, 2014b). In this study, we used the projected sustainable export potential of the Biomass Policies project (Fritsche & Iriarte, 2014), but assumed an additional delay of 5 years given the lack of ongoing activities and the time required before actual harvesting. Despite the assumed delay in the DC scenario, Brazil still adds over 25% to the total extra-EU potential of solid biomass in 2030 (Figure 15).

4.1.5 Sub-Saharan Africa

To determine the export potential of Sub-Saharan Africa, results of the Biomass Policies project were used. Fritsche et al. (2014) determined the sustainable export potential for Mozambique as being one of the future potential exporting regions in Sub-Saharan Africa. The lack of actual investments in biomass supply as well as infrastructure to mobilize and export biomass, also for this region we assumed a delay of 5 years compared to the Biomass Policies study (Fritsche & Iriarte, 2014). In total the export potential of solid biomass was estimated to be 3.8 Mt in 2025/a increasing to 5.7 Mt/a in 2030.

4.1.6 Northwest Russia

Russia has over 20% of global forest cover, IRENA estimated that almost 76 Mtoe of forest resources could become available from Russia (Nakada *et al.*, 2014). Therefore, there is a large potential of underutilized forest resources that could potentially be mobilized. However, as a result of lacking investments in infrastructure and equipment, the productivity is also very low. To increase the export potential, large investments are needed to upgrade facilities. Furthermore, the 6-month winter makes it difficult to mobilize resources and non-economic barriers need to be mitigated including bureaucracy, business culture and language barriers (Proskurina *et al.*, 2015). According to Pöyry, the wood pellet industry will not grow substantially in Northwest Russia with total pellet supply increasing moderately from 1.4 Mt in 2014 to 1.9 Mt in 2025. We used similar estimates in the DC scenario and assumed no further growth beyond 2025.

4.1.7 Other export regions

The supply of solid biomass from agriculture residues, including palm kernel shells from Southeast Asia, straw pellets (agripellets) from Ukraine and wood pellets from Australia and New Zealand in 2020 are based on Lamers et al. (2014b). We used similar estimates in the DC scenario and assumed that these potentials will remain constant between 2020 and 2030. Note that we did not take into account Scenarios for solid biomass imports from outside the EU

4.2 Scenarios for solid biomass imports from outside the EU

Figure 15 shows the scenario of extra-EU solid biomass (**DC**) developed for this study compared to the EmployRES-II Conservative scenario (**EPR**). The total supply of wood pellets in the EPR scenario in 2030 is almost similar to the sustainable export potential determined in the Biomass Policies project (Fritsche & Iriarte, 2014). The export potential determined in this study for 2025 is more consistent with the demand driven projection of Pöyry for 2025 (32 Mt) (Lechner & Carlsson, 2014). Note that domestic wood pellet production in the EU28 as well as competing demand from Japan and South Korea are not included in Figure 15, thus these scenarios cannot be compared with the global wood pellet market developments. The US Southeast is assumed to remain the largest region of international wood pellet export, with sustaining growth towards 2030. A more conservative growth trend is assumed for Canada and Northwest Russia whereas wood pellets from dedicated energy crops or forestry plantations in Sub-Saharan Africa and Latin America are assumed to become significant from 2025 onwards. Similar developments could also occur elsewhere, for example in Ukraine of which the export potential is conservative in this study.

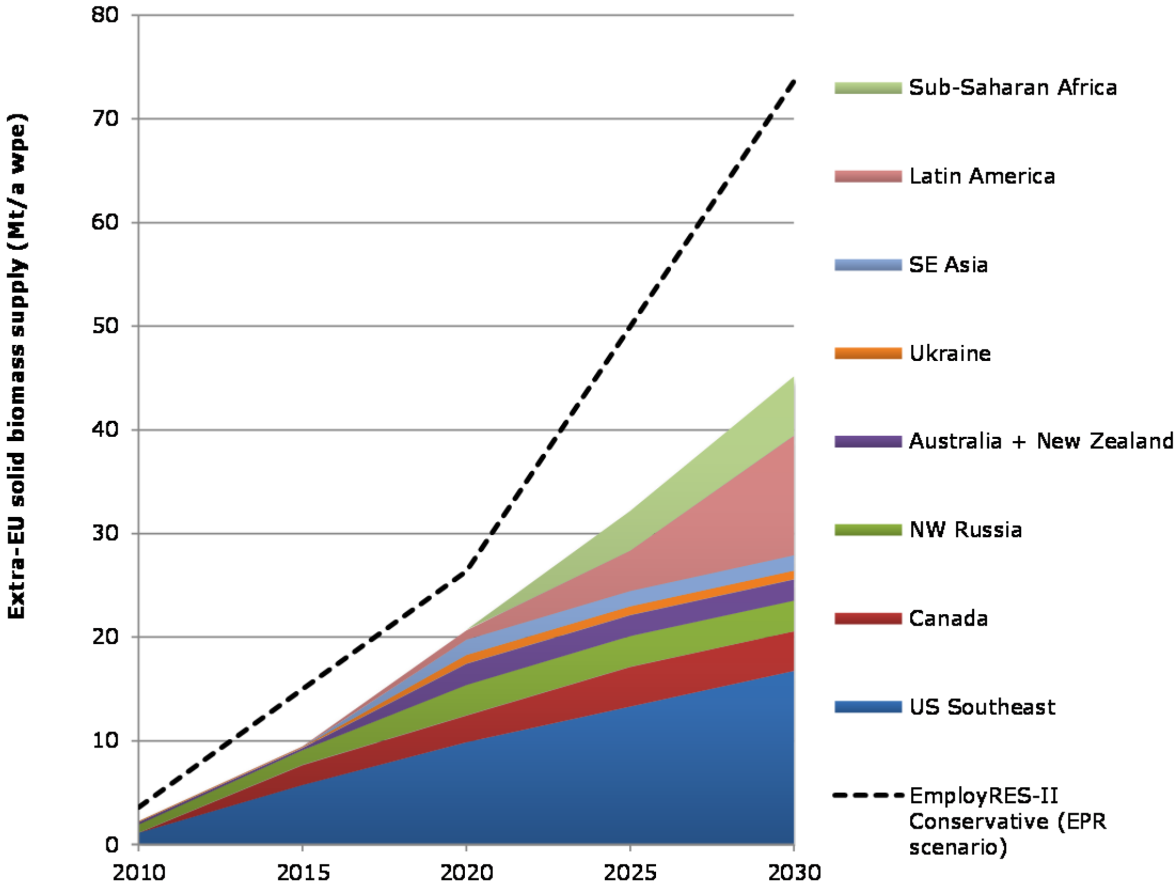


Figure 15 Extra-EU supply scenarios of solid biomass between 2010 and 2030 of the Dia-Core study compared to the scenarios of extra-EU solid biomass supply of the EmployRES—II study (Duscha *et al.*, 2014)

5 Scenario pathways for bioenergy in the EU28 towards 2030

This section describes trends of RES deployment in the EU28 to 2030 as projected with the Green-X model. Although the scenario pathways cover a broad set of results including RES deployment, cost, avoided primary energy and GHG emissions, the main focus of this section is on the role of bioenergy supply, the need for biomass and international bioenergy trade. A detailed overview of the RES deployment pathways compared to the NREAPs is provided in the Appendix of this report (Table A 1 and Table A 2).

5.1 RES deployment and the role of bioenergy

With current levels of support, the share of renewable energy in the EU28 will increase moderately to 18% in 2020, thus not meeting its target of 20%, and 21% in 2030 (Figure 16). The decline in renewable energy beyond 2020 in the Baseline scenario is mainly the result of phasing out biofuel support as also shown in the QUO-27 noBF sensitivity scenario. In scenarios with support, 27% renewable energy, as agreed on by European countries, appears to be feasible. Bioenergy will increase in absolute terms, even in the baseline scenario. However, the share of bioenergy in total RES production is projected to decline moderately from about 60% today to between 51% and 55% in 2030 as a result of strong increases in wind and solar energy. Nevertheless, bioenergy will remain the largest source of renewable energy to 2030.

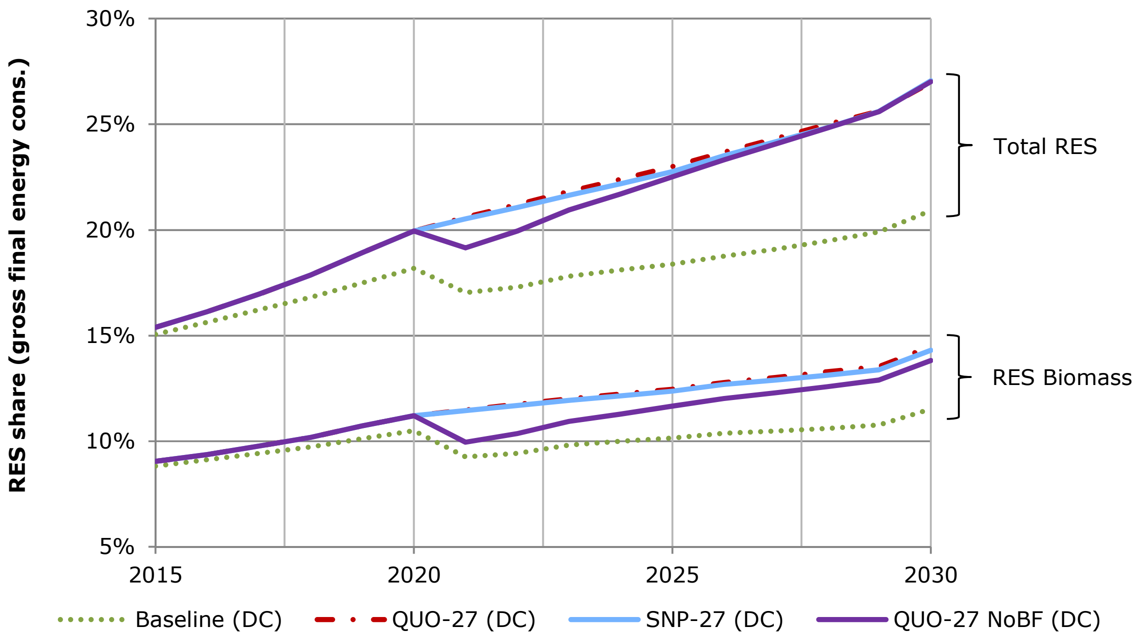


Figure 16 Share of renewable energy in gross final energy consumption in the EU28 to 2030. Results of the EPR scenarios are provided in Appendix Table A 1 and A 2.

In terms of final energy, heat will remain the largest source of bioenergy providing over two-thirds of total final bioenergy supply to 2030 and well over one-third of renewable energy generation in all scenarios (Figure 17). Total renewable energy generation increases from 182 Mtoe in 2015 to between 213 Mtoe (Baseline) and 236 Mtoe in 2020 and up to 318 Mtoe in 2030 (QUO-27 EPR). The small variation in total renewable energy generation between the scenarios of 27% renewable energy can be explained by the error margin.

The growth in biofuels is driven by the 2020 target of 10% renewable energy in transport. In scenarios where biofuel support is phased out beyond 2020 (Baseline and noBF), biofuel will still be produced in the EU28. However, extra-EU imports of biofuels will stagnate in these scenarios reducing the share of biofuels in total renewable energy generation to 5% in 2030. Note also that heat shows more variation resulting from increased extra-EU solid biomass supply in the EPR scenarios compared to electricity and 2nd generation biofuels. From these results it can also be observed that, in case of reduced extra-EU supply of solid biomass, alternative sources of renewable energy will increase (mainly wind and solar) rather than increased supply of domestic biomass supply.

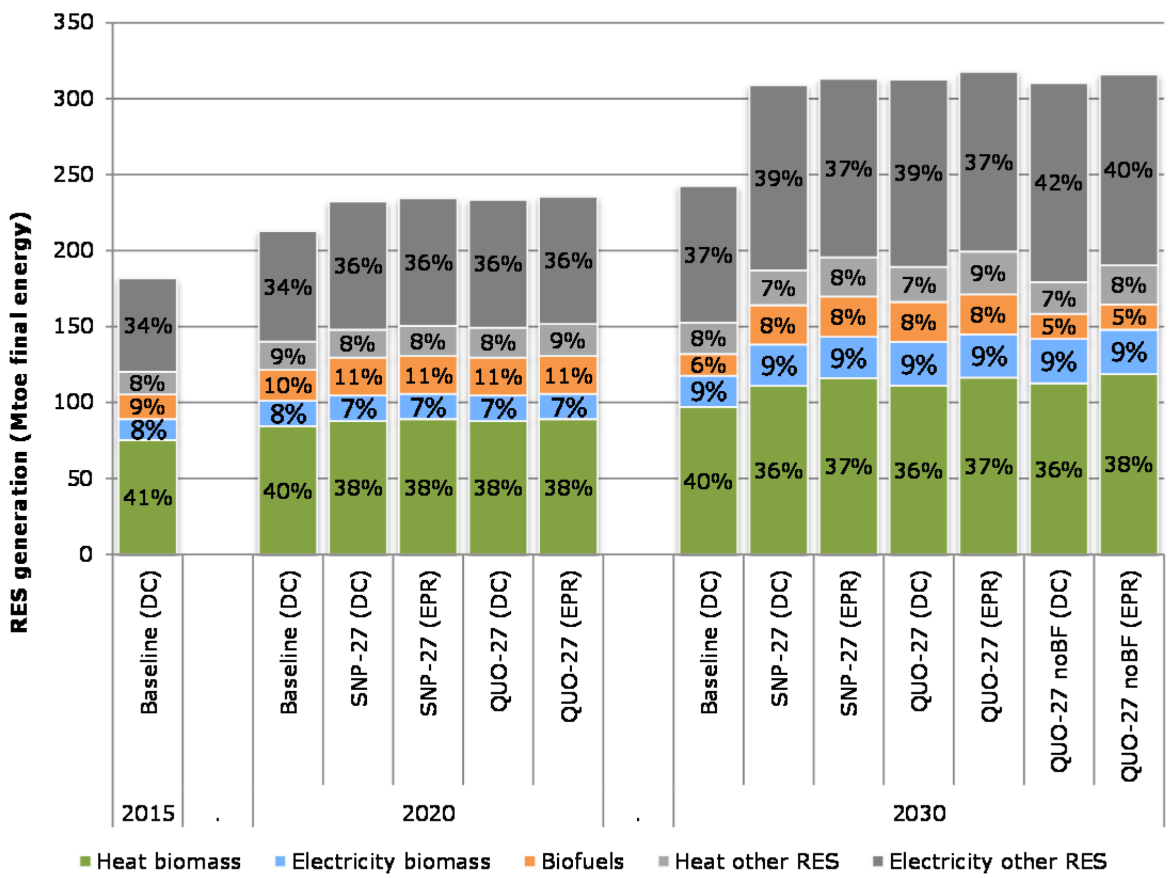


Figure 17 Renewable generation in the EU28 to 2030 in final energy terms. The chart labels depict the share of each category relative to total final renewable energy generation.

5.2 Biomass demand

Green-X projections of total renewable energy deployment and related primary biomass demand in the EU28 in main the scenarios are compared to the sensitivity scenarios in Figure 18 (Baseline), Figure 19 (SNP-27) and Figure 20 (QUO-27). According to the projections, primary biomass demand will grow moderately with 28% between 2015 and 2030 if current policy support for renewable energy is phased out beyond 2020 (Baseline scenario). Growth is anticipated in heat from imported biomass given that it is a relatively autonomous development (Hawkins Wright, 2014). Note however that this autonomous development is still uncertain. Others consider that support will be needed to develop these markets (Thomson & Liddell, 2015). Imports of liquid biofuels will stop beyond 2020 as a result of phasing out support for biofuels. The Extra-EU supply potential biomass is fully exploited in case of the DC scenario. In case of the EPR scenario, 70% of the extra-EU supply potential is projected to be exploited in 2030 (21.1 Mtoe, 50 Mt wpe).

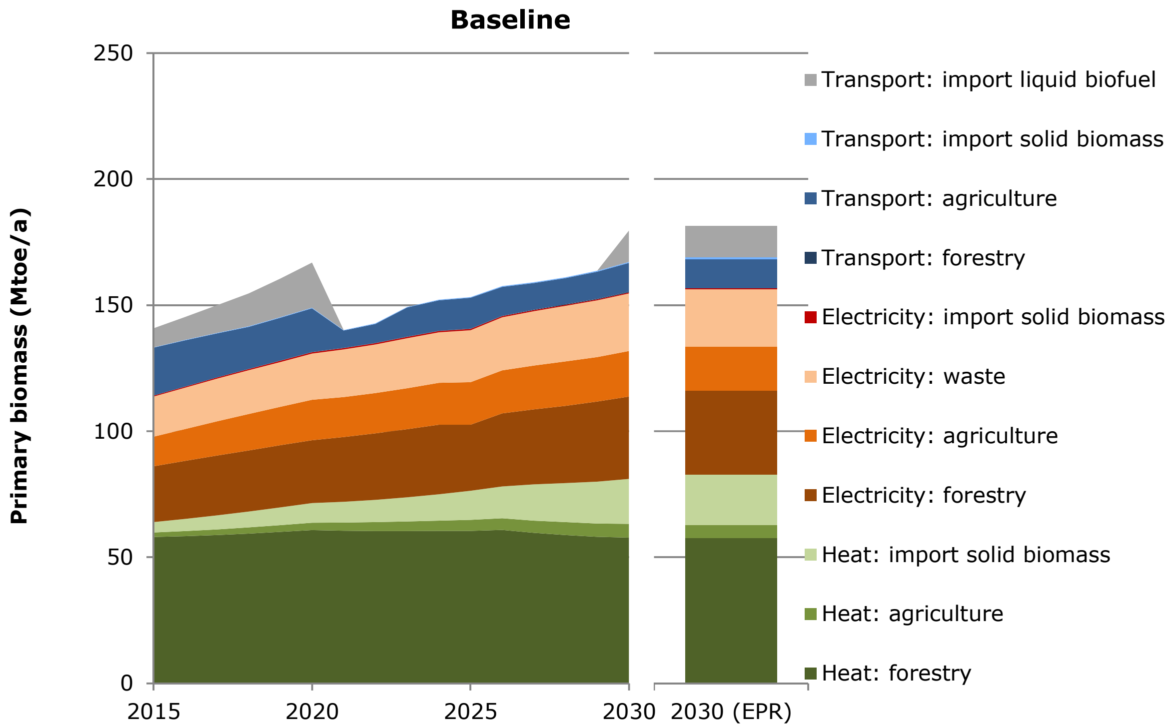


Figure 18 Primary biomass consumption for heat, electricity and transport[10] in the Baseline (DC) scenario (area) and Baseline (EPR) scenario (column) to 2030.

The SNP-27 and QUO-27 scenarios show a full exploitation of the extra-EU supply potential with in the QUO-27 scenario, increased demand for imported wood pellets for renewable electricity generation. In the SNP-27 scenarios, primary biomass demand increases up to 55% in DC scenario and up to 60% in the EPR scenario compared to 2015. The SNP-27 and QUO-27 scenarios show a strong growth in primary biomass demand for electricity generation, mainly from agriculture (mainly agriculture residues) and biomass waste. According to the results, primary biomass demand for electricity generation in scenarios that meet the 27% RES target in 2030 is projected to become larger than primary biomass demand for heat beyond 2020. However, in terms of final energy generation, heat will remain largest.

[10] Imported biofuels are expressed in primary energy assuming a conversion efficiency of 50% similar to Nakada et al. (2014).

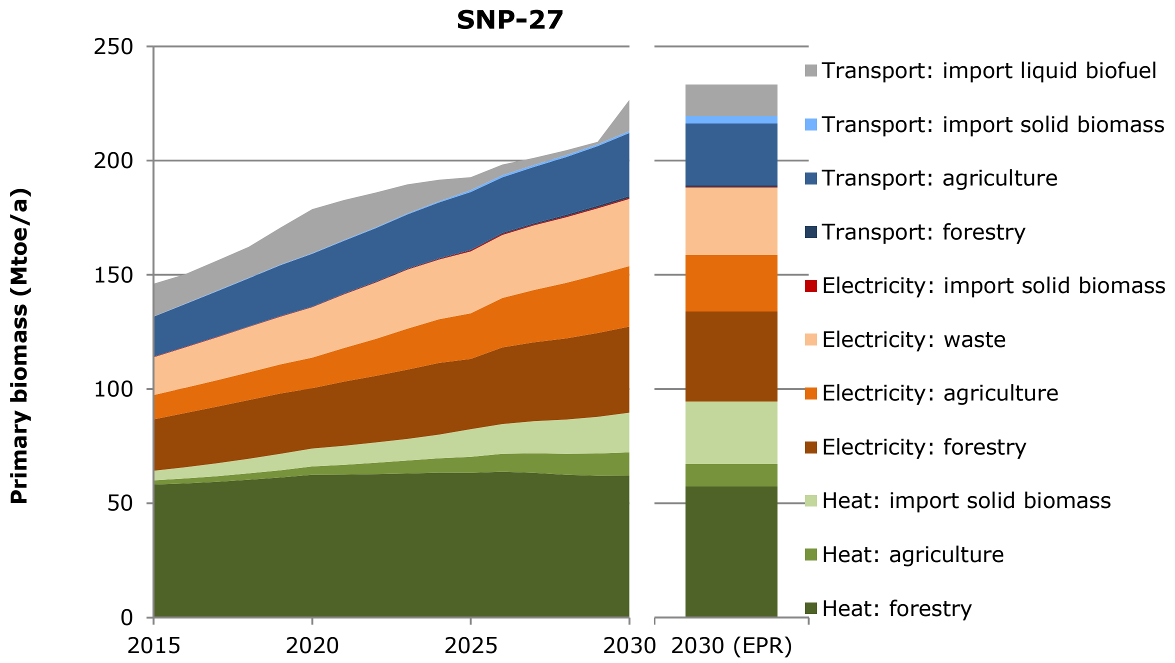


Figure 19 Primary biomass consumption for heat, electricity and transport[10] in the SNP-27 (DC) (area) scenario and SNP-27 (EPR) scenario (column) to 2030.

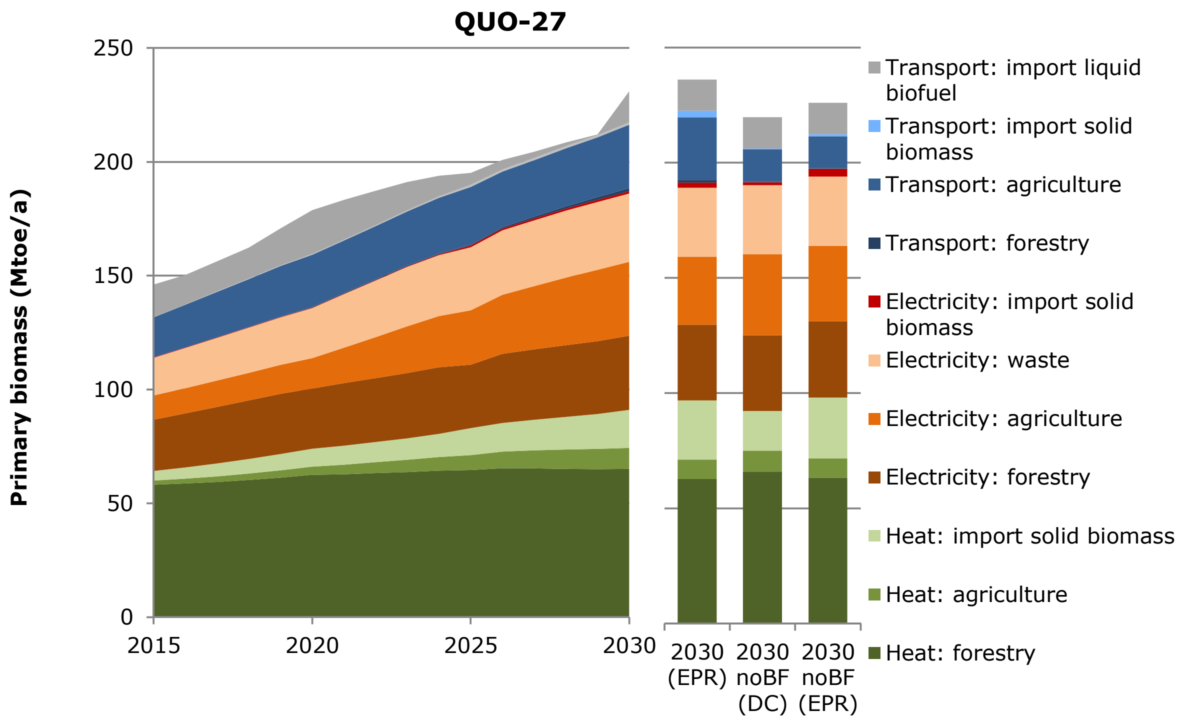


Figure 20 Primary biomass consumption for heat, electricity and transport[10] in the QUO-27 (DC) scenario (area) and QUO-27 (EPR), QUO-27 noBF (DC/EPR) scenarios (columns) to 2030.

5.3 Role of solid biomass trade

Although most biomass is projected to be supplied from domestic resources in the scenarios to 2030, a strong increase in both Intra-EU and Extra-EU trade of solid biomass is observed (Figure 21). The supply potential of extra-EU solid biomass is almost fully exploited in all scenarios including the baseline scenario with the main difference between the assumed supply potentials of extra-EU biomass supply in the DC and EPR scenarios. These results show that, regardless of additional support Extra-EU imports of solid biomass, heat markets for Extra-EU imports of solid biomass might grow (Figure 18 - Figure 20) as a result of competitive price levels compared to fossil heating fuels (LPG, heating oil, natural gas) (Hawkins Wright, 2014). It should be noted however that the supply logistics and related cost for residential markets are not modelled explicitly. This results in an underestimation of wood pellet supply cost for residential markets compared to industrial wood pellet markets (AEBIOM, 2014), see Section 3.2.5. Similar to extra-EU trade of solid biomass, trade of solid biomass within the EU is projected to increase. Intra-EU trade projections do however show to be more sensitive to the policy scenario conditions assumed. In the Baseline scenario, Intra-EU trade of solid biomass increases to 13.6 Mt wpe (5.7 Mtoe) compared to 30.6 Mt wpe (12.8 Mtoe) in the QUO-27 scenario without biofuel support beyond 2020 (noBF).

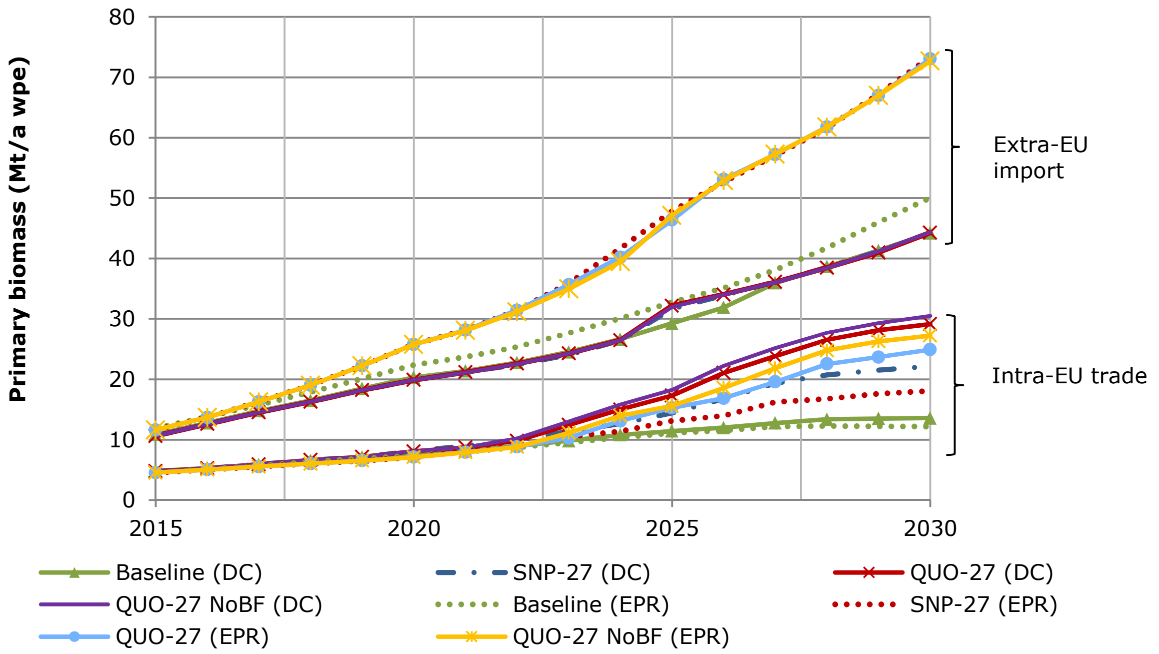


Figure 21 Intra-EU and Extra-EU solid biomass trade in the scenarios to 2030.

Figure 22 and Figure 23 zoom in at member state level for the main importing countries of solid biomass in 2020 and 2030 respectively. Currently, Germany is a net exporting of wood pellets. Nevertheless, given the strong growth in primary bioenergy demand, Germany is projected to become the largest importing country of intra-EU and extra-EU solid biomass in all scenarios in 2020 and 2030. In 2030, Germany is projected to import between 15.4 and 25.3 Mt, or 26%-28% of total solid biomass trade in the EU28 or higher than the total wood pellet market in 2013 (Figure 4). Other key importing countries, including the UK, Italy, Belgium, Austria, the Netherlands, Belgium and Denmark, are more consistent with the market expectations described in Section 3. In total, the countries depicted in Figure 22 and Figure 23 make up between 76% and 80% of the solid biomass trade market in the scenarios in 2030.

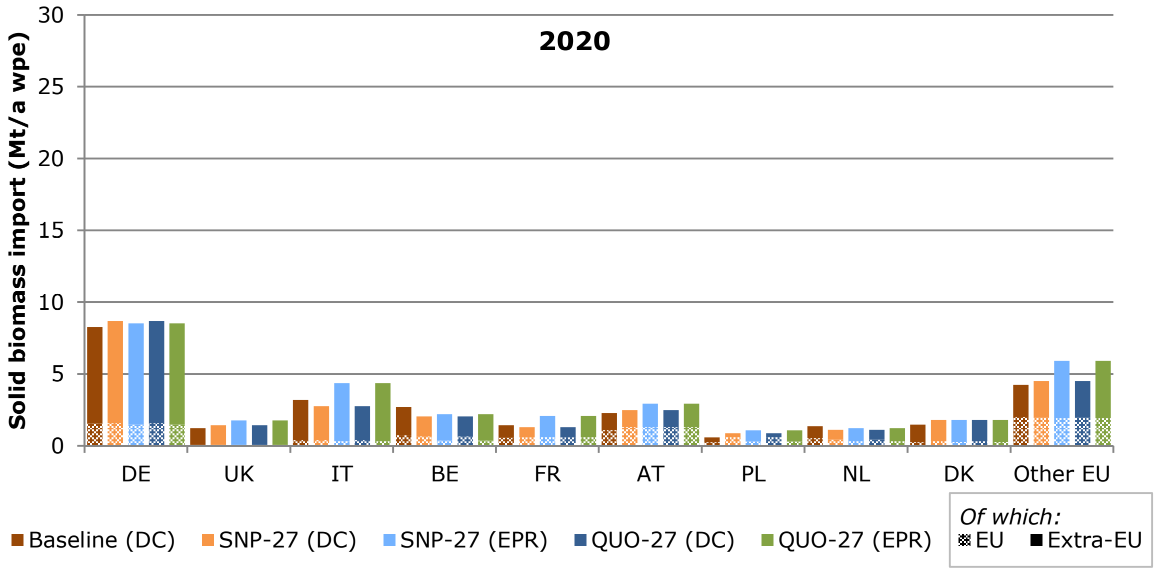


Figure 22 Projections of solid biomass trade in key importing member states and other EU in 2020 in Mt wood pellet equivalent (WPE).

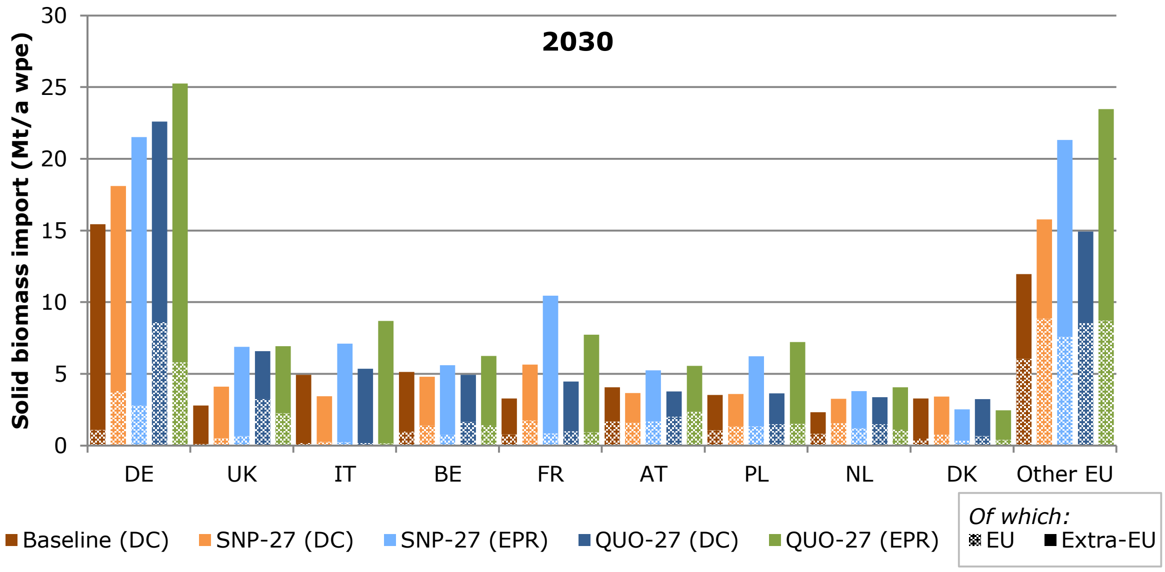


Figure 23 Projections of solid biomass trade in key importing member states and other EU in 2030 in Mt wood pellet equivalent (WPE).

6 Conclusion

Bioenergy is and is expected to remain the largest source of renewable energy. With the binding EU RES targets of 20% by 2020, and the recently adopted EU-wide RES target of achieving at least 27% as RES share in gross final energy demand, bioenergy as well as other RES need to increase substantially. To facilitate and coordinate an efficient and sustainable deployment of biomass for bioenergy to 2020 and to 2030, this study provides insight in the prospective supply and demand markets, as well as intra- and extra-EU trade of solid biomass.

Solid biomass trade, and in particular wood pellets, has grown exponentially in the last decade with the EU28 being one of the main markets. The consumption of wood pellets in the EU28 increased to 8 Mtoe (19 Mt) in 2013 of which 2.5 Mtoe (5.9 Mt) was imported from outside the EU. However recent trends show that growth of pellet markets might slow down. For this reason, this study developed an extra-EU supply scenario taking into account recent market developments (DC scenario). Together with the existing EmployRES-II extra-EU supply scenario and four EU RES policy scenarios, model projections have been made with the Green-X model to provide insight in the possible effects of extra-EU biomass supply and the impact of harmonizing EU RES policy strategies compared to further improvement of existing RES policies at member state level.

The scenarios show that the agreed target of 27% RES is feasible within the EU under sufficient support. Bioenergy is projected to remain the dominant source of renewable energy to 2030. However, the share of bioenergy in total RES production is projected to decline moderately from about 60% today to between 51% and 55% in 2030 as a result of strong increases in other RES (mainly wind and PV). In terms of final energy, heat will remain the largest source of bioenergy providing over two-thirds of total final bioenergy supply to 2030 and well over one-third of total renewable energy generation in all scenarios.

In terms of primary energy demand, electricity is projected to become the largest consuming sector of primary bioenergy in some scenairos. The major share of biomass will still be supplied from domestic sources, but the role of traded biomass trade and especially extra-EU trade is becoming increasingly important. Except for the baseline scenarios, the extra-EU biomass supply is almost fully exploited by 2030 regardless of the supply scenario. The share of extra-EU biomass increases up to 7% in 2020 and up to 13% in 2030. The main driver for increased trade of solid biomass is the heat sector. Furthermore, up to 15% of extra-EU solid biomass import is projected to be used for advanced biofuel production by 2030.

Currently, extra-EU imports of wood pellets are mainly used for industrial purposes including large scale electricity generation and CHP whereas pellet heating is mainly supplied from domestic resources or imported from neighboring countries. According to the model results, Germany will become the largest importing region of extra-EU solid biomass as a result of traded biomass shifting from industrial markets to heating markets. Although a convergence of industrial and residential pellet markets is currently ongoing, these model projections might underestimate the high fragmentation of actual residential markets as well as lack of distribution networks and required investments.

References

Abt KL, Abt RC, Galik CS, Skog KE (2014) *Effect of Policies on Pellet Production and Forests in the U.S. South A Technical Document Supporting the Forest Service Update of the 2010 RPA Assessment*. Asheville, NC, 40 pp.

ACM (2013) *ACM analysis of closing down 5 coal power plants as part of SER Energieakkoord*. Den Haag, The Netherlands.

AEBIOM (2014) *European Bioenergy Outlook 2014- a growing sector in figures*. Brussels, Belgium, 158 pp.

Argus (2015) Argus Biomass Markets. *Spot wood pellet prices cif ARA pellet*.

Argus Media (2013) GDF Suez cancels UK biomass conversion. *Argus Media*.

Beurksens L, Hekkenberg M (2010) Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States, Database.

Bradley D, Hektor B, Wilde M et al. (2014) *Low Cost, Long Distance Supply Chains*. 66 pp.

Cocchi M, Nikolaisen L, Junginger M (2011) Global wood pellet industry market and trade study. *IEA Bioenergy Task 40*.

Coelho S, Escobar J (2013) *Possibilities of sustainable woody energy trade and impacts on developing countries: Country Case Study Brazil*. Sao Paulo.

Davis C (2012) Enipedia. *Power Plants, Enipedia, TU Delft*.

Duscha V, Ragwitz M, Breitschopf B et al. (2014) *Employment and growth effects of sustainable energies in the European Union - FINAL REPORT*. Karlsruhe, 181 pp.

EC (2009) Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance). *Official Journal of the European Union*, **160**, 16–62.

EC (2013) *EU Energy, Transport and GHG Emissions Trends to 2050 - Reference Scenario 2013*. Brussels, Belgium.

Ehrig R, Behrendt F, Wörgetter M, Strasser C (2015) *APPLIED SCIENCES AND TECHNOLOGY Economics and Price Risks in International Pellet Supply Chains* (ed Andreas Öchsner, Southport Queensland A). Springer Cham Heidelberg New York Dordrecht London.

EP (2015) Parliament supports shift towards advanced biofuels. *European Parliament - Environment*, 2.

EUROSTAT (2015a) Energy from renewable sources.

EUROSTAT (2015b) EUROSTAT Trade by CN8 code: wood pellets.

Fritsche U, Iriarte L (2014) *Biomass Policies - Task 2.4: Sustainable Imports. Cost supply curves for medium-to longer-term potentials for sustainable biomass and bioenergy (pellets, biomethane, liquid biofuels) imports to the EU-27.* Darmstadt, Madrid, 52 pp.

Galik CS, Abt RC (2015) Sustainability guidelines and forest market response: an assessment of European Union pellet demand in the southeastern United States. *GCB Bioenergy*, n/a–n/a.

Giuntoli J, Agostini, Alessandro L, Edwards R, Marelli (2015) *Solid and gaseous bioenergy pathways: input values and GHG emissions - Calculated according to the methodology set in COM(2010) 11 and SWD(2014) 259*. Ispra (VA), Italy, 248 pp.

Goetzl A (2015) *Developments in the Global Trade of Wood Pellets - Office of Industries Working Paper*. Washington DC, 26 pp.

Goh CS, Junginger M, Cocchi M et al. (2013) Wood pellet market and trade: a global perspective. *Biofuels, Bioproducts and Biorefining*, **7**, 24–42.

Hawkins Wright (2014) *The Outlook for Wood Pellet Demand - Demand, supply, costs and prices*.

HM R&C (2015) Climate Change Levy: removal of exemption for electricity from renewable sources. *Business tax – policy paper, HM Revenue & Customs*.

Hoefnagels R, Resch G, Junginger M, Faaij A (2014) International and domestic uses of solid biofuels under different renewable energy support scenarios in the European Union. *Applied Energy*.

Junginger M, Sheng Goh C, Schouwenberg P-P, Kranzl L, Schipfer F, Al E (2015) Global Bioenergy Trade - An Overview of the Status, Drivers and Trends. In: *23rd European Biomass Conference & Exhibition*. Vienna.

Lamers P, Hamelinck C, Junginger M, Faaij A (2011) International bioenergy trade—A review of past developments in the liquid biofuel market. *Renewable and Sustainable Energy Reviews*, **15**, 2655–2676.

Lamers P, Junginger M, Hamelinck C, Faaij A (2012) 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, Heinimö J, Steierer F (2014a) Global Woody Biomass Trade for Energy. In: *International Bioenergy Trade*, Vol. 17 (eds Junginger M, Goh CS, Faaij A), pp. 41–63. Springer Netherlands, Dordrecht.

Lamers P, Hoefnagels R, Junginger M, Hamelinck C, Faaij A (2014b) Global solid biomass trade for energy by 2020: an assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints. *GCB Bioenergy*, n/a–n/a.

Lang A (2015) How Can Global Demand for Wood Pellets Affect Local Timber Markets in the U.S. South? *Stumpage Forecasting, Timber Market Analysis, Wood Bioenergy, Wood Demand & Procurement*.

Lechner H, Carlsson J (2014) *The Risk of Indirect Wood Use Change - Final report prepared for Energie Nederland*. London, 34 pp.

Nakada S, Saygin D, Gielen D (2014) *Global Bioenergy Supply and Demand Projections - A Working Paper for REmap 2030*. Bonn, 88 pp.

Pelkmans L (2015) *Policy landscapes: European Union: Deliverable 3.1 of the Biomass Policies project*. Belgium.

Pelkmans L, Brown G, Panoutsou C (2014a) *National policy landscapes : United Kingdom, Deliverable 3.1 of the Biomass Policies project*.

Pelkmans L, Devriendt N, Dael M Van (2014b) *National policy landscapes: Belgium, Deliverable 3.1 of the Biomass Policies project*. Mol, Belgium.

Piddington PC (2015) Benchmark your strategies in response to policy uncertainty to mitigate risk and seize upon opportunities as they emerge in biomass power production. In: *World Biomass Power Markets, Amsterdam 18th February 2015*. RWE.

Proskurina S, Heinimö J, Mikkilä M, Vakkilainen E (2015) The wood pellet business in Russia with the role of North-West Russian regions: Present trends and future challenges. *Renewable and Sustainable Energy Reviews*, **51**, 730–740.

Rebiere M (2014) *The Italian Pellet Market - Pathways to Prosperity*.

Resch G, Busch S, Liebmann L (2014) *Dia-Core Interim report on Prospects for RES in Europe up to 2030* -. Vienna, 44 pp.

Rijksoverheid (2015) *Kamerbrief over duurzaamheidscriteria vaste biomassa voor energietoepassingen*. Den Haag, The Netherlands, 3 pp.

Sackett J (2015) *Wood Pellet Plants and European Export*. Charlottesville, VA, US, 4 pp.

Sikkema R, Junginger M, Pichler W, Hayes S, Faaij APC (2010) The international logistics of wood pellets for heating and power production in Europe: Costs, energy-input and greenhouse gas balances of pellet consumption in Italy, Sweden and the Netherlands. *Biofuels, Bioproducts and Biorefining*, **4**, 132–153.

Thomson H, Liddell C (2015) The suitability of wood pellet heating for domestic households: A review of literature. *Renewable and Sustainable Energy Reviews*, **42**, 1362–1369.

Voegele E (2015) EU to investigate U.K. support of Lynemouth biomass conversion. *Biomass Magazine*.

Walker S (2014a) *Global Pellet Demand & Trade Webinar*.

Walker S (2014b) *Global Pellet Market Update: Canadian Perspective*.

XE (2105) XE US Dollar to Euro exchange rate 1999 - 2015.

Appendix

Table A 1 Overview of final RES generation in the scenarios in 2015 and 2020 (Green-X projections) compared to the NREAPs

	2015	2020					
	Baseline (DC)	Baseline (DC)	SNP-27 (DC)	SNP-27 (EPR)	QUO-27 (DC)	QUO-27 (EPR)	NREAP[a]
Electricity (ktoe y^{-1})							
Biomass	**13,743**	**16,455**	**16,698**	**16,657**	**16,698**	**16,657**	**19,916**
Biogas	3,514	4,350	4,117	4,117	4,117	4,117	5,501
Solid biomass[b]	8,386	9,965	9,950	9,908	9,950	9,908	13,319
Biowaste[b]	1,843	2,140	2,631	2,631	2,631	2,631	
Bioliquids[b]							1,096
Hydro	31,376	32,183	32,118	32,107	32,118	32,107	31,192
PV & solar thermal electricity	8,179	9,745	14,963	14,972	14,963	14,972	8,884
Tide & wave and geothermal	750	966	1,370	1,369	1,370	1,369	1,496
Wind	21,283	29,703	35,750	35,521	35,750	35,521	42,499
Total renewable electricity	**75,331**	**89,052**	**100,900**	**100,625**	**100,900**	**100,625**	**103,636**
Goss final electricity consumption	**292,684**	**292,117**	**292,117**	**292,117**	**292,117**	**292,117**	**303,526**
Renewable share of gross final elec. cons.	25.7%	30.5%	34.5%	34.4%	34.5%	34.4%	34.1%
Biobased share of gross final elec. cons.	4.7%	5.6%	5.7%	5.7%	5.7%	5.7%	6.6%
Heating and cooling (ktoe y^{-1})							
Biomass	**75,348**	**84,580**	**87,921**	**89,144**	**87,921**	**89,144**	**89,885**
Biogas	2,003	2,528	2,146	2,146	2,146	2,146	4,476
Solid biomass[b]	69,914	78,146	81,140	82,363	81,140	82,363	80,993
Biowaste[b]	3,431	3,906	4,636	4,636	4,636	4,636	
Bioliquids[b]							4,416
Heat pumps, geothermal, solar thermal	14,742	18,627	19,678	19,670	19,678	19,670	20,075
Total renewable heat	**90,090**	**103,207**	**107,600**	**108,814**	**107,600**	**108,814**	**111,582**
Gross final heat consumption	**560,644**	**540,146**	**540,146**	**540,146**	**540,146**	**540,146**	**520,583**
Renewable share of gross final heat cons.	16.1%	19.1%	19.9%	20.1%	19.9%	20.1%	21.4%
Biobased share of gross final heat cons.	13.4%	15.7%	16.3%	16.5%	16.3%	16.5%	17.3%
Transport[c] (ktoe y^{-1})							
First generation	11,900	9,461	12,742	12,742	12,742	12,742	16,079
Second generation	622	2,123	2,590	2,586	2,590	2,586	2,626
Imported biofuels	3,779	8,929	9,641	9,649	9,641	9,649	11,041
Total renewable transport	**16,302**	**20,513**	**24,973**	**24,977**	**24,973**	**24,977**	**29,746**
Gross final consumption transport	**353,811**	**338,317**	**338,317**	**338,317**	**338,317**	**338,317**	**312,352**
Share biobased	4.6%	6.1%	7.4%	7.4%	7.4%	7.4%	9.5%
Total (ktoe y^{-1})							
Total renewable	**181,723**	**212,772**	**233,473**	**234,416**	**233,473**	**234,416**	**244,964**
Of which biobased	**105,393**	**121,548**	**129,593**	**130,778**	**129,593**	**130,778**	**139,546**
Total gross final consumption	**1,207,138**	**1,170,580**	**1,170,580**	**1,170,580**	**1,170,580**	**1,170,580**	**1,189,314**
Share of total gross final energy cons.	15.1%	18.2%	19.9%	20.0%	19.9%	20.0%	20.6%
Biobased off total gross final energy cons.	8.7%	10.4%	11.1%	11.2%	11.1%	11.2%	11.7%

a) NREAP data is derived from the Renewable Energy Projections Tables 1 (Additional Energy Efficiency Scenario), 10, 11, 12 digitized by ECN (Beurksens & Hekkenberg, 2010)

b) Solid biomass in the NREAP also covers organic wastes. Renewable electricity, heating and cooling from liquid biomass are not covered in Green-X.

c) Excluding renewable electricity transport.

Table A 2 Overview of final RES generation in the scenarios in 2030 (Green-X projections)

	2030						
	Baseline (DC)	SNP-27 (DC)	SNP-27 (EPR)	QUO-27 (DC)	QUO-27 (EPR)	QUO-27 noBF (DC)	QUO noBF (EPR)
Electricity (ktoe y^{-1})							
Biomass	**20,709**	**27,254**	**27,283**	**28,809**	**28,397**	**29,189**	**29,194**
Biogas	4,755	5,926	5,834	6,672	6,249	7,143	6,740
Solid biomass[b]	13,180	17,888	18,007	18,668	18,679	18,577	18,985
Biowaste[b]	2,774	3,441	3,442	3,469	3,469	3,470	3,469
Bioliquids[b]							
Hydro	33,291	32,984	32,949	34,213	34,121	34,315	34,259
PV & solar thermal electricity	10,886	24,608	23,923	20,979	19,174	24,022	21,157
Tide & wave and geothermal	1,186	5,437	5,348	2,039	2,018	2,090	2,039
Wind	44,553	58,893	55,121	66,104	63,291	69,883	67,237
Total renewable electricity	**110,625**	**149,176**	**144,625**	**152,144**	**147,001**	**159,499**	**153,885**
Goss final electricity consumption	**312,446**	**312,446**	**312,446**	**312,446**	**312,446**	**312,446**	**312,446**
Renewable share of gross final elec. cons.	35.4%	47.7%	46.3%	48.7%	47.0%	51.0%	49.3%
Biobased share of gross final elec. cons.	6.6%	8.7%	8.7%	9.2%	9.1%	9.3%	9.3%
Heating and cooling (ktoe y^{-1})							
Biomass	**97,062**	**111,062**	**115,952**	**111,112**	**116,348**	**112,731**	**118,744**
Biogas	2,426	2,739	2,673	3,164	2,861	3,519	3,219
Solid biomass[b]	90,268	102,901	107,854	102,624	108,164	103,888	110,202
Biowaste[b]	4,367	5,422	5,425	5,323	5,323	5,323	5,323
Bioliquids[b]							
Heat pumps, geothermal, solar thermal	20,590	27,726	25,913	23,245	22,825	24,403	23,511
Total renewable heat	**117,651**	**138,788**	**141,865**	**134,357**	**139,173**	**137,134**	**142,255**
Gross final heat consumption	**516,611**	**516,611**	**516,611**	**516,611**	**516,611**	**516,611**	**516,611**
Renewable share of gross final heat cons.	22.8%	26.9%	27.5%	26.0%	26.9%	26.5%	27.5%
Biobased share of gross final heat cons.	18.8%	21.5%	22.4%	21.5%	22.5%	21.8%	23.0%
Transport[c] (ktoe y^{-1})							
First generation	4,372	5,599	5,599	5,599	5,599	5,034	5,034
Second generation	3,573	13,344	14,127	13,776	14,172	4,648	4,795
Imported biofuels	6,216	6,841	6,841	6,841	6,841	6,792	6,792
Total renewable transport	**14,162**	**25,784**	**26,568**	**26,216**	**26,612**	**16,474**	**16,621**
Gross final consumption transport	**330,210**	**330,210**	**330,210**	**330,210**	**330,210**	**330,210**	**330,210**
Share biobased	4.3%	7.8%	8.0%	7.9%	8.1%	5.0%	5.0%
Total (ktoe y^{-1})							
Total renewable	**242,438**	**313,748**	**313,058**	**312,717**	**312,787**	**313,107**	**312,761**
Of which biobased	**131,932**	**164,100**	**169,804**	**166,137**	**171,358**	**158,394**	**164,559**
Total gross final consumption	**1,159,267**	**1,159,267**	**1,159,267**	**1,159,267**	**1,159,267**	**1,159,267**	**1,159,267**
Share of total gross final energy cons.	20.9%	27.1%	27.0%	27.0%	27.0%	27.0%	27.0%
Biobased off total gross final energy cons.	11.4%	14.2%	14.6%	14.3%	14.8%	13.7%	14.2%

b) Solid biomass in the NREAP also covers organic wastes. Renewable electricity, heating and cooling from liquid biomass are not covered in Green-X.

c) Excluding renewable electricity transport.