Universiteit Utrecht

Port of Rotterdam

Port of Rotterdam

Capacity Study for Solid Biomass Facilities

Scenarios for supply and demand of solid biomass for electricity and heat generation in North West Europe

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Contents

Acronyms and abbreviations

BAU	business-as-usual
BAU-BM	business-as-usual - barriers mitigated
BE	Belgium
boe	barrel of oil equivalent
CHP	Combined Heat and Power
CO_2	Carbon dioxide
DE	Germany
DECC	Department of Energy & Climate Change
DK	Denmark
EC	European Commission
ETS	Emission Trading Scheme
EU-27	The European Union (27 member states)
FiT	Feed-in tariff
GC	green certificate
GDP	Gross Domestic Product
GEC	Green Certificate Scheme
GW	Gigawatt
kt	thousand metric ton
MAP	market incentive programme
MEP	feed-in premium system of the Netherlands (Milieukwaliteit Electriciteitsproductie)
MS	member state
Mt	million metric ton
MW	megawatt
MWe	megawatt electrical
MWh	megawatt hour
MWth	megawatt thermal
NL	Netherlands
NREAP(s)	National Renewable Action Plan(s). A plan written by each member state of the EU-27 for the European Commission how to meet the renewable energy targets for 2020. These targets should result in an overall share of 20%. renewable energy by 2020.
PV	Photovoltaic
RED	Renewable Energy Directive (2009/28/EC)
RES	renewable energy
RES-E	renewables in electricity
RES-H	renewable in heat
RES-T	renewables in transport
SDE(+)	Incentive Scheme for Sustainable Energy Production (SDE) and its successor (plus). A feed-in premium subsidy for renewable energy production in the Netherlands.
SNP	Strengthened National Policies
toe	tonne of oil equivalent (1 toe = 41.868 GJ)
TWh	terawatt hour
UK	United Kingdom
Green-X	Partial equilibrium model of the energy sector covering the EU-27 and other European countries (Croatia, Norway, Switzerland, Turkey) and focusing on renewable energy. Developed by the Energy Economics Group (EEG) of the Technical University of Vienna.
PRIMES	Agent based and price driven model of the energy system covering 35 European countries. Developed by the National Technical University of Athens.

Summary

Background

The growing awareness for climate change and security of supply leads to a increasing share of renewable energy in which biomass plays an important role. Especially in the European Union (EU-27), where member states have agreed on a binding target of a 20% renewable energy share of total energy consumption by 2020 (Renewable Energy Directive, 2009/28/EC), biomass use for bioenergy is expected to grow substantially. Moreover, the gap between domestic supply and domestic demand is growing, resulting in increasing imports of solid biomass from both EU and non-EU countries. In northwest Europe, sea ports play an important role because they provide access to (inter-continental) sources of biomass from countries with domestic supply exceeding domestic demand (for example Canada, US, Russia). To facilitate further growth of bulk solid biomass trade, the Port of Rotterdam wants to stimulate the development of a Biomass Hub concept. Insight is therefore required in the current and future biomass trade flows and the potential role of ports as a result of biomass use in northwest Europe.

Objectives and approach

This study aims to quantify potential trade flows used for heat and electricity generation in the captive and contestable hinterland of Rotterdam to 2030. Countries considered relevant for solid biomass trade in the port of Rotterdam region are the Netherlands as well as Belgium, Denmark Germany and the United Kingdom (northwest Europe). To assess the potential trade flows of solid biomass, first scenarios are developed based on existing model projections and biomass resource assessments. This report (Report I), describes the background data and the scenarios. The second report (Report II) will include a more detailed assessment of the biomass supply potentials in key supply regions in the world such as Brazil, the US and Russia. Furthermore, the demand of solid biomass in northwest Europe will be assessed in more detail to update the scenarios with actual market and policy information. It is therefore possible that the demand, as described in this report, based on existing scenario projections, will deviate from the final scenario projections in Report II that will include more actual details. For example, plans for co-firing in northwest Europe have been changed in the last years. Therefore, these scenarios will be complemented with available market information on plant level in northwest Europe.

Based on the scenarios and refined scenario parameters for global biomass supply, geographic explicit cost-supply curves of biomass will be created for biomass export regions represented by export sea ports and FOB prices of biomass. These will be linked with key demand regions, represented by import sea ports. For northwest Europe, the demand for solid biomass will be geographically modeled using existing locations of current and planned coal-fired capacities and the related co-firing potential. These demand nodes will be linked to the supply nodes via distribution terminals, including important sea ports in northwest Europe. A linear problem solver is used in combination with a geographic explicit intermodal transport model, running in ESRI's ArcGIS to model biomass trade flows assuming maximum profit or minimum cost of biomass distribution.

Scenarios

The scenarios included in this study are summarized in Table 1. Furthermore, a set of sensitivity scenarios is included to assess the implications of uncertainties that both policy makers and utilities are currently facing with respect to the support of co-firing and large scale conversion of coal-fired power plants. Scenarios for biomass demand in northwest Europe are based on the Re-Shaping

project (Ragwitz, Steinhilber et al. 2012). The Business as Usual (BAU) scenario assumes a continuation of current policies to 2030 whereas in the BAU-barriers mitigated scenario, non-economic barriers are mitigated resulting in faster technology substitution. In the Strengthened National Support (SNP) scenario, support policies are optimized and fine-tuned in order to meet the binding 20% renewable energy targets of the European Renewable Energy Directive by 2020. After 2020, these support policies are assumed to continue to 2030.

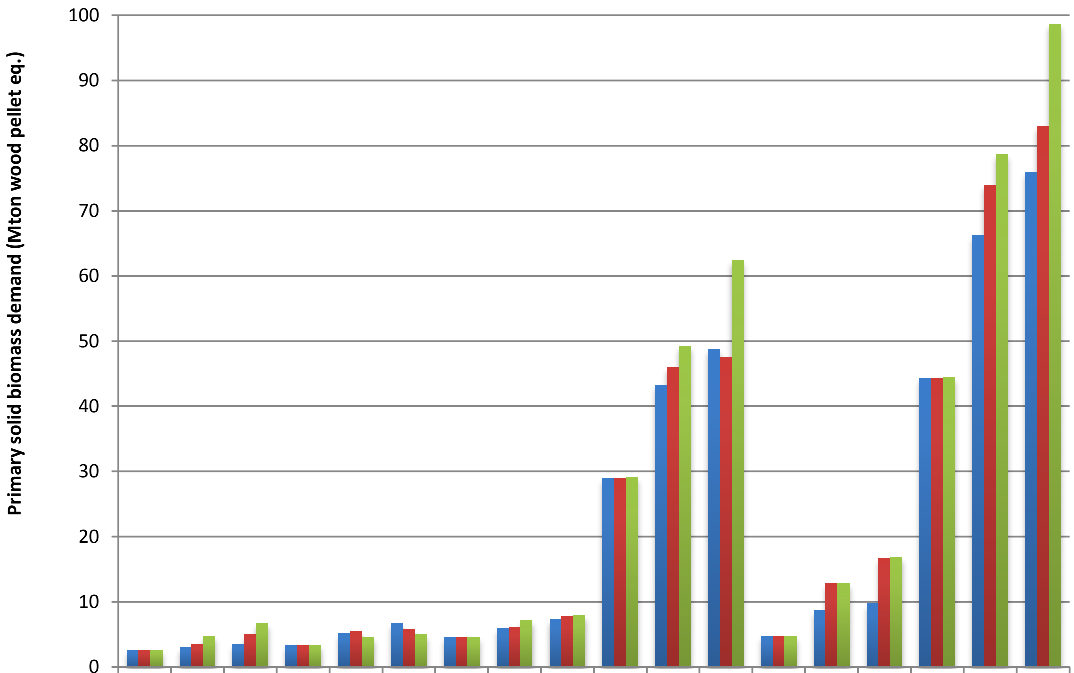
To estimate the global export potential of solid biomass for heat and electricity, we used the total global potential of biomass and assumed that domestic demand for renewable energy (heat, electricity and transport fuels) is prioritized over export. Furthermore, we assumed that the demand for transport fuels is prioritized over heat and electricity generation. The export potential of solid biomass is therefore defined as the net difference between the domestic supply potential, the domestic demand and the global demand for transport fuels. We use global model projections for the OECD-Environmental Outlook for the reference trade scenario and show the implications of trade barriers and low export potentials in a Low Trade scenario and a scenario in which global actions are taken to keep greenhouse gas emissions below 450 parts per million in order to limited global temperature rises below 2 ^{o}C in the High Trade 450 scenario. The combination of the SNP demand scenario and the Reference Trade scenario explores a scenario where Europe remains front-runner for renewable energy whereas other regions remain more conservative on renewable energy deployment. In the SNP – High Trade 450 scenario, the US, but also China become large users of solid biomass in order to reduce greenhouse gas emissions, resulting in decreasing export potentials in the US and increased import demand in other regions such as China. The BAU – Low Trade scenario explores a conservative scenario with trade barriers and limited deployment of renewable energy in the EU-27.

Table 1 Scenarios for biomass demand in northwest Europe and global biomass export and trade

Demand scenarios Northwest Europe	Global biomass export supply scenarios		
	Reference Trade	High Trade 450	Low Trade
Business as Usual	X		X
Business as Usual - Barriers Mitigated	X	X	
Strengthened National Support (SNP)	X	X	

Solid biomass demand in the scenarios

The import of wood pellets in northwest Europe, 3.2 Mton in 2010, is expected to increase rapidly as a result of the increasing share of renewable energy from biomass in all scenarios (Figure 1). These trends are also confirmed by the NREAPs in which the contribution of biomass is over 50% to meet the EU targets of 20% renewable energy shares in 2020. The amount of imported solid biomass, excluding organic waste and biogas, depends on the demand for electricity, heat and biofuels and the cost competitiveness of domestic biomass, import and demand in other countries and will be explored in Report II of this study using the model tool. Figure 1 shows the demand for solid biomass for heat and electricity in wood pellet equivalent (net calorific value of 17.6 MJ/kg). It is not expected that the increase demand will only be met by imported biomass. Especially in Germany, domestic supply is expected to increase as Germany is already a net exporting country of solid biomass, but also the UK is planning to increase the supply of domestic biomass including cultivation of dedicated energy crops to meet their growing demand.



	NL			BE			DK			DE			UK			NW-Europe		
	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030
BAU	2.6	3.0	3.5	3.4	5.2	6.7	4.6	5.9	7.3	28.9	43.3	48.7	4.8	8.7	9.8	44.3	66.2	76.0
BAU-BM	2.6	3.5	5.1	3.4	5.5	5.8	4.6	6.1	7.8	28.9	45.9	47.6	4.8	12.8	16.76	44.3	73.9	83.0
SNP	2.6	4.7	6.6	3.4	4.6	5.0	4.6	7.1	7.9	29.1	49.3	62.4	4.7	12.8	16.83	44.4	78.6	98.7

Figure 1 Projections of solid biomass demand in the core scenarios for northwest Europe including electricity and heat (centralized and residential).

In principle, there is sufficient biomass available in the EU-27 to meet the demand for transport fuels, electricity and heat in all scenarios. Nevertheless, it is expected that biomass trade will cover a large part of the domestic demand for the countries in northwest Europe because domestic production of dedicated energy crops in northwest Europe is more expensive than import of solid biomass from countries with excess supply of low value biomass sources or cheaper production costs of dedicated energy crops.

Further work

Based on the geographic export potential of global biomass resources, as determined in this study, cost supply curves will be developed per supply region. These cost-supply curves will be developed for important harbor nodes in the biomass trade model. The model will calculate the use of imported and domestic biomass based on cost optimization taking the logistic cost into account.

1 Introduction

The increasing awareness for climate change and security of supply leads to a growing share of renewable energy in the energy mix. Especially in the European Union (EU-27), where member states have agreed on a binding target of a 20% renewable energy share of total energy consumption by 2020 in the Renewable Energy Directive (2009/28/EC). In the recently National Renewable Action Plants (NREAPs), member states have provided information on how they expect to meet the national binding targets for renewable energy for 2020. According to the NREAPs, electricity production from biomass will double between 2010 and 2020 whereas heat production will increase with 50% resulting in a strong increase in solid biomass. Because the demand for solid biomass already exceeds the domestic supply, especially in North West Europe (Cocchi, Nikolaisen et al. 2011), it is expected that there will be a strong growth in import of solid biomass.

The demand for wood pellets, the main traded solid biomass commodity (Lamers, Junginger et al. 2012), already increased with 43% between 2008 and 2010 to 9.2 Mt in the EU-27. This resulted in a gap of 2.1 Mt between domestic production and domestic demand in the EU-27 in 2010 (Cocchi, Nikolaisen et al. 2011). A growing amount of wood pellets is therefore imported from non-EU countries such as the U.S. (southeast), Canada (British Columbia) and Russia to European countries with large sea ports including Belgium, the Netherlands and the UK. In these countries, wood pellets are mainly used for co-firing in pulverized coal plants.

Sea ports play an important role in the logistic supply chain of solid biomass. To facilitate further growth of bulk solid biomass trade, the Port of Rotterdam wants to stimulate the development of a Biomass Hub concept. Insight is therefore required in the expected demand of solid biomass in North West Europe from both European and non-European resources, the expected trade routes and logistic processes including the selected ports, transhipment, storage and hinterland transport to end-users.

Therefore, a solid biomass capacity study is conducted that aims to:

- Quantify the current and future demand of solid biomass in North West Europe[1] for the medium term (2020) and long term (2030)
- To assess the potential and related ranges from important supply regions (for example the US, Canada, Brazil, Russia and Africa) and the impact of demand development in Asia
- To assess the potential of alternative solid biomass commodities such as torrefied pellets

This report describes the scenarios of the capacity study for solid biomass that will be used to assess the potential demand of solid biomass in northwest Europe and the supply potential. The results of this study, including the expected trade flows of solid biomass will be published in the second report of this study.

[1] Belgium, Denmark, Germany, Netherlands, United Kingdom

2 Approach

2.1 Overview

Figure 2 depicts the scheme of the methodology applied in this study and the related reports that present the results. To assess the potential use of solid biomass for heat and electricity from both domestic and imported resources, this study combines global scenarios for net biomass export (blue boxes in Figure 2) with detailed scenarios on the national level for the countries in northwest Europe (green boxes in Figure 2).

Report I includes the estimated demand and supply of biomass for bioenergy on a global level and detailed demand projections on a national level for northwest Europe based on existing scenario projections. These scenarios are selected based on the following criteria: their relevance for bioenergy, regional scope, level of detail and have to include the most recent data and information available. In Report II, the potential of biomass resources is assessed in more detail to create cost-supply curves of key biomass export regions. Also, actual market information is added to the scenario projections that are not included in the existing model projections. For example, recent plans on co-firing or conversion of coal-fired power plants to biomass in the UK will be translated to scenario parameters. Furthermore, locations of biomass use in current and planned pulverized coal fired power plants are added to the scenario database. Finally, trade flows are modelled using the supply and demand databases and scenario projections.

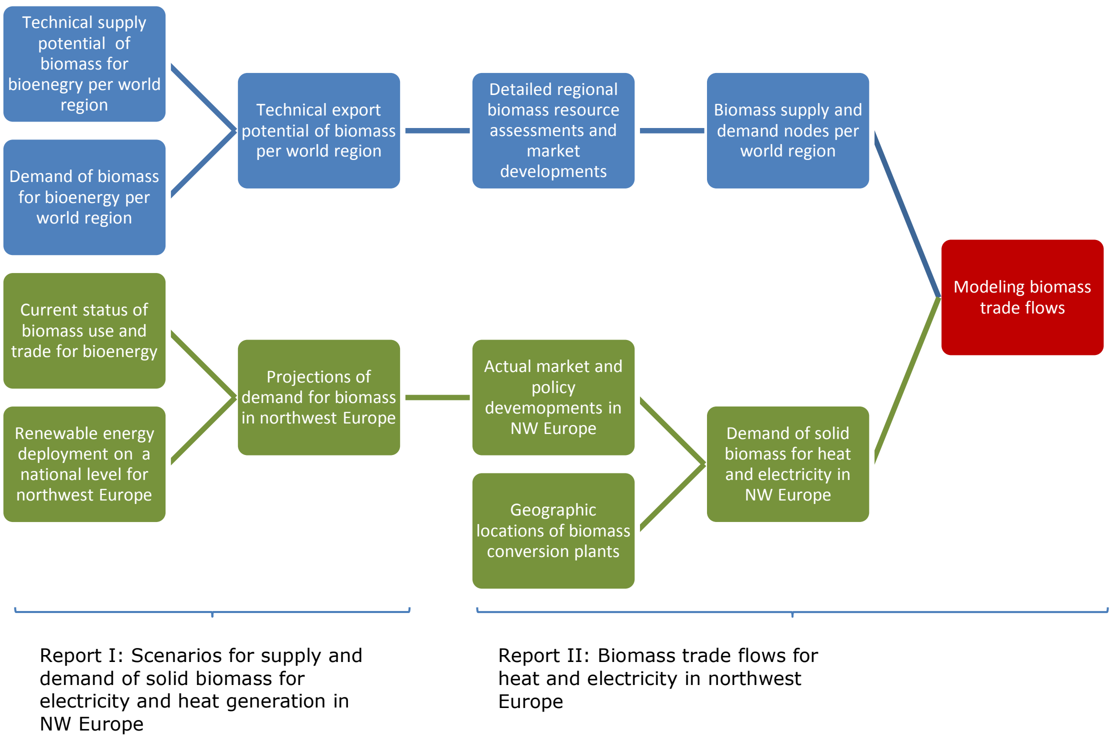


Figure 2 Scheme of the methodology and related report outputs

2.2 Scope

This study focuses on the **demand** for solid biomass for electricity generation (RES-E) and heat generation (RES-H) in northwest Europe. Transport fuels and biobased chemicals are excluded from this study.

Solid biomass sources in this study include lignocellulosic biomass sources from forest products and residues and dedicated woody energy crops (e.g. eucalyptus) that are processed in to wood chips or wood pellets before long distance transport. Waste wood is considered to be used domestically and not traded internationally.

The **supply regions** include both EU and non-EU (global) regions that are already exporting solid biomass (mainly wood pellets) or have a large potential to become exporting regions.

The **time frame** of this study covers the period 2010 to 2030.

2.3 Scenarios

2.3.1 Demand in Northwest Europe

The assessment of the potential demand and supply of solid biomass for electricity and heat, will be based on a set of scenarios. These scenarios explore the ranges and key uncertainties in the demand of solid biomass in northwest Europe on the one hand and on the other hand, explore the domestic as well as global supply of solid biomass based on existing and future developments in renewable energy policies, the technical potential and cost effectiveness of biomass and competing renewable energy systems (for example wind, hydropower or solar PV).

For this study, scenario projections were selected from the Re-Shaping project with a detailed focus on renewable energy potentials, current policies and consequences of future policy choices in the EU-27 (Ragwitz, Steinhilber et al. 2012). The scenarios comply with the following criteria:

- Include country specific results for the selected region in this study (Belgium, Denmark, Germany, Netherlands, UK);
- Up-to date, including renewable energy targets of the Renewable Energy Directive (RED 2009) and recent policy changes (up to 2011);
- Cover the period 2010 to 2030;
- Include detailed technology representation of renewable energy systems, both biobased and competing renewable energy technologies;
- Include both business as usual and ambitious scenarios for the deployment of renewable energy.

The estimated potential of renewable energy, the related costs and avoided greenhouse gas emissions from fossil fuels in the Re-Shaping project were assessed using the Green-X model. The Green-X model is a partial general equilibrium model of the energy sector (electricity, heat and transport fuels) covering the EU-27 and other European countries. The model has been developed by the Energy Economics Group (EEG) of the Technical University of Vienna and includes an in-depth energy policy representation in combination with detailed resource and technology characterization for renewable energy. The main purpose of the Green-X model is to assess the effectiveness and economic impact of different policies and support systems on renewable energy deployment in Europe. A detailed description of the Green-X model is available on a dedicated website: www.green-x.at.

For this study, these existing scenarios were used for North West Europe. In order to address for uncertainties and technology details on renewable electricity and heat, the main focus of this study, additional information, data and policy assumptions have been added to the existing scenarios. These include for example a plant specific database of all coal fired power plants in North West

Europe, existing markets and international trade of wood pellets and future expectations from literature and other sources (e.g. utilities, NREAPs etc.).

2.3.2 Scenarios for global export of biomass

To estimate the supply potential of both domestic and international solid biomass available for heat and electricity generation, scenarios are developed that take both global bioenergy supply potentials into account and the global demand for bioenergy. We used the geographic biomass potential from the IMAGE model for the OECD-Environmental Outlook reference scenario (van Vuuren, van Vliet et al. 2009) as a baseline and use the IPCC Special Report on Emissions Scenarios (Hoogwijk, Faaij et al. 2005) to show the upper and lower ranges in supply as a result of different development pathways.
For key supply regions, the geographic potential of these global resource assessments will be compared with regional and national studies and actual market information in Report II of this study. With the additional data, cost-supply curves will be created of the solid biomass export potential for heat and electricity.

2.4 Modelling biomass trade flows

To model biomass trade flows, a geographic explicit intermodal transport model will be used. A first tool was already developed at the Copernicus Institute as described in Hoefnagels et al. (2011), but requires major additions and changes to be able to address plant specific demand of biomass as well as supply and demand of biomass from export/import terminals in other world regions. A full description of the model approach will be presented in Report II of this study.

3 Current markets for solid biomass in North West Europe

3.1 Solid biomass demand and trade

Trade of solid biomass has increased rapidly from 3.5 Mt in 2000 to 18 Mt in 2010. Especially trade of wood pellets has increased strongly to 6.6 Mt in 2010 of which two thirds (4.2 Mt) was traded within the EU-27. Other imported wood traded flows included wood waste and fuel wood (both 4 MT in 2010) (Lamers, Junginger et al. 2012). Figure 3 shows the global trade flows of wood pellets in 2010 that were larger than 10 kt. Table 2 shows the import and export to northwest Europe based on Eurostat statistics for wood pellets and production data from Sikkema et al (2011) and Cocchi et al. (2011). There are significant discrepancies between the net import and net export statistics indicating that these statistics are not free of errors. In this study, data that was obtained directly from utilities, for example via questionnaires conducted by IEA Bioenergy Task 40, was considered more accurate than the statistical data from EUROSTAT. For example, EUROSTAT reports that gross import of wood pellets in the Netherlands was 1.0 Mton in 2010 as shown in Table 2. Based on interviews with utilities, IEA Bioenergy Trade Task 40 estimated that the gross import of biomass in 2010 was almost 1.6 Mton in 2010 (Goh, Junginger et al. 2011). In this study, data directly derived from industries by IEA Task 40 was considered more reliable and therefore used when available (Figure 4).

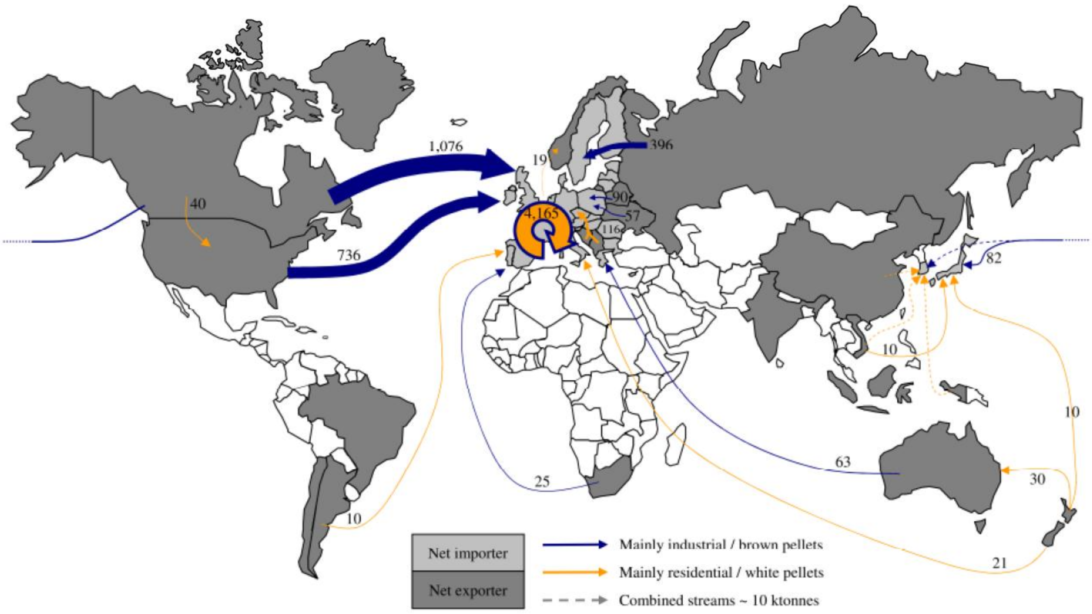


Figure 3 Wood pellet trade flows (> 10 kt/year) in 2010 (Lamers, Junginger et al. 2012)

Table 2 Wood pellet trade, production and markets in northwest Europe in 2009 and 2010 (Sikkema, Steiner et al. 2011, EUROSTAT 2012, Cocchi, Nikolaisen et al. 2011).

	Unit	Belgium		Denmark		Germany		Netherlands		United Kingdom	
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Import	kton	453	316	879	1445	71	270	960	1025	45	551
Of which:	%	United States: 41%	United States: 27%	Estonia: 26%	Estonia: 17%	Austria: 20%	Denmark: 30%	Canada: 43%	Canada: 50%	Estonia: 41%	Canada: 56%
	%	Canada: 19%	Canada: 24%	Latvia: 12%	Latvia: 14%	Czech Republic: 19%	Russia: 12%	United States: 33%	United States: 34%	Finland: 15%	United States: 34%
	%	Netherlands: 14%	Netherlands: 23%	Sweden: 11%	Russia: 11%	Russia: 10%	Latvia: 10%	Portugal: 7%	Australia: 6%	Portugal: 14%	Portugal: 6%
	%	Others: 26%	Others: 26%	Others: 50%	Others: 57%	Others: 50%	Others: 49%	Others: 17%	Others: 9%	Others: 30%	Others: 4%
Intra-EU	kton	127	144	746	1119	53	183	167	30	42	40
Extra-EU	kton	326	172	132	327	18	88	792	995	3	511
Export	kton	29	38	17	35	740	741	58	135	12	60
Of which:	%	Netherlands: 62%	Netherlands: 49%	Germany: 70%	Germany: 88%	Spain: 23%	Denmark: 21%	Belgium: 64%	Germany: 61%	Netherlands: 74%	Denmark: 93%
	%	Germany: 17%	France: 26%	Sweden: 12%	Sweden: 9%	Denmark: 14%	Italy: 21%	Germany: 21%	Belgium: 24%	Sweden: 23%	Netherlands: 7%
	%	France: 13%	Luxembourg: 14%	United Kingdom: 10%	Finland: 2%	Sweden: 12%	Austria: 16%	Denmark: 6%	United Kingdom: 7%	Spain: 1%	Ireland: 0%
	%	Others: 8%	Others: 11%	Others: 8%	Others: 1%	Others: 50%	Others: 43%	Others: 9%	Others: 8%	Others: 2%	Others: 0%
Intra-EU	kton	29	38	17	35	710	707	58	135	12	60
Extra-EU	kton	0	0	0	0	30	34	1	0	0	0
Production	kton	326	289	180	138	1560	1700	120	164	138	197
Net import	kton	424	278	862	1410	-669	-471	902	890	33	491
Consumption	kton	750	567	1042	1548	891	1229	1022	1054	171	688
Main market		Large scale power		Bulk district heating		Bulk residential heating		Large scale power		Large scale power	

To provide insight in the markets and trade of wood pellets in northwest Europe, Figure 4 shows the amount of wood pellets used per country and per sector, the domestic production of wood pellets and the net import per country. The main markets for wood pellets in northwest Europe include large scale electricity generation (dedicated or co-firing), district heating (CHP or heat) and domestic heat. Belgium, the Netherlands and the UK are mainly bulk markets of wood pellets for electricity generation whereas Denmark has both a bulk market (CHP and large scale district heating) as well as small scale (domestic) use. In Germany almost all wood pellets are used for domestic heat from domestically produced pellets. Note that the Tilbury plant in the UK, started electricity generation from wood pellets in 2011. The amount of wood pellets increased therefore significantly between 2010 and 2011. Moreover, wood pellet statistics in the UK are incomplete.
Most pellets for small scale uses such as domestic heat are produced domestically or imported from neighbouring countries whereas bulk markets mainly import from overseas (Sikkema, Junginger et al. 2010). Also, the logistic supply chain of large bulk centralized and small scale decentralized (mainly bags) and the related cost are very different (Sénéchal, Grassi 2009, Sikkema, Junginger et al. 2010).

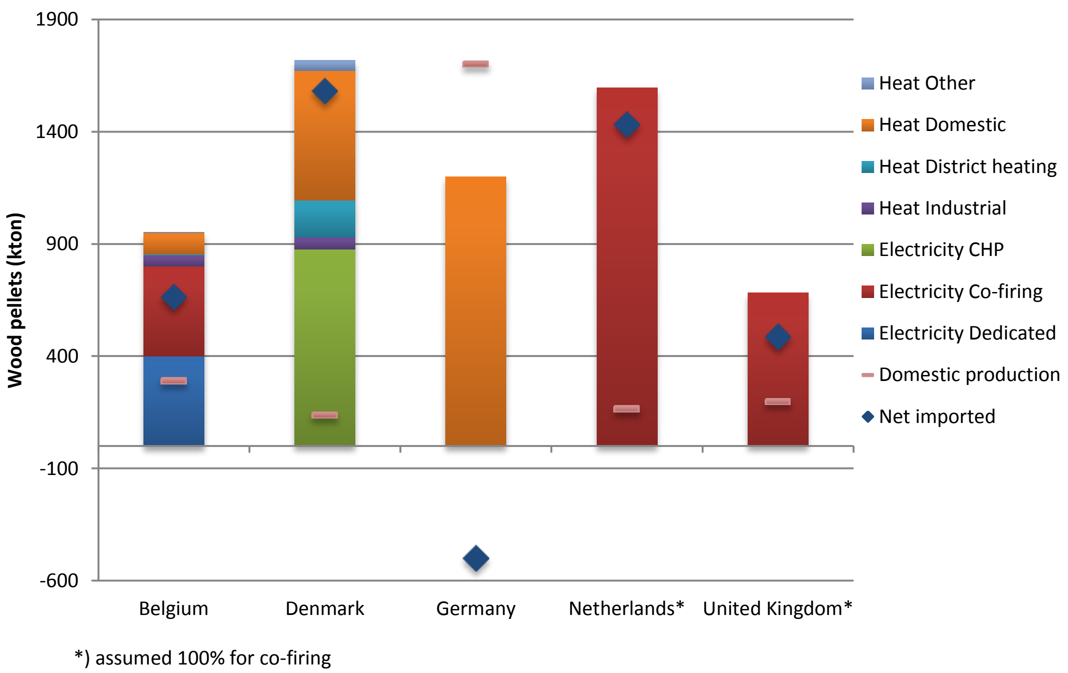


Figure 4 Wood pellet consumption per sector, domestic production and import (negative = export) in northwest Europe in 2010. Based on Chocchi et al. .

The data from Figure 4 is also provided in Table 6 in appendix A.

3.2 Drivers, policies and outlook

In order to increase the share of renewable energy, different support measures that mainly apply to electricity generation have been implemented in the EU-27. Quota obligations, combined with feed-in tariffs for small-scale projects are applied in Belgium and the UK. In Denmark and the Netherlands, Feed in premium systems are applied whereas in Germany, a feed-in tariff system is applied (Figure 5). Renewable heat is mainly supported via tax exemptions or investment grants (Ragwitz, Held et al. 2011). These support systems and the future changes of these systems are important for the potential of renewable energy and the potential share of bioenergy as discussed in more detail in the following subsections.

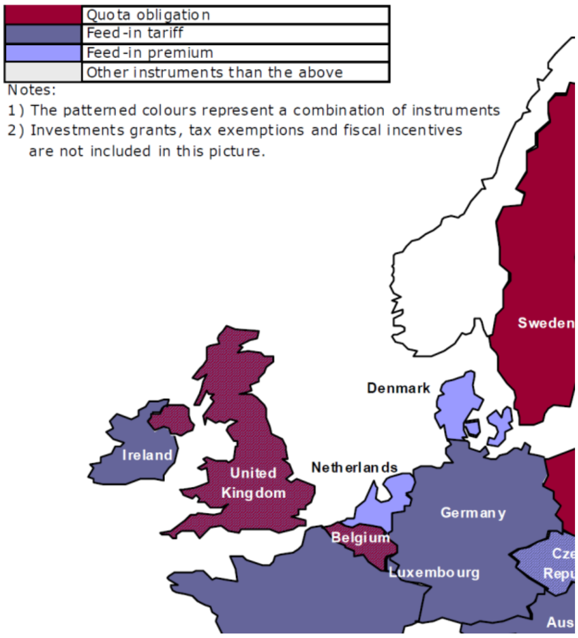


Figure 5 Most important support instruments for renewable electricity in northwest Europe (Ragwitz, Held et al. 2011)

3.2.1 Belgium

Electricity from renewable energy in Belgium is stimulated via the Green Certificate Scheme (GEC) that obliges electricity suppliers to deliver a number of Green Certificates or pay a penalty. The system is different in Wallonia, Brussels region and Flanders. In Flanders, Green Certificates for electricity are calculated based on the avoided fossil energy in the supply chain. In Wallonia and Brussels region, the Green Certificates are calculated based on the amount of greenhouse gases avoided based on a fossil reference plant (natural gas combined cycle with an efficiency of 55%). Because the CO_2 intensity of the fossil reference plant is relatively compared to a coal fired power plant for co-firing, co-firing only qualifies for Green Certificates if the biomass to coal ratio is at least 70% (mass based). To receive GC the 80 MWe coal fired power plant Les Awirs, Unit 4 in Wallonia was converted to 100% biomass (Stappen, Marchal et al. 2007). From 2010 onwards, the GEC support for co-firing was reduced to 50% whereas the support for dedicated plants remained 100% (Cocchi, Nikolaisen et al. 2011). Heating and small scale electricity is supported by a fiscal tax reduction for home-owners when they install a pellet boiler and enterprises who invest in renewable energy for biomass electricity CHP or heat (Cocchi, Nikolaisen et al. 2011).

3.2.2 Denmark

In Denmark, the main drivers for pellet consumption are tax exemptions and binding targets on the use of renewable energy for utilities. The CHP plant Avedøre II started production of electricity and heat from biomass in 1993 and had a major impact on the total pellet demand in Denmark (Cocchi, Nikolaisen et al. 2011).
Denmark estimates that the demand of wood for bioenergy production will increase from 77 PJ in 2006 to 109 PJ in 2020. The increase in wood demand (32 PJ) is expected to be mainly covered by wood pellets that will be used in central CHP plants. Currently, most wood pellets are imported from EU countries, but Denmark expects that non-EU countries might also become important for pellet supply (NREAP Denmark).

3.2.3 Germany

In contrast to the other countries in northwest Europe, the Germany feed-in tariff system in the Renewable Energy Act (EEG) only supports small biomass systems (up to 20 MWe) and only systems that generate 60% in CHP. Large scale stand-alone electricity and co-firing of biomass is therefore not supported. Nevertheless, Germany has a fast growing pellet for pellet boilers and stoves for small and medium scale systems as shown in Figure 6. The main drivers for the growth of small-scale systems are the Market incentive Programme (MAP) and the Renewable Energies Heat Act (EEWärmeG) (Cocchi, Nikolaisen et al. 2011). Despite the rapid growth, Germany is still a net exporting country of wood pellets and exported about 500 kton wood pellets in 2010 to other countries within Europe (Figure 4 and Table 2).

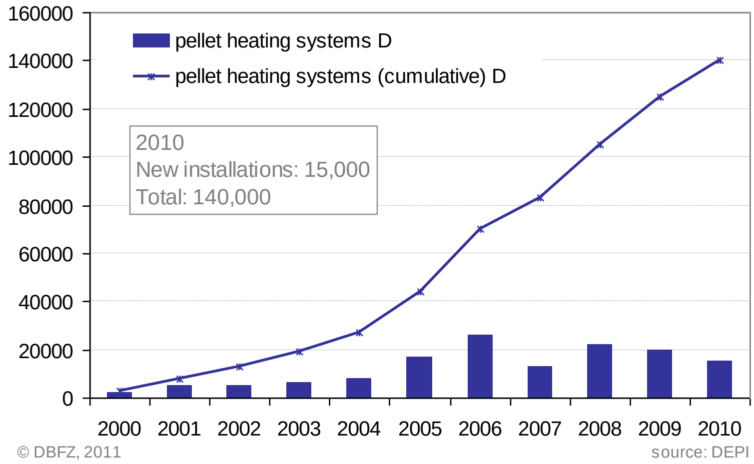


Figure 6 deployment and cumulative number of pellet heating systems in Germany (Cocchi, Nikolaisen et al. 2011)

A recent study initiated by the German Energy Agency (DENA) estimated that, if German coal plants would co-fire 10% biomass, around 7 Mt wood pellets would be required. Because it is considered a cost-efficient method to increase the share of renewable energy, Germany might support co-firing if it cannot meet the RES 2020 targets otherwise. In this study, a sensitivity scenario with co-firing in Germany will be included.

3.2.4 Netherlands

In the Netherlands, renewable electricity generation is stimulated with a feed-in premium system. The incentive scheme for sustainable energy production (SDE and SDE+) are the successor of the feed-in premium system MEP (Milieukwaliteit Electriciteitsproductie) that did not allow for new projects after 2006. The important difference between the MEP and SDE is that the SDE excludes large scale electricity generation and supports the production of green gas that is injected into the grid. The latest schemes, including co-firing) under the MEP will continue up to 2012-2014. Currently, a mandatory co-firing for electricity suppliers is being discussed with a share of 10% biomass. However, no final decisions have yet been made (Cocchi, Nikolaisen et al. 2011).
In the NREAP of the Netherlands, co-firing is an important system to meet the RES 2020 targets. The Netherlands estimates that total electricity generation from co-firing will increase from 3.1 TWh in 2010 to 8.5 TWh in 2020 which is more than 50% of total renewable electricity generation from biomass and 17% of total renewable electricity generation in the Netherlands in 2020.

3.2.5 United Kingdom

The UK supports the use of biomass for electricity generation via the Renewable Obligation, the Electricity Market Reform and the Feed in Tariff (Cocchi, Nikolaisen et al. 2011). The Renewable Obligation (RO) has to be met by electricity suppliers in the United Kingdom via a minimum amount of Renewable Obligation Certificates (ROCs). If a supplier cannot meet the number of required certificates in the obligation period, it has to pay an equivalent amount to a fund. Based on the renewable technologies and type of fuel, specific bands are laid down by the government with specific numbers of ROCs per MWh generated.

Other important support systems are the Feed-in tariff system that was introduced in 2010 and the Renewable Heat Incentive (RHI) that was introduced in 2011. The aim of the RHI is to increase production of renewable heat to 57 TWh and to save 44 Mt carbon by 2020 (Cocchi, Nikolaisen et al. 2011).

At its introduction in 2002, support of renewable energy in the UK was technology neutral with each MWh of renewable energy generated receiving the same amounts of support. In 2009, banding was introduced with different levels of support for different renewable energy technologies. At this moment, banding levels for the period 2013 – 2017 are being reviewed that will become affective in April 2013. There are some important changes to the support levels and banding of large scale electricity generation that have been published recently. The UK government now incentivizes full conversion of coal-fired power plant units to 100% biomass by introducing a new band for biomass conversions as was already proposed by the Department of Energy and Climate Change (DECC). The current and decided new support levels are shown in Table 3.

Biomass is expected to contribute significantly to total electricity generation and the RES 2020 targets with estimated shares of 5 – 11% (20 – 40 TWh). After 2020 however, DECC expects that biomass electricity generation will decrease rapidly due to the need for 'hard-to-decarbonize' sectors such as shipping and aviation. Furthermore, coal-to-biomass plants are expected to phase out before 2030 (DECC 2012).

According to the NREAP of the UK, domestic biomass supply, if fully developed, could be sufficient to meet the total demand for heat and power to 2020. Because biomass is increasingly becoming a globally traded commodity, it is expected that the UK will also import biomass. No estimations have been made on the share of domestic and imported biomass in 2020 for the NREAP of the UK.

Table 3 Current support and post-consultation decisions of bandings of solid biomass technologies (DECC 2012).

Renewable electricity technologies	Current support (2012-2013) ROCs per MWh	Post-consultation decisions	
		Level of support (ROCs per MWh)	Comment and other changes
Biomass conversion	No current band but 1.5 ROCs under current banding arrangements	1	New band. Unit by unit approach. No energy crops uplift. Change to definition of relevant fossil fuel generating station.
Biomass conversion with CHP	No current band but 2 ROCs under current banding arrangements	1.5 in 2013/14 and 2014/15	New band. Unit by unit approach. No energy crops uplift. Change to the definition of relevant fossil fuel generating station. Close band to new accreditations from 1 April 2015.
Co-firing of biomass (standard)	0.5	Solid and gaseous biomass (less than 50% biomass co-fired in a unit): 0.3 (proposed) in 2013/14 and 2014/15; 0.5 from 2015/16. Bioliquids (less than 100% biomass co-fired in a unit): 0.3 (proposed) in 2013/14 and 2014/15; 0.5 from 2015/16.	Unit by unit approach. ROC levels in 2013/14 and 2014/15 subject to further consultation.
Co-firing of biomass (enhanced)	No current band but 0.5 ROCs under current banding arrangements	Mid-range co-firing (50-less than 85%): 0.6 High-range co-firing (85-less than 100%): 0.7 in 2013/14; 0.9 from 2014/15	New band. Unit by unit approach. Excludes bioliquids (other than energy crops). Cost control mechanism to be introduced, subject to consultation
Co-firing of biomass with CHP (standard)	1	0.5 ROC uplift in addition to prevailing ROC support available to new accreditations until 31 March 2015	Unit by unit approach. Close band to new accreditations from 1 April 2015.
Co-firing of biomass with CHP (enhanced)	No current band but 1 ROC/MWh under current banding arrangements	0.5 ROC uplift in addition to prevailing ROC support available to new accreditations until 31 March 2015	New band. Unit by unit approach. Close band to new accreditations from 1 April 2015.
Co-firing of energy crops (standard)	1	0.5 ROC uplift in addition to prevailing ROC support for co-firing of biomass (standard). No uplift available for mid-range or high-range co-firing.	Band to be closed, subject to consult-ation. Unit by unit approach. Changes to definition of energy crops.
Co-firing of energy crops with CHP (standard)	1.5	0.5 ROC uplift in addition to prevailing ROC support for co-firing of energy crops (standard). Band not available for mid-range or high-range co-firing.	Band to be closed, subject to consultation Unit by unit approach. Changes to the definition of energy crops. Close band to new accreditations from 1 April 2015.
Dedicated biomass	1.5	1.5 until 31 March 2016; 1.4 from 1 April 2016	Introduction of a supplier cap, subject to consultation
Dedicated biomass with CHP	2	2 in 2013/14 and 2014/15	Changes proposed to add fossil derived bioliquids, to exclude biomass conversion and to close this band to new accreditations from 1 April 2015
Dedicated energy crops	2	2 in 2013/14 and 2014/15; 1.9 in 2015/16 and 1.8 in 2016/17	Changes to the definition of energy crops
Dedicated energy crops with CHP	2	2 in 2013/14 and 2014/15; 1.9 in 2015/16 and 1.8 in 2016/17	Changes to the definition of energy crops.

3.3 Share of biomass in the National Renewable Action Plans

Based on the NREAP data, as collected by ECN (2011), the final energy demand for heat and electricity generation is depicted in Figure 7. By using current and future expected conversion efficiencies for heat, CHP and electricity plants, the total primary demand for biomass was calculated as shown in Figure 8 because most member states of the EU-27 did not include these estimates in the NREAPs. The assumed conversion efficiencies and methodology to calculate the primary demand for biomass are explained in the appendix of Hoefnagels et al. (2011).

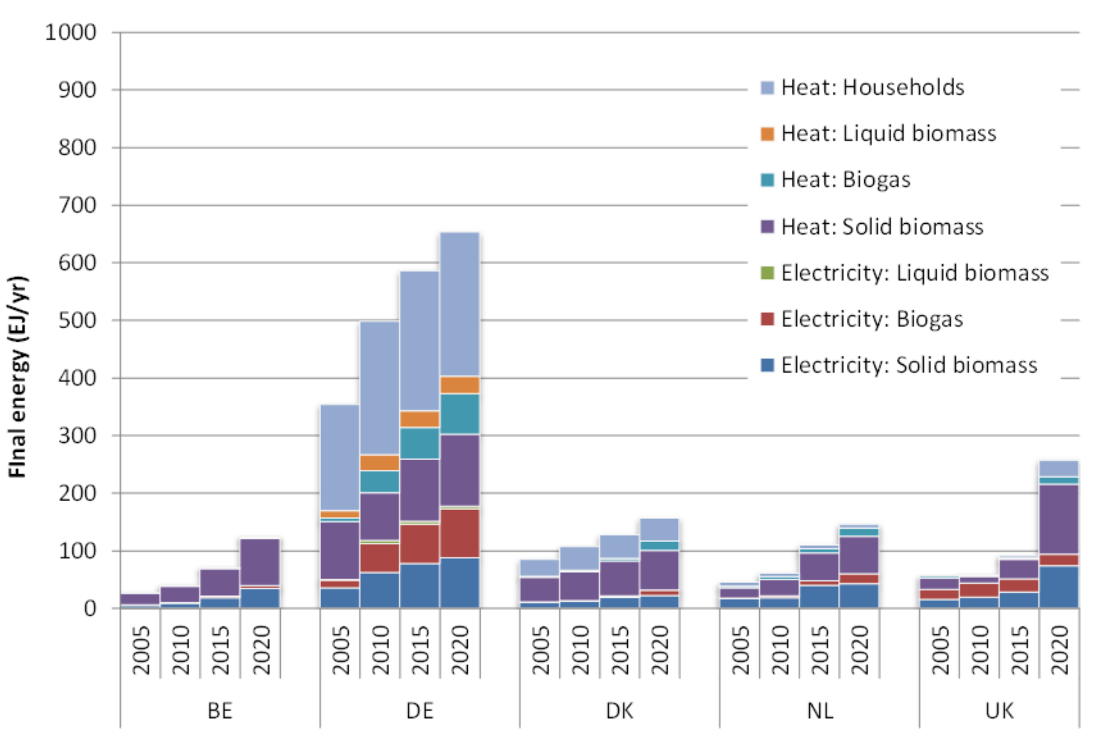


Figure 7 Final energy production (heat and electricity) from biomass in the NREAPs of northwest Europe in 2020.

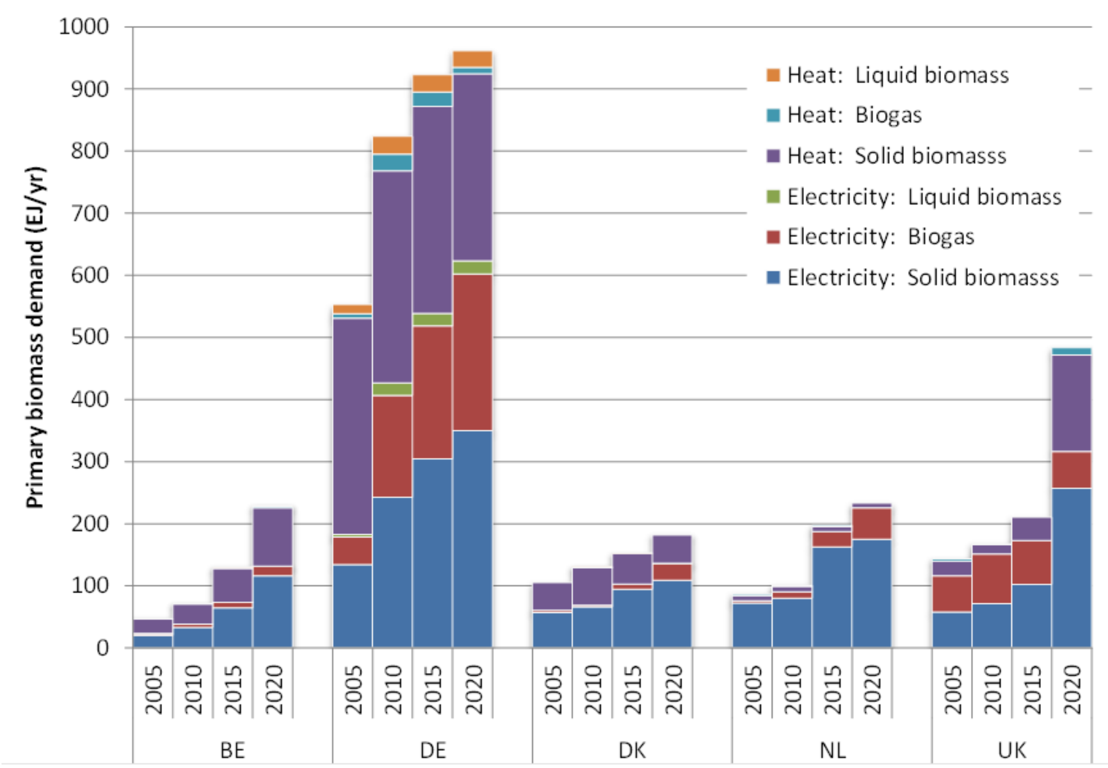


Figure 8 Primary biomass demand for heat and electricity generation, calculated based on final energy projections in the NREAPs in 2020.

4 Assumptions and background information

This study builds on existing pathway projections of the development of renewable energy in the EU-27. These projections were made using the Green-X model for the Re-Shaping project (Ragwitz, Steinhilber et al. 2012). Parts of the input assumptions of the Green-X model were based on the PRIMES reference scenario (Section 4.1). The Green-X projections are covered in section 4.2.

4.1 Input assumptions from the PRIMES Reference scenario (2011)

The PRIMES Reference scenario, 2011 (NTUA 2011) is the most recent scenario update that includes the full implementation of legislations on the ETS, renewable energy and energy efficiency. This scenario is covered in the Energy Roadmap 2050 of the European Commission (EC 2011b).

4.1.1 Macro-economic assumptions

The projections on macro-economic developments in the EU-27 take the recent crisis into account followed by gross domestic product (GDP) growth from 2010 onwards similar to the baseline scenario (update 2009) (EC 2010) of the EU Energy Trends to 2030. The crisis was estimated to have a long term effect on the economy with a slow recovery in the period 2005-2010 (0.6% GDP growth/year) followed by an increasing GDP growth of 2% per year to 2030 (EC 2011b). These macro-economic assumptions have a large impact on the final energy demand for transport, electricity and heat, but sensitivities on GDP growth and related effects on the total demand for bioenergy are uncertain. However, because existing scenarios are used in this study that uses the same macro-economic assumptions, it is not possible to assess the impact of GDP growth on the demand of bioenergy in this study.

4.1.2 Energy prices

International energy price projections in the Energy Roadmap 2050 for coal, gas and oil are based on the PROMETHEUS stochastic world energy model as shown in Figure 9. Consistent fossil fuel price assumptions are used in the Green-X model and in this study. **Oil** is estimated to increase from 85 $\$_{2008}$/bbl (barrel of oil) to 88 $\$_{2008}$/bbl in 2020 and 106 $\$_{2008}$/bbl in 2030. **Natural gas** prices are estimated to increase almost parallel to the projected oil price trend from 53 $\$_{2008}$/boe (barrel of oil equivalent, 6.12 GJ) in 2010 to 62 $\$_{2008}$/boe in 2020 and 77 $\$_{2008-}$/boe in 2030. For **Coal**, a more moderate price development was projected with prices projected to increase from 23 $\$_{2008}$/boe in 2010 to 29 $\$_{2008}$/boe in 2020 and 33 $\$_{2008}$/boe in 2030. These prices are similar to the EU Energy Trends to 2030 baseline scenario (update 2009) (EC 2010).
Although energy prices fluctuate and future projections are uncertain, all scenarios used in this study are based on similar price projections for fossil fuels. If fossil fuel prices would increase, bioenergy could become more competitive compared to fossil fuels. Note however that the scenarios in this study depend heavily on policies for renewable energy. If higher or lower fossil fuel prices would be assumed, this would have a direct impact on the required levels of support, but would have a less pronounced effect on the deployment levels of renewable energy.

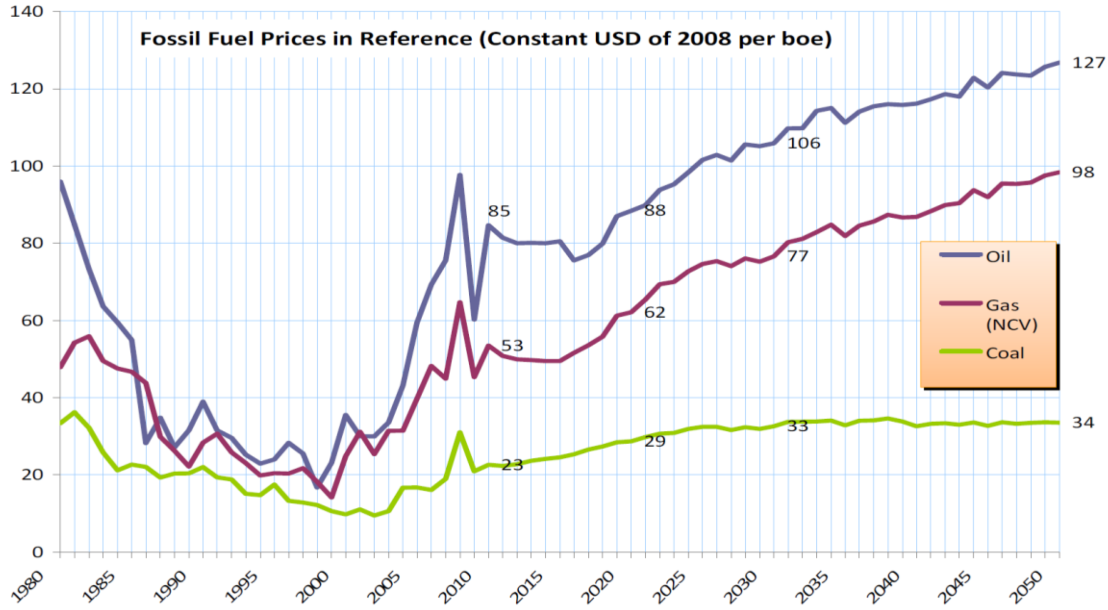


Figure 9 Fossil fuel import price assumptions (EC 2011b)

4.2 Green-X renewable energy scenarios

For this study, three scenario cases projected with the Green-X model were selected that were made for the Re-Shaping project (Ragwitz, Steinhilber et al. 2012). These scenario cases were selected because they take recent policy developments into account and represent the spread on deployment of renewable energy in the EU-27 based on different policy variants. These scenarios build on the PRIMES reference case (Section 4.1) for sectoral energy demand, primary energy prices, conventional energy supply portfolio and efficiencies and CO_2 intensities per sector. A detailed description is provided on the Re-Shaping website: http://www.reshaping-res-policy.eu/.

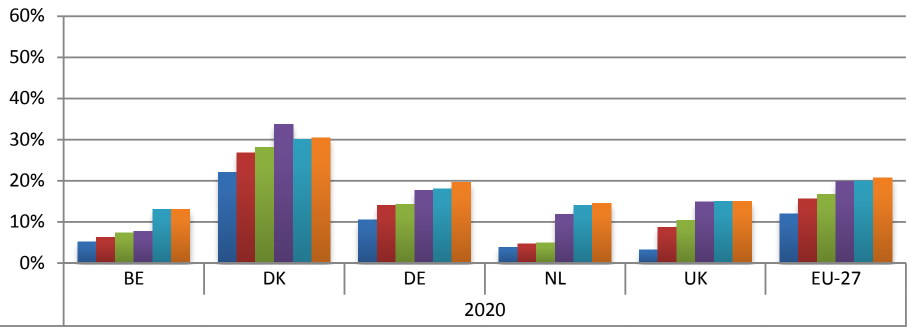
The scenarios are:

- **Business as usual (BAU):** continuation of current renewable energy support and policy instruments to 2030, but the RES-2020 targets will not be met.
- **Business as Usual, barrier mitigated (BAU-bm):** similar to the BAU scenario, a continuation of current policies is assumed, but non-economic barriers[2] will be mitigated.
- **Strengthened National Policies (SNP)***:* improvement and fine-tuning of current policies implemented to meet the RES 2020 targets. No changes in policies and support for renewable energy between 2020 and 2030.

Figure 10 and Figure 11 show the renewable energy shares in gross final energy demand in the Re-Shaping scenarios as projected with the Green-X model compared to the binding targets of the Renewable Energy Directive (2009/28/EC) and the and the PRIMES baseline projections used for the European energy trends to 2030 (EC 2010) and the PRIMES Reference and PRIMES high renewables, used for the Energy Roadmap 2050 (EC 2011a). A detailed comparison of these scenarios with each other and with the NREAPs for the EU-27 is provided in Ragwitz et al. (Ragwitz, Steinhilber et al. 2012).

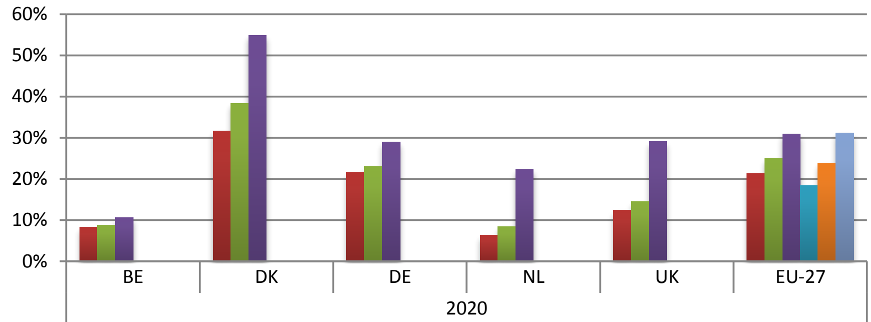
[2] Despite sufficient financial support, the deployment of renewable energy is hampered for reasons that are not directly linked to financial support. These non-economic barriers include: administrative deficiencies, administrative deficiencies (e.g. a high level of bureaucracy), diminishing spatial planning, problems associated with grid access, possibly missing local acceptance, or even the nonexistence of proper market structures (Resch et a. 2008)(Resch, Faber et al. 2008).

The projections show that current support and policies for renewable energy, as implemented in the BAU scenario, are not sufficient to meet the RES targets for 2020 (15.7% in 2020). Most member states overachieve their national targets in the NREAPs resulting in a total share of renewable energy of 20.7% in 2020 compared to 19.8% in the SNP scenario projected with Green-X. Although the SNP scenario aims to achieve the RES 2020 binding targets, renewable energy trade between member states results in lower country specific shares of renewable energy. In the Netherlands for example, the RES share increases to 11.8% in 2020 (binding target is 14.0%). The remaining share is projected to be produced in other member states.



	BE	DK	DE	NL	UK	EU-27
Current (2010)	5.1%	22.1%	10.5%	3.8%	3.2%	11.9%
BAU	6.3%	26.8%	14.0%	4.7%	8.7%	15.7%
BAU-BM	7.3%	28.2%	14.3%	5.0%	10.4%	16.8%
SNP	7.6%	33.7%	17.7%	11.8%	14.8%	19.8%
Binding RES target	13.0%	30.0%	18.0%	14.0%	15.0%	20.0%
NREAPs (tables 1-4)	13.0%	30.5%	19.6%	14.5%	15.0%	20.7%

Figure 10 Share of renewable energy in northwest Europe and the EU-27 in 2010 and 2020 in the Re-Shaping scenarios (Ragwitz, Steinhilber et al. 2012)**, the NREAPs and the binding targets in the 2009/28/EC directive** (EREC 2011)**.**



	BE	DK	DE	NL	UK	EU-27
BAU	8.3%	31.6%	21.8%	6.4%	12.4%	21.4%
BAU-BM	8.7%	38.4%	23.1%	8.4%	14.5%	25.0%
SNP	10.7%	54.9%	29.0%	22.5%	29.1%	30.9%
PRIMES baseline						18.40%
PRIMES reference						23.90%
PRIMES high renewables						31.20%

Figure 11 Share of renewable energy in northwest Europe and the EU-27 in 2030 in the Green-X scenarios and PRIMES Energy Roadmap 2050 scenarios (Ragwitz, Steinhilber et al. 2012)**.**

4.3 Biomass supply potential

4.3.1 Introduction

Northwest Europe is one of the net largest importing regions of solid biomass for renewable energy generation from both European and inter-continental regions (Section 3.1). The future global supply potential that is available for Europe will therefore be important as these countries expect to import increasing amounts of biomass in the future. For this study, the global supply potential is assessed per region that is available for export and use for heat and electricity. Therefore, we use the following priority scheme:

1. Land area to produce biomass for food, feed and fibre and residues used for non-energy use;
2. Domestic demand for bioenergy (RES-E, RES-H, RES-T);
3. Export demand for the production of 1st and 2nd generation biofuels[3]
4. Export potential of solid biomass for heat and electricity.

The priority scheme implies that no land required for food, feed or fibres will be used for bioenergy production and no land or no residues required for domestic demand of bioenergy will be used for export.

4.3.2 Technical potential of biomass

First, the future technical potential that is available taking competing land uses as well as technical and non-technical constraints and into account (see Box 1). The technical potential of for the following resources is considered:

- Dedicated energy crops
- Residues from agriculture
- Forestry products
- Forestry residues

The future potential of biomass available for bioenergy is inherently complex and uncertain resulting in large ranges between future potentials from zero (no biomass available for bioenergy) to over 1500 EJ of primary biomass technically available for bioenergy in 2050 (Smeets, Faaij et al. 2007, IPCC 2011). These large ranges between different studies and scenarios are mainly related to methodologies applied, the type of potential, the types of biomass included and datasets used.

Box 1: types of bioenergy potentials

There are basically three types of biomass potentials (Smeets, Faaij et al. 2007, Vis, Berg 2010): i) the theoretical potential, ii) the technical potential and iii) the market (economic) potential. The theoretical potential defines the potential that could be produced only taking bio-physical limits into account. The technical potential defines the fraction of the theoretical potential taking technical limitations and non-technical constraints into account as well as competition with other uses of land and biomass (e.g. food, feed and fiber production). If to the technical potential also restrictions related to biodiversity, soil and water are taken into account; it is also called the sustainable potential. The market or economic potential includes the fraction of the technical potential which is economically feasible to produce (e.g. relative to fossil fuel prices, other renewable technologies, CO_2 prices). Alternatively, when economic, institutional

[3] The distinction between 1st and 2nd generation biofuels is important because 1st generation biofuels (food crops) have significantly lower yields compared to 2nd generation biofuels (lignocellulosic crops and residues). Technology development and related diffusion rate of 2nd generation biofuels will therefore also impact the supply potential of biomass for electricity and heat production.

and social constraints and policy incentives are included, the amount that can be implemented in a certain time frame is defined as the implementation potential (Batidzirai, Smeets et al. 2012). The hierarchic reduction in potential from the highest (technical potential) to the lowest (implementation potential) and the overlap between market and ecological potential are depicted in Figure 12. The axis in Figure 12 are dimensionless, but could represent for example ecological criteria and economic availability resulting in different overlaps between the market and ecologic potential. Note that combinations of these potentials are also possible (e.g. economic-implementation potential).

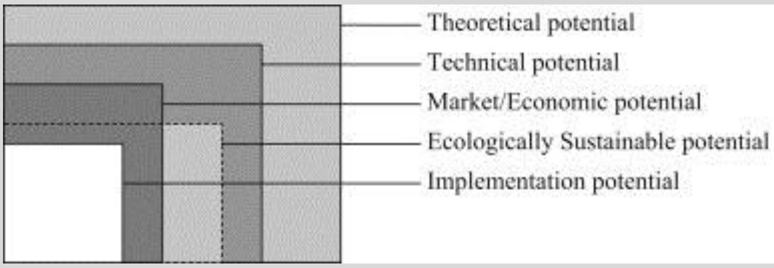


Figure 12 Overlap between theoretical, technical and market potentials (Batidzirai, Smeets et al. 2012)

To illustrate the differences between different studies, Figure 13 shows the estimated technical potential of bioenergy and the deployment potential based on based on an expert review of available literature from the IPCC SRREN (IPCC 2011) for 2050. Currently about 50 EJ of biomass is used for bioenergy of which 11.3 EJ is used for modern purposes (electricity, CHP, modern heating or transport fuels) and based on an expert review of available literature, the IPCC estimated that the deployment potential would be 100 - 300 EJ in 2050 (IPCC 2011). As the focus of this study is to 2030, we also included the global projected demand of biomass in 2030 according to the IEA World Energy Outlook 2011 current policies (lower range) and 450 scenarios (upper range) in Figure 13. These demand projections are used to identify potential regions with surplus or deficits in domestic biomass supply.

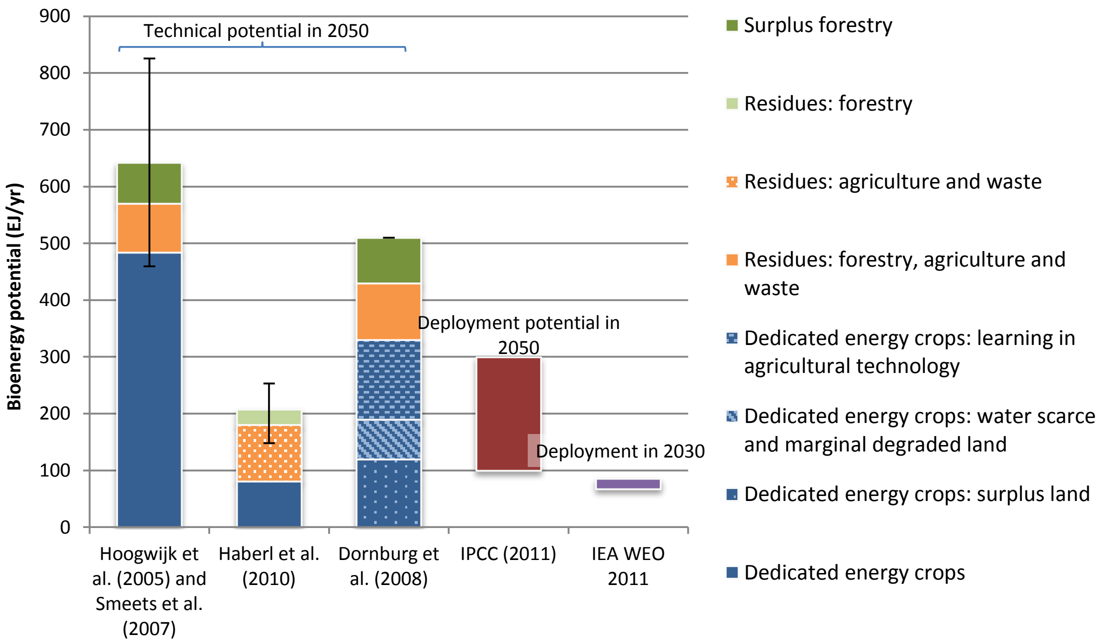


Figure 13 Technical potential of bioenergy in 2050 as assessed by Hoogwijk et al. (2005) **for dedicated energy corps and Smeets et al.** (2007) **for residues and waste, Haberl. et al.** (2010) **and Dornburg et al.** (2008)**, the deployment potential**

in 2050 (IPCC 2011) **and the projected deployment of biomass and waste in the current policies and 450 scenario of the IEA World Energy Outlook 2011** (IEA CCC 2012)

The differences between the technical potentials in Figure 13 are to a large extend related to the supply potential of dedicated energy crops produced on surplus agricultural land, abandoned crop land and water scarce and marginal degraded land and the inclusion of surplus forestry.
The supply potential of dedicated energy crops is determined by the available area and the specific yield of that area for specific crop types. The differences between studies and scenarios are mainly the result of differences in estimated available land and yield assumptions (Haberl, Beringer et al. 2010). Hoogwijk et al. (2005) estimated the technical potential of bioenergy crops for the four IPCC Special Report on Emission Scenarios (SRES). The total potential between the SRES scenarios in 2050 ranges from 311 - 657 EJ. Because residues from forestry and agriculture were not taken into account, estimated potentials were added from Smeets et al. (2007). Haberl et al. (2010) estimated that the global technical supply potential would be 160 to 270 EJ. More strict sustainability criteria and more conservative estimates on yield improvements and available land results in these more conservative estimated biomass potentials. Dornburg et al. (Dornburg, Van Vuuren et al. 2010, Dornburg, Faaij et al. 2008) reviewed several biomass resource assessment studies taking sustainability criteria into account. They estimated that over 500 EJ could be sustainably available supplied by 2050.
The SRREN also assessed the amount of biomass used globally using integrated assessment models (IAMs) for two greenhouse gas mitigation scenarios. Such models include other CO_2 mitigation technologies, CO_2 taxes and prices for fossil and bioenergy fuels. These models estimated that the total deployment of bioenergy would be 80 - 150 EJ for a medium ambitious climate policy scenario (440-600 ppm) and 118 to 190 EJ in case of a more stringent climate policy scenario (<440 ppm). These scenarios show that deployment levels are therefore mostly lower than the estimated technical potentials of bioenergy, but could also be close to the upper level of estimated potentials if conservative estimated potentials and high deployment levels are considered.

Box 3: geographic supply potential ranges

The geographic technical potential of biomass as estimated by Smeets et al. (2007) for residues and forestry growth and Hoogwijk et al. (2005) for energy crops is shown in Figure 14. The uncertainty bars show the differences in supply potentials for the different storylines of the IPCC SRES scenarios of which the IPCC SRES A2 (lower bound) and SRES B1 scenario (upper bound) show the largest ranges. The A2 scenario is characterized by low technology change, regional orientation, self-reliance and preservation of local identities with relatively high population growth. The B1 scenario, on the other hand, is characterized by global orientation and trade, relatively low population growth and high levels of technology development (IPCC 2011, Hoogwijk, Faaij et al. 2005). These different storylines of world development result in very different bioenergy supply potentials. Especially developing regions (for example sub-Saharan Africa) could become high potential supply regions, but are also very uncertain depending on how these regions might develop. Next to uncertainty in regional development, more conservative estimated potentials are shown in Figure 15 based on Haberl et al. (2010).

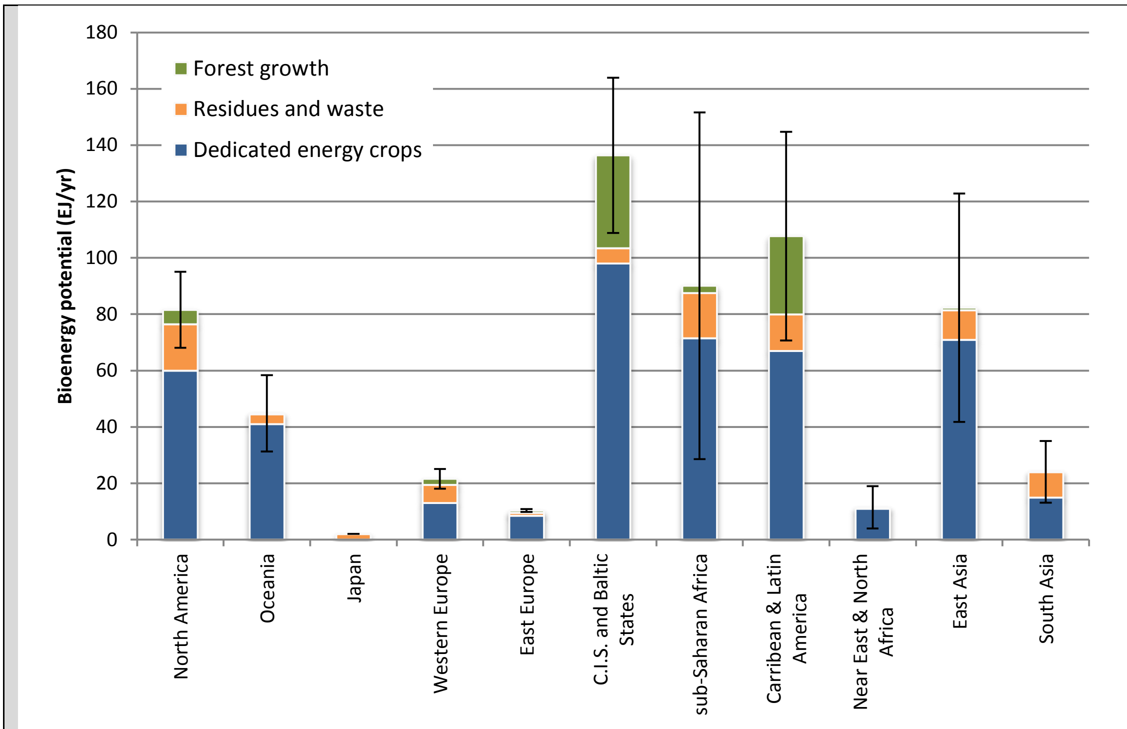


Figure 14 Average technical supply potential of energy crops (Hoogwijk, Faaij et al. 2005) **and residues, waste and surplus forestry** (Smeets, Faaij et al. 2007) **per region in 2050 of four scenarios and ranges of the total supply potential.**

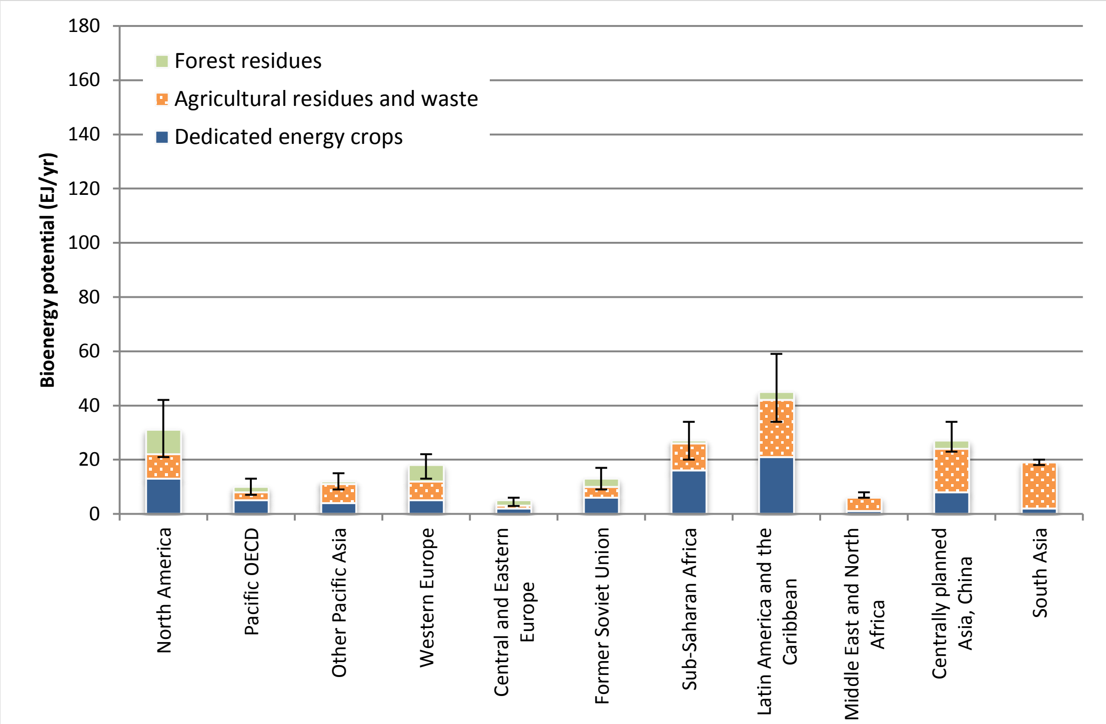


Figure 15 Technical potential of bioenergy per region in 2050 and uncertainty ranges of the total supply potential (Haberl, Beringer et al. 2010)**.**

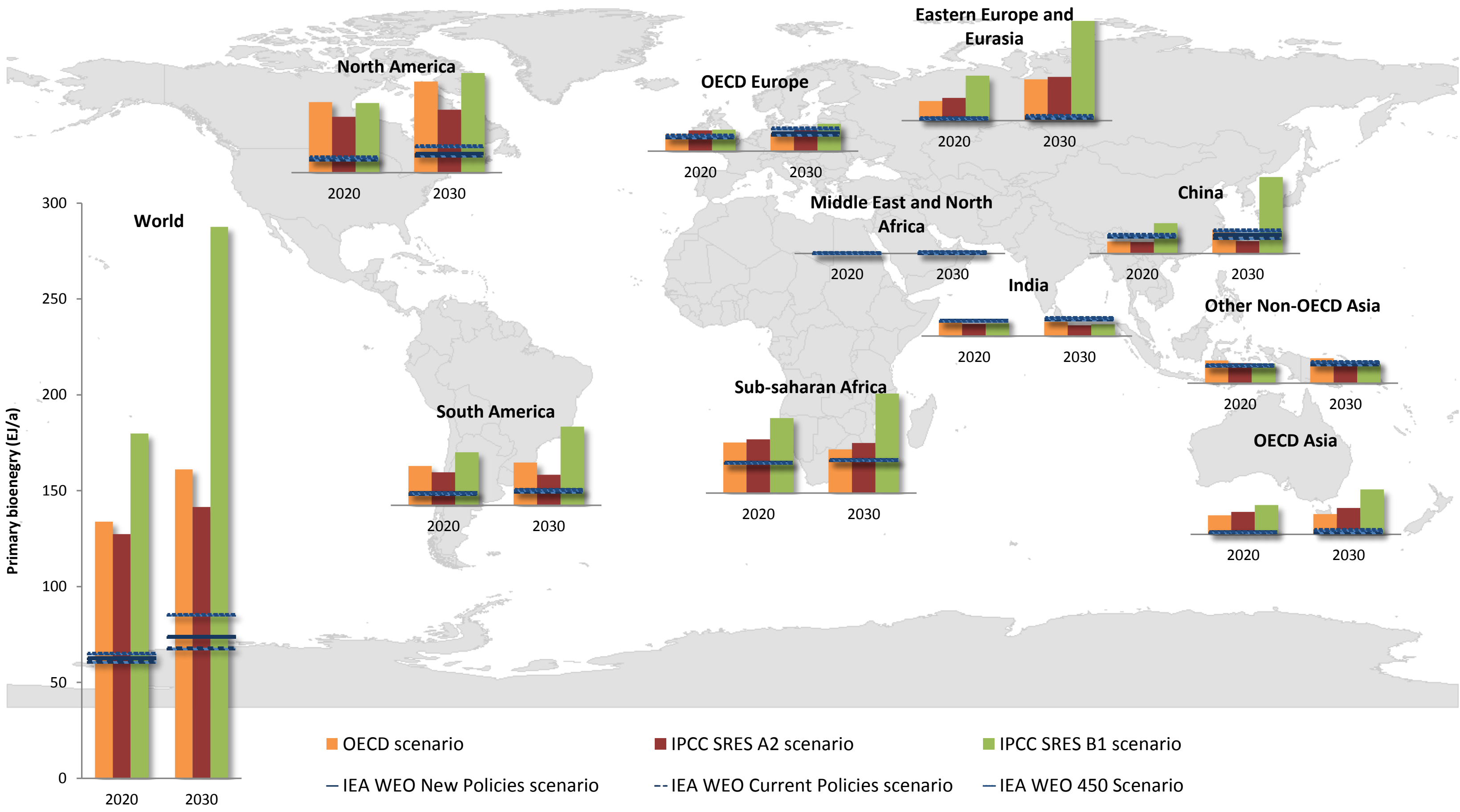


Figure 16 Technical supply potential of energy crops and residues in the OECD (van Vuuren, van Vliet et al. 2009) **and IPCC SRES A2 and B1 scenarios** (Hoogwijk, Faaij et al. 2005) **and demand of bioenergy and organic waste in the IEA World Energy Outlook 2011 scenarios** (IEA 2011)**.**

5 The scenarios

5.1 The core scenarios for biomass demand

For this study, three core scenarios are assessed based on the scenario projections for the EU-27 of the Re-Shaping project. These scenarios are:

- Business as usual (BAU)
- Business as Usual, barriers mitigated (BAU-bm)
- Strengthened National Policies (SNP)

5.1.1 Business as Usual (BAU)

The Business as Usual scenario (BAU) assumes that renewable energy policies that are currently implemented will remain applied to 2030, but without any adaptation. These assumptions are similar to the PRIMES baseline scenario (EC 2010). Primary energy prices, sectoral energy demand and CO_2 intensities, the conventional (non-renewable) portfolio and efficiencies are derived from the PRIMES baseline scenario. Also for co-firing of biomass, it is assumed that current implemented policies remain active, but unchanged.

5.1.2 Business as Usual – barriers mitigated (BAU-bm)

The BAU-Barriers mitigated scenario (BAU-bm) is similar to the BAU scenario, but non-economic barriers that hamper the deployment of renewable energy in the BAU scenario, are assumed to be mitigated in this scenario as explained in Section 4.2.

5.1.3 Strengthened national support (SNP)

In this scenario, also a continuation of national renewable energy policies is assumed, but these policies will be optimised for effectiveness and efficiency. Fine-tuning is required in order to meet the renewable energy 2020 target of 20% required by the European Commission. This scenario is based on the PRIMES reference case used in the Energy Roadmap 2050. The PRIMES reference scenario also assumes the fulfilment of the RES 20% targets for 2020. For the period after 2020, no targets are defined (Ragwitz, Steinhilber et al. 2012). Although policies are not assumed to change after 2020, both PRIMES and Green-X project increasing shares or renewable energy as show in Figure 10.

5.2 The demand sensitivity scenarios

To assess the impact of key parameters in the development of solid biomass demand, supply and trade, three sensitivity scenarios are included that assess the impact of policies specific to the support of co-firing and the impact of the restricted availability of non-European biomass sources. The sensitivity scenarios will be applied to the BAU scenario and the SNP scenario:

- *BAU – European biomass*
- *BAU – No co-firing support*
- *BAU - High co-firing support*
- *SNP –European biomass*
- *SNP - No co-firing support*
- *SNP - High co-firing support*

5.2.1 European biomass (BAU-EU and SNP-EU)

The supply of non-European biomass depends for a large extent on the domestic demand in exporting regions and the demand in other demand regions such as Asia. In these scenarios, it is assumed that large demand in non-EU countries and limited global sustainable biomass production, forces European countries to use biomass from other member states or neighbouring countries such as Ukraine and North-West Russia. This results in higher exploitation of domestic biomass and trade flows from East to Western Europe.

5.2.2 No co-firing support (BAU-NC and SNP-NC)
The continuous support for biomass co-firing is uncertain. In this scenario, policies that support co-firing of biomass will be phased out and replaced by policies that support stand-alone electricity and decentralized CHP and heat plants. This results in the deployment of biomass in smaller, decentralized conversion plants. Pulverized coal plants are assumed to shift to combustion of coal or will be decommissioned.

5.2.3 High co-firing support (BAU-HC and SNP-HC)
This scenario assumes that the potential of co-firing of biomass with coal will be fully used in Belgium, Denmark, the Netherlands and the UK as a result of high support for co-firing. For Germany, co-firing is assumed to be supported in plants that already use imported coal with existing transport infrastructure. Most lignite plants will therefore be excluded. The first quick scan of the co-firing potential in northwest Europe is described in Appendix C.

5.3 Renewable energy in northwest Europe

5.3.1 Final renewable energy generation in the core scenarios
Figure 17, Figure 18 and Figure 19 show the total electricity generation from renewables between 2010 and 2030 in northwest Europe as projected in the BAU, BAU-bm and SNP scenario respectively. The detailed country results are provided in Appendix B. The sensitivity scenarios will be based on the outcomes of the model that will be developed for this study and can therefore not be provided here.

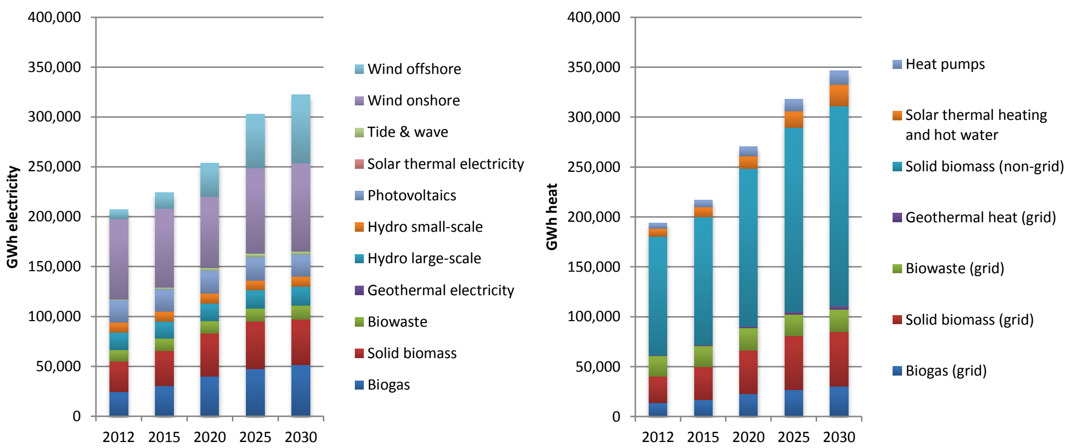


Figure 17 electricity generation (left) and heat generation (right) from renewable energy: the BAU scenario case.

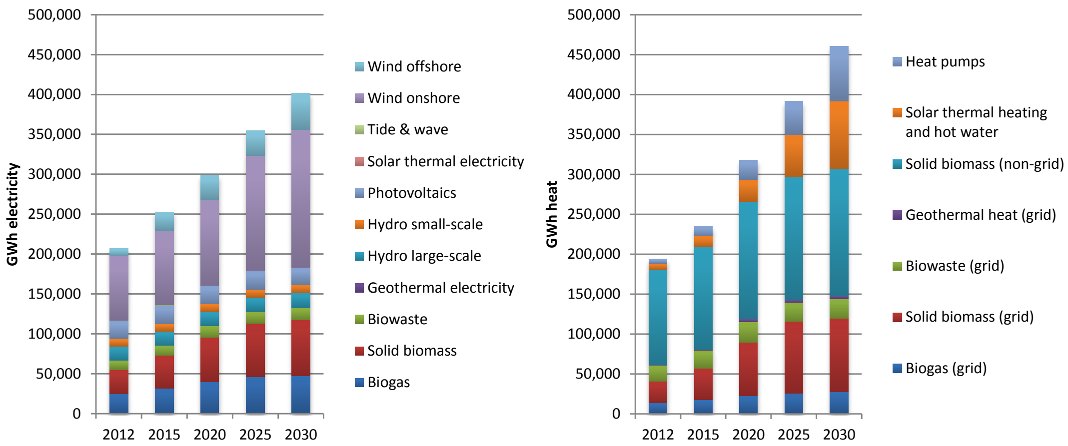


Figure 18 electricity generation (left) and heat generation (right) from renewable energy: the BAU-BM scenario case.

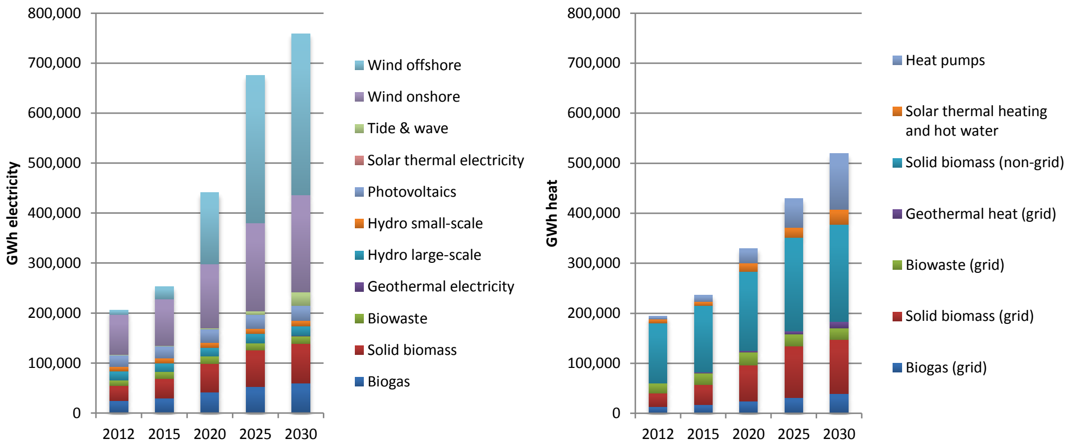


Figure 19 electricity generation (left) and heat generation (right) from renewable energy: the SNP scenario case.

5.3.2 Primary biomass demand in the core scenarios

Based on the total generation of final energy (heat and electricity) and the conversion efficiencies of bioenergy plants, the total demand for solid biomass and biogas was calculated in the Green-X model for the core scenarios. Because trade of solid biomass is mainly related to the use for centralized heat and electricity generation, the growth in primary biomass demand is also presented relative to 2010. Solid biomass use for households was excluded from these figures but is taken into account in the model. The detailed results are also presented in the data tables in Appendix B.

In the BAU scenario, primary biomass demand in northwest Europe increases from 1235 PJ in 2010 to 2176 PJ in the BAU scenario, 2284 PJ in the BAU-BM scenario and 2705 PJ in the SNP scenario as shown in Figure 20, Figure 22 and Figure 24 respectively. Solid biomass contributes the largest in the scenarios. The share of solid biomass increases from 63% in 20110, excluding organic waste and increases to 67% in the BAU-BM scenario and 80% in the SNP scenario. Note however that solid biomass for households (domestic heat), covers an important part of the total demand for solid biomass which is mainly sourced from local biomass. The relative growth of primary biomass demand is therefore shown for electricity generation and centralized heat only in Figure 20, Figure 22 and Figure 24 for the BAU, BAU-BM and SNP scenarios respectively.
In all scenarios, biomass for electricity generation and centralized heat is projected to increase. Despite the conservative ambitions in the BAU scenario,

the demand for solid biomass is projected to be 170% larger in 2030 compared to 2010 in the Netherlands and up to 203% in the SNP scenario for the Netherlands. Centralized heat is relatively small in northwest Europe and despite the large relative growth; absolute growth is small compared to solid biomass for electricity generation. The total solid biomass demand for centralized heat generation in northwest Europe increases from 27 PJ in 2010 to 76-131 PJ (4-7 Mt pellet equivalent)[4] in 2030 in the BAU and SNP scenarios respectively whereas the demand for electricity generation increases to 540 - 911 PJ (31-52 Mt wood pellet equivalent) for the same scenarios in 2030.

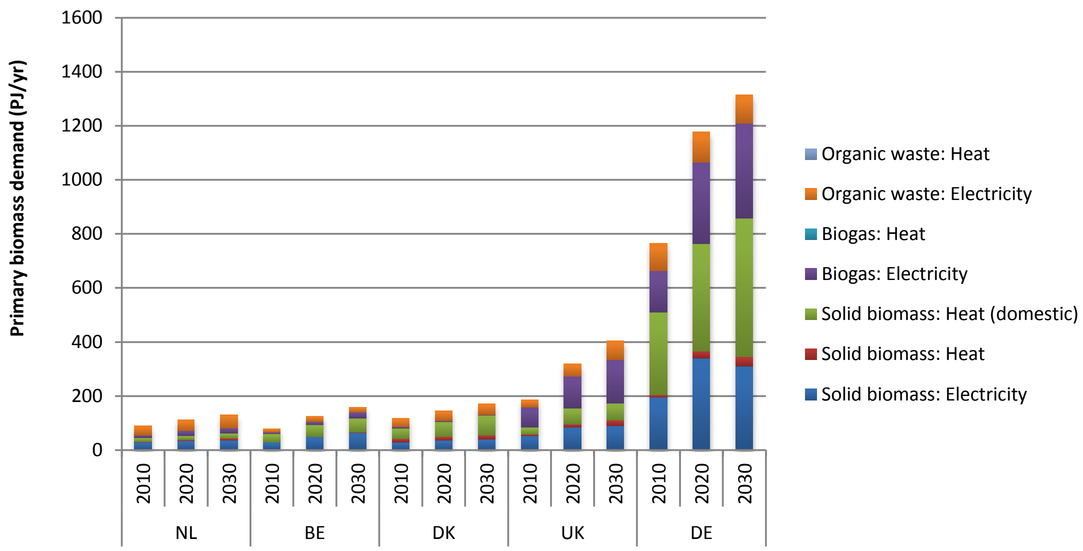


Figure 20 Total primary demand of solid biomass for electricity and heat in the BAU scenario.

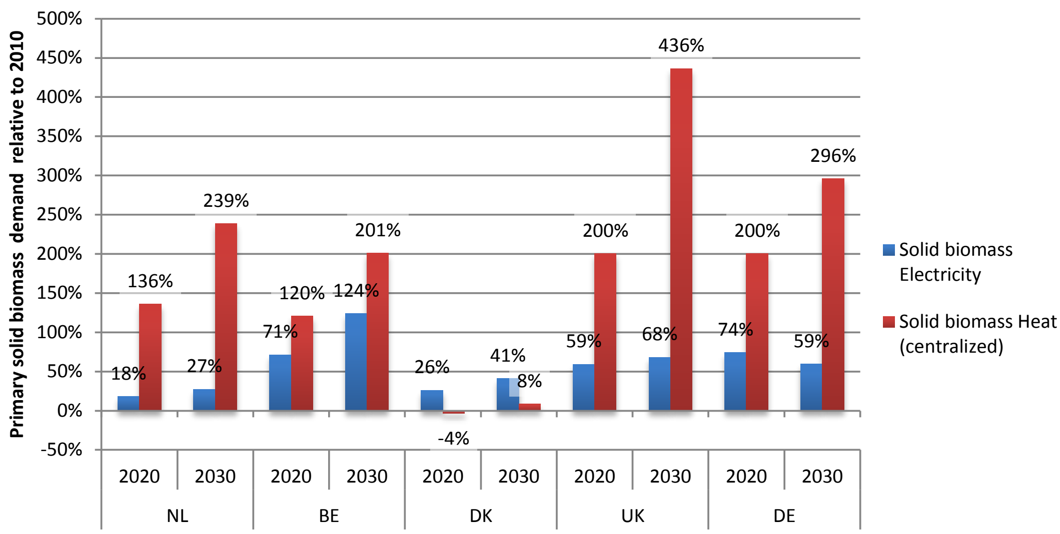


Figure 21 Primary solid biomass demand for electricity generation and centralized heat (excluding households) in 2020 and 2030 relative to 2010 in the BAU scenario.

[4] Assuming a net calorific value of 17.6 MJ/kg

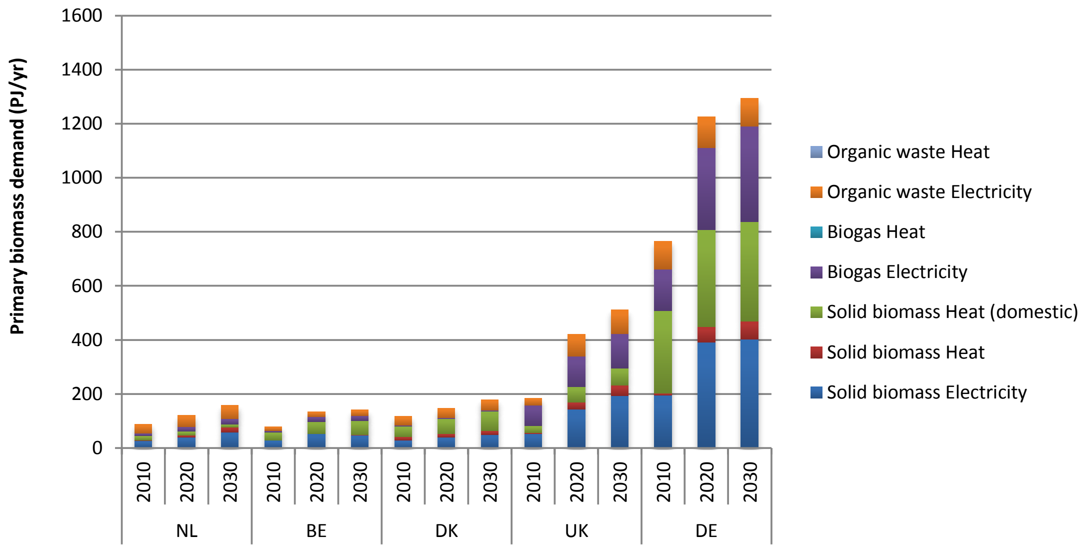


Figure 22 Total primary demand of solid biomass for electricity and heat in the BAU-bm scenario.

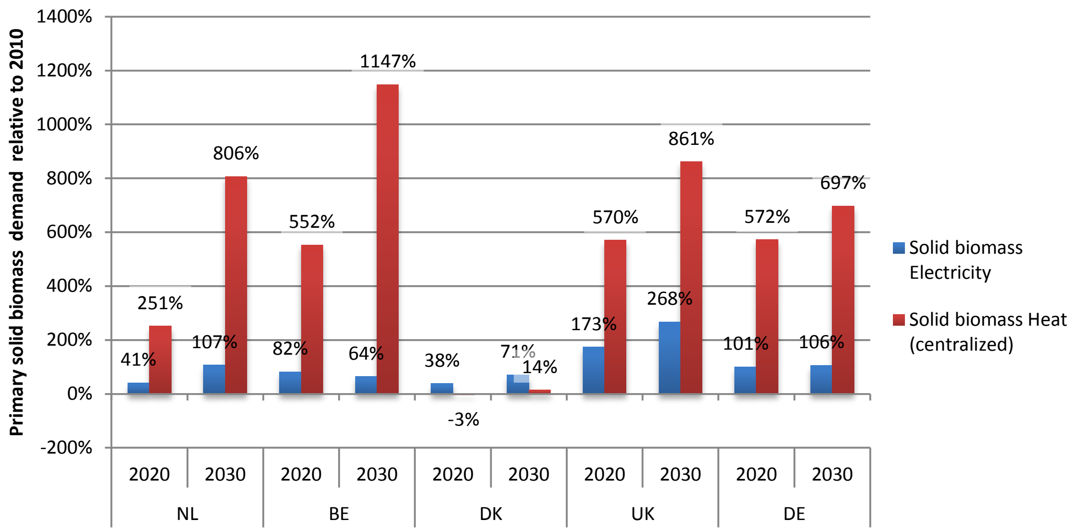


Figure 23 Primary solid biomass demand for electricity generation and centralized heat (excluding households) in 2020 and 2030 relative to 2010 in the BAU-BM scenario.

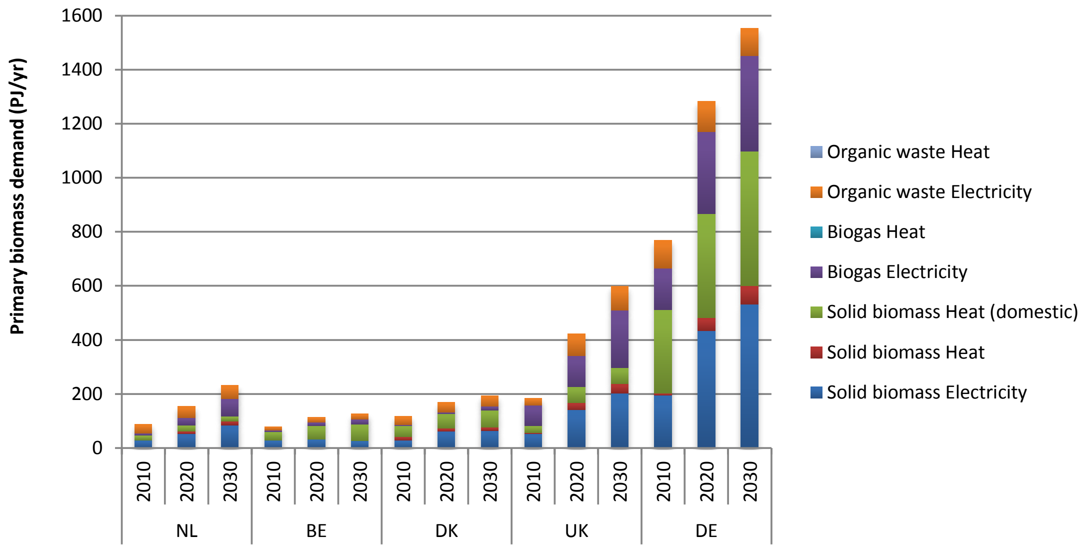


Figure 24 Total primary demand of solid biomass for electricity and heat in the SNP scenario.

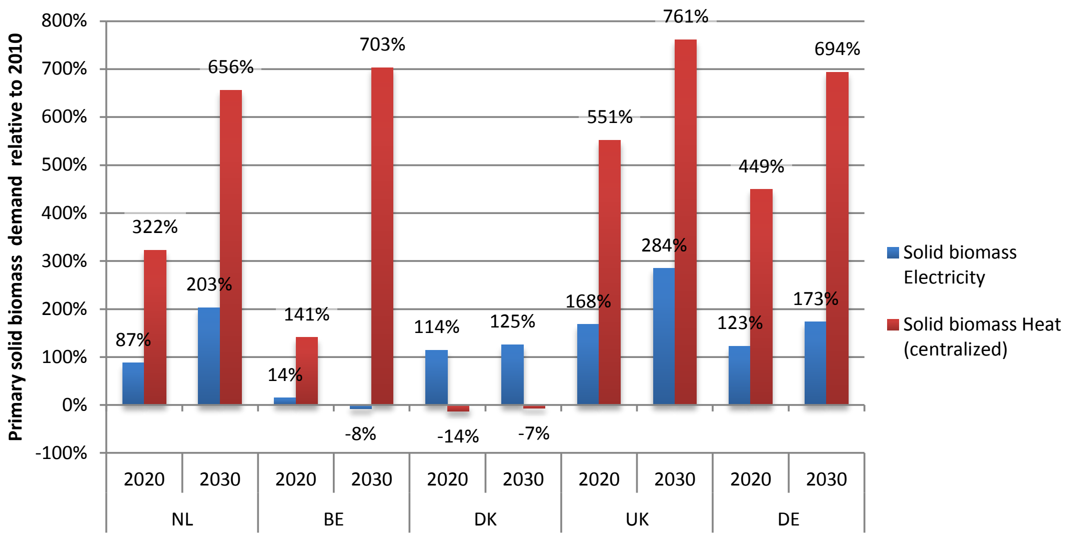


Figure 25 Primary solid biomass demand for electricity generation and centralized heat (excluding households) in 2020 and 2030 relative to 2010 in the SNP scenario.

5.4 Biomass supply scenarios

5.4.1 Biomass supply scenarios

To estimate the supply potential of solid biomass available for export, scenarios are developed that take both the technical supply potential of biomass for bioenergy into account and the domestic demand of biomass. We covered the ranges in the following scenarios:

- Reference Trade
- High Trade 450
- Low Trade

The main assumptions of the scenarios are summarized in Table 4. Table 5 shows the combination of the demand scenarios for biomass in northwest Europe and the supply scenarios.

Table 4 Global biomass trade scenarios

	Reference Trade	High Trade 450	Low Trade
Technology development	Medium[1]	High[2]	Low[3]
Orientation and trade	Global, high trade[4]	Global, high trade[5]	Local, low trade[6]
Global biomass demand	Medium[1]	High[2]	Low[3]

1) Based on IEA WEO New Policy Scenario/OECD Env. Outlook scenario, 2) Based on IEA WEO 450 Scenario/OECD 450 scenario, 3) Based on IEA WEO Current Policy Scenario/OECD Trade barriers scenario.

4) Based on OECD-EO Reference Scenario, 5) Based on IPCC SRES A2 Scenario, 6) Based on IPCC SRES B1 Scenario.

Table 5 Combination of demand scenarios and supply scenarios

Demand scenarios Northwest Europe	Global biomass export supply scenarios		
	Reference Trade	High Trade 450	Low Trade
Business as Usual	X		X
Business as Usual - Barriers Mitigated	X	X	
Strengthened National Support (SNP)	X	X	

For the **supply of biomass**, we used the geographic biomass potential from Hoogwijk et al. (2005) and Vuuren et al. (2009) as projected by the IMAGE-TIMER model. We selected the OECD-Environmental Outlook (OECD-EO) reference scenario for the Reference Trade and Reference Trade 450 scenarios. The OECD-EO scenario is a ‘medium development’ scenario with almost all agricultural land expansion to occur in developing countries with the biomass supply potential is estimated to be in between the IPCC SRES A2 scenario and the IPCC SRES B2 Scenario (van Vuuren, van Vliet et al. 2009). For the High Trade and Low Trade scenario, we used the biomass supply potential of the IPCC SRES A2 scenario and IPCC SRES B1 scenario as projected per region by Hoogwijk et al. (2005). The IPCC SRES B1 scenario represents high economic development, global trade, and low population with relatively a meat extensive diet and sustainably oriented. This results in a high bioenergy potential in both developed and developing regions. In contrast, the IPCC SRES A2 scenario represents a highly populated and politically fragmented world with low technology development and low income. Due to lack of international trade and low yields, the potential for bioenergy remains small (Van Vuuren, Bellevrat et al. 2010, Hoogwijk, Faaij et al. 2005). Note that the results in Hoogwijk et al. (2005) are higher than the projections used in this study due to updated storylines of the SRES scenarios with higher land abandonment and a lower accessibility factor for abandoned land (van Vuuren, van Vliet et al. 2009).

For the regional **demand of biomass** for electricity, heat and biofuels, we used the projections of the IEA World Energy Outlook 2011 (IEA 2011). The Reference scenario is based on the IEA New Policy Scenario[5], whereas the Reference 450 and the High Trade 450 scenarios are based on biomass demand of the IEA 450 Scenario[6]. The Low Trade scenario is based on biomass demand of the IEA Current Policies Scenario[7]. Technology development and related diffusion rate of 2nd generation biofuels is also consistent with the IEA WEO 2011 scenarios.

The geographic potential and demand of biomass for the scenarios, as depicted in Figure 16, are used to calculate the net surplus or deficit per region and scenario as shown in Figure 26. The lower bars show the potential surplus/deficit of biomass for the Low Trade scenario in which low demand of biomass, based on the IEA WEO Current Policies scenario, still does not result in higher potentials as a result of lack of land for bioenergy crop production in this scenario (based on IPCC SRES A2). Although total exploitation levels of biomass are not above 60% in all scenarios in 2030, there are regions with higher biomass demand than can be produced.
The reference scenario shows that the potential of China is underestimated in the OECD-EO scenario as it is lower than current total primary bioenergy demand. This is mainly the result of data uncertainty and the exclusion of waste in the potential supply that has to be assessed. It depends on policy ambitions for renewable energy and the development pathway if there will be a net surplus or demand in the future. Also OECD Europe is projected to become a net demand region for biomass as the total demand is higher than the total domestic potential.

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[5] New Policies Scenario: "A scenario in the World Energy Outlook which takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced" (IEA 2012).

[6] 450 Scenario: "A scenario presented in the World Energy Outlook, which sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO2" (IEA 2012).

[7] Current Policies Scenario: "A scenario in the World Energy Outlook that assumes no changes in policies from the mid-point of the year of publication (previously called the Reference Scenario)" (IEA 2012).

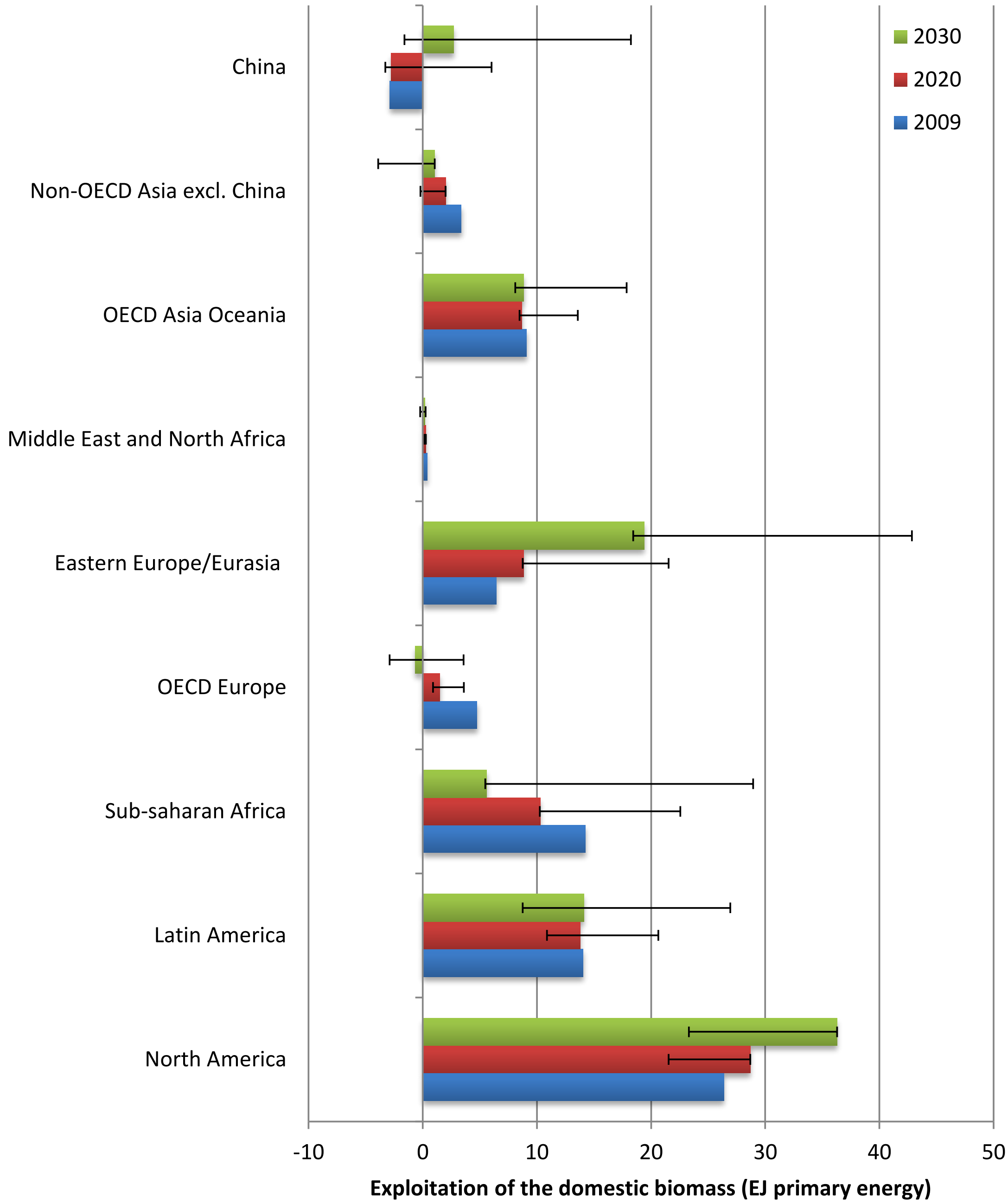


Figure 26 Exploitation of the domestic potential (geographic potential – domestic demand) for the Reference Trade scenario and ranges of the different scenarios.

5.4.2 Geographic biomass export potential

To estimate supply and demand of bioenergy, potential supply regions and potential demand regions were identified as shown in Figure 16 and Figure 26. This study focuses on key biomass production regions that already export biomass for bioenergy or have the potential to become key biomass export regions. Within these key regions, representative countries were selected (between brackets):

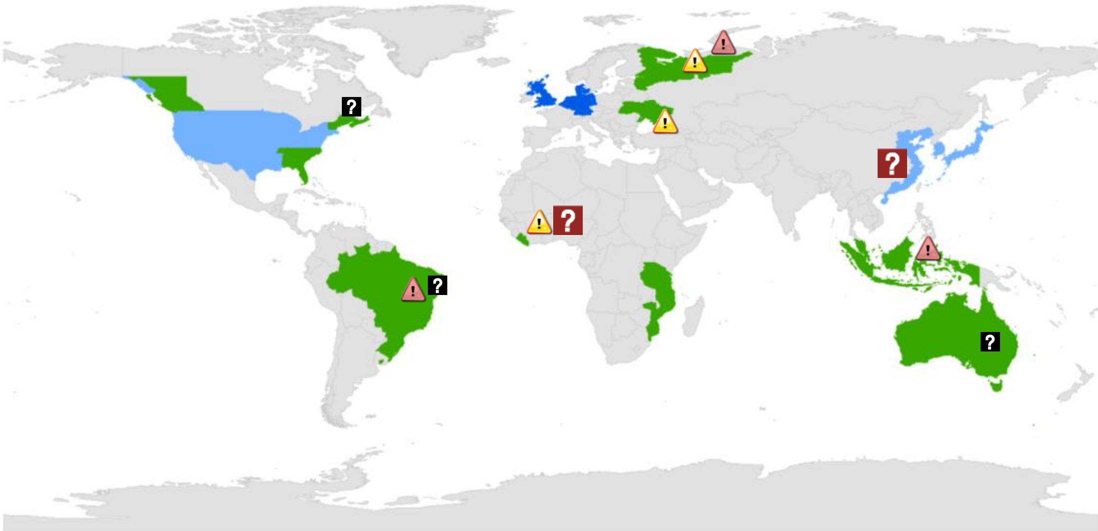
- North America (British Columbia, South East US and North-East Canada/US)
- Latin America (mainly Brazil)
- Sub-Saharan Africa (Liberia, Tanzania, Mozambique)
- Russia (Northwest Russia)
- Eastern Europe (Ukraine)

- Oceania and South East Asia (Australia, Indonesia, Malaysia).

Key demand regions that impact or will potentially impact the supply of non-European biomass available for north-west Europe are also selected. These include:

- The U.S.
- China
- Japan
- South Korea

The selected regions for biomass export, current and potential regions for biomass import with demand exceeding domestic supply are shown in Figure 27. In the next phase of this project, the supply potential will be assessed in more detail to provide improved ranges of uncertainties and to assess the sustainable supply. Figure 27 illustrates regions with key risks for investments due to for example policy uncertainties, risks for sustainability (land use change, water, soil, biodiversity) and data uncertainties. These risks and uncertainties are based on a quick-scan of available literature. Further improvement is required in the next phase of this project.



Biomass supply/demand	Risks and uncertainties (quick-scan results, work in progress)
(Potential) biomass supply regions	Sustainability
(Potential) biomass demand regions (others)	Investment/policy
Biomass demand regions (NW Europe)	Medium data availability/uncertainty
	Low data availability/High uncertainty

Figure 27 Key regions for future potential biomass supply, demand and trade in the scenarios and the quick scan results of data availability and risks

5.4.3 Supply and demand regions

5.4.3.1 North America

Although North America is currently the largest exporting region of wood pellets to northwest Europe (Section 3.1) and pellet production capacity is still increasing, domestic use of biomass is also expected to increase. The domestic supply of biomass in North America is likely sufficient to meet the domestic demand, but if only the potential will be used that can be mobilized according to Pöyry (PÖYRY 2011), it might only be sufficient to meet the domestic demand in 2020. The recently published update of the Billion Ton Study (U.S. DOE 2011) estimated that the total economic potential of bioenergy, including dedicated energy crops, residues and waste for the U.S. could be 9.6 EJ available with production cost < 3 $/GJ and 22.2 EJ for production cost of < 5 $/GJ. Although short to medium supply in North America, including supply from mountain pine beetle infected trees in Canada (PÖYRY 2011), will result in increasing supply to Europe, overall, it can be concluded that North America will probably be able to be self-sufficient, but it is highly questionable if the increasing export trend seen in recent years form Canada and the US will continue after 2020.

5.4.3.2 Latin America

Latin America is considered one of the largest potential regions for biomass production including conservative studies on estimated potentials (see Figure 16). Next to already large scale production of sugar cane ethanol, also pulp wood is becoming an important export product from Latin America. Large plantations of fast growing woody biomass in Brazil, Argentina and Chili are expected to increase from 7.6 million hectares to 13 million hectares in 2020 (PÖYRY 2011). Beyond 2020, this trend is expected to increase resulting one of the most imported export regions of lignocellulosic biomass. There are however also concerns with regards to land use change and more research is required on the sustainable potential in this region. These issues will be taken into account in the detailed assessment of the next phase of this project.

5.4.3.3 Sub-Saharan Africa

The technical potential of biomass in Sub-Saharan Africa is large (Figure 16) and it is one of the largest regions of traditional biomass use (IPCC 2011). If these large supply potentials could be realized to 2030 is however uncertain. Key factors that determine the potential are the shift from traditional use of biomass to more efficient fuels and stoves. Furthermore, productivity levels on agricultural land are still low. Although the potential to improve productivity are large by mechanization, use of fertilizers and land management, it would also require political, social and economic incentives. It is currently difficult to estimate the developments and its impact on the agricultural sectors to 2030. Other issues regarding the mobilization of the technical potential are political instability and inferior logistics is many parts of Sub-Saharan infrastructure. Studies on eastern Africa for, amongst others Mozambique (van der Hilst, Faaij 2012) improve insight in key factors and the impact on the technical and economic potential in these regions.

5.4.3.4 Northwest Russia and Ukraine

Russia has a large technical potential for the production of biomass from both forestry, residues and dedicated energy crops and the domestic demand is small. Especially forest rich areas in northwest Russia and Siberia could supply large amounts of forest products and forest residues. In northwest Russia, it was estimated that more than 30 million m^3 of forest residues are available annually, equivalent to over 200 PJ primary bioenergy (Gerasimov, Karjalainen 2011).

Although Russia aims to increase the share of co-firing and full conversion of fossil based boilers and biomass CHP plants to meet the 4.5% renewable energy target, still excess biomass will be available for export. Considerable efforts are therefore already taking place to export solid biomass including European investments in pellet production and harbor facilities to meet the renewable energy targets in Europe (Cocchi, Nikolaisen et al. 2011).

In addition, there is a large potential for dedicated lignocellulosic energy crop production in Ukraine. In the REFUEL project, de Wit et al. (2010) estimated that up to 5 EJ could be produced on arable and pasture land under precondition that considerable investments are being made in agricultural management to increase productivity.

5.4.3.5 Oceania and Asia

Southeast Asia, including Indonesia and Malaysia has been an important source country for liquid biomass (palm oil) and residues including palm kernel shells. The region has a large potential for bioenergy, but there are major risks for land use change if biomass is produced unsustainably (Wicke, Sikkema et al. 2011). For this study, we assumed that residues from palm oil production and dedicated energy crops are exported to demand regions in Asia, including China, South Korea and Japan (Lamers, Junginger et al. 2012).
Australia is also considered an important export region for biomass. There are uncertainties related to if supply markets will grow in Australia and if European markets can compete with Asian demand markets with shorter transport distances. The current scenario estimates do not take potential supply from Australia into account. In the next phase of this project, more detailed research will be conducted on this region to estimate potential supply for Asian and European markets.

5.4.4 An example of the supply potential for the EU-27

The supply potential for northwest Europe will be based on the economic potential of net exporting regions relative to the domestic economic potential of key importing regions in Report II of this study. As an example, the potential of wood pellets are provided here for the EU-27 as projected by Junginger (2012) and depicted in Figure 28. These results are first indications and the results will change for this study based on the model tool being developed for this study. Figure 29 shows an example if pan-European biomass would only be available. In the model projections of Report II, these projections will not be pre-defined but based on competitive use between regions.

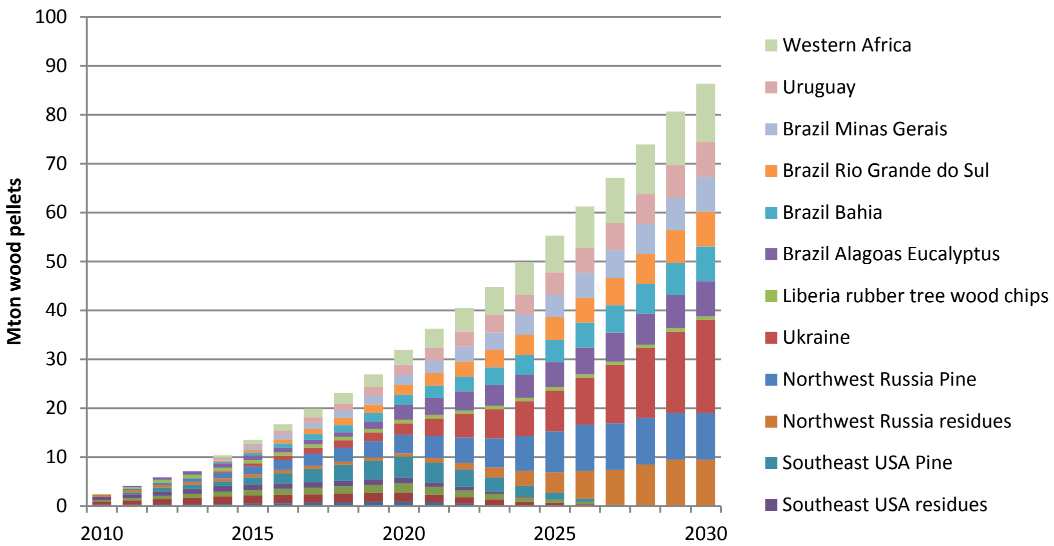


Figure 28 Example of potential of wood pellets from non-EU-27 countries available for the EU-27 based on a quick scan.

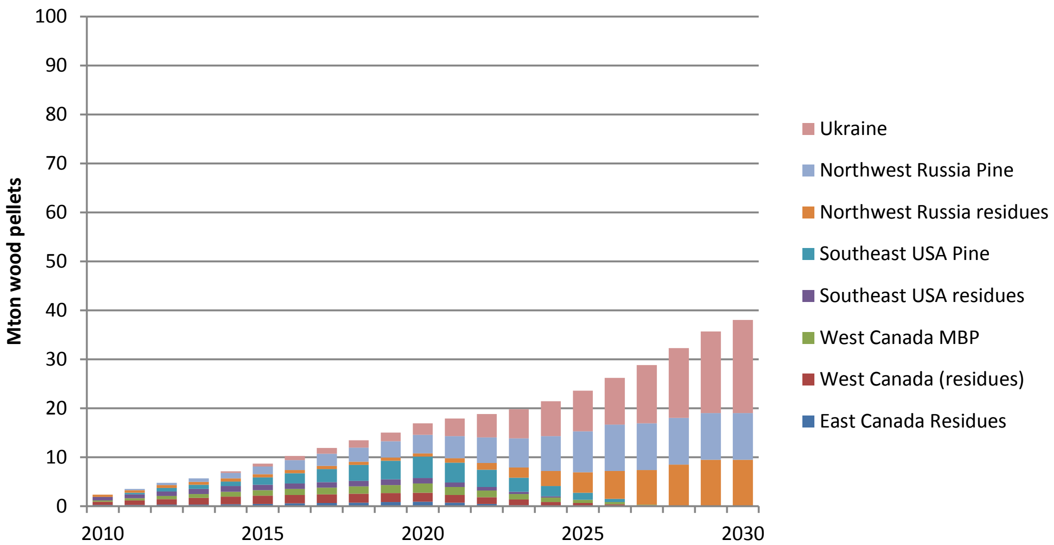


Figure 29 Example of potential of wood pellets from non-EU-27 countries available for the EU-27 in the European biomass scenarios based on a quick scan.

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Appendix A: data tables

Table 6 Wood pellet consumption per sector, domestic production and import (negative = export) in northwest Europe in 2010 in kton. Based on Chocchi et al. (Cocchi, Nikolaisen et al. 2011)**.**

Country		Belgium	Denmark	Germany	Netherlands*	United Kingdom*
Electricity	Dedicated	400				
	Co-firing	400			1597	683
	CHP		876			
Heat	Industrial	50	54			
	District heating	4	163			
	Domestic	98	577	1200		
	Other	1	48			
Total		953	1719	1200	1597	683
Domestic production		289	138	1700	164	197
Net imported		664	1581	-500	1432	486

*) Allocated to co-firing

Appendix B: scenario tables

Accompanying this report is the Excel file Scenarios_Biomass_Demand_PoR.xlsx that includes the projections of biomass demand in the scenarios for northwest Europe.

Appendix C: plant details and technical potential of co-firing in coal fired power plants

Co-firing, technical potential and use

Based on the IEA Coal Power database and the assumptions in Table 10 and Table 11 that are partly consistent with Hansson et al. (2009), the technical potential of co-firing in North West Europe was estimated. The economic potential will be determined in phase two of this project taking the geographic locations of the power plants into account and the accessibility (for example access to waterways). The estimated economic potential will be used for the high co-firing sensitivity scenarios. The results shown in Figure 30 should be considered as first estimates because all coal fired plants and units in northwest Europe will be evaluated individually in the next phase of this study. This will likely have an impact on both the technical and economic potential of co-firing biomass because the database used in this study (IEA Coal Power) is not always accurate.

Table 7 Efficiency and availability factor

Age / steam pressure	Efficiency	Availability factor
Subcritical		
31-40 years	30%	70%
21-30 years	35%	70%
0-10 years	40%	85%
Under construction/planned	43%	85%
Supercritical (SC)	43%	85%
Ultra supercritical (USC)	45%	85%

Table 8 Co-firing share per boiler type/plant type

Boiler type	Co-firing share
Grate-fired	15%
Fluidized bed	10%
Pulverized coal	10%
IGCC	10%

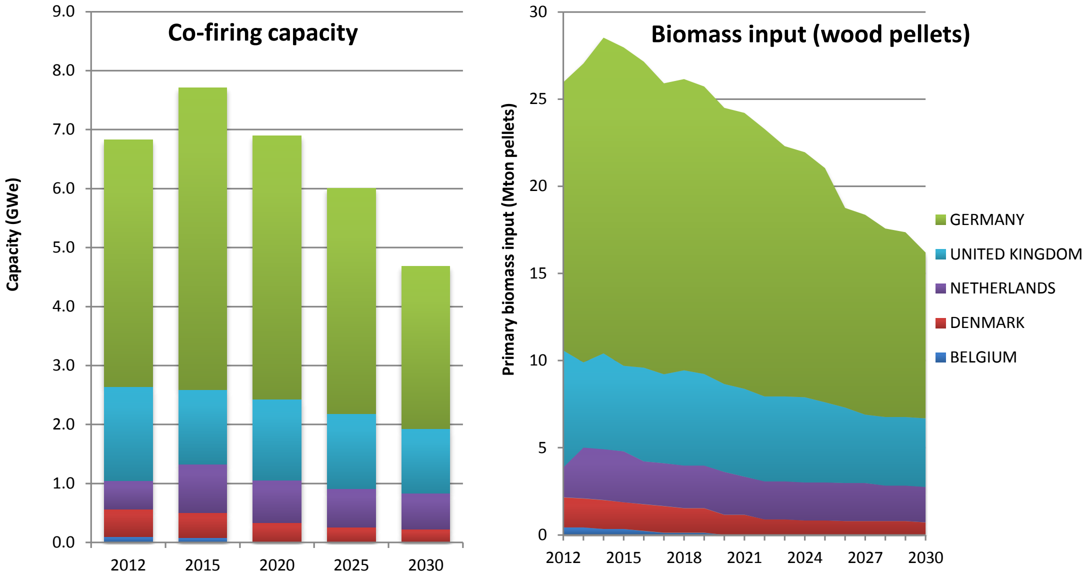

Figure 30 Technical potential of co-firing in coal fired power plants in North West Europe. Capacity (left) and technical biomass input potential (right). Lifetime = 40 years.

Country data

This section presents the results of the first review of current large solid electricity generation plants in Belgium, the Netherlands and the United Kingdom. A plant – by – plant analysis for northwest Europe, including Germany and Denmark, will be conducted in the next phase of this project and available in Report II.

The Netherlands

The Netherlands has 4.17 GWe coal and co-firing power plants in operating of which one 250 MWe IGCC plant and the remaining 3.92 GWe are pulverized coal plants. Currently, 3.5 GWe additional pulverized coal capacity is under construction in Eemshaven (1.6 GWe) and two plants in the Maasvlakte (1.1 and 0.8 GWe capacity). An IGCC plant was also originally planned to be built in Eemshaven (Nuon/Vattenfall Magnum power plant), but is now built to run on natural gas only. Future ambitions are still to add gasification technology to convert coal and biomass into syngas and to add capture CO_2 systems (phase 2), but these plans are highly depended on market conditions and future support measures. In this study, we assume that the additional gasification units of the Nuon/Vattenfall Magnum power plant will not be built in the future due to the relatively large installed coal fired capacity in the Netherlands and unfavorable policy conditions (a coal tax is considered in the Netherlands).
Biomass co-firing in the Netherlands is currently supported by the MEP subsidy scheme (see Section 3.2.4) that will be phased out by 2015. A Green Deal is currently negotiated between electricity companies and the Dutch government to co-fire 10% biomass up to 2015. It is still unclear what will happen after 2015, but a collective capacity of 1.3 to 1.6 GWe is proposed by electricity companies in the Netherlands (Hawkins Wright, 2011).

RWE Power could increase the share of biomass in the Amer Power plant, now capable of co-firing 12% in Unit 8 and 32% in Unit 9 (direct and indirect co-firing), to 40% (50% by mass base) by 2015 depending on the Green Deal (Willeboer, 2012). Planned increased co-firing shares from 10% now, to 50 - 70% in the near future are mentioned for the Nuon/Vattenfall Buggenum plant (#Broek, 2012). The GDF Suez/Electrabel power plant that is currently constructed on the Maasvlakte could also potentially co-fire biomass up to 50%.

Gas fired plants in Zwolle (Harcullo) and Maasbracht (Claus) have co-fired liquid biomass including vegetable oils and liquid residues. Liquid biomass is outside the scope of this study and not likely to be used in large quantities for electricity generation.

Box 2: Large Combustion Plants (LCP) Directive
The Large Combustion Plants Directive (LCP directive, 2001/80/EC) limits emission levels of certain pollutions (NOx, SO_2 and dust/particular matter) for power plants equal or larger than 50 MW for all types of fuels. The directive is now, with 7 other directives replaced with the Industrial Emission Directive (IED), but is still effective to power plants that are opted-out and have 20000 hours of operation remaining between 2008 and 2015.

For continued operation beyond 2015 of power plants that are opted-out under the LCPD, there are various options available (PB, 2011):

- Plant upgrade – installation of pollution control measures;
- Plant refurbishment – replacement of main plant equipment i.e. boilers, turbines;
- Plant conversion – conversion to alternative fuel source or technology;
- Reuse of site – completely replace plant on existing site.

Although conversion to biomass mainly results in reduced CO_2 emissions that are not covered by the LCPD, biomass conversion (100% biomass firing) has become a valuable alternative in countries with policies that support conversion of coal fired power plants such as in the UK and in Belgium.

In total, 22 units in northwest Europe are planned to be opted out by the end of 2015 under the LCP directive including 17 units (of which 8 units are coal power plants) in the UK, 3 units in Belgium and 2 units in Denmark (EC 2011c).

Belgium
The capacity of coal fired power plants in Belgium is limited and relatively old (power plants still in operation are built between 1963 and 1979). In total, there are 5 units that are currently in operation of which two power plants are opted out under the LCP directive (Box 2). These plants include Electrabel SA Rodenhuize and Mol (EC 2011c). However, Rodenhuize Unit 4 has been converted to operate with 100% biomass in 2011 with a generation capacity of 180 MWe and will therefore remain operational to contribute to the RES 2020 targets of Belgium. Electrabel SA Mol coal is still in use, but will likely be decommissioned in 2015 as required by the LCP directive. Electrabel SA les Awirs has already been converted to 100% biomass (80 MWe generation capacity) in 2005 whereas E.on aims to convert the Genk Langerlo plant to 100% biomass in 2014. Electrabel SA Ruien co-fires biomass with ratios up to 26% in unit 5 (direct and indirect co-firing).