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Capacity Study for Solid Biomass Facilities

A tool to assess scenarios of global supply, demand and trade of solid biomass for northwest Europe

Energy & Resources
Copernicus Institute of Sustainable Development
Utrecht University

Authors

Ric Hoefnagels
Thijs Cornelissen
Martin Junginger
André Faaij

Energy & Resources
Copernicus Institute of Sustainable Development
Utrecht University

Universiteit Utrecht

Version: Final

Date: April 2013

Foreword

The main objective of the Capacity Study for Solid Biomass Facilities is to provide insight in the future potential trade flows of solid biomass for the purpose of renewable energy generation in northwest Europe. This project was undertaken by the Copernicus Institute of Sustainable Development – Utrecht University under auspices of the Working Group Solid Biomass (Werkgroep Vaste Biomassa) and the Steering Committee Bioport Rotterdam; Port of Rotterdam.

The authors would like to thank the Port of Rotterdam for the financial and intellectual support of this project. Furthermore, the authors would like to thank the Energy Economics Group (EEG) – TU Wien for providing the Green-X model results of the Re-Shaping project.

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 and objective

International trade of solid biomass for bioenergy purposes could develop rapidly in the coming decades as a result of the geographic imbalance between supply regions and regions of demand. Especially in northwest Europe, where domestic supply is relatively low or expensive and demand could grow rapidly to meet the binding renewable energy targets of 20% renewable energy in the EU-27 in 2020. In this region, large amounts of solid biomass (mainly wood pellets) are already being imported from overseas (for example Canada or the southeast of the US) to supply woody biomass for co-firing or to fully converted former coal power plants. Although it is expected that international bioenergy trade will grow in the future, its future shape remains uncertain. The port of Rotterdam aims to facilitate further development of international solid biomass trade by means of a biomass hub concept. However, they also have to cope with uncertainties related to the potential future deployment of biomass and related throughput in ports. The key objective of this study is to create insight in future possible development pathways and possible ranges of biomass trade flows in northwest Europe and the potential role of sea ports of in the captive and contestable hinterland of the port of Rotterdam.

Model tool

To assess the potential trade flows of solid biomass, this study uses a model tool developed for this study existing of two sub-models: a Biomass Transport Model and a Biomass Allocation Model. The Biomass Transport Model calculates the lowest cost routes between origins of biomass supply and destinations of biomass demand taking an intermodal transport network into account (ocean, short sea, inland waterway road, rail) and locations of terminals to load solid biomass from one mode to another mode of transport (for example from a bulk ocean carrier to a rail car) for each possible route between origins and destinations (OD-matrix). The Biomass Allocation model uses these OD-matrices calculated by the Biomass Transport Model in combination with the cost at the source of supply and the required demand nodes to allocate supply to demand optimized for the lowest cost taking the cost of biomass supply and transport into account.

Scope and scenarios

The scenarios assessed in this study cover ranges in renewable energy support policies in the EU-27, the key driver for biomass demand. Outside the EU-27, different economic, agriculture and industrial development pathways are considered that determine export potentials of solid biomass (Table 2). Table 1 summarizes the scope of this study.

Table 1 Scope

Period	2010 – 2030 (5 year interval)
Supply and demand outside the EU-27	Locations of supply outside the EU-27 are represented by major sea ports of export countries in North America (Canada, US), South America (Brazil, Uruguay), Sub-Saharan Africa, CIS (Russia, Ukraine), Oceania (Australia). Locations of demand outside the EU-27 cover major sea ports in potential importing countries in Asia (China, Japan, South Korea).
Supply and demand in the EU-27 and northwest Europe	Within the EU-27, locations of biomass supply and demand are represented by the geographic centers of NUTS-1 regions for each member state. In northwest Europe (Belgium, Denmark, Germany, the Netherlands, United Kingdom), also the locations of large power plants are included with plant-specific demand of solid biomass for electricity generation.
Demand sectors	
Biomass sources	EU-27: Primary and secondary woody biomass from forestry (excluding organic wastes) and agriculture (short rotation coppice). Agriculture products (grassy crops) and residues (straw). Outside the EU-27: wood pellets produced from primary and secondary forestry products and residues and dedicated energy crops (short rotation coppice). All solid biomass transported internationally is assumed to be processed into pellets before long distance transport.

The scenarios for the EU-27 are based on existing scenarios of the Re-Shaping project (Ragwitz et al., 2012; Resch, 2012):

- A business as usual scenario (BAU), assuming a continuation of current support policies, but lacking ambitions to meet the binding renewable energy targets of 2020.
- A scenario with non-economic barriers being mitigated (BAU-BM)
- A scenario combining strengthened policy support (SNP) and mitigation of non-economic barriers aiming to meet the binding EU renewable energy targets of 2020. The SNP scenario is, in terms of renewable energy ambitions, in range with the national renewable action plans (NREAPs). After 2020, these support policies are assumed to continue to 2030.

The three scenarios for supply and demand of solid biomass outside the EU-27 are developed for this study and loosely based on the OECD-Environmental Outlook scenario (van Vuuren et al., 2009), the IPCC SRES B1 and A2 scenarios of socio-economic and technical development (Hoogwijk et al., 2005) and IEA World Energy Outlook scenarios of energy demand (IEA, 2011).

- The Reference Trade scenario represents a moderate scenario with further expansion of current exporting regions of solid biomass to 2020 (North America) and moderate development of new exporting regions (for example South America and Sub-Saharan Africa).
- The High Trade 450 scenario assumes that 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 resulting in high domestic demand in north America, but also Asian countries (loosely based on the IEA WEO 450 scenario). It is assumed that such ambitions will also enhance industrial and economic development in developing countries and newly industrialized countries resulting in higher export potentials in new exporting regions (loosely based on the IPCC SRES B1 scenario).
- The Low Trade scenario assumes regional oriented development (loosely based on the IPCC SRES A2 scenario) with the EU-27 focusing on domestic supply of solid biomass and cheap residues (such as saw dust) from existing export regions. Due to lack of environmental ambitions in the IPCC SRES A2 scenario, the Low Trade supply scenario is only combined with the BAU demand scenario (Table 2).

Table 2 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	

The development pathways of wood pellet supply for export outside the EU-27, the demand for imported wood pellets in competing importing regions and the net resulting net availability for the EU-27 in the scenarios to 2030 are depicted in Figure 1. Although the Reference Trade scenario and High Trade 450 scenario result in almost similar net potentials of wood pellets for the EU-27, the geographic sources of supply are different resulting in different trade flows and cost of supply. The cost of imported wood pellets from outside the EU are based on Free On Board (FOB) prices at export sea ports ranging from 97 – 121 €/t pellets in 2010 and increasing to 112 – 139 €/t pellets in 2030. The total supply cost depend on the transport distance, charter rates, fuel prices and other logistic costs.

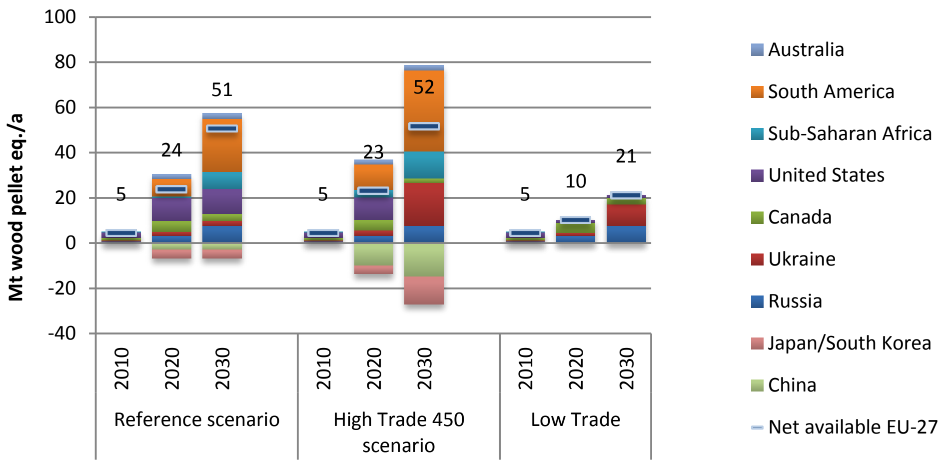


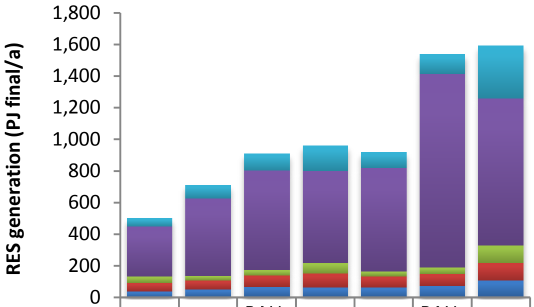
Figure 1 Supply of wood pellets from key exporting regions outside the EU-27 (positive columns), demand in competing importing regions (negative columns) and net availability for the EU-27 (markers) in the global biomass scenarios.

Results

Renewable energy-generation

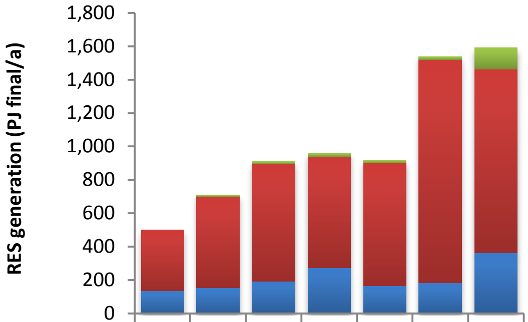
Projections of renewable energy generation from the Green-X scenarios have been adapted with power plant specific assumptions on electricity generation and used in the scenarios to estimate ranges of biomass demand. In total, renewable energy generation is projected to increase up to 960 PJ final energy in 2020 and up to 1,600 PJ final energy in 2030 the SNP scenario (Figure 2).

The largest growth is projected for renewable heat generation. In Germany, heat from solid biomass could become more than 2.5 times larger in 2030 (BAU-BM scenario) compared to 2010 levels resulting in rapid growth of solid biomass demand. Strengthened support to meet the EU renewable energy 2020 targets (SNP scenario) results in increased generation of renewable electricity and advanced transport fuels and lower generation of renewable heat in Germany compared to the BAU-BM scenario (Figure 3).



	2010	BAU (2020)	BAU-BM (2020)	SNP (2020)	BAU (2030)	BAU-BM (2030)	SNP (2030)
UK	50	84	106	159	100	123	333
DE	316	490	628	582	652	1,226	930
NL	42	28	36	69	31	41	110
DK	53	59	71	86	71	75	112
BE	39	51	68	65	65	75	109

Figure 2 Renewable energy generation from solid biomass per country (PJ/a).



	2010	BAU (2020)	BAU-BM (2020)	SNP (2020)	BAU (2030)	BAU-BM (2030)	SNP (2030)
RES-Tadv	0	12	12	24	20	20	129
RES-H	364	544	706	665	734	1,337	1,102
RES-E	136	155	192	272	165	183	362

Figure 3 Renewable energy generation from solid biomass in northwest Europe per type of renewable energy generation (electricity, heat and advanced transport fuels) (PJ/a).

As a result of increased generation of renewable energy from solid biomass, the demand for solid biomass is projected to grow in all scenarios (Table 3). With continuation of current support, the demand for solid biomass (mainly for heating), could still increase from 45 Mt in 2010 to 78 Mt in 2030. With strengthened national support to meet the renewable energy 2020 targets, total demand for solid biomass in northwest Europe could grow to 110 Mt in 2030 with 34 Mt imported from outside the EU-27 (31% of the total demand). In the Netherlands, up to 4.9 Mt solid biomass is projected to be imported in the SNP scenario in 2020. In comparison the national renewable action plan of the Netherlands estimates that 69 PJ or 3.9 Mt wood pellets is required for co-firing in coal plants in 2020 with most of it likely being imported to the Netherlands, compared to 1.4 Mt in 2010 (Cocchi et al., 2011).

Table 3 Demand and supply of all solid, lignocellulosic biomass in northwest Europe in the Reference Trade scenarios (Mt wood pellet eq. /a)

		2020			2030		
	2010	BAU	BAU-BM	SNP	BAU	BAU-BM	SNP
Total demand	**44.6**	**67.3**	**78.2**	**93.3**	**77.8**	**84.7**	**109.1**
Domestic	**40.4**	**53.9**	**53.1**	**57.5**	**56.3**	**62.6**	**74.8**
BE	2.8	3.3	3.3	2.9	3.4	3.4	3.2
DK	2.9	5.9	4.9	5.5	6.1	5.6	7.8
NL	1.7	2.5	1.5	2.3	2.4	2.0	2.7
DE**	28.9	33.3	33.4	36.5	34.5	39.6	48.5
UK	4.1	8.9	10.0	10.3	9.9	11.9	12.6
Import EU*	**2.2**	**13.4**	**17.5**	**15.6**	**4.6**	**2.9**	**0.3**
BE	0.2	1.9	0.4	0.3	0.1	0.0	0.0
DK	1.3	0.1	0.0	0.0	1.3	0.0	0.0
NL	0.2	0.5	0.2	0.4	0.2	0.0	0.0
DE	0.0	10.1	12.0	9.8	1.6	1.2	0.3
UK	0.5	0.8	4.9	5.2	1.4	1.8	0.0
Import non-EU*	**1.9**	**0.0**	**7.6**	**20.2**	**16.8**	**19.3**	**33.9**
BE	0.5	0.0	2.0	2.7	3.2	3.0	2.8
DK	0.2	0.0	2.5	2.5	0.0	1.4	1.5
NL	1.2	0.0	2.5	4.5	0.9	2.4	3.8
DE	0.0	0.0	0.6	3.8	12.7	6.8	17.9
UK	0.0	0.0	0.0	6.7	0.0	5.6	7.9

*) Import figures for 2010 only include wood pellets (based on EUROSTAT (2012)). Domestic demand includes all lignocellulosic, solid biomass used for bioenergy purposes.
**) Germany already uses large amounts of solid biomass , mainly for renewable heat generation in residential sectors. In 2010, the total solid biomass demand for residential heat generation in Germany was 305 PJ or 17 Mt wood pellet equivalent of which 1.2 Mt wood pellets produced from domestic sources.

The role of sea ports in northwest Europe

Sea ports in northwest Europe have a crucial role in imports of solid biomass and further hinterland transport to end-users. This is especially true for biomass imported from non-EU regions that require inter-continental shipping, but also for many intra-European trade routes, short sea shipping is the most efficient mode of transport. For selected ports in northwest Europe, the total throughput is depicted in Figure 4. Note that biomass could also be transported via other sea ports that are not included in the port calculation tool. For example, power plants in Eemshaven (the Netherlands) are directly supplied from intermodal terminals in Eemshaven and do not require transloading or storage in other ports such as Amsterdam or Rotterdam.

In all scenarios, biomass used in the Maasvlakte power plants is supplied via the port of Rotterdam (up to 1.4 Mt). When high charter rates are assumed, also the Amer power plant is supplied via the Port of Rotterdam resulting in a total throughput of 2.5 Mt in the SNP scenario in 2030 (black error bars in Figure 4). In addition, large amounts of biomass are projected to be imported via the port of Rotterdam and re-exported to Germany. In total, up to 16 Mt biomass (SNP – Reference trade 2030) is projected to be transported via Rotterdam. If Germany would be excluded from the model projections, the total throughput in the port of Rotterdam would therefore become substantially smaller.

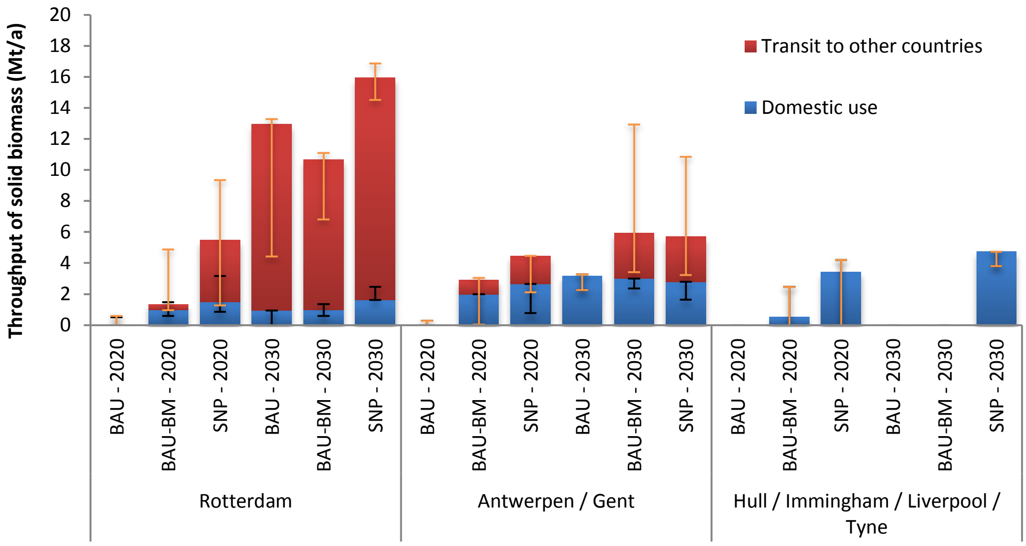


Figure 4 Throughput in selected sea ports northwest Europe for domestic markets and re-export to other EU member states (Mt/a) in 2020 and 2030 for the Reference Trade scenarios. The error bars show ranges of the alternative supply and sensitivity scenarios for domestic use (black) and total throughput (orange).

Conclusion

A model tool has been developed to estimate likely trade flows of solid biomass for different scenarios of biomass supply and demand and a range of sensitivity scenarios. The scenario projections show that solid biomass demand increases in all scenarios relative to 2010 levels. The magnitude of growing demand for solid biomass depends on changes in support policies and mitigation of non-economic barriers. Imports of solid biomass could increase up to 34 Mt in northwest Europe in 2030 (34% of the total demand for solid biomass used for energy purposes in northwest Europe) of which most solid biomass is projected to be imported from outside the EU-27 despite additional cost implied by long distance transport. However, such large trade flows would only emerge if important pre-conditions are met. Firstly, it would require mitigation of non-economic barriers and strengthened support policies for renewable energy as assumed in the SNP scenario. Secondly, it would require further mobilization and development of sustainable biomass supply regions such as the US, Canada, Russia and Brazil since northwest Europe remains for a large extent dependent on imported biomass sources.

The demand in northwest Europe and supply of overseas resources, also determines the role of sea ports. In a scenario with high support, to meet the EU renewable targets, over 16 Mt could potentially go via the port of Rotterdam. On the other hand, with a continuation of current support levels and with remaining non-economic barriers for renewable energy and with trade barriers (BAU - Low trade), the total throughput was projected to be 4.4 Mt in the same year (orange minus error bar, BAU - 2020 in Figure 4). Other factors, including charter rates for ocean bulk carriers, port fees and charges and the utilization rate of coal and fully converted coal power plants also impact the throughput in these sea ports. For example, if all sea ports are assumed to have similar costs, also solid biomass going to the Amer power plant in the Netherlands will go via the Port of Rotterdam instead of via the port of Antwerp increasing the total throughput of solid biomass imported for domestic markets from 1.5 Mt to 3.2 Mt in the SNP scenario in 2020 (black plus error bar, SNP - 2020 in Figure 4).

Finally, it is important to note that the results presented in this study are based on model projections that have important limitations. Real trade flows of biomass depend on many factors of which only some can be parameterized in a model. Although cost have been specified for selected ports, storage facilities and time dynamic biomass flows could not be modeled due to limitations of the modeling framework.

Given the complexity and uncertainty of potential supply, demand and trade of biomass for bioenergy purposes in an international context, the Biomass Allocation Tool is also made available to the Port of Rotterdam for exploring alternative scenario assumptions of cost, supply and demand of solid biomass to the scenarios assessed in this report.

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 final 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 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, Hamelinck 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 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 or coal plants that have been fully converted to biomass.

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. However, the international market for trade of biomass commodities has not yet matured and the future development depends on governmental support, competing renewable energy technologies and market developments. 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

For this project, two reports have been published. Report I, Scenarios for Supply and Demand of Solid Biomass for Electricity and Heat Generation in Northwest Europe, presents a description of the scenarios and background data. This report, Report II, presents a description of the model tool developed to assess potential trade flows of solid biomass and the results of the model projections for different scenarios.

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

2 Approach and input data

2.1 Scope

This study focuses on supply and demand of solid, lignocellulosic biomass that is pre-processed into pellets before long distance transport between 2010 and 2030 (Table 4). Wood waste is excluded from this project. Although wood wastes are traded for energy generation, for example between the Netherlands and Germany (Lamers et al., 2012), it is unlikely that wood waste will become a global tradable commodities due to heterogeneity, risks of contaminations and regulations for exporting or importing (organic) wastes.

For intra-European trade of solid biomass, it is in general more cost effective to transport wood chips than wood pellets and intra-European trade of wood chips is still larger than wood pellets (Lamers, Junginger, Marchal et al., 2012). However. the used model approach, is limited to trade optimization of a single commodity. Therefore, we assumed that biomass will be converted into pellets for both inter-EU and intra-EU trade.

For global supply, wood pellets are included produced from wood residues (e.g. as sawdust), primary forest products (e.g. roundwood) and wood from forest plantations and short rotation coppice (SRC) (e.g. roundwood produced in the Southeast of the U.S., Eucalyptus from Brazil). Biomass supply within the EU-27 also includes agriculture residues (straw pellets).

Sectors of solid biomass demand include residential heat generation (RES-H non-grid), heat generation in central units or combined heat and power (CHP) plants (RES-H grid), the production of 2nd generation biofuels from lignocellulosic biomass (RES-Tadv.).

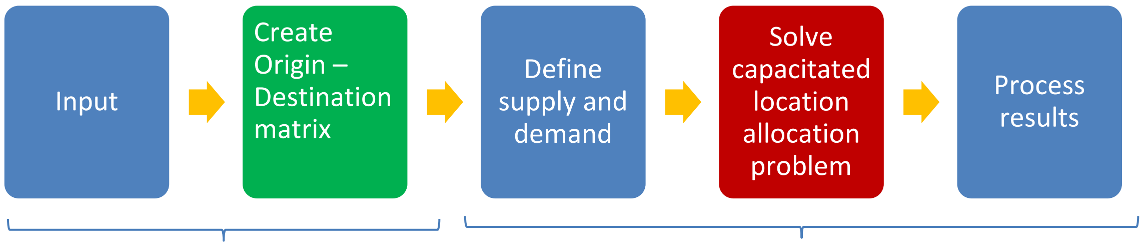
Table 4 Scope

Period	2010 - 2030 (five year time interval)
Supply regions	Global
Demand regions	Demand in the EU-27 and in Asia (China, Japan, South Korea)
Sectors and	
Demand projections	Pre-defined (Green-X projections)
Demand sectors	**RES-H grid** (centralized heat generation)
	RES-H non-grid (residential heat, decentralized)
	RES-Tadv. (advanced biofuels from lignocellusic biomass, for example Fischer-Tropsch diesel from woody crops)
	RES-E allocated (plant specific demand for electricity generation in co-fired or converted coal fired power plants in northwest Europe)
	RES-E unallocated (remaining electricity generation)
Biomass feedstocks	Forest residues: Yes, both EU-27 and global resources
	Forest products: Yes, both EU-27 and global resources, including forest plantations
	Agriculture residues (e.g. straw): Yes, only EU-27
	Agriculture products: Yes, only EU-27
	Food/feed co-products (e.g. PKS): No
Transport commodities	Densified (pellets)
Export terminal	Detailed: FOB cost-supply per export terminal (sea ports)
Import terminal	Detailed: detailed cost structures of logistic processes in sea ports (ports in NW Europe) and other intermodal terminals
Transport (inter-continental)	Detailed: intermodal transport model in ArcGIS
End-use	RES-E allocated: transport to factory gate
	Other: transport to geographic centers (centroids) of NUTS-1 regions

2.2 Overview of the model framework

In the last decade, development of solid biomass supply, demand and trade has been driven by different policy and market factors (Cocchi et al., 2011; Lamers et al., 2012). Key factors on the supply side include feedstock cost and supply as well as the cost of transport. On the demand side, markets range from small-scale residential users (RES-H non-grid) to large scale electricity generation in fully converted coal power plants (RES-E). With the demand for residential markets largely being met by domestic biomass resources or import from neighbouring countries, co-firing and converted coal fired power plants are mainly supplied by imported biomass from long-distance intercontinental supply chains.
It is impossible to capture all dynamics of market and policy dynamics into a model. For this study, a model has been developed that is, on the one hand, capable of addressing for special explicit logistic processes of global biomass supply chains and, on the other hand, capable of allocating biomass supply from different regions to the multi-demand locations for minimized cost of solid biomass supply.
The developed model tool exists of two sub-models: a Biomass Transport Model and a Biomass Allocation Model (Figure 5). The Biomass Transport Model, described in detail in Section 2.3, is a geographic explicit intermodal transport model that calculates the lowest-cost routes between origins and destinations using ESRI's ArcGIS 10.1 Network Analyst software. The Biomass Allocation Model, described in detail in Section 2.4, allocates biomass supply nodes (for example an export terminal in Savannah (USA) to destinations (for example a power plant in the Netherlands) in such a way that the total demand is met, supply potentials of each supply node are considered and the total cost of biomass supply, including transport, are minimized. The least cost routes are calculated with the Biomass Transport model in origin – destination matrices of each possible route.

The main advantage of using two individual sub-models is that different scenarios of supply and demand can be calculated efficiently without having to recalculate the Origin-Destination matrices. Furthermore, the Biomass Allocation Model only requires Microsoft Excel 2010 in combination with free, open source software to solve the biomass allocation problem. It is therefore possible to assess different scenarios of biomass supply, cost and demand without the required ArcGIS licenses and additional datasets.



1. Biomass Transport Model
Fuel prices
Bulk density
Transport cost (e.g. charter rates)
Transport mode parameters (e.g. fuel economy)
Supply and demand nodes
Intermodal transport network

2. Biomass Allocation Model
Cost-supply per supply node (4 levels)
Demand per centroid or allocated to plant
Allocate supply to demand nodes
Least cost approach (price at origin + transport)

Microsoft Excel 2010
ESRI ArcGIS 10.1 Network Analyst
Pulp (interface) with Coin-or Linear Programming solver
Python script

2.3 Biomass Transport Model

2.3.1 Intermodal Transport, a hub-spoke approach

In this study, we used GIS software to assess least-cost routes between supply and demand nodes of solid biomass based on existing transport networks and intermodal terminals for transloading solid biomass from one transport mode, for example a bulk ocean carrier, to another transport mode, for example rail. A so-called hub-spoke approach was used, similar to Winebrake et al. (2008), to link different transport networks via intermodal transport hubs as shown in Figure 6. The linkages include attributes for transport. For example, long distance maritime shipping links include distance, maximum ship size (Handysize, Supramax, Panamax) and freight rates per ship type. If traveled over a connector (spoke), cost attributes for unloading or loading are taken into account. For sea ports, these connectors also include harbor dues, mooring, towage and pilotage attributes.
In addition to transloading terminals, also end-use facilities are included that are linked to the different network nodes only by unloading connectors. Figure 7 shows different intermodal terminal locations in Rotterdam Maasvlakte I and end use facilities (power plants). Intermodal terminals (transport hubs in Figure 6) in the Biomass Transport Model are based on ETISplus, a European Transport policy Information System that includes a geographic explicit database of terminals in Europe and related terminal facilities (ETIS, 2012).

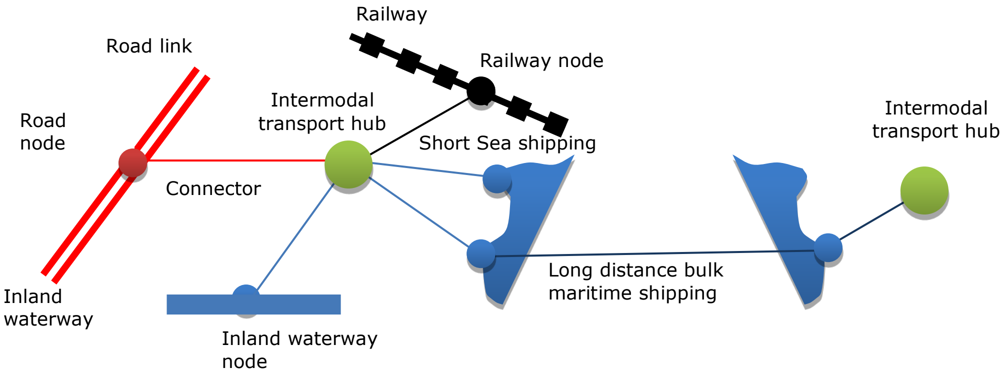


Figure 6 The hub-spoke approach of intermodal transport

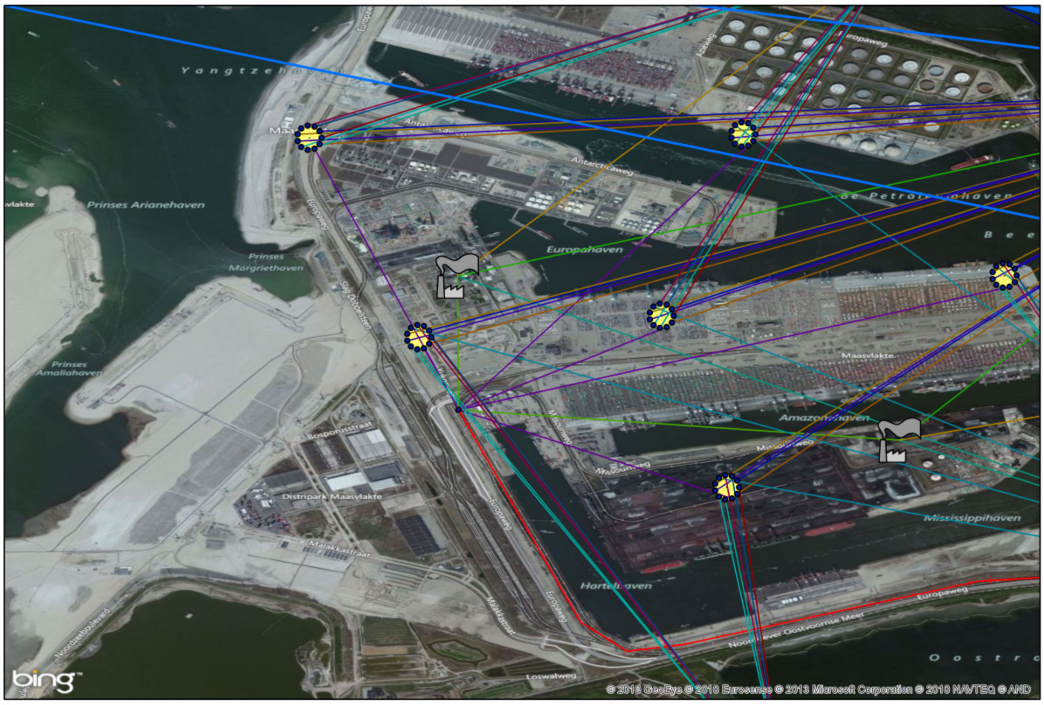


Figure 7 Intermodal terminals (ETIS, 2012) and end use nodes (power plants) (Davis et al., 2012). A depiction of the Rotterdam Maasvlakte I area. Background: Bing Maps®

Transport network data for road, rail and inland waterways for Europe are based on the TRANS-TOOLS V2 model (JRC 2009), a decision support model for transport impact analyses. This network database was updated with European Short Sea Shipping links and ports using the RRG GIS database on Short Sea Shipping Routes and Ports of Europe (RRG 2008). These routes were derived from the RRG short sea shipping network, a subset of inland waterways and shipping in the GIS Database of Trans-European Transport Networks (RRG 2008). The links in this database represent the most important shipping routes between almost 900 ports in Europe covering the Atlantic Ocean the North Sea, the Baltic Sea, the Mediterranean Sea and the Black Sea.
For the ocean shipping routes, the Oakridge National Laboratory Center for Transportation Analysis (ORNL-CTA) transportation network database was used. This database covers transportation networks for road, rail, inland waterways, great lakes and deep sea for North America (ORNL 2000). To link the global seaways of the ORNL-CTA network to ports, ports have been added from the World Port Index (NGA, 2011). Links and the related distances between the global

seaways and these ports have been added using ArcGIS. The network layers and related databases are depicted in Figure 8.

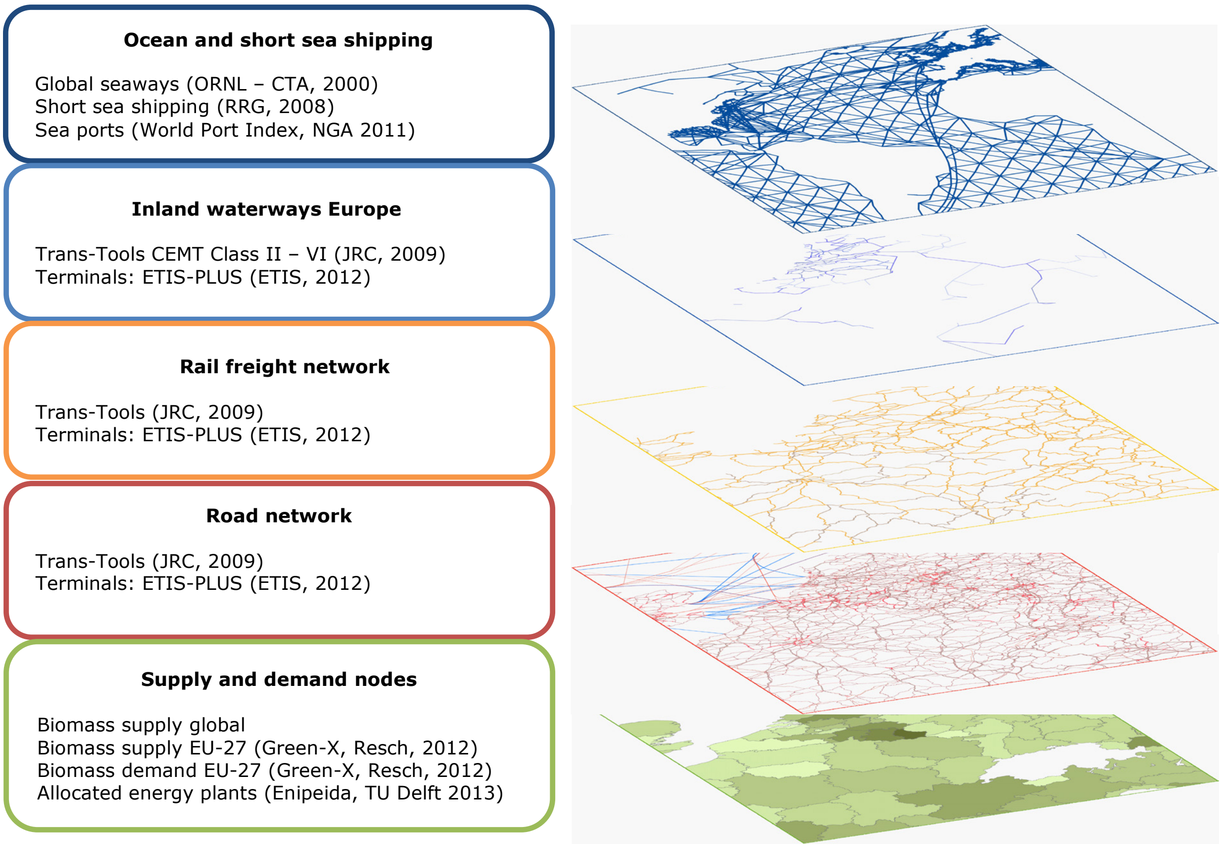


Figure 8 Transport network layers in the Biomass Transport Model

The model assumptions on transport and transhipment are depicted in Table 5. The specific transport cost depends on the fuel and labour costs which vary per country. For road transport by truck, also the speed, which varies per road type and for some highways, toll cost impact the total transport cost. The ranges in loading and unloading cost are based on country specific labour cost per country. For inland navigation, four ship types are included as not all ship sizes can navigate on all cannels or rivers. Main data sources for cost and other parameters include NEA (2004), TML (2005) and Smeets et al. (2009) as described in detail in Hoefnagels et al. (2011). Time cost for ocean shipping (charter rates) are based on the Baltic Exchange shipping indices as shown in Figure 10. The freight rates of the main scenarios are based on the median bulk dry freight rates between 2007 and 2011 that have been reported in the Baltic Dry Index, but also sensitivity runs have been conducted for the upper and lower range in the same period (Section 3.1.2.2).

Table 5 Performance parameters of hinterland transport in the EU-27 (based on NEA 2004, TML 2005, Smeets et al. 2009).

Network	Unit	Road	Rail	Inland waterways				
Transport mode		Truck	Dry bulk railcars	Small, dry bulk	Middle, dry bulk	Large dry bulk	Large dry bulk 2	Large dry bulk push tug
Labor (person/v)	Person/h	1.0		1.3	1.4	2.6	2.6	3.8
Time cost	€/h	18.4		10.3	21.9	72.2	106.7	214.2
Variable cost	€/km	0.30	0.06	0.00	0.00	0.74	0.93	17.84
Fuel type		Diesel	Diesel	MDO	MDO	MDO	MDO	MDO
Fuel consumption full	MJ/km	13	207	220	314	470	470	717
Fuel consumption empty	MJ/km	8	207	177	272	425	425	661
Maximum load	t	27	1,820	550	950	2,500	2,500	10,800
Maximum load	m^3	120	4,550	642	1,321	3,137	3,137	14,774
Speed (max)	km/h	80	80	5.42	5.80	6.71	8.64	9.00
Load factor (capacity use during laden trips)		100%	100%	71%	85%	77%	77%	83%
Laden trips of total trips		56%	50%	100%	100%	100%	100%	100%
Design ratio	kg/m^3	225	400	857	719	797	797	731

Table 6 Transport parameters of short sea transport in northwest Europe and intercontinental bulk ocean transport (based on NEA, 2004, IMO,2009) and charter rates (Baltic Exchange 2012).

Network	Unit	Short sea	Ocean		
Transport mode		>7,500 DWT	Handysize	Supramax	Panamax
Labor (person/v)	Person/h				
Time cost	€/h	224.9	450.6	627.5	735.1
Variable cost	€/km	11.20			
Fuel type		IFO380	IFO380	IFO380	IFO380
Fuel consumption full	MJ/km	1,430	1,761	2,185	2,553
Fuel consumption empty	MJ/km	1,430	1,466	1,742	1,987
Maximum load	t	9,600	26,000	37,000	53,400
Maximum load	m^3	16,000	43,333	61,667	89,000
Speed (max)	km/h	31.5	26.4836	26.67	26.67
Load factor (capacity use during laden trips)		100%	100%	100%	100%
Laden trips of total trips		100%	55%	55%	55%
Design ratio	kg/m^3	600	600	600	600

2.3.2 Supply and demand outside the EU-27

For supply and demand of biomass outside the EU-27, key regions that are already or could become large importing or exporting regions of solid biomass have been identified as described in Report I of this study (Hoefnagels et al., 2012). For each of these regions, export terminals (sea ports) represent the export or import nodes of solid biomass as shown in Figure 9 and in Table 7. Free on board (FOB) prices of solid biomass in combination with the locations of these sea ports, the distance to importing regions, the maximum ship sizes and shipping cost determine the total cost of supply of importing solid biomass from these regions.

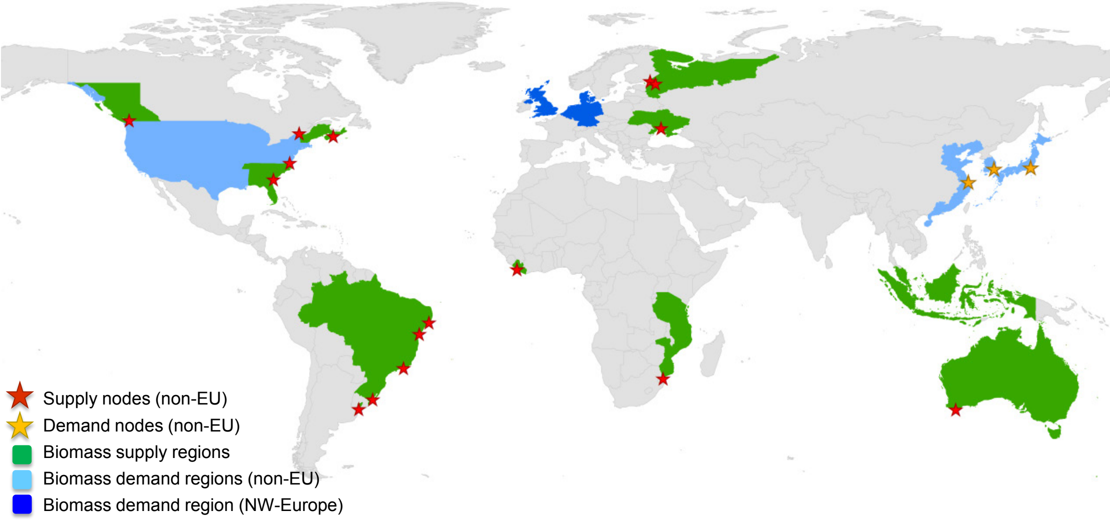


Figure 9 Sea ports representing global supply/demand nodes outside the EU-27, locations and port specifications based on World Port Index (NGA, 2011)

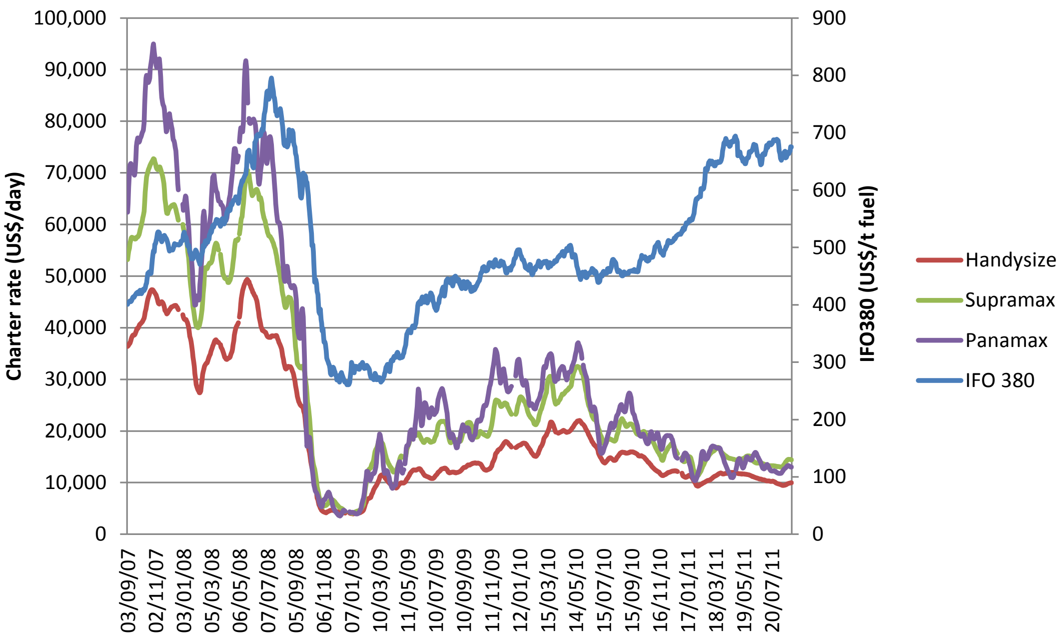


Figure 10 Charter rates and heavy fuel (Baltic Exchange, 2012)

Table 7 Ports and maximum ship size (NGA, 2011)

Country	Port	Port size	Max. ship size
Australia	Albany	S	Supramax
Belgium	Gent	M	Panamax
Belgium	Antwerpen	L	Panamax
Brazil	Rio Grande	L	Panamax
Brazil	Porto De Maceio	S	Panamax
Brazil	Port De Salvador	M	Panamax
Brazil	Rio De Janeiro	L	Panamax
Canada	Vancouver	L	Panamax
Canada	Halifax	L	Panamax
Canada	Montreal	L	Panamax
China	Shanghai	L	Panamax
Japan	Yokohama Ko	L	Panamax
Liberia	Buchanan	V	Panamax
Mozambique	Maputo	M	Supramax
Netherlands	Vlissingen	M	Handysize
Netherlands	Rotterdam	L	Panamax
Netherlands	Amsterdam	L	Panamax
Netherlands	Maassluis (Rotterdam)/ Europoort	L	Panamax
Russia	Sankt-Peterburg	L	Handysize
Russia	Vyborg	M	Handysize
South Korea	Pusan	L	Panamax
Ukraine	Dnipro-Buzkyy	S	Handysize
United Kingdom	Tyne	M	Panamax
United Kingdom	Hull	M	Panamax
United kingdom	Immingham	M	Panamax
United kingdom	Liverpool	L	Panamax
Uruguay	Montevideo	M	Panamax
USA	Savannah	M	Panamax
USA	Norfolk	L	Panamax

2.3.3 Supply and demand in the EU-27

Within the EU-27, both biomass demand and the economic-implementation potential of solid biomass supply in the Green-X model are specified on country level per EU member states. For this study, both supply and demand of solid biomass per EU member state are geographically distributed to the geographic centers (centroids) of NUTS-1[2] regions of each EU member states based on the following assumptions:

- For distribution of biomass supply, the area size (in m^2) of each NUTS-1 region relative to the total country size represents the supply potential share of these NUTS-1 regions relative to the total potential per country;
- For distribution of biomass demand, the population per NUTS-1 region, relative to the total population of that country was assumed to represent the demand share per NUTS-1 region.

A list of these regions, the population and the area sizes per region are provided in Table 24 in Appendix I. For RES-E generation in northwest Europe and the related demand of solid biomass, power plant specific demand nodes have been included in the Biomass Transport Model. Figure 11 shows the NUTS-1 centroids and locations of power plants. The locations of these power plants are based on the Enipedia Power Plant database (Davis et al., 2012) and corrected if required using satellite data from the Bing Maps aerial layer in ESRI ArcGIS (Cornelissen, 2012). An example of these layers is depicted in Figure 7.

[2] NUTS (Nomenclature of Territorial Units for Statistics) level 1 regions.

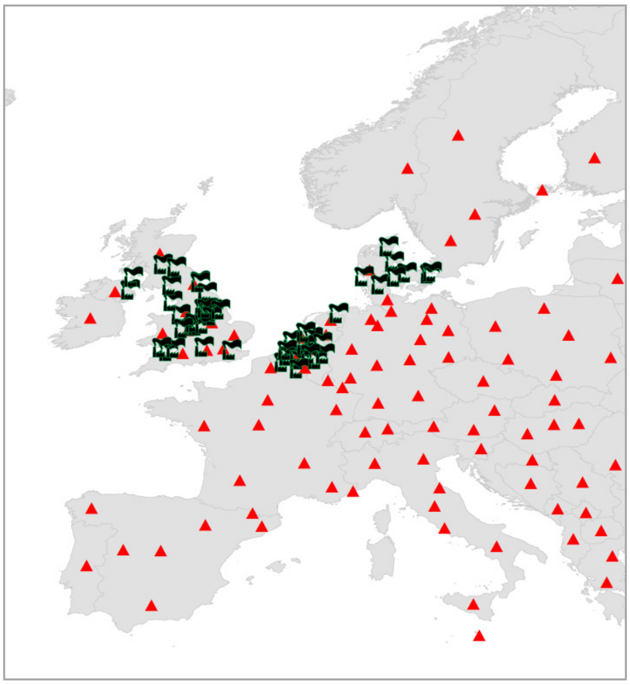


Figure 11 Geographic centers (centroids) of NUTS-1 regions in the EU-27 and the locations of coal fired power plants in northwest Europe based on Enipedia (Davis et al., 2012)

2.3.4 Origin-destination matrices

For each year and transport scenario, Origin-Destination (OD) matrices are calculated with the Biomass Transport Model. Figure 12 shows an example of straight line routes between origins of biomass supply outside the EU-27 and power plant demand nodes within northwest Europe. Note that these straight lines only represent the linkage between origins and destinations. The real, intermodal transport routes are calculated and used in the model, but not shown graphically.

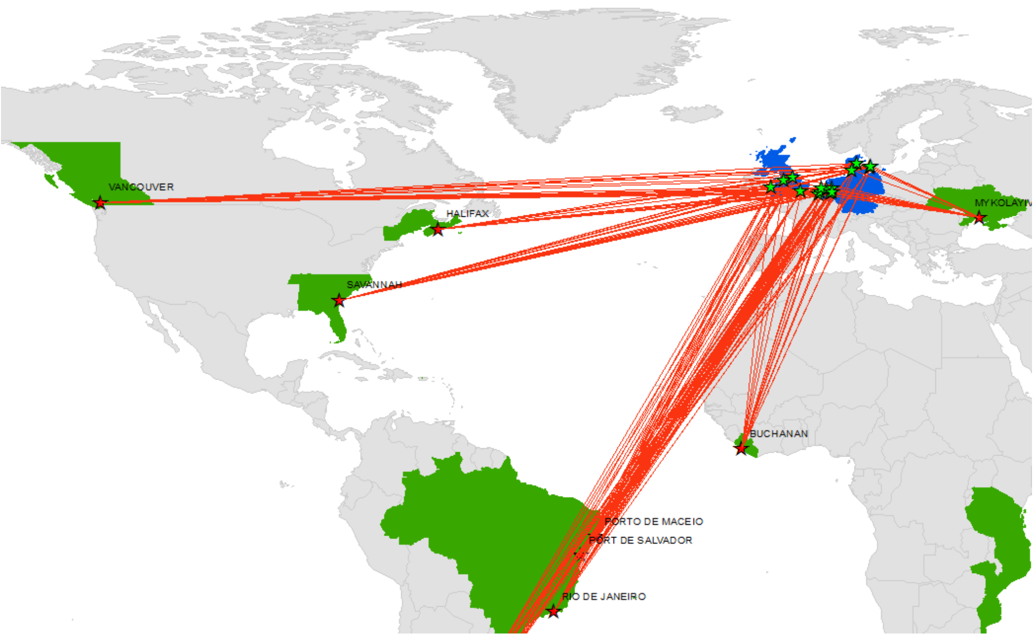


Figure 12 Origin – Destination matrix (straight lines) of selected origins outside the EU-27 and destinations (power plants) (Cornelissen, 2012)

2.4 Biomass Allocation Model

The Biomass Allocation Model is based on ESRI's Allocation Tools for ArcGIS 10 Module (ESRI, 2011) that starts with calculating least cost routes between all possible origins and destinations in OD-Cost matrices (see Section 2.3). With these least-cost routes and required capacities of supply and demand, a linear programming problem is formulated and solved using the free, open source solver COIN-OR. A detailed description of the Biomass Allocation Model can be found in Cornelissen (2012).

For each location of biomass supply, four levels of biomass cost and supply can be defined. The demand for solid biomass for RES-H, RES-E and RES-T is aggregated to a single demand node if the location is unknown. For known locations of RES-E generation, the demand for solid biomass can be defined explicitly.

Based on the supply and demand per node, the model allocates biomass supply to demand nodes so that the total demand is being met and the total cost of biomass supply are minimized.

3 Scenarios

3.1 Demand scenarios

3.1.1 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)

3.1.1.1 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, 2010a). 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.

3.1.1.2 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.

3.1.1.3 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 et al., 2012). Although policies are not assumed to change after 2020, both PRIMES and Green-X project increasing shares or renewable energy due to technology change and related decreasing cost of renewable energy technologies and the increasing cost of fossil fuels.

3.1.2 Sensitivity scenarios

Next to the core scenarios, a set of sensitivity scenarios have been assessed by changing key parameters relative to the main scenarios. The following sensitivity scenarios are included:

- Low Co-firing (reduced potential of biomass co-firing and conversion);
- Low Charter rates (low bulk freight rates for intercontinental transport);
- High Charter rates (high bulk freight rates for intercontinental transport);
- Bulk density/transport of torrefied pellets (TOPs) (transport of torrefied wood pellets with higher bulk density and calorific value compared to wood pellets);
- Port neutral fees and charges (all sea ports have similar fees/charges).

3.1.2.1 Low Co-firing

The future status of coal fired power plants with and without co-firing of biomass is uncertain as a result of planned or suggested taxes on coal consumption and/or CO_2 emissions, the impact of changing natural gas prices by shale gas markets and (peak) generation of renewable energy. For example, in the Netherlands, coal taxation is now being discussed. Such a taxation will increase the marginal cost of electricity generation from coal fired power stations. In combination with peak supply from renewable energy generation both domestically and imported from

neighbouring countries (e.g. Germany), coal-fired power generation loses its preeminence in the merit order (SQ Consult, 2012).
In this sensitivity scenario, it is assumed that the capacity factor of all coal-fired power plants with biomass co-firing and converted coal fired power plants will be 50% from 2015 onwards. Furthermore, coal fired power plants that have been commissioned before 1980s will be mothballed before 2015. These assumptions only apply to allocated demand in the scenarios (RES-$E_{allocated}$). The Green-X projections for solid biomass demand remain similar to the baseline scenarios.

3.1.2.2 Charter rates low/high
In the last 5 years, time charter rates of bulk ocean carriers have fluctuated heavily due to changes in supply and demand as shown in Figure 10 by macro-economic developments. In the main scenarios, time charter rates are based on the median bulk dry freight rates between 2007 and 2011 that have been reported in the Baltic Dry Index by Baltic Exchange (Baltic Exchange, 2012). To assess the impact of low and high bulk freight rates, the minimum and the maximum charter rates reported by the Baltic Exchange for each ship size between 2007 and 2011 have been assumed for the LowCharterRates and HighCharterRates scenarios respectively (see Table 8).

Table 8 Charter rates in the main scenarios and sensitivity scenarios

Scenario	Handysize	Supramax	Panamax
Main scenarios	451 €/h	628 €/h	735 €/h
LowCharterRates	124 €/h	128 €/h	112 €/h
HighCharterRates	1557 €/h	2293 €/h	2995 €/h

Exchange rate: 1.32 $/€

3.1.2.3 Bulk density (transport of torrefied pellets (TOPs))
In the main scenarios, we assumed that all biomass is processed into pellets before long distance transport. In this scenario, we assess the impact of increasing the bulk density and calorific value of transport biomass by torrefaction as shown in Table 9. Although torrefaction is considered more expensive than pelletization, reduced cost of transport, storage and higher combustion efficiencies could level out these cost differences (Deutmeyer et al., 2012). In this sensitivity scenario, no changes have been made to the cost of biomass supply from outside Europe (FOB prices in sea ports) and within Europe and cost changes in handling and storage.

Table 9 Properties of wood pellets and torrefied pellets (TOPs)

Feedstock	Moisture content [% ar]	Density (bulk) [kg/m3]	Net calorific value [MJ/kg ar]
Pellets	10	610	17.6
TOPs	3	800	22.0

3.1.2.4 Neutral port fees and charges
The cost for mooring, towing, pilotage and harbor dues have been specified in the model for relevant sea ports in Belgium (Ghent, Antwerp), the Netherlands (Amsterdam, Rotterdam, Vlissingen) and United Kingdom (Immingham, Kingston upon Hull, Liverpool, Tyne) based on reported cost. However, negotiated (long term) contracts can have significantly lower prices. Therefore, a sensitivity scenario has been conducted that assumes similar upfront cost for all ports based on the average cost of sea ports in Belgium and the Netherlands.

3.2 Biomass supply scenarios

3.2.1 Biomass supply EU

The input database of the Green-X model includes the economic-implementation potential[3] of 20 different resources for each country in Europe (Table 10). A detailed description and comparison with other supply studies is presented in Report D10 of the Re-Shaping project (Hoefnagels, Junginger, Panzer et al., 2011). These potentials are used in the biomass allocation model to determine the cost and supply of solid biomass in the EU-27 for all scenarios. Lignocellulosic energy crops (e.g. willow), or grassy crops (e.g. miscanthus) are included, but organic waste or energy crops for 1st generation biofuels (e.g. wheat, maize) are outside the scope of this study and therefore excluded as depicted in Table 10.
For reasons of model efficiency, the demand of solid biomass in each sector is assumed to be partly met by pre-defined domestic use. For example, the demand for RES-H non grid (decentralized, residential heating in for example household stoves) is subtracted from the total supply of currently used forestry products (FP1). There is hardly any international trade of solid biomass for residential, decentralized heating in northwest Europe. This approach avoids that biomass, that is currently being used for stoves in households, could also become available for trade and use in large scale electricity generation in the biomass allocation model. The pre-defined resource categories and RES sectors are depicted in the last column of Table 10. For RES-E allocated (co-firing and converted pulverized coal plants), it is assumed that tradable biomass is used.
For reasons of model efficiency, solid biomass supply in the EU-27 is aggregated into four resource categories: Agriculture Products (AP), Agriculture residues (AR), Forest Products (FP) and Forest residues (FR). After subtraction of pre-defined domestic use, the sum of remaining potential the weighted average cost represent the cost-supply potential of tradable solid biomass.

[3] The economic-implementation potential is the potential that is economically feasible within a certain time frame taking institutional and social constraints into account as well as policy incentives (see Report I (Hoefnagels et al., 2012) pp. 25 -26 for a description of different types of biomass supply potentials).

Table 10 Biomass resource types in the Green-X model (Resch et al. 2012) and resources included in this study.

Category Type	Included	Transported as	Pre-defined use
Agriculture products (energy crops)			
AP1 (rape & sunflower)	No		
AP2 (maize, wheat - corn)	No		
AP3 (maize, wheat - whole plant)	No		
AP4 (SRC willow..)	Yes	Wood pellets	
AP5 (miscanthus)	Yes	Grass pellets	
AP6 (switch grass)	Yes	Grass pellets	
AP7 (sweet sorghum)	No		
Agriculture residues			
AR1 (straw)	Yes	Straw pellets	RES-Tadv.
AR2 (other agri residues)	Yes	Straw pellets	RES-H grid
Forest products			
FP1 (forestry products - current use (wood chips, log wood)	Yes	Wood pellets	RES-H non grid
FP2 (forestry products - complementary fellings (moderate))	Yes	Wood pellets	
FP3 (forestry products - complementary fellings (expensive))	Yes	Wood pellets	
Forest residues			
FR1 (black liquor)	Yes, only domestic		RES-E unallocated
FR2 (forestry residues - current use)	Yes	Wood pellets	RES-E unallocated
FR3 (forestry residues - additional)	Yes	Wood pellets	
FR4 (demolition wood, industrial residues)	Yes	Wood pellets	
FR5 (additional wood processing residues (sawmill, bark)	Yes	Wood pellets	
Organic waste			
BW1 (biodegradable fraction of municipal waste)	No		
BG (agricultural biogas)	No		
LG (landfill gas)	No		
SG (sewage gas)	No		

3.2.2 Biomass supply outside the EU

Three scenarios have been defined to explore the potential of biomass export from outside the EU-27 as described in detail in Report I (section 5.4):

- Reference Trade
- High Trade 450
- Low Trade

The **Reference Trade** scenario considers expected developments in different world regions that are or are likely to become key exporting or key importing regions of solid biomass for bioenergy. This scenario is loosely based on the OECD Reference scenario and World Energy Outlook New Policy scenario as described in Report I (Section 5.4). The **High Trade 450** scenario assumes on the supply side a pathway with enhanced socio-economic and technological development and enhanced global orientation of trade resulting higher yields and supply potentials of dedicated energy crops in developing regions. Global demand also increases in this scenario as a result of ambitions to keep the atmospheric CO_2 concentration below 450 ppm in order to limit global temperature rises to 2 °C, consistent with the IEA WEO 450 Scenario (IEA, 2011). The **Low Trade** scenario describes a scenario with low technological development, resulting in low yields and low potentials of dedicated energy crops. In this scenario, export to the EU-27 exists of forestry residues from regions that are currently already exporting wood pellets (e.g. Canada), in combination with increased supply of European countries outside the EU-27 (Russia and Ukraine).

Although in Report I of this study it was considered that the wood pellet potentials from outside the EU-27 will be directly derived from the global technical potential and projected demand from existing energy models. This approach has proven to be infeasible due to the level of aggregation in these global model projections. Therefore, global export potentials are based on actual market developments, as assessed by IEA Bioenergy Trade Task 40 (Cocchi et al., 2011) in combination with updated information from ongoing work at the Copernicus Institute of Sustainable Development (Lamers et al., 2013). Figure 13 depicts the supply potential of wood pellets in the three scenarios of this study. The negative bars show the demand in regions outside (Asia) the EU-27 that will compete for the same resources.

Up to 2020, the Southeast of the US remains the largest exporting region of wood pellets. The utilization rate of pellet mills in the US is currently low (33%) (Cocchi et al., 2011), but the capacity of pellet mills has increased rapidly in recent years. In the US South[4] alone, the capacity is already 10 Mt/a ('Biomass Magazine', 2013) and still expected to increase. Based on the installed capacity and announced market developments, the South of the US is expected to export over 9 Mt/a wood pellets in 2015 increasing to 10 Mt/a in 2020 in the Reference Trade and High Trade 450 scenario with primary wood from forest plantations as the main source of wood fibers. After 2020, domestic demand for wood fibers will reduce the export potential in the High Trade 450 scenario, but will remain available in the Reference Trade scenario up to 2030.
Although the potential in Latin America is large and many for the development of production of plantation wood have been announced. It is not expected that these projects will develop in the short term (Lamers et al., 2013). However, beyond 2020, Latin America is still expected to become the main supplier of wood pellets for export increasing from 7.5 Mt/a in 2020 to 23.5 Mt/a in 2030 in the Reference Scenario. In the High Trade 450 scenario, wood plantations are projected to growth more rapidly, consistent with the projections of the High Import scenario in Cocchi et al. (2011). Similar, for Sub-Saharan Africa and Ukraine, development of forest plantations in the Reference scenario is expected to be low due as a result of low policy ambitions, non-economic barriers and agricultural development. These barriers are assumed to be mitigated in the High Trade 450 scenario resulting in large export potentials of wood pellets from energy crops in Ukraine (up to 19 Mt/a in 2030) and Sub-Saharan Africa (up to 12 Mt/a in 2030).

The supply cost of wood pellets from outside Europe are based on average FOB prices per supply region as published between May and November 2012 (Argus, 2012) as shown in Figure 14. Future prices are based on oil price in the scenarios and the estimated impact on pellet prices. Note that the prices at destination differ per import region depending on freight rates, fuel cost, harbor dues and other transport costs.

[4] Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia, West Virginia.

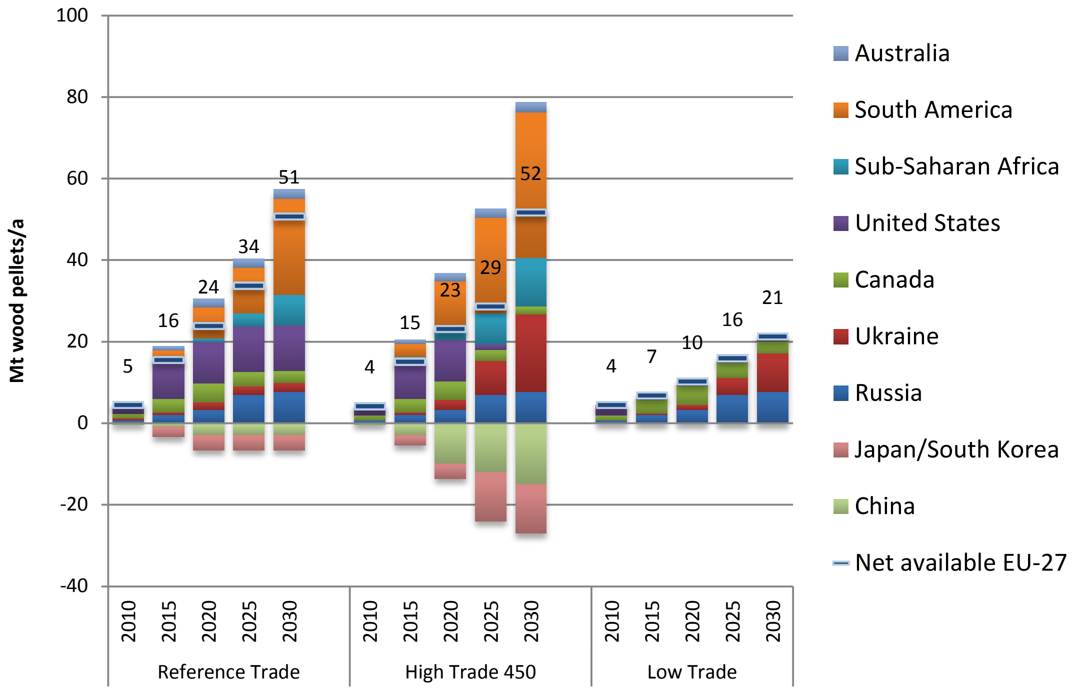


Figure 13 Scenarios of wood pellet production for export and demand for imported wood pellets in Asia

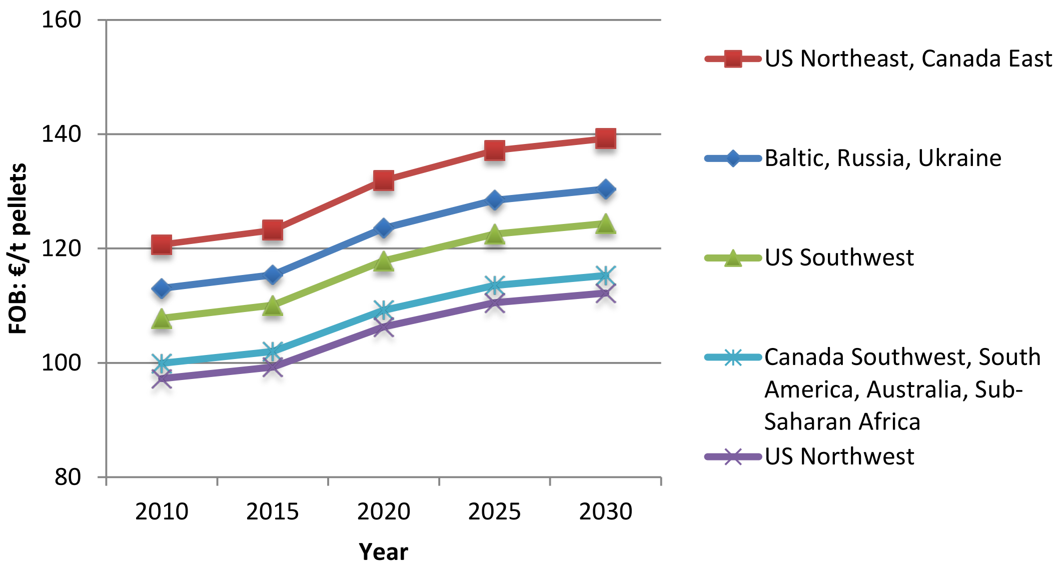
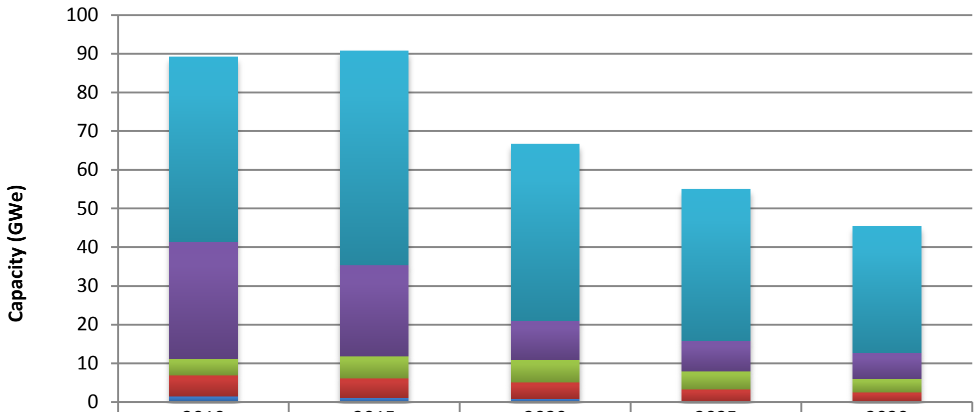


Figure 14 FOB prices of wood pellets per region

4 Renewable energy generation and supply of solid biomass

4.1 Current and future generation of RES-E (co-firing and conversion)

The Green-X projection of renewable energy demand from the Re-Shaping study as described in Report I (Hoefnagels et al., 2012) are made in 2011. Recent market developments and announcements already show that solid biomass demand might be different from these scenario projections. In order to update the existing scenarios and to allocate solid biomass demand to specific plants, a review of market announcements and updated plans from magazines, workshop presentations and websites has been conducted. This section summarizes these updates per country in northwest Europe.



	2010	2015	2020	2025	2030
GERMANY	47.8	55.3	45.6	39.2	32.7
UNITED KINGDOM	30.3	23.5	10.1	7.8	6.7
NETHERLANDS	4.2	5.8	5.8	4.7	3.5
DENMARK	5.5	5.1	4.3	3.3	2.5
BELGIUM	1.5	1.1	0.9	0.0	0.0

Figure 15 Capacity of coal fired and converted coal fired power plants in northwest Europe (GWe) (IEA CCC, 2012). Lifetime = 45 years.

4.1.1 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) (Figure 15). Currently, there are 5 units that are still in operation of which two power plants are opted out under the LCP directive (Box 1). 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 (Power-Technologies, 2012; Ryckmans, March 2012). 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 (Ryckmans, March 2012). Furthermore, E.on aims to convert the Genk Langerlo plant to 100% biomass in 2014 (E.on, 2012). The Electrabel SA Ruien power plant can co-fire biomass with ratios up to 26% in unit 5 (direct and indirect co-firing). Units 3 and 4 have also co-fired biomass (olive cake and wood dust) (Ryckmans, March 2012), but these units have been closed recently (winter 2012) resulting in a 50% reduction in total plant output.

Table 11 Scenario assumptions RES-E Allocated, Belgium

BAU	BAU-BM	SNP
The Rodenhuize plant is assumed to remain operational to at least 2015 but the Awirs and Ruien plants are assumed to be decommissioned before 2015. Plans for additional biomass capacity are assumed to be cancelled (for example, conversion of the Genk Langerlo plant).	Both the Awirs and Ruien plant remain operational until 2020 and 2015 respectively. The Rodenhuize plant will not contribute to the RES 2020 targets due to lack of support. The Genk Langerlo Plant will be converted to biomass before 2015.	Different from the BAU-BM scenario, the Awirs plant remains operational until 2020 to contribute to the RES 2020 targets. Other plant assumptions are similar to the BAU-BM scenario.

Box 1: 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).

4.1.2 Denmark

In Denmark 11 coal fired power plants or converted coal power plants with a total capacity of 5.5 GWe are currently in operation according to the IEA (IEA CCC, 2012). Dong energy is the largest owner/operator of these plants in Denmark with the majority already co-fire biomass (straw, wood chips, wood pellets) or are planned for conversion to biomass multifuel (Figure 16) (Dalsgaard, 2012). Important plans for future biomass include:

- Avedore vaerket, Unit 1 is planned to be converted to 100% biomass and Unit 2 is planned to increase from 80% biomass to 100% in 2013 (Sørensen, 2011).
- Studstrup vaerket, unit 3 will either be converted from co-firing (currently) to multifuel or be decomissioned.
- Skærbækværket, gas station planned to be converted to multifuel.

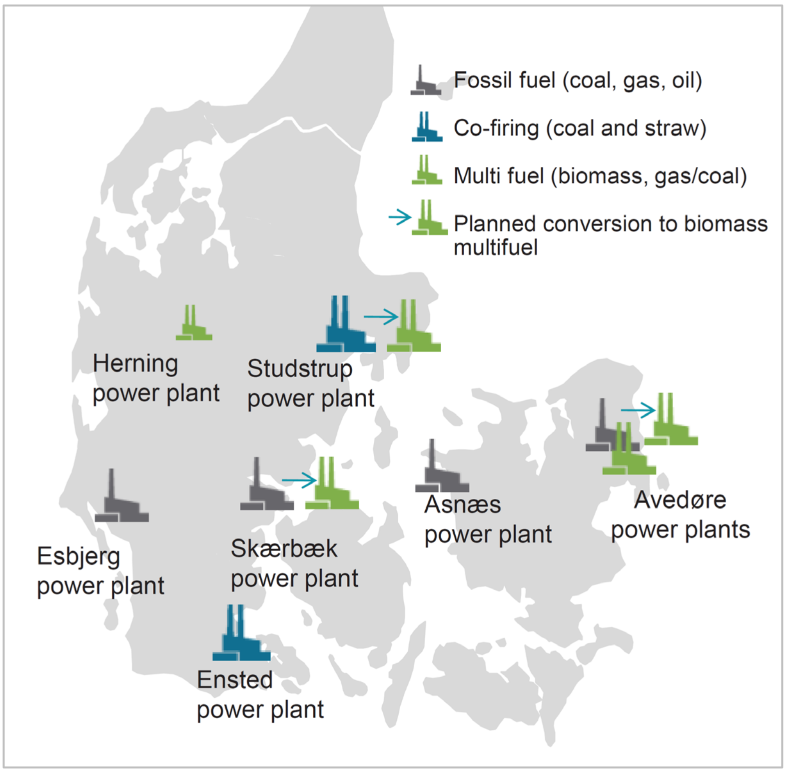


Figure 16 Development in DONG Energy CHP portfolio in Denmark (Dalsgaard, 2012)

Table 12 Scenario assumptions RES-E Allocated, Denmark

BAU	BAU-BM	SNP
In Denmark, support for co-firing of solid biomass, including agriculture residues, is assumed to end in 2015. The Avedore vaerket Unit 1 will not be converted to biomass.	The Avedore vaerket Unit 1 will be converted to biomass before 2015. Studstrup vaerket and Skærbækværket will be converted to multifuel plants. Other biomass units will remain operational after 2015.	The plant specific assumptions in the SNP scenario for Denmark were assumed to be similar to the BAU-BM scenario.

4.1.3 Germany

Despite the large capacity of coal fired power plants in Germany (almost 50 GWe, Figure 15) and additionally 12 GWe of new proposed capacity (Yang & Cui, 2012), it is not expected that Germany will start co-firing of biomass or convert coal-fired power plants to biomass at large scale. In Germany, support for electricity generation from solid biomass in the Renewable Energy Act (EEG) is limited to co-generation plants with capacities up to 20 MWe and no major changes with regards to co-firing or conversion of coal fired power plants are foreseen in this study. Note however that RES-E generation in Germany still increases significantly in the Green-X scenario projections. Especially in the SNP scenario, RES-E generation could still become more than three times larger in 2030 (44 TWh) compared to 2010 (13 TWh) (Figure 19).

4.1.4 Netherlands

The Netherlands has over 4 GWe coal and co-firing power plants that are currenly in operating of which one 250 MWe IGCC plant. The remaining capacity exists of pulverized coal plants. Furthermore, 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) (IEA CCC, 2012). An IGCC plant was also originally planned to be built in Eemshaven (Nuon/Vattenfall Magnum power plant). Phase 1 includes the installation of two gas turbine combined cycle (GTCC) units. 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 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. 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). The Nuon/Vattenfall Buggenum plant is scheduled to be decommissioned before 2015, despite announced plans to increasing the co-firing shares from 10% now, to 50 - 70% in the near future. The GDF Suez/Electrabel power plant that is currently constructed on the Maasvlakte could 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 in the future.

Table 13 Scenario assumptions RES-E Allocated, Netherlands

BAU	BAU-BM	SNP
The current MEP subsidy scheme will end in 2015. No new support policies are assumed in the BAU scenario resulting in a discontinuation of co-firing biomass in the Netherlands.	Co-firing support is continued at current levels to 2015, based on a green deal with the Dutch government. Gelderland G13 will be decommissioned before 2020.	In the SNP scenario, co-firing in Amer will increase to 39% and a 2nd gasifier will be added. Gelderland will remain operational until 2020. Co-firing shares in the new Eemshaven power plant will increase from 10% in the BAU-BM scenario to 15% in the SNP scenario. The Electrabel plant at Maasvlakte will co-fire 39% biomass, whereas E.on will increase co-firing to 10% and 14% in the existing and new units at Maasvlakte respectively.

4.1.5 United Kingdom

According to the IEA Coal Power database (IEA CCC, 2012), the installed capacity of coal fired power stations is currently 30 GWe with 8 units planned to be opted out under the LCPD (Box 1). These include E.on's Ironbridge (970 MWe) and Kingsnorth (1,940 MWe) power stations, RWE nPower's Didcot A (2,000 MWe) and Tilbury B (750 MWe)[5] power stations, SSE Ferrybridge C (1,970) and Cockenzie (1,200 MWe) reducing the installed capacity with over 9 GWe in 2015 if no measures are taken to continue operation (EC, 2011c; IEA CCC, 2012). For example, Tilbury B, already fully converted to biomass, aims to relicense the power plant to continue operation beyond 2015 as a slid biomass power station. Driven by the ROC's quota system (Report I), also other power stations now aim to convert coal power stations to 100% biomass. These include:

- Alcan Lynemouth (420 MWe), which has been recently sold from Rio Tinto to RWE. In 2013, RWE is expected to decide if the plant will be converted to biomass;
- Drax power station (4,000 MWe), the largest power station in the UK, plans to convert 3 out of 6 units to biomass with the first unit operational in the 2nd quarter of 2013, the 2nd in 2013-2014 and the 3rd scheduled for

[5] Original capacity: 1,050 MWe coal, but converted to 750 MWe biomass.

2016. Also the remaining 3 units are under consideration for conversion to biomass.
- Rugely power station (1,026 MWe). The economic and technical feasibility of biomass conversion is currently being assessed.
- Ironbridge power station (970 MWe) is being converted to 100% biomass with up to 600 MWe biomass capacity, but is still aimed to be decommissioned in 2015 under the LCPD.
- Eggborough[6] power station (2,000 MWe), might also be converted to biomass as announced recently.

In addition to conversion of existing coal fired power plants to biomass, also many new dedicated biomass power plants have been announced (Argus, 2012). Many of these plans are currently on hold or cancelled as a result of amongst others uncertainty in long term support (ROCs) and liquidity problems. These projects have not been included in this study.

Table 14 Scenario assumptions RES-E Allocated, United Kingdom

BAU	BAU-BM	SNP
In the UK, the converted Tilbury power plant is assumed to be opted out under the LCPD before 2015. Plans to convert the Drax power plant to 100% biomass are assumed to be cancelled in this scenario. The plant will remain co-firing 13% (e/e) biomass until 2015.	Drax 3 Units will be converted to 100% biomass. The remaining 3 units will remain coal fired. Tilbury B will be decomissioned after 2015. Plans to convert Alcan Lynemouth and Rugeley to biomass will be cancelled.	The remaining coal fired units of the Drax Power station will be converted to biomass after 2020. Tilbury B remains operational until 2025 using 100% biomass. Alcan Luynemouth and Rugeley power stations will be converted to biomass before 2015.

4.2 Allocated generation of electricity from solid biomass in the scenarios

The market for solid biomass use for co-firing and conversion of pulverized coal plants is dynamic and uncertain. A review of the current situation and plans and announcements on future changes, as summarized in Section 4.1, is translated in the three scenarios of solid biomass demand covered per country in Table 11 - Table 14. When available, the Green-X model projections of electricity generation with solid biomass have been substituted with plant specific assumptions per scenario. In the BAU-BM scenario (Figure 18) and SNP scenario (Figure 19), plant specific electricity generation from solid biomass (RES-E allocated) exceed the Green-X projections resulting in higher demand of solid biomass in this study compared to the original Green-X Re-Shaping scenarios (green markers in Figure 17 - Figure 19). In the BAU scenario (Figure 17), RES-E generation and related demand for solid biomass is almost similar to the original scenarios. In this study, co-firing or conversion of large scale coal fired power plants is not considered in Germany. Projections of solid biomass demand for RES-E in Germany are therefore similar to the Re-Shaping scenarios.

[6] The announced plan for full conversion of Eggborough are not implemented in the scenarios in this report as it was not available at the time of modeling.

4.2.1 Business as Usual (BAU)

In the BAU scenario, allocated generation of RES-E is lower than the total projected generation of RES-E in northwest Europe as a result of discontinued support (Figure 17). The demand for solid biomass RES-E is therefore consistent with the Green-X scenarios.

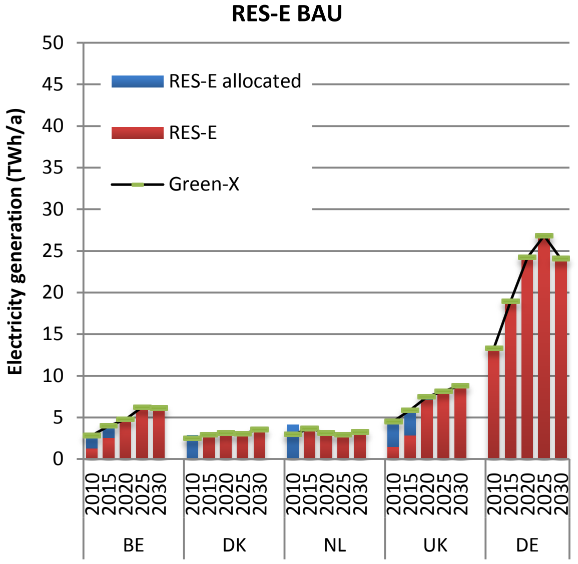


Figure 17 Allocated and unallocated generation of RES-E: BAU scenario

4.2.2 BAU – Barriers Mitigated (BAU-BM)

Similar to the BAU scenario, a continuation of current RES support policies is assumed in the BAU-BM scenario, but with mitigation of non-economic barriers. The translation of mitigating non-economic barriers to the level of co-firing and conversion in northwest Europe is difficult. Therefore, country specific assumptions have been made resulting in an average scenario between BAU and SNP.

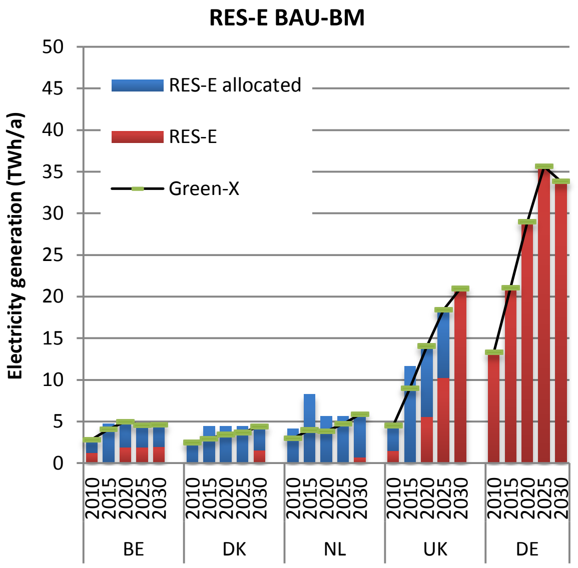


Figure 18 Allocated and unallocated generation of RES-E: BAU-BM scenario

4.2.3 Strengthened National Support (SNP)

The SNP scenario covers most announced plans of biomass co-firing and conversion that have been published for northwest Europe as described in Section 4.1. For example, recently announced plans in the Netherlands for high co-firing shares of up to 40% could result in higher generation of RES-E than anticipated in the Green-X projections. Also in the UK, plans to convert existing coal fired power plants to biomass including Tilbury B and Drax, could result in RES-E generation that exceed the projections of Green-X (Figure 19). Still, these scenario projections are in range with the planned generation of renewable energy from solid biomass in NREAPs and other projections as shown in Table 15.

Table 15 RES-E generation from solid biomass (GWh/a) in the SNP scenario, the NREAPs (Tables 11) and ECN (Verdonk & Wetzels, 2012).

	2010	2020	2030
UK			
SNP PoR	4,542	20,488	18,807
NREAP UK	5,500	20,590	
NL			
SNP PoR	3,615	10,833	8,042
NREAP NL	5,103	11,975	
Of which co-firing	3,078	8,350	
ECN Co-firing (planned policy scenario)	3,611	8,056	5,278

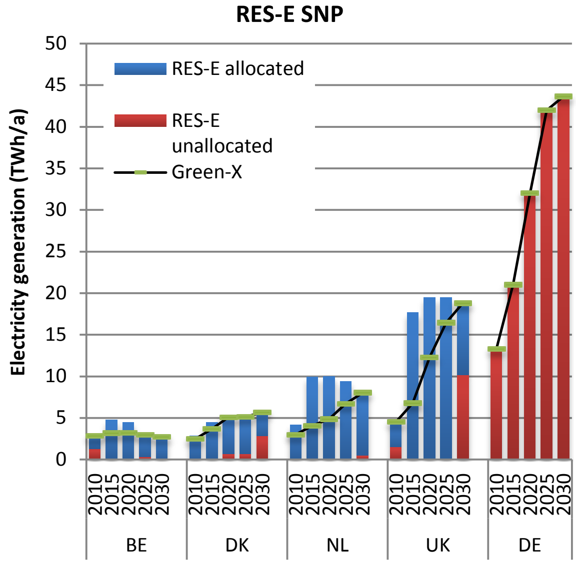


Figure 19 Allocated and unallocated generation of RES-E: SNP scenario

4.3 Contribution of solid biomass to renewable energy supply

The Re-Shaping scenarios, as discussed in Report I, show that with a continuation of current levels of support for renewable energy (BAU scenario), the national targets will not be met in 2020 and that both mitigation of non-economic barriers (BAU-BM scenario) as well as a strengthening of support are required to meet these targets (SNP scenario). Table 16 compares the original Re-Shaping scenario results with the binding national RES 2020 targets of the EC and the national goals as laid down in the national renewable action plans (NREAPs).

The main difference between the Green-X scenario projections of the Re-Shaping project and the NREAPs is that, apart from Denmark, the other member states in northwest Europe will import renewable energy to meet the national targets whereas the NREAPs show a slight overshoot of the binding targets in 2020 based on domestic RES generation.

In the SNP scenario, for example, the RES share in gross final energy demand is projected to increase to 11.8% in 2020 whereas 14.5% is aimed for in the NREAP of the Netherlands for the same year. With updated plans of co-firing, as described in Section 4.2, the total RES share used in this study increase to 12.7% in 2020 in the SNP scenario (Figure 22). Total RES deployment in the BAU scenario (Figure 20) is similar to the Re-Shaping scenarios because allocated electricity generation does not exceed the Green-X projections (Figure 17).

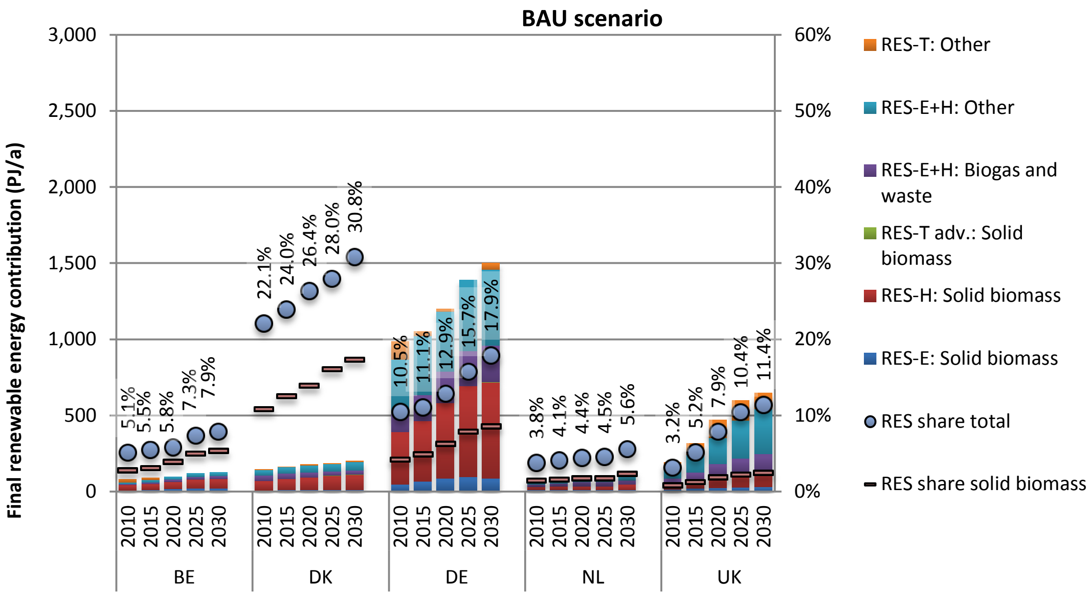


Figure 20 Renewable energy and contribution of renewable energy from solid biomass: BAU scenario

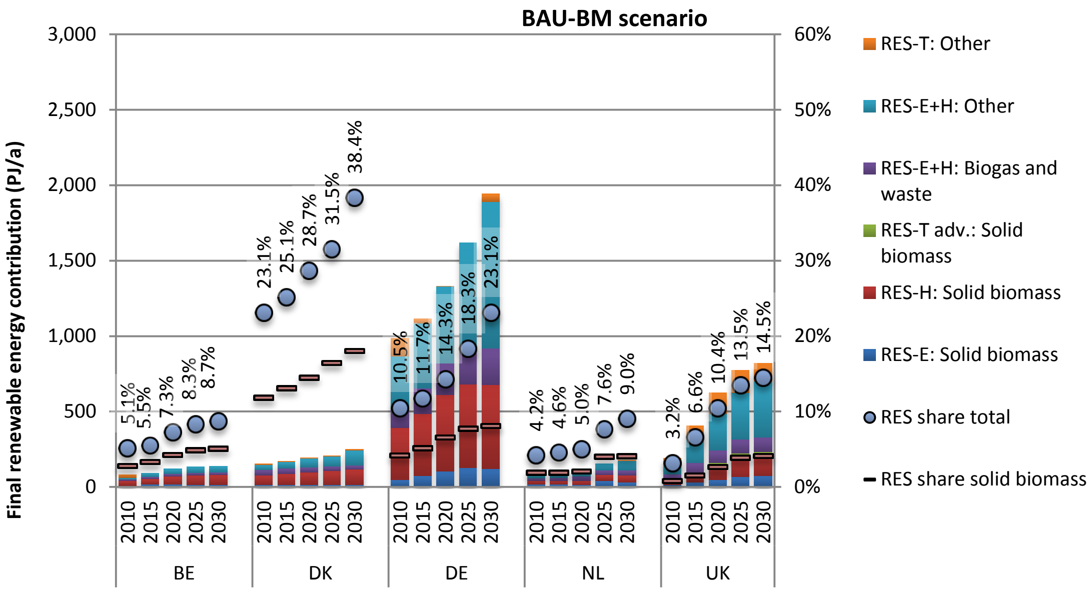


Figure 21 Renewable energy and contribution of renewable energy from solid biomass: BAU-BM scenario

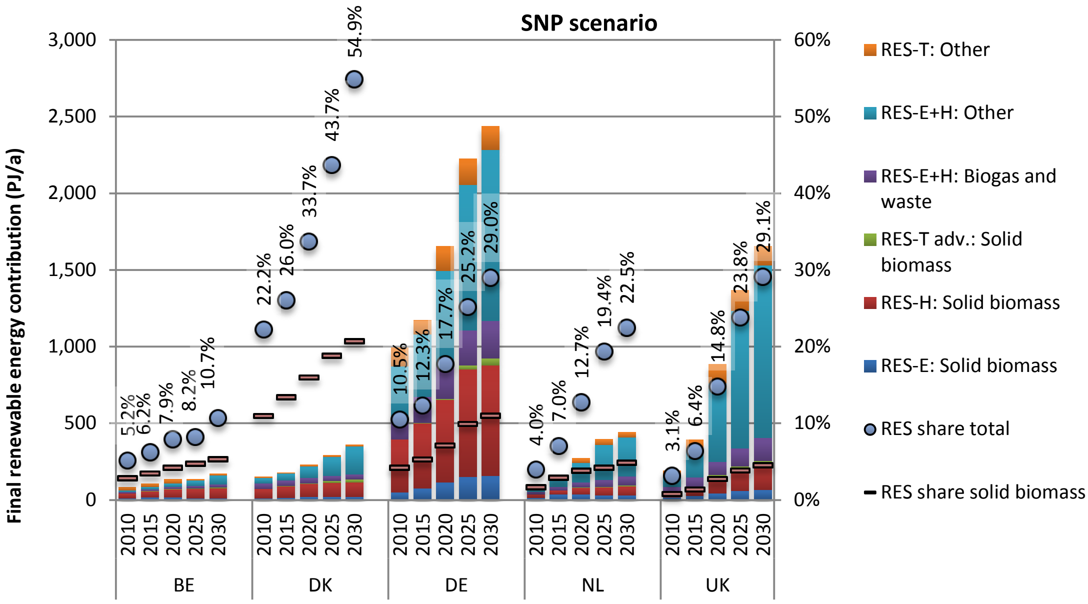


Figure 22 Renewable energy and contribution of renewable energy from solid biomass: SNP scenario

Table 16 RES shares in gross final energy demand. The original projections of the Green-X model (excluding the additional scenario assumptions for RES-E generation of this report), and NREAPs and the binding national RES targets of the EC (EC, 2010b).

Scenario/target	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%

5 Demand and trade of solid biomass

The primary demand for solid biomass for RES-H, RES-E and RES-Tadv. generation in the scenarios, as projected with the Green-X model in combination with the calculated demand of allocated electricity in this study, are applied to the Biomass Allocation Model to calculate biomass supply. This section covers the total demand for solid biomass in the demand scenarios and the related supply from domestic, European and non-European resources and related trade flows as calculated with the Biomass Allocation model.

5.1 Primary solid biomass demand

Total primary solid biomass demand in the scenarios includes solid biomass demand for residential heating (RES-H non-grid) and heat from centralized heating systems or CHP plants (RES-H grid), solid biomass demand for electricity generation in allocated power plants (RES-E allocated) and unallocated use, as projected by the Green-X model (RES-E unallocated) and use for advanced biofuels (RES-Tadv.). Figure 23 depicts the total primary demand for solid biomass in northwest Europe for 2010 to 2030 in the BAU, BAU-BM and SNP scenarios. The line bars represent the pre-defined use of solid biomass that can only be supplied by domestic resources (mainly for RES-H non-grid). The remaining demand can be met by domestic resources, imported from other EU member states or imported from outside Europe depending on the total cost of supply.

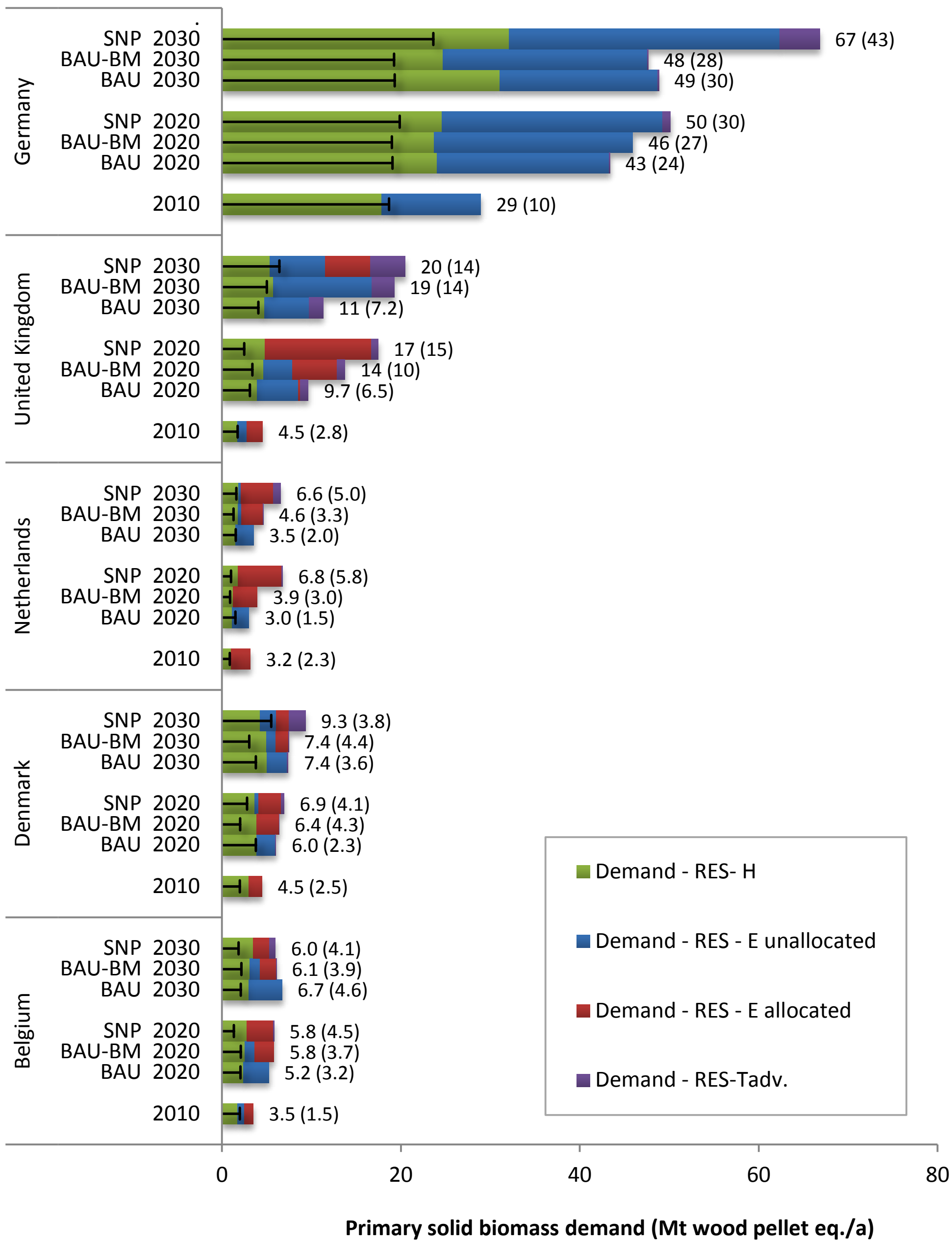


Figure 23 Primary solid biomass demand (expressed in wood pellet equivalent, 17.6 MJ_{hv}/kg_{ar}) with pre-defined domestic use of non-tradable biomass (positive error bars). The labels show the total demand for solid biomass and demand for tradable biomass between brackets.

Total demand for solid biomass in northwest Europe increases with 75% in the BAU scenario and up to almost 150% in the SNP scenario between 2010 and 2030 as a result of increased generation of renewable energy from biomass. In 2020, projected demand for solid biomass in Germany could be higher than the total demand for solid biomass in northwest Europe in 2010 (780 PJ, 45 Mt wood pellet eq.). In the Netherlands and the United Kingdom, plans for co-firing and full conversion of coal fired power plants, for example the conversion of UK's largest coal power plant to biomass Drax, results in rapid growth of solid biomass for RES-E allocated between 2010 and 2020 in the SNP scenario. In Germany, demand is driven by RES-H generation and RES-E generation in stand-alone dedicated biomass electricity plants in the SNP scenario to 2020 and additional advanced transport fuel production between 2020 and 2030.

5.2 Supply and trade of solid biomass

Based on the demand for solid biomass in the scenarios (Section 5.1), combined with the economic-implementation potential of solid biomass in the EU-27 and other key exporting regions (Figure 13), biomass supply scenarios are assessed with the Biomass Allocation Model.

To estimate biomass trade flows, first, biomass resource categories have been allocated to use categories. The net difference between the supply potential of the resource category and the domestic primary energy use is used in the biomass trade model. For example, current domestic supply of solid biomass used in local heating systems (houses) is allocated to the same sector. Also for centralized heat generation (RES-H grid), advanced biofuels from lignocellulosic biomass (RES-T advanced) and electricity generation at unknown locations (RES-E unallocated), similar assumptions have been made:

- RES-H (residential): Forest products, current use
- RES-H (grid): Agriculture residues
- RES-T (advanced): Agriculture residues (straw)
- RES-E (unallocated): Forest residues, current use

The remaining supply and demand of solid biomass has been allocated based on linear optimization (lowest cost). Depending on the domestic cost-supply potential and the total cost of importing biomass resources, domestic resources are used or biomass is imported from other EU member states (import EU) or imported from outside the EU-27 (import non-EU).

5.2.1 Supply of solid biomass: Reference Trade

Figure 24 summarizes the supply of solid biomass in the Reference Trade scenarios (BAU - Reference Trade, BAU-BM – Reference Trade, SNP – Reference Trade) to 2030. Domestic supply is shown in the chart labels (D.), but excluded from the chart bars as it would increase the chart scale substantially reducing its readability. Current import of solid biomass (2010) only include wood pellets based on statistical data from EUROSTAT and data from IEA Bioenergy Trade Task 40 (Cocchi et al., 2011), but exclude trade of other solid biomass such as wood chips.

The demand for solid biomass from imported resources in Figure 24 has been categorized in two main types based on the different supply chains: industrial use and residential use. Residential use covers the use of solid biomass for residential heating (RES-H non-grid), for example in wood stoves. Industrial demand of imported biomass covers electricity generation (RES-E), heat generation in centralized (CHP) plants (RES-H grid) and the production of advanced biofuels (RES-Tadv.).

In Belgium, the import of solid biomass is projected to increase up to almost fivefold in the BAU scenario (3.3 Mt wood pellet eq. in 2030) compared to the net import of wood pellets in 2010 (0.7 Mt wood pellet eq. in 2030). In Denmark, the highest import is projected in the BAU-BM and SNP scenario in 2020 (2.5 Mt wood pellet eq. from outside the EU-27). In the Netherlands and United Kingdom, the highest demand for solid biomass is projected in the SNP scenario for 2020 as a result of allocated use in electricity generation plants from high co-firing levels in the Netherlands and full conversion of coal fired units to biomass. However, the BAU scenario shows that with current support policies and EU member states not meeting the binding RES 2020 targets, the demand for imported biomass in 2020 could also be substantially lower than current import of wood pellets.

In all scenarios, Germany, currently a net exporting country of wood pellets, becomes a net importing country as a result of the projected increases in solid biomass demand for RES-H and RES-E (Figure 23). In 2020, when the demand is highest in the Netherlands and the UK, supply of imported solid biomass in Germany comes mainly from other EU-27 member states. In 2030 however, large amounts (almost 18 Mt wood pellet eq.) are projected to be imported from outside the EU in the SNP scenario.

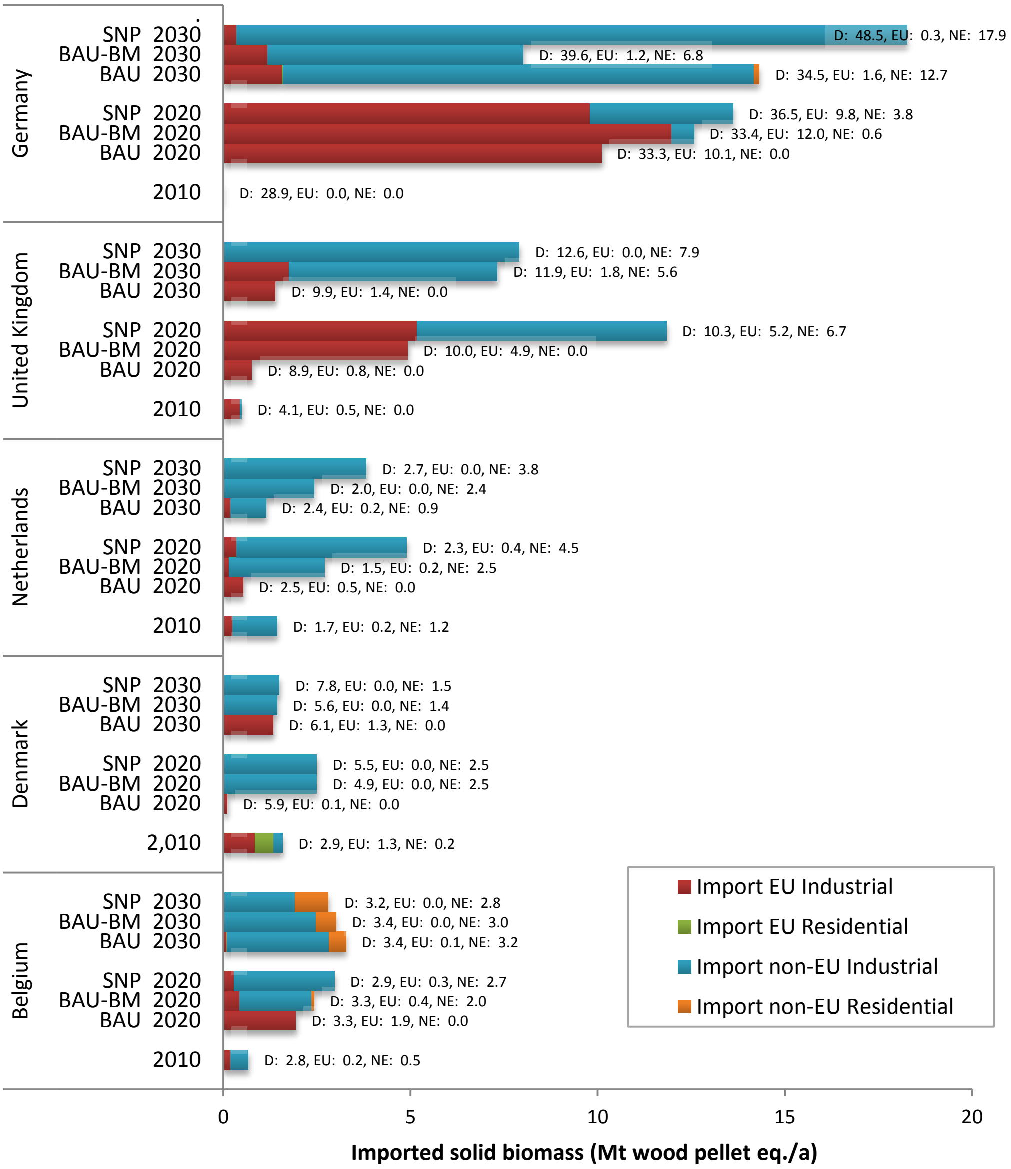


Figure 24 Import of solid biomass in wood pellet equivalent (17.6 MJ/kg) from other EU member states (Import EU) and from outside the EU (Import non-EU) in the Reference Trade scenarios. The labels show total domestic demand (D.), Total import EU-27 (EU) and Total Import non-EU (NE).

5.2.2 High Trade 450 and Low Trade scenarios

Alternative scenarios on supply of biomass from outside the EU-27, as described in Section 3.2.2, are compared to the Reference Trade scenarios in Table 17. The Low Trade scenario assumes 21 Mt wood pellets to be available from outside the EU-27 in 2030 compared to 51 Mt wood pellets in the Reference Trade scenario. In both the BAU-Reference Trade and BAU-Low Trade scenario, hardly any wood pellets are projected to be imported from outside the EU-27 to northwest Europe in 2020. In 2030, more biomass is projected to be imported from other EU member states (13.5 Mt) compared to the BAU – Reference Trade scenario (4.6 Mt). The total supply potential of wood pellets from non-EU resources is almost similar in the Reference Trade and High Trade 450 scenario (51 and 52 Mt wood pellets in 2030 in the Reference Trade and High Trade 450 scenario respectively). Nevertheless, geographic shifts in supply and demand, decreases imports of biomass from outside Europe and increased imports from other EU member states. The difference between imports from non-EU countries in the High Trade 450 scenario compared to the Reference Trade scenario remains small however (up to 2.6 Mt less imports from outside the EU-27 in the BAU-BM scenario in 2030).

Table 17 The impact of alternative global biomass supply scenarios on supply, demand and trade of solid biomass relative to the Reference Trade scenario in northwest Europe in 2020 and 2030 (in Mt wood pellet equivalent/a). Industrial use: RES-H grid, RES-E, RES-Tadv.. Residential use: RES-H non-grid (residential use, mainly stoves).

		Demand scenario: BAU						Demand scenario: BAU-BM						Demand scenario: SNP					
		Reference Trade		Low Trade		% change		Reference Trade		High Trade 450		% change		Reference Trade		High Trade 450		% change	
		2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Belgium																			
Domestic	Non-tradable	2.1	2.1	2.1	2.1	0%	0%	2.1	2.2	2.1	2.1	0%	-2%	1.3	1.9	1.3	1.9	0%	0%
	Tradable	1.2	1.3	1.2	1.3	0%	0%	1.2	1.3	1.2	1.2	0%	-2%	1.5	1.3	1.5	1.3	0%	0%
Import EU	Industrial	1.9	0.1	1.9	1.4	0%	1658%	0.4	0.0	0.6	0.0	43%	0%	0.3	0.0	0.3	0.0	0%	0%
	Residential	0.0	0.0	0.0	0.2	0%	1658%	0.0	0.0	0.0	0.0	43%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	2.7	0.0	1.4	0%	-49%	1.9	2.5	1.7	2.6	-9%	4%	2.7	1.9	2.7	1.9	0%	0%
	Residential	0.0	0.4	0.0	0.2	0%	-49%	0.1	0.5	0.1	0.5	-9%	1%	0.0	0.9	0.0	0.9	0%	0%
Denmark																			
Domestic	Non-tradable	3.8	3.8	3.8	3.8	0%	0%	2.0	2.6	2.0	2.0	0%	-22%	2.8	5.5	2.8	5.5	0%	0%
	Tradable	2.2	2.3	2.2	2.4	0%	6%	2.9	3.0	2.9	3.8	0%	27%	2.7	2.3	2.7	2.3	0%	0%
Import EU	Industrial	0.1	1.3	0.1	1.2	0%	-11%	0.0	0.0	1.6	0.1	0%	0%	0.0	0.0	0.0	0.0	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	0.0	0.0	0.0	0%	0%	2.5	1.4	0.9	2.4	-63%	68%	2.5	1.5	2.5	1.5	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Germany																			
Domestic	Non-tradable	19.1	19.3	19.1	19.3	0%	0%	19.0	19.2	19.0	19.1	0%	-1%	19.9	23.6	19.9	23.6	0%	0%
	Tradable	14.2	15.2	14.2	16.8	0%	11%	14.4	20.4	14.4	20.3	0%	-1%	16.7	24.9	16.7	26.3	0%	6%
Import EU	Industrial	10.1	1.6	10.1	9.8	0%	522%	12.0	1.2	12.0	6.1	0%	416%	9.8	0.3	9.8	0.3	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	-100%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	12.6	0.0	2.9	0%	-77%	0.6	6.8	0.6	4.0	0%	-42%	3.8	17.9	3.8	16.5	0%	-8%
	Residential	0.0	0.1	0.0	0.0	0%	-100%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Netherlands																			
Domestic	Non-tradable	1.5	1.5	1.5	1.5	0%	0%	0.9	0.9	0.9	0.7	0%	-26%	1.0	1.6	1.0	1.6	0%	0%
	Tradable	1.0	0.9	1.0	1.1	0%	26%	0.6	1.1	0.6	1.0	0%	-8%	1.2	1.1	1.2	1.1	0%	0%
Import EU	Industrial	0.5	0.2	0.5	0.9	0%	371%	0.2	0.0	0.7	0.0	344%	0%	0.4	0.0	0.4	0.0	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	0.9	0.0	0.0	0%	-100%	2.5	2.4	2.0	2.7	-21%	11%	4.5	3.8	4.5	3.8	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
United Kingdom																			
Domestic	Non-tradable	3.1	4.1	3.1	4.1	0%	0%	2.6	5.0	2.6	4.2	0%	-17%	2.5	6.4	2.5	6.4	0%	0%
	Tradable	5.8	5.8	5.8	5.9	0%	2%	7.4	6.9	7.4	6.2	0%	-10%	7.9	6.2	7.9	6.2	0%	1%
Import EU	Industrial	0.8	1.4	0.8	0.0	0%	-100%	4.9	1.8	4.9	0.3	0%	-85%	5.2	0.0	5.2	0.3	0%	0%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	0.0	0.0	1.3	0%	0%	0.0	5.6	0.0	4.5	0%	-20%	6.7	7.9	6.7	7.5	0%	-5%
	Residential	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%	0.0	0.0	0.0	0.0	0%	0%
NW-Europe																			
Domestic	Non-tradable	29.5	30.8	29.5	30.8	0%	0%	26.7	29.9	26.7	28.1	0%	-6%	27.5	39.0	27.5	39.0	0%	0%
	Tradable	24.4	25.5	24.4	27.6	0%	8%	26.5	32.6	26.5	32.5	0%	0%	30.0	35.8	30.0	37.3	0%	4%
Import EU	Industrial	13.4	4.6	13.4	13.3	0%	192%	17.5	2.9	19.8	6.4	13%	120%	15.6	0.3	15.6	0.7	0%	89%
	Residential	0.0	0.0	0.0	0.2	0%	685%	0.0	0.0	0.0	0.0	43%	0%	0.0	0.0	0.0	0.0	0%	0%
Import non-EU	Industrial	0.0	16.3	0.0	5.6	0%	-66%	7.6	18.7	5.3	16.1	-30%	-14%	20.2	33.0	20.2	31.3	0%	-5%
	Residential	0.0	0.6	0.0	0.2	0%	-60%	0.1	0.5	0.1	0.5	-9%	1%	0.0	0.9	0.0	0.9	0%	0%

5.2.3 Cost-supply curves

In order to illustrate how biomass supply is allocated to biomass demand regions with the Biomass Allocation Model, Figure 25 - Figure 54 show the cost-supply curves of exploited biomass for the BAU and SNP scenarios. If biomass is imported from different countries outside the EU, the cost will differ per origin as a result of different FOB prices and cost of transport. Only the weighted average costs per type are shown in these cost-supply curves. A description of the resource categories and origins of resources is provided in Table 18. For all resources of solid biomass, imported biomass is assumed to be pelletized before transport. The cost-supply curves include the cost of biomass at farm gate, pre-processing (pelletization) if exported, and transport to the end-users.

Table 18 Abbreviations and descriptions of types of solid, lignocellulosic biomass resources and origins used in Figure 25 - Figure 54

Origin	Description
Dom.	Domestic use of domestic biomass (no pre-processing required).
Import EU	Import from other EU member states, densification required before transport (pelletization). Costs of feedstock, densification and transport included.
Import non-EU	Import of pellets from outside the EU-27, based on FOB prices and transport cost.
Type	**Description**
FR	Forest residues (e.g. sawdust,).
FP	Forest products (e.g. whole tree harvesting).
AR	Agriculture residues (e.g. straw).
AP	Lignocellulosic agriculture products (short rotation coppice (e.g. willow) and energy grasses (e.g. miscanthus)).
Type	**Description**
Dom. FR*	Non-tradable use of forest residues (RES-E unallocated)
Dom. FP*	Non-tradable use of forest products (RES-H non grid)
Dom. AR*	Non-tradable use of agriculture residues (RES-H grid/RES-Tadv.)

5.2.3.1 Belgium

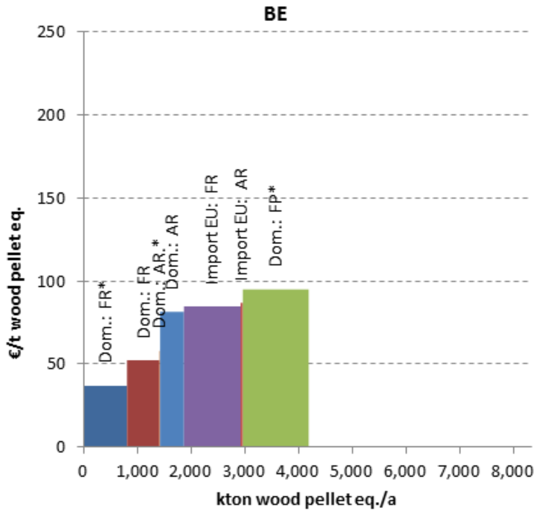


Figure 25 BAU 2015 Belgium

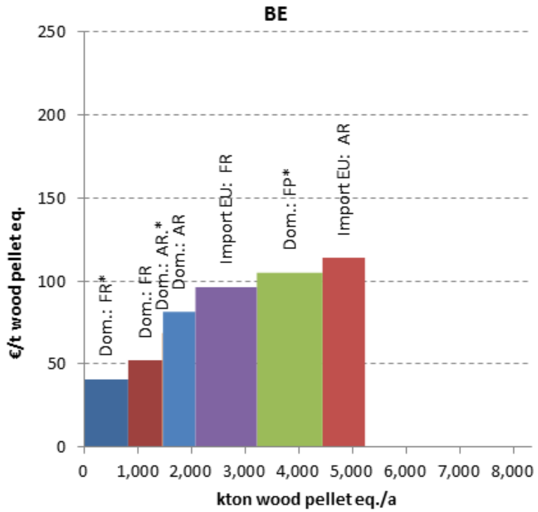


Figure 26 BAU 2020 Belgium

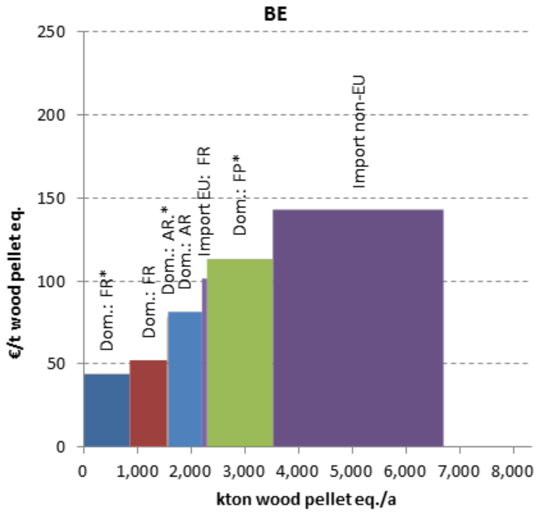


Figure 27 BAU 2030 Belgium

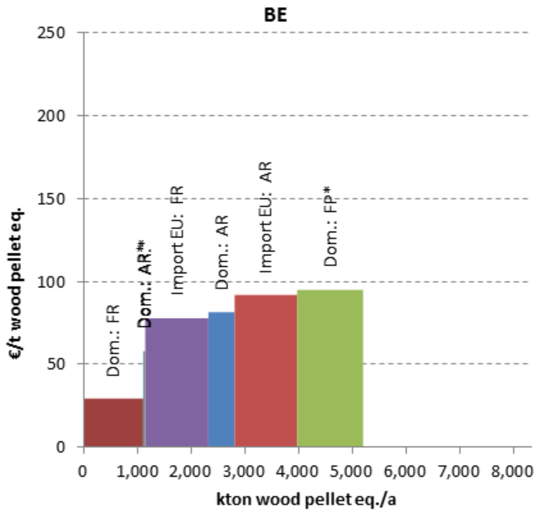


Figure 28 SNP 2015 Belgium

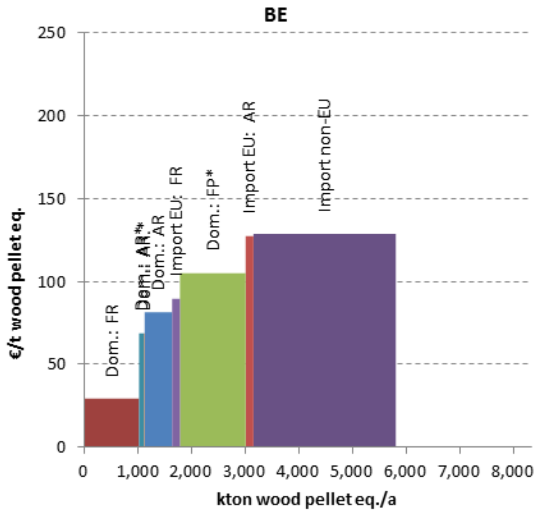


Figure 29 SNP 2020 Belgium

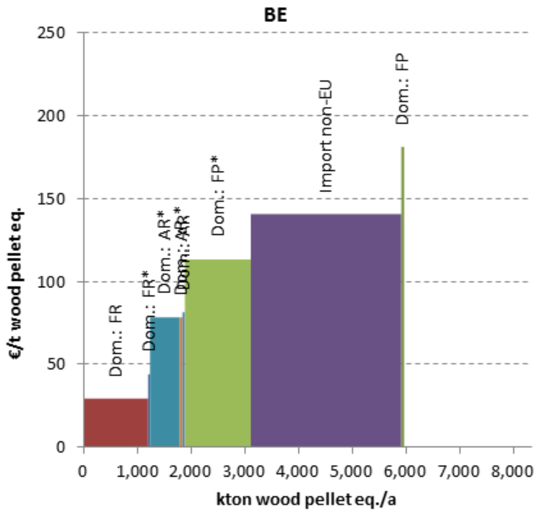


Figure 30 SNP 2030 Belgium

5.2.3.2 Netherlands

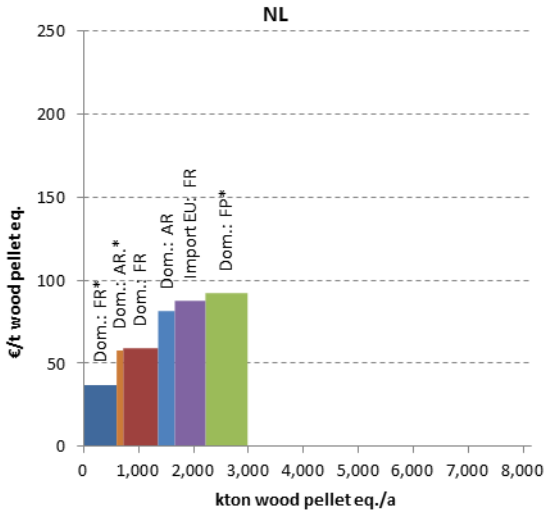


Figure 31 BAU 2015 Netherlands

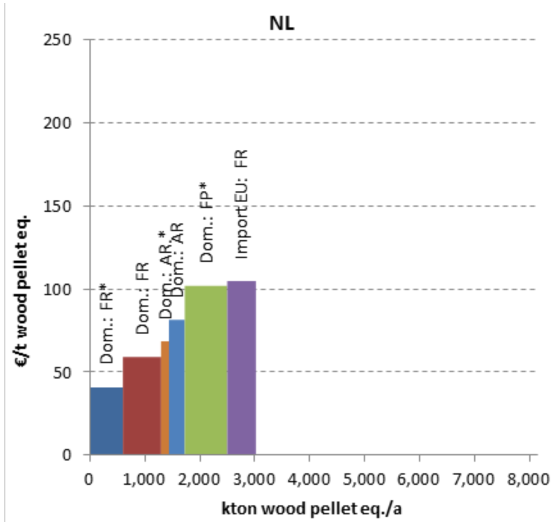


Figure 32 BAU 2020 Netherlands

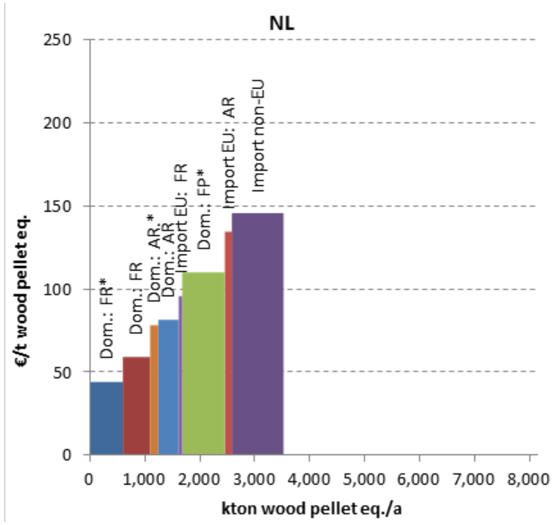


Figure 33 BAU 2030 Netherlands

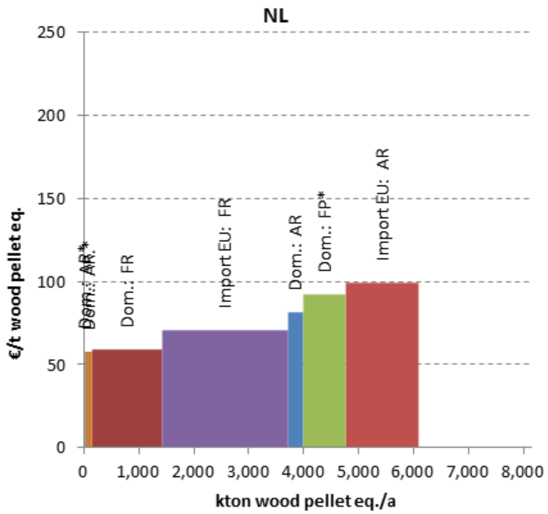


Figure 34 SNP 2015 Netherlands

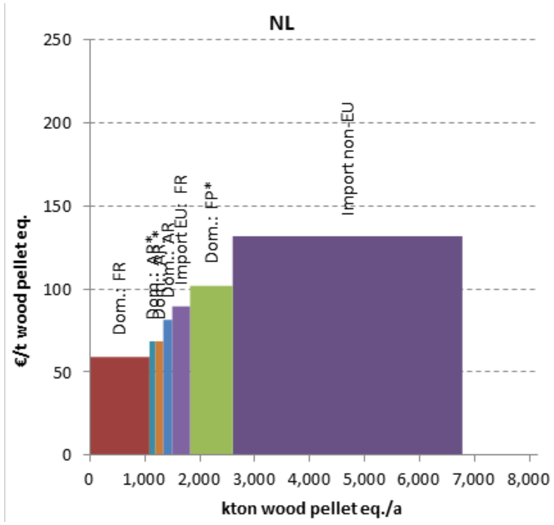


Figure 35 SNP 2020 Netherlands

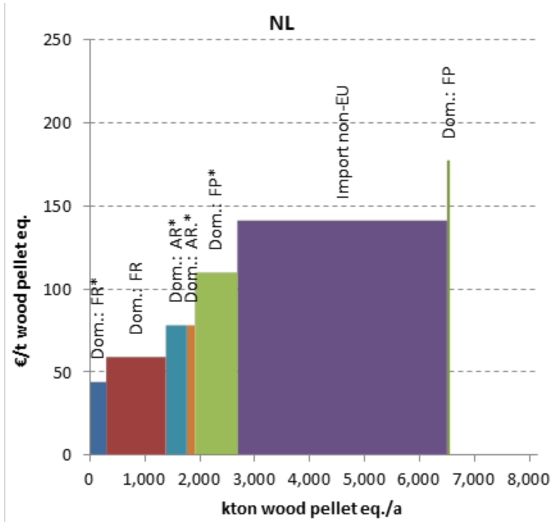


Figure 36 SNP 2030 Netherlands

5.2.3.3 Denmark

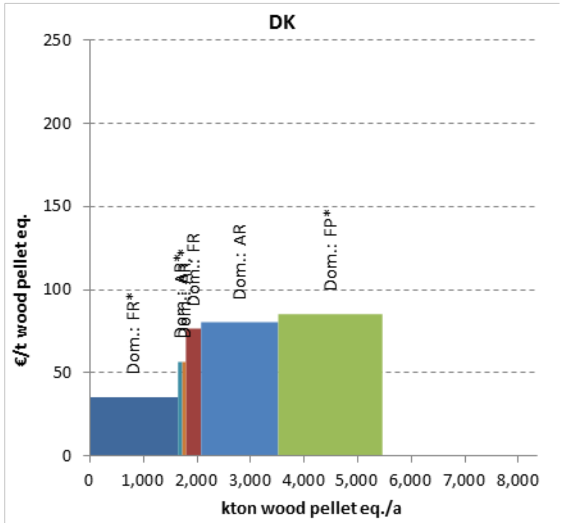


Figure 37 BAU 2015 Denmark

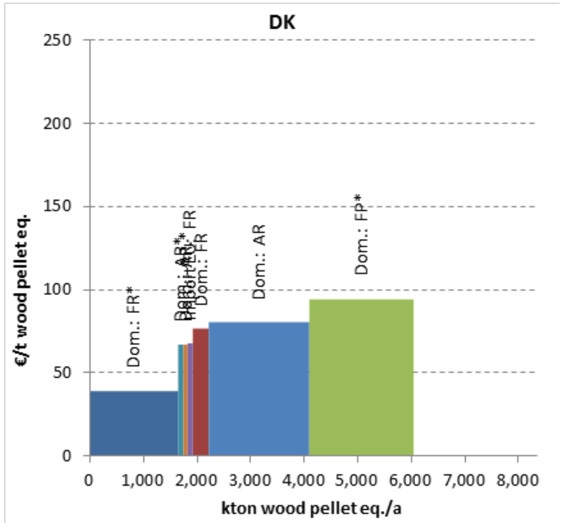


Figure 38 BAU 2020 Denmark

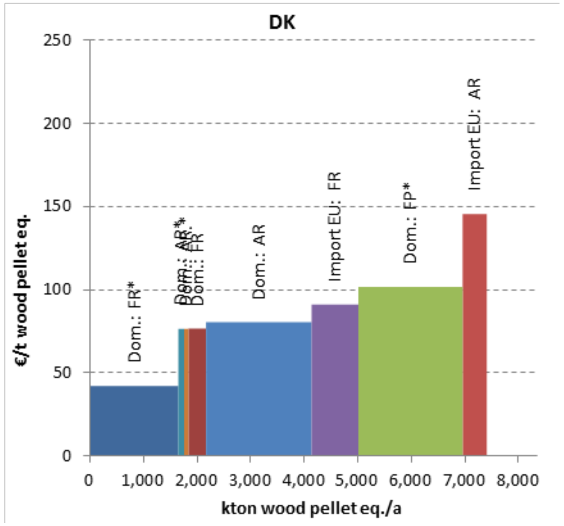


Figure 39 BAU 2030 Denmark

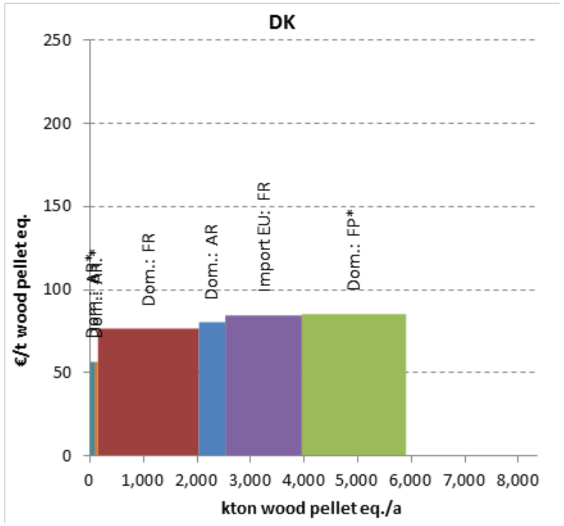


Figure 40 SNP 2015 Denmark

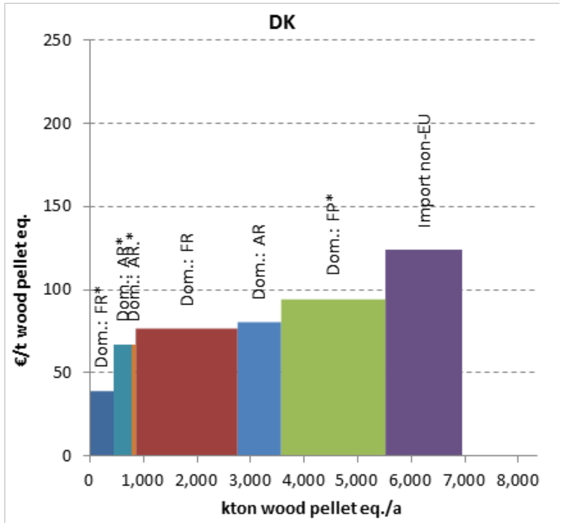


Figure 41 SNP 2020 Denmark

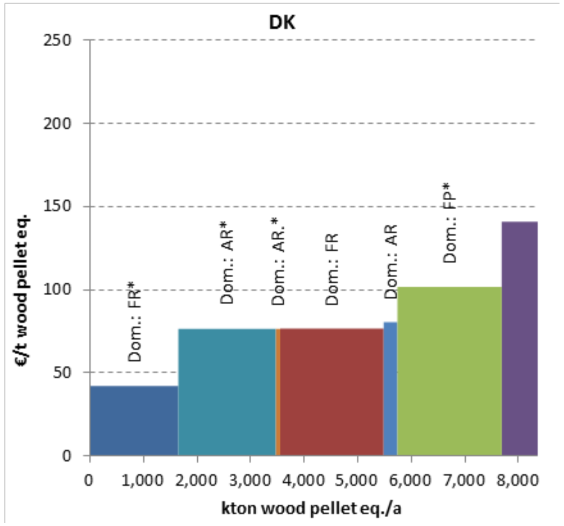


Figure 42 SNP 2030 Denmark

5.2.3.4 Germany

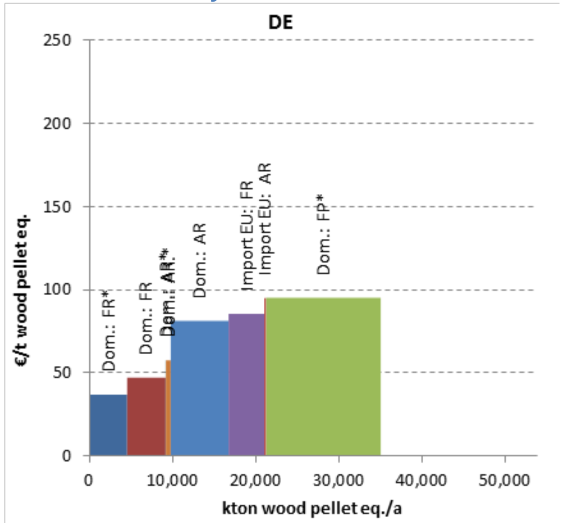


Figure 43 BAU 2015 Germany

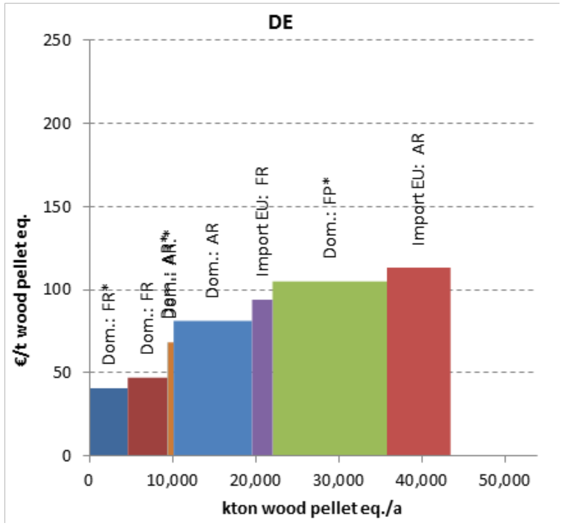


Figure 44 BAU 2020 Germany

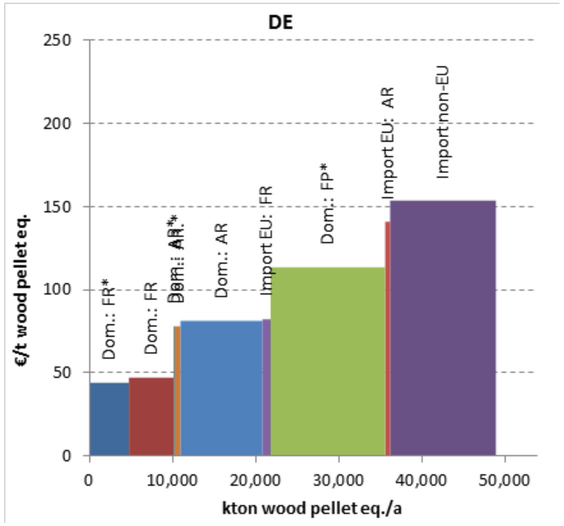


Figure 45 BAU 2030 Germany

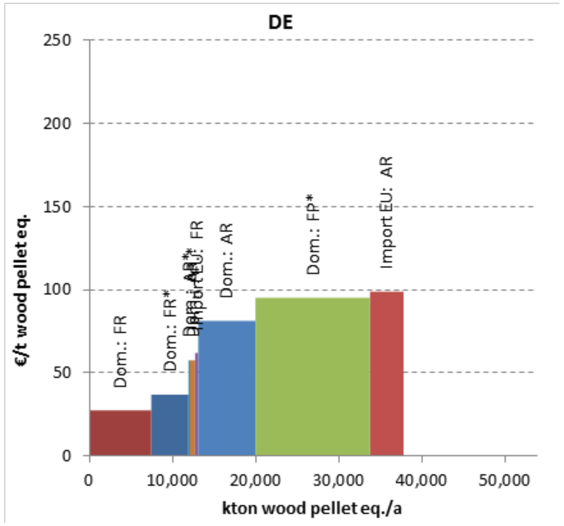


Figure 46 SNP 2015 Germany

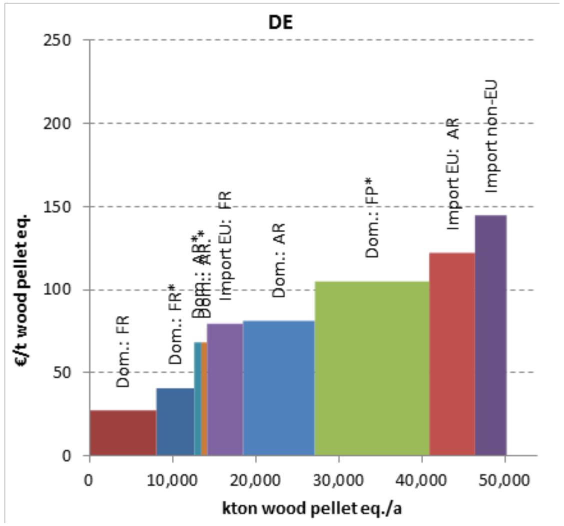


Figure 47 SNP 2020 Germany

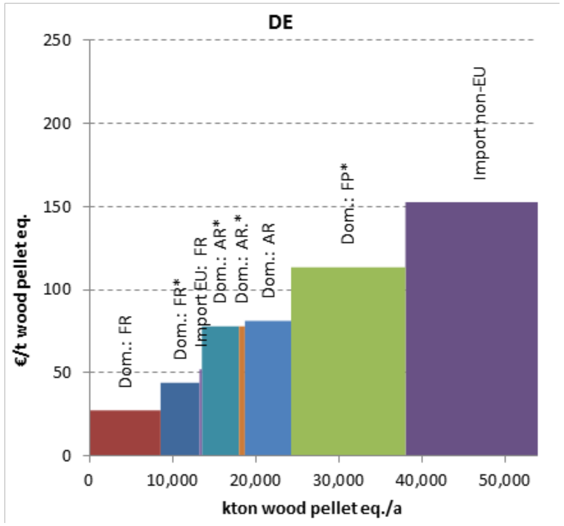


Figure 48 SNP 2030 Germany

5.2.3.5 United Kingdom

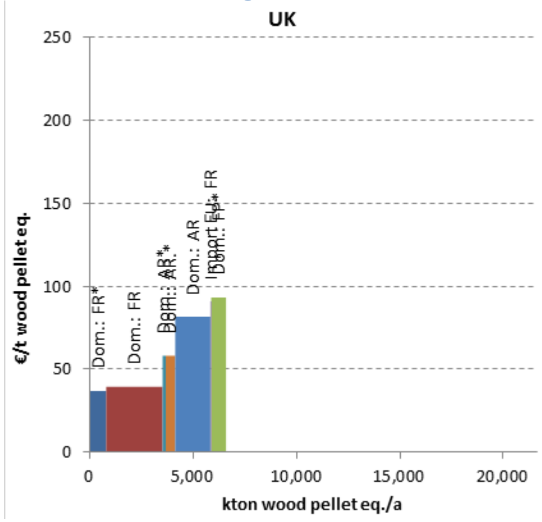


Figure 49 BAU 2015 United Kingdom

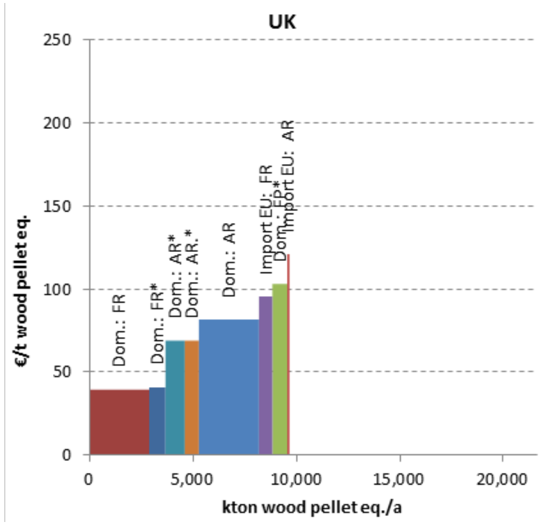


Figure 50 BAU 2020 United Kingdom

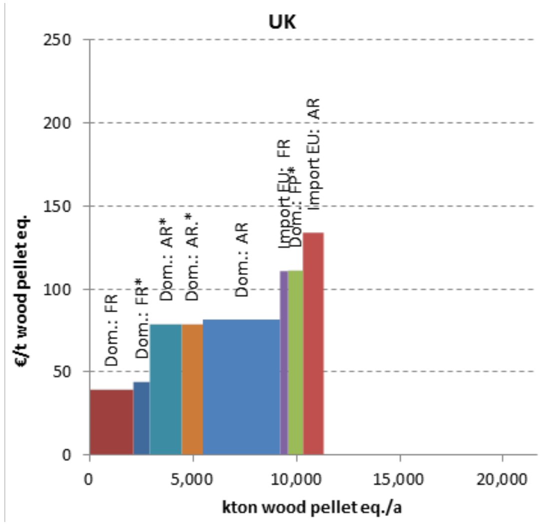


Figure 51 BAU 2030 United Kingdom

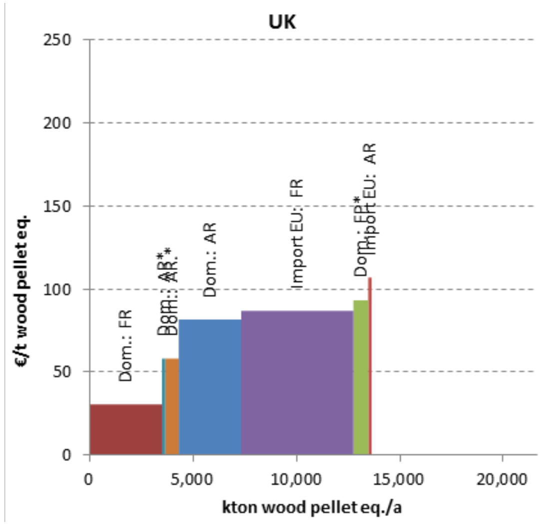


Figure 52 SNP 2015 United Kingdom

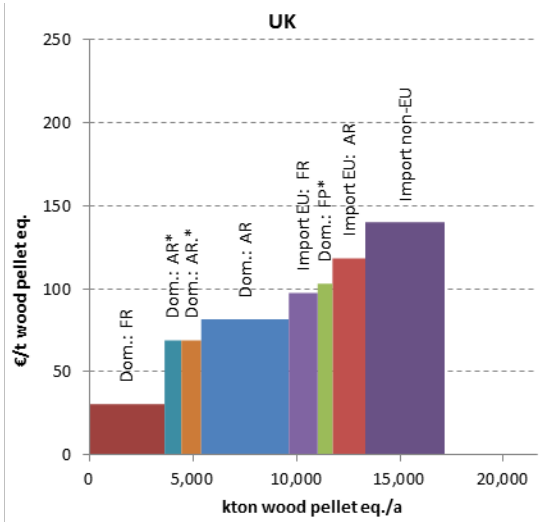


Figure 53 SNP 2020 United Kingdom

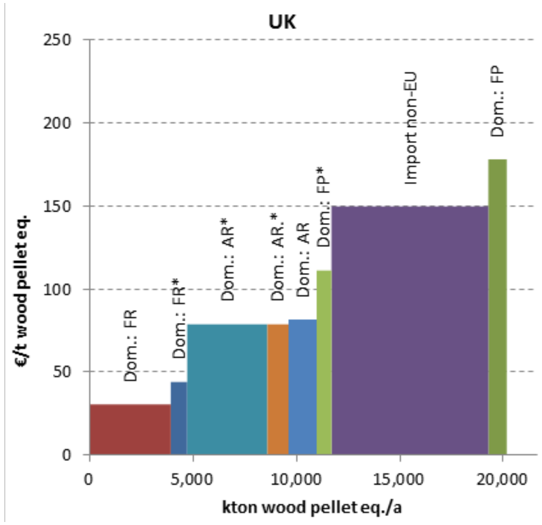
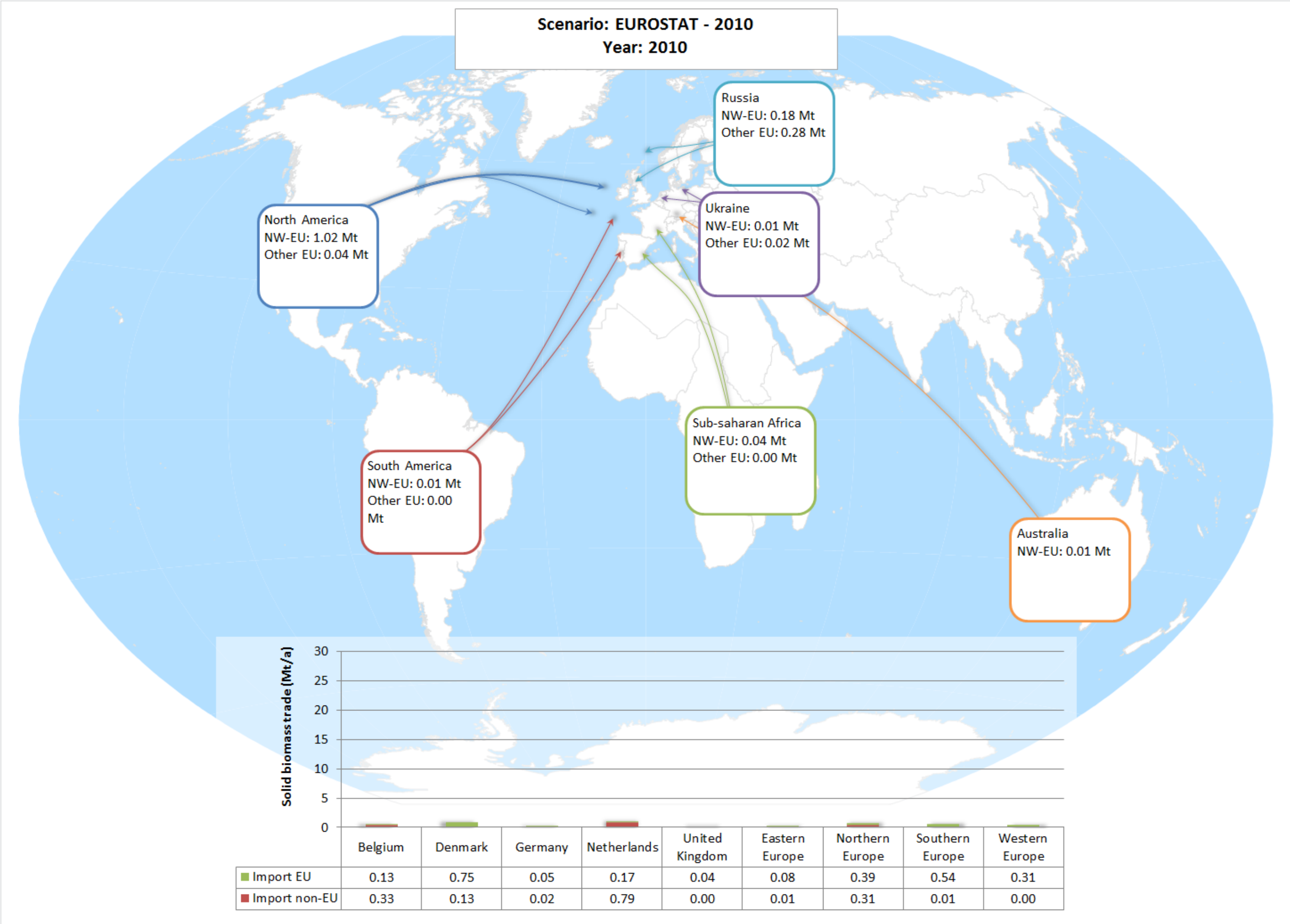


Figure 54 SNP 2030 United Kingdom

5.2.3.6 Trade flows of solid biomass from outside the EU and Eastern Europe

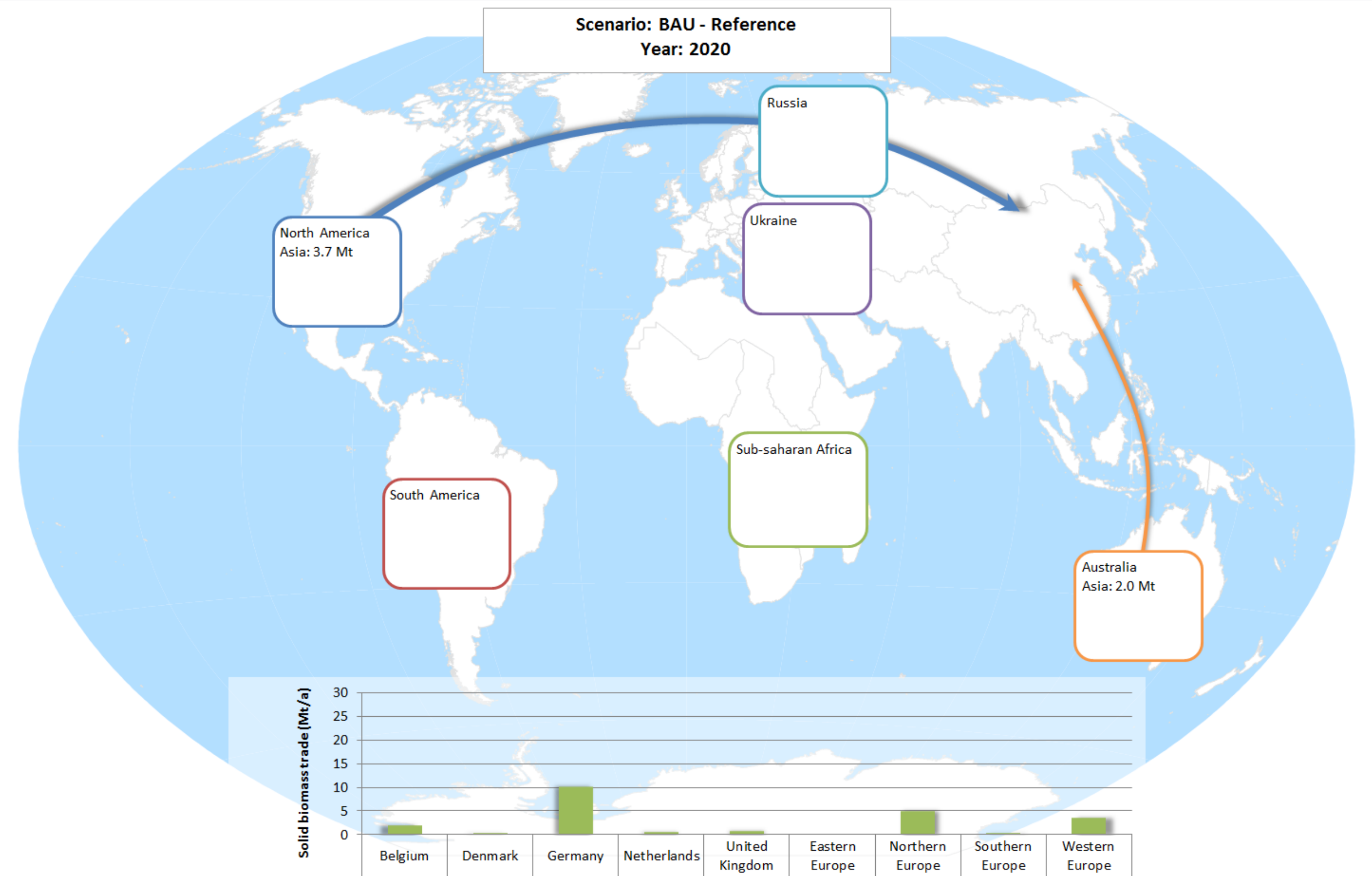
Since 2009, wood pellets are recorded in EUROSTAT statistics with its own standard CN code. Although these statistical datasets still include errors and should be considered indicative (Sikkema et al., 2011), they provide some insight into intra and extra European trade flows of wood pellets. Figure 55 shows the trade flows of wood pellets for 2010, the base year of this study, based on EUROSTAT data (EUROSTAT, 2012). The largest wood pellet trade flows in 2010 consists of wood pellets from North America (West Canada and the Southeast of the U.S.) imported to northwest Europe. Russia mainly exports to countries in Scandinavia including Denmark whereas few shipments were also made from Australia and countries in Sub-Saharan Africa. Since 2010, expansion of pellet production capacity in the Southeast of the U.S. resulted in a sharp increase in supply of wood pellets from established trade routes between North America and the EU-27 (Lamers et al., 2012).

All scenario projections reflect optimum allocation results between supply sources and demand nodes in the EU-27 and Asia. The domestic supply of low-cost solid biomass within the EU-27, such as forest residues, is limited and when demand increases, either high cost primary resources such as forestry products or dedicated energy crops have to be used or, alternatively, biomass has to be imported. Especially in northwest Europe, with high demand and relatively low supply of cheap solid biomass, imports of solid biomass are projected to increase in all scenarios to 2030. In the BAU – Reference trade scenario in 2020 (Figure 56), sufficient supply and relatively low demand in the EU-27 results in trade limited to low cost forestry residues and domestic resources. After 2020, inter-European trade flows are projected to increase again with Germany becoming the largest importer of solid biomass (over 14 Mt in 2030) (Figure 57).
With competing demand from Asia in the Reference Trade scenario, increasing amounts of solid biomass are projected to be shipped from western Canada, but also Australia and Sub-Saharan Africa are projected to export wood pellets to Asia as a result of the cost-distance between supply and demand. In the EU-27, increasing amounts are therefore imported from South America and the Southeast of the US, with export terminals located closer to import terminals in the EU-27. Still, in scenarios with high demand, northwest Europe remains the largest importer of solid biomass from north and south America with 12 Mt imported from north America and 21 Mt imported from south America in the SNP Reference scenario in 2030 (Figure 61). If domestic demand in North America would increase, as assumed in the High Trade 450 scenario, larger exports are projected from Brazil and Ukraine (Figure 62). It is important to note that such a scenario would require large investments and techno-economic development to mobilize these potentials.



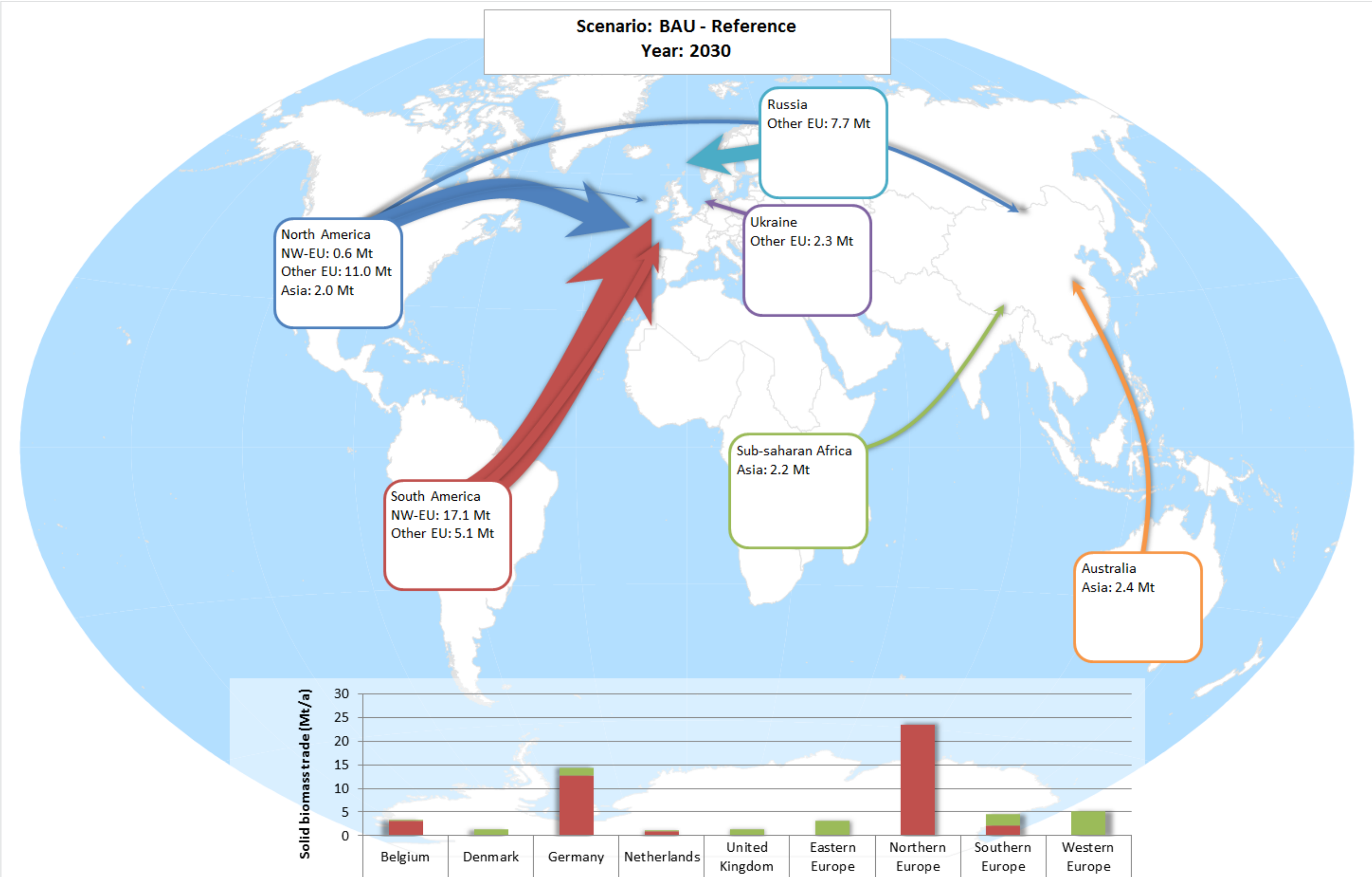
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Import EU	0.13	0.75	0.05	0.17	0.04	0.08	0.39	0.54	0.31
Import non-EU	0.33	0.13	0.02	0.79	0.00	0.01	0.31	0.01	0.00

Figure 55 Intra and inter EU Trade of wood pellets (EUROSTAT, 2012) with arrows showing only inter-European trade.



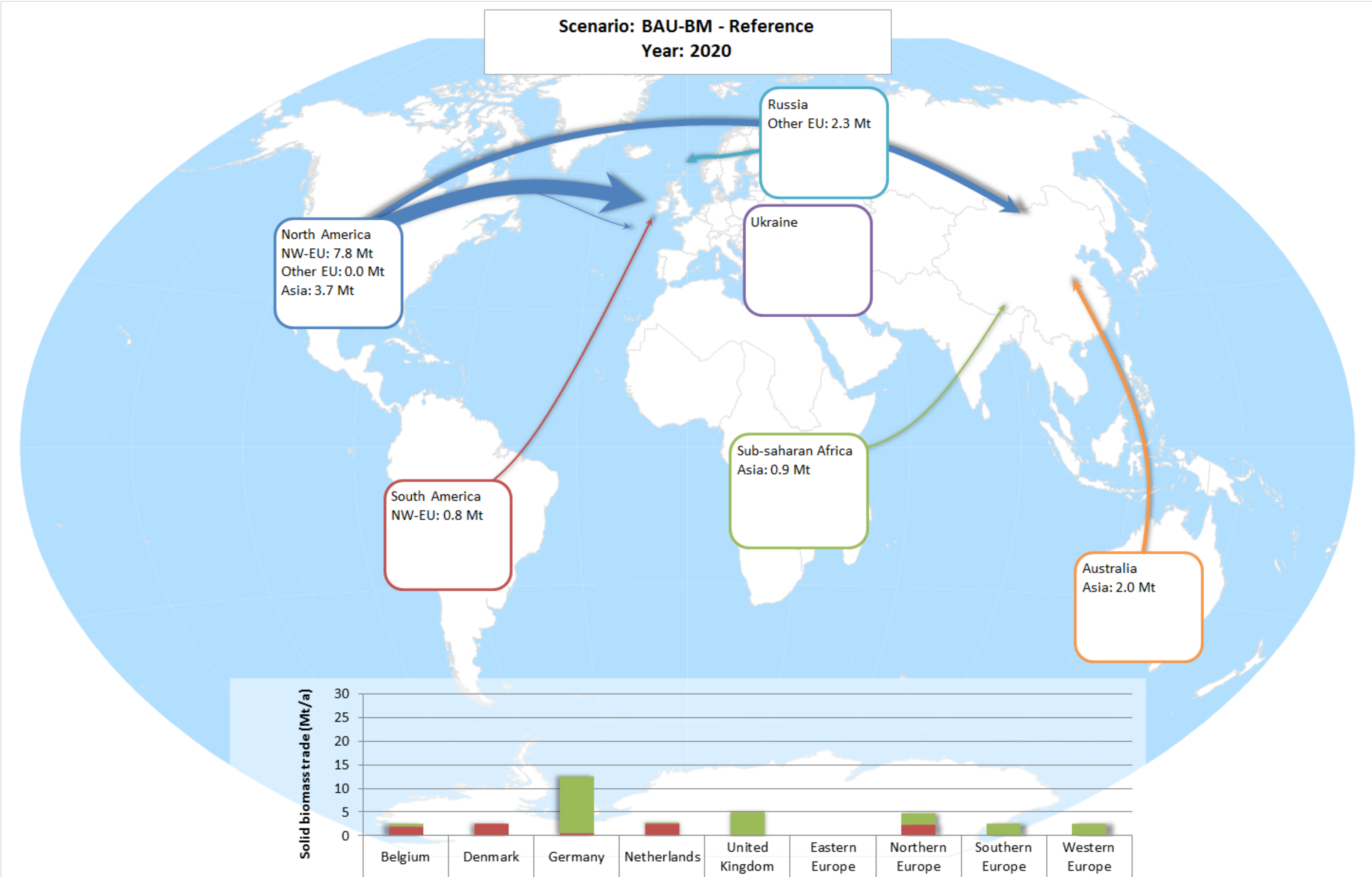
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	5.2	6.0	43.4	3.0	9.7	37.7	60.8	33.7	46.4
Domestic	3.3	5.9	33.3	2.5	8.9	37.7	55.9	33.5	42.9
Import EU	1.9	0.1	10.1	0.5	0.8	0.0	4.9	0.2	3.5
Import non-EU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 56 Trade flows of solid biomass BAU Reference Trade 2020 with arrows showing only inter-European trade.



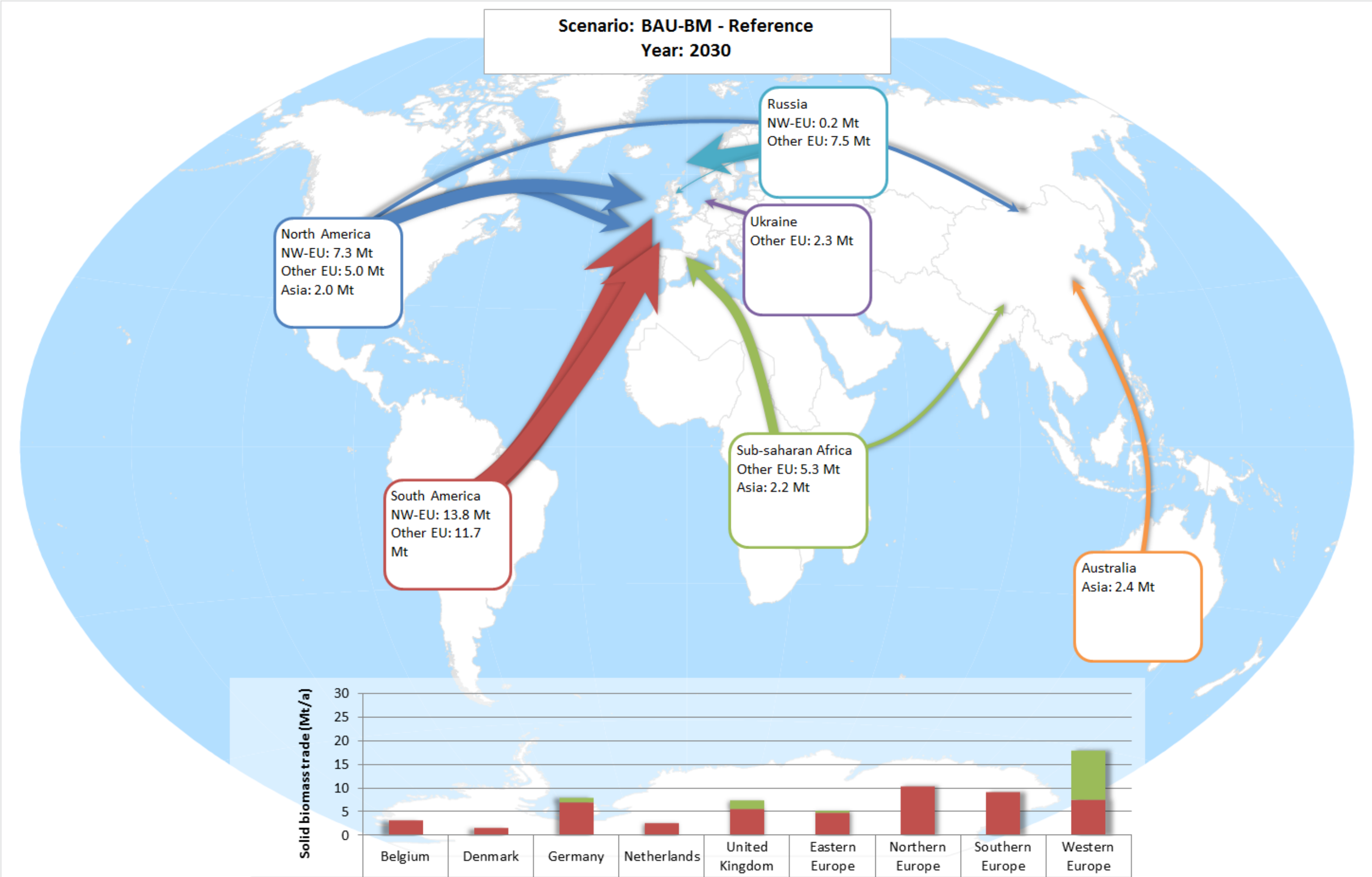
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	6.7	7.4	48.8	3.5	11.3	56.3	83.1	48.9	60.7
Domestic	3.4	6.1	34.5	2.4	9.9	53.1	59.4	44.4	55.5
Import EU	0.1	1.3	1.6	0.2	1.4	3.1	0.0	2.4	5.0
Import non-EU	3.2	0.0	12.7	0.9	0.0	0.1	23.7	2.1	0.1

Figure 57 Trade flows of solid biomass BAU Reference Trade 2030 with arrows showing only inter-European trade.



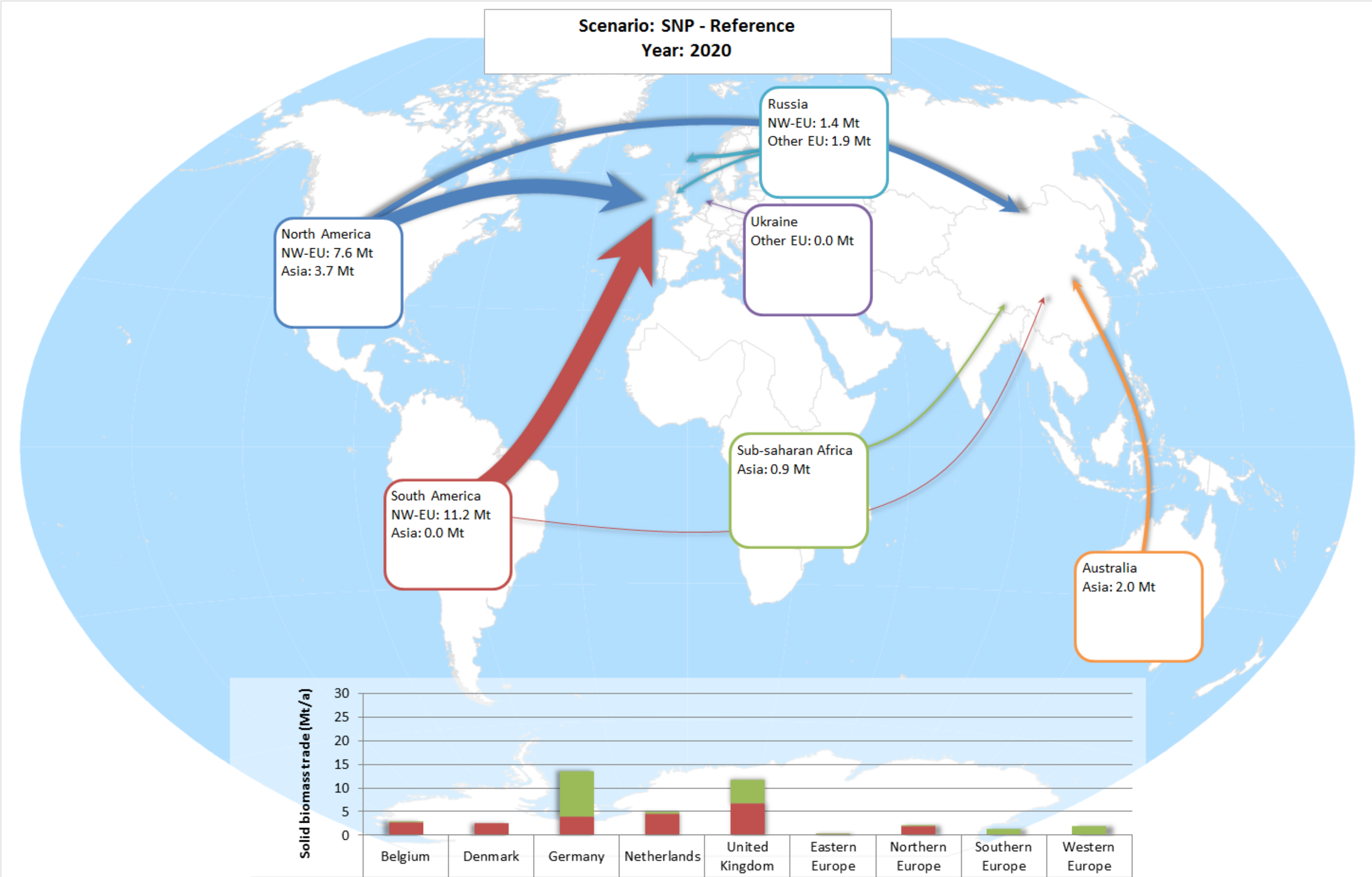
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	5.7	7.4	45.9	4.2	14.9	44.3	61.1	40.9	55.1
Domestic	3.3	4.9	33.4	1.5	10.0	44.3	56.4	38.3	52.5
Import EU	0.4	0.0	12.0	0.2	4.9	0.0	2.4	2.5	2.6
Import non-EU	2.0	2.5	0.6	2.5	0.0	0.0	2.3	0.0	0.0

Figure 58 Trade flows of solid biomass BAU-BM Reference Trade 2020 with arrows showing only inter-European trade.



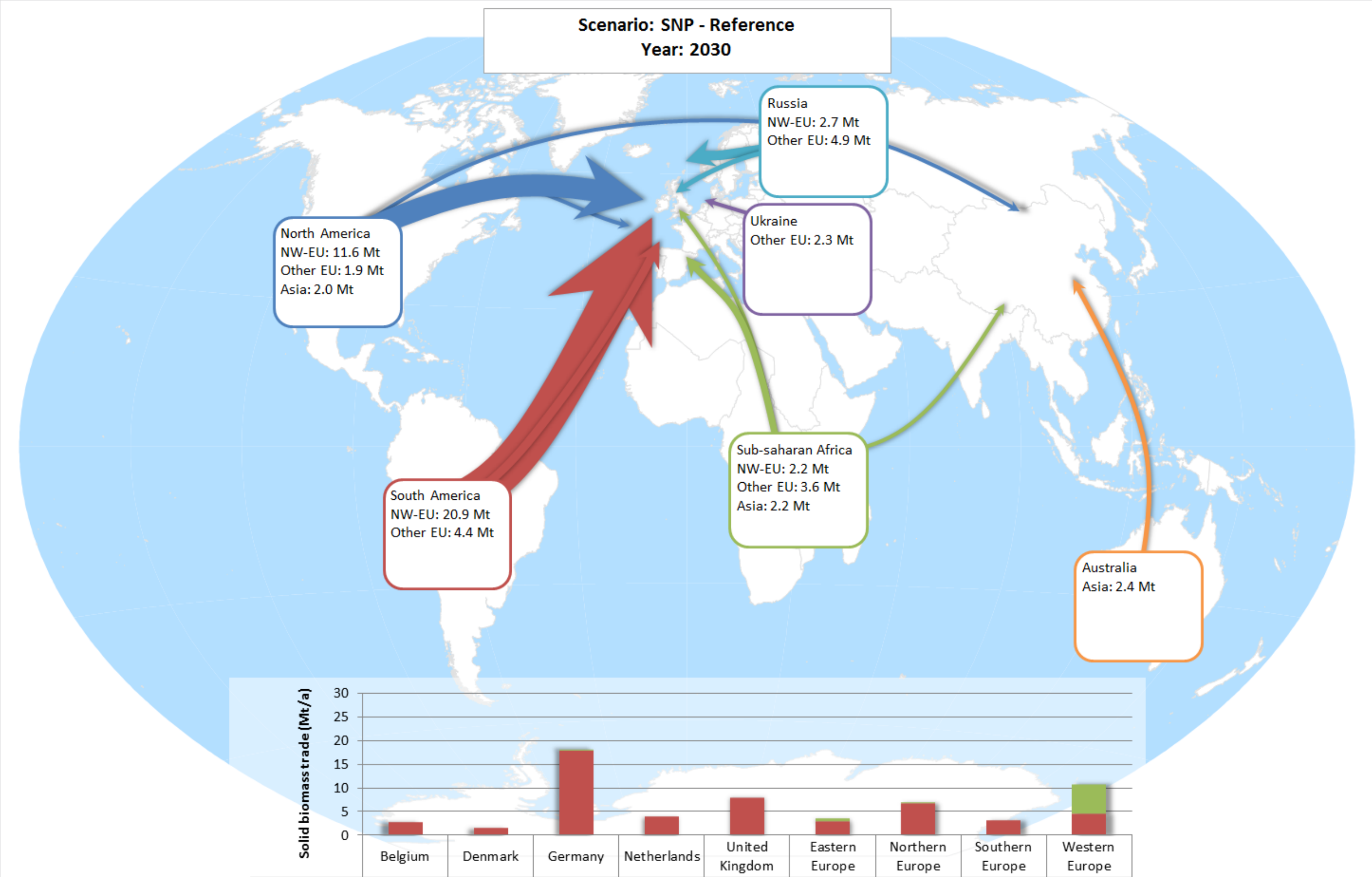
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	6.4	7.0	47.6	4.4	19.3	69.2	83.1	59.6	89.1
Domestic	3.4	5.6	39.6	2.0	11.9	64.1	72.7	50.5	71.1
Import EU	0.0	0.0	1.2	0.0	1.8	0.2	0.0	0.0	10.5
Import non-EU	3.0	1.4	6.8	2.4	5.6	4.8	10.4	9.1	7.5

Figure 59 Trade flows of solid biomass BAU-BM Reference Trade 2030 with arrows showing only inter-European trade.



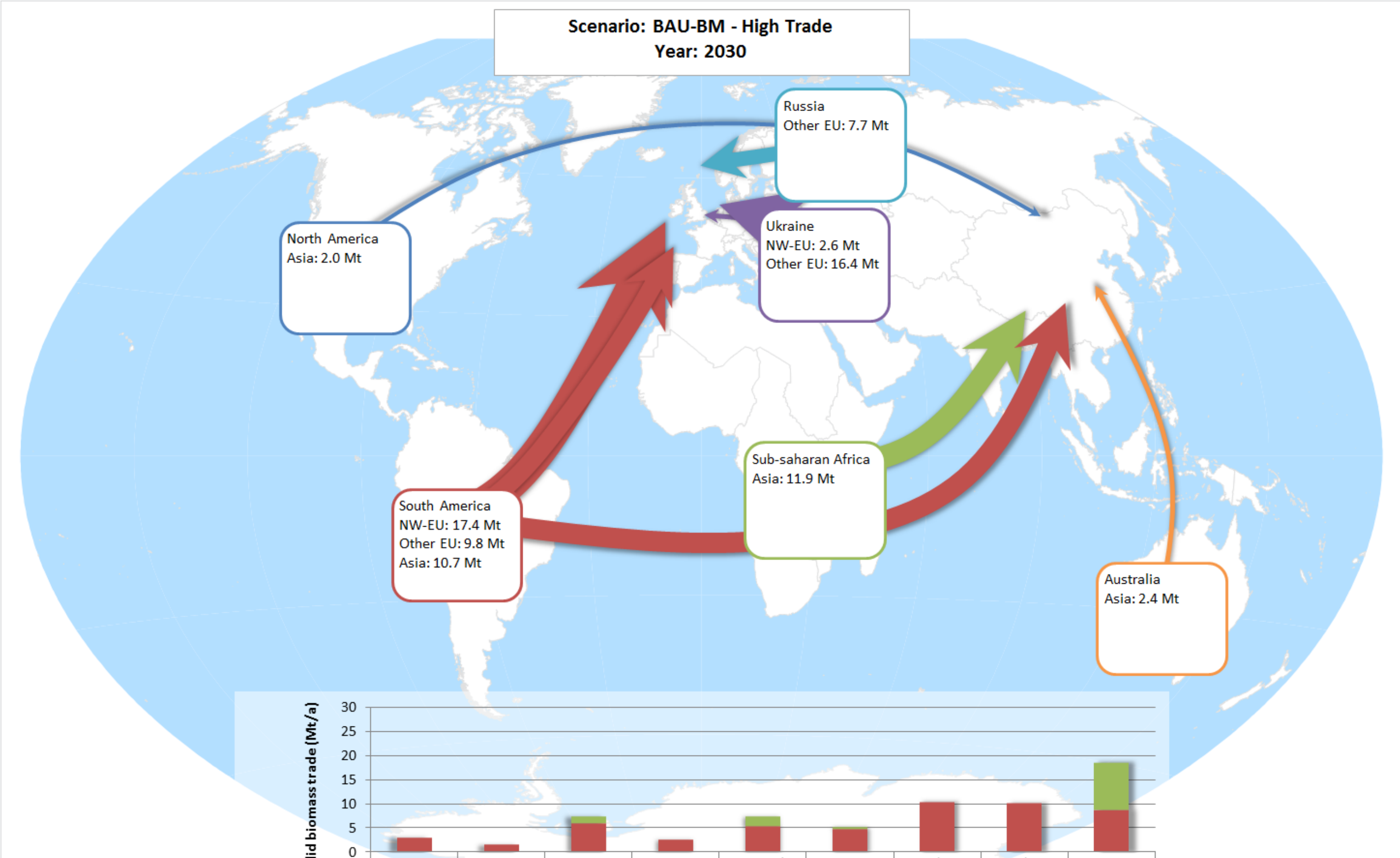
	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	5.8	8.0	50.1	7.2	22.2	54.3	65.9	45.2	54.1
Domestic	2.9	5.5	36.5	2.3	10.3	53.9	63.9	43.8	52.1
Import EU	0.3	0.0	9.8	0.4	5.2	0.3	0.0	1.4	2.0
Import non-EU	2.7	2.5	3.8	4.5	6.7	0.0	1.9	0.0	0.0

Figure 60 Trade flows of solid biomass SNP Reference Trade 2020 with arrows showing only inter-European trade.



	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	6.0	9.3	66.8	6.6	20.5	74.6	85.7	70.9	84.3
Domestic	3.2	7.8	48.5	2.7	12.6	71.1	78.9	67.7	73.5
Import EU	0.0	0.0	0.3	0.0	0.0	0.5	0.1	0.0	6.4
Import non-EU	2.8	1.5	17.9	3.8	7.9	2.9	6.7	3.2	4.4

Figure 61 Trade flows of solid biomass SNP Reference Trade 2030 with arrows showing only inter-European trade.



	Belgium	Denmark	Germany	Netherlands	United Kingdom	Eastern Europe	Northern Europe	Southern Europe	Western Europe
Total	6.4	7.0	47.6	4.4	19.3	69.2	83.1	59.6	89.1
Domestic	3.5	5.6	40.3	2.0	11.9	64.0	72.7	49.6	70.5
Import EU	0.0	0.0	1.5	0.0	2.0	0.4	0.0	0.0	9.9
Import non-EU	2.9	1.4	5.9	2.4	5.3	4.8	10.4	10.1	8.7

Figure 62 Trade flows of solid biomass SNP High Trade 450 2030 with arrows showing only inter-European trade.

5.3 Throughput in ports

To assess the potential role of seaports in northwest Europe, a port-counting tool has been added to the Biomass Allocation model. This tool counts the amounts of biomass going via sea ports considered important for solid biomass trade. The selected ports are depicted in Table 7. It is imported to note that biomass trade flows also goes via other ports not included in the port-counting tool. For example, demand in Eemshaven in the Netherlands does not have to go via the selected ports Amsterdam, Rotterdam or Vlissingen, but can be directly supplied via intermodal terminals in Eemshaven. Total trade is therefore lager in the scenarios than shown for the selected ports in this section.

5.3.1 Reference Trade and SNP High Trade scenarios

The total throughput in the selected sea ports in northwest Europe is projected to increase from almost 5 Mt in 2015, 14 Mt in 2020 and up to 26 to 27 Mt wood pellets in the SNP Reference Trade and SNP High Trade scenarios in 2030 (Figure 63). In all scenarios, most solid biomass is transloaded from ocean carriers or short sea dry bulk carriers to other modes of transport in the Port of Rotterdam. In total, throughput in the port of Rotterdam ranges from zero in the BAU Reference Trade scenario to 5.5 Mt in the SNP scenarios in 2020 and up to 16 Mt in the SNP – Reference Trade scenario in 2030. Most biomass imported via Rotterdam is however not used domestically in the Netherlands. Hinterland connections such as inland waterways, make Rotterdam a key transit port to other EU member states. Table 19 shows the total import of biomass per port and the amounts used domestically and re-exported to other countries. For example, in the SNP – Reference Trade scenario in 2020, 5.5 Mt is projected to be imported via the port of Rotterdam of which 1.4 Mt is used domestically and 4.0 Mt is projected to be re-exported to other EU member states such as Germany. Some demand nodes in the Netherlands are also supplied by ports in Belgium. For example, the Amer plant is projected to be supplied via the port of Antwerp due to favorable upfront cost. In contrast to ports in Belgium and the Netherlands, all solid biomass imported via ports in the UK is projected to be used domestically.

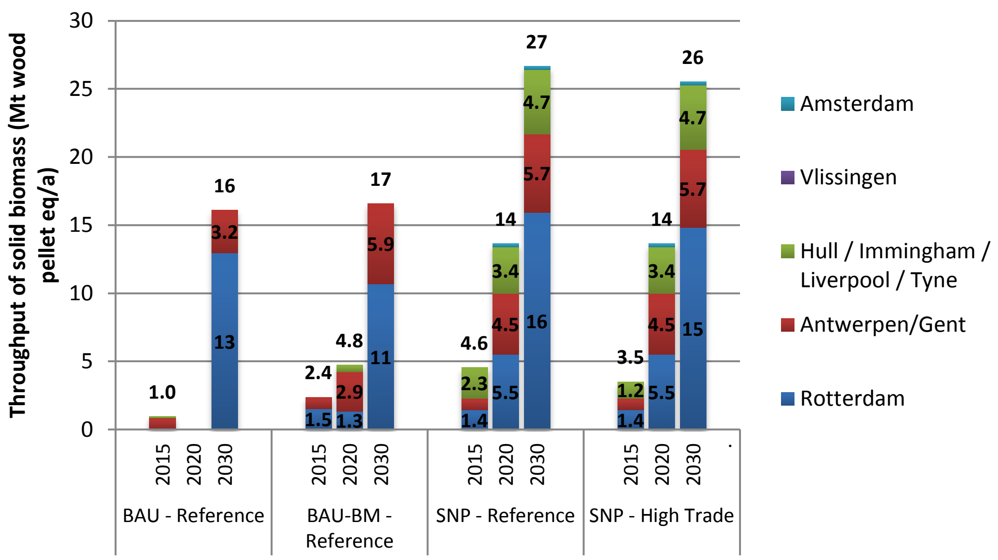


Figure 63 Throughput of solid biomass in selected seaports northwest Europe in the Reference Trade scenarios and SNP – High Trade scenario.

5.3.1.1 Alternative scenario cases

Table 20, Table 21 and Table 22 show the throughput in sea ports in northwest Europe for alternative scenario cases for the BAU, BAU-BM and SNP demand scenarios respectively as described in detail in Section 3.1.2. The Low and High

Trade scenarios assume alternative export potentials of wood pellets from outside Europe. The Charter Rate Low and High assess low and high charter rates for ocean bulk carriers based on the maximum and minimum time charter rates reported by the Baltic Exchange between 2007 and 2011. The SNP-Av. harbor cost assumes similar cost for all selected ports in northwest Europe. The TOPs scenario assumes higher bulk energy densities of transported pellets based on the calorific value of torrefied pellets.
The BAU – Low Trade scenario strongly reduces imports of solid biomass resulting in reduced throughputs in sea ports. In Rotterdam, total throughput decreases from 12.9 Mt in the Reference Trade scenario to 4.4 Mt in the Low Trade scenario in 2030 (Table 20). The High Trade scenario does not impact total imports and throughput of solid biomass in sea ports significantly compared to the Reference Trade scenario.
If all selected ports in northwest Europe are assumed to have similar upfront cost, the port of Rotterdam becomes more competitive to ports in Belgium. Domestic use of solid biomass imported via the port of Rotterdam therefore increases from 1.5 Mt in the SNP Reference Trade scenario in 2020 to 3.2 Mt in the SNP-Av. harbor cost scenario in 2020. However, total throughput in the port of Rotterdam decreases as a result of reduced transit to other EU member states in this scenario (Table 22).

Table 19 Throughput of solid biomass in the selected sea ports of northwest Europe in the Reference Trade scenarios (Mt wood pellet equivalent/a).

	BAU				BAU-BM				SNP			
	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Rotterdam												
Total			6.1 Mt	12.9 Mt	1.5 Mt	1.3 Mt	11.5 Mt	10.7 Mt	1.4 Mt	5.5 Mt	11.6 Mt	16.0 Mt
For use NL				**0.9 Mt** NL: 0.9 Mt	**1.5 Mt** Maasvlakte Biomass (NL): 1.5 Mt	**1.0 Mt** Maasvlakte Biomass (NL): 1.0 Mt	**1.0 Mt** Maasvlakte Biomass (NL): 1.0 Mt	**1.0 Mt** Maasvlakte Biomass (NL): 1.0 Mt	**1.4 Mt** Maasvlakte Biomass (NL): 1.4 Mt	**1.5 Mt** Maasvlakte Biomass (NL): 1.3 Mt Gelderland (NL): 0.2 Mt	**1.4 Mt** Maasvlakte Biomass (NL): 1.4 Mt	**1.6 Mt** Maasvlakte Biomass (NL): 1.4 Mt NL: 0.2 Mt
To other countries			**6.1 Mt** DE	**12.0 Mt** DE: 11.9 Mt		**0.4 Mt** DE: 0.4 Mt	**10.6 Mt** DE: 8.6 Mt	**9.7 Mt** DE: 6.0 Mt		**4.0 Mt** DE: 4.0 Mt	**10.2 Mt** DE: 10.2 Mt	**14.3 Mt** DE: 14.1 Mt CZ: 0.2 Mt
Antwerpen/Gent												
Total	0.9 Mt		1.9 Mt	3.2 Mt	0.9 Mt	2.9 Mt	5.9 Mt	5.9 Mt	0.9 Mt	4.5 Mt	5.7 Mt	5.7 Mt
For use BE	**0.9 Mt** Rodenhuize (BE): 0.9 Mt		**1.9 Mt** BE: 1.9 Mt	**3.2 Mt** BE: 3.2 Mt	**0.9 Mt** Rodenhuize (BE): 0.9 Mt	**2.0 Mt** Genk Langerlo (BE): 1.8 Mt Awirs (BE): 0.1 Mt BE: 0.1 Mt	**3.1 Mt** Genk Langerlo (BE): 1.8 Mt BE: 1.3 Mt	**3.0 Mt** Genk Langerlo (BE): 1.8 Mt BE: 1.2 Mt	**0.9 Mt** Rodenhuize (BE): 0.9 Mt	**2.7 Mt** Genk Langerlo (BE): 1.8 Mt Rodenhuize (BE): 0.9 Mt	**2.5 Mt** Genk Langerlo (BE): 1.8 Mt BE: 0.7 Mt	**2.8 Mt** Genk Langerlo (BE): 1.8 Mt BE: 1.0 Mt
To other countries						**0.9 Mt** Borssele (NL): 0.5 Mt Amer (NL): 0.5 Mt	**2.7 Mt** FR: 1.6 Mt Amer (NL): 0.6 Mt Borssele (NL): 0.5 Mt	**2.9 Mt** FR: 2.0 Mt Borssele (NL): 0.5 Mt Amer (NL): 0.4 Mt		**1.8 Mt** Amer (NL): 1.3 Mt Borssele (NL): 0.5 Mt	**3.2 Mt** Amer (NL): 1.7 Mt FR: 1.1 Mt Borssele (NL): 0.5 Mt	**2.9 Mt** FR: 1.6 Mt Amer (NL): 0.9 Mt Borssele (NL): 0.5 Mt
Hull / Immingham / Liverpool / Tyne												
Total	0.1 Mt					0.5 Mt	2.5 Mt		2.3 Mt	3.4 Mt	4.5 Mt	4.7 Mt
Use UK	**0.1 Mt** Drax (UK): 0.1 Mt					**0.5 Mt** Drax (UK): 0.5 Mt	**2.5 Mt** Drax (UK): 2.5 Mt		**2.3 Mt** Drax (UK): 2.3 Mt	**3.4 Mt** Drax (UK): 3.4 Mt	**4.5 Mt** Drax (UK): 4.2 Mt Rugeley (UK): 0.3 Mt	**4.7 Mt** Drax (UK): 4.7 Mt
To other countries												
Amsterdam												
Total										0.3 Mt	0.3 Mt	0.3 Mt
For use NL										**0.3 Mt** Hemweg (NL): 0.3 Mt	**0.3 Mt** Hemweg (NL): 0.3 Mt	**0.3 Mt** Hemweg (NL): 0.3 Mt
To other countries												

Table 20 Throughput of solid biomass in the selected sea ports of northwest Europe in the alternative BAU scenarios (Mt wood pellet equivalent/a).

	BAU - Low Trade		BAU -Charter Rate Low		BAU -Charter Rate High		BAU -Av. harbor cost		BAU -TOPs		BAU -low support	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Rotterdam												
Total		**4.4 Mt**	**0.5 Mt**	**13.3 Mt**		**11.8 Mt**	**0.6 Mt**	**8.4 Mt**		**12.9 Mt**		**12.9 Mt**
For use NL		**0.1 Mt**	**0.5 Mt**	**0.9 Mt**				**0.2 Mt**		**0.9 Mt**		**0.9 Mt**
		NL: 0.1 Mt	NL: 0.5 Mt	NL: 0.9 Mt				NL: 0.2 Mt		NL: 0.9 Mt		NL: 0.9 Mt
To other countries		**4.4 Mt**		**12.4 Mt**		**11.8 Mt**	**0.6 Mt**	**8.2 Mt**		**12.0 Mt**		**12.0 Mt**
		DE: 4.4 Mt		DE: 12.3 Mt				DE: 8.2 Mt		DE: 11.9 Mt		DE: 11.9 Mt
Antwerpen/Gent												
Total		**2.3 Mt**	**0.2 Mt**	**3.3 Mt**		**3.1 Mt**	**0.3 Mt**	**3.0 Mt**		**3.2 Mt**		**3.2 Mt**
For use BE		**2.3 Mt**	**0.2 Mt**	**3.3 Mt**		**3.1 Mt**	**0.3 Mt**	**3.0 Mt**		**3.2 Mt**		**3.2 Mt**
		BE: 2.3 Mt	BE: 0.2 Mt	BE: 3.3 Mt		BE: 3.1 Mt	BE: 0.3 Mt	BE: 3.0 Mt		BE: 3.2 Mt		BE: 3.2 Mt
To other countries												
Hull / Immingham / Liverpool / Tyne												
Total												
Use UK												
To other countries												
Amsterdam												
Total												
For use NL												
To other countries												

Table 21 Throughput of solid biomass in the selected sea ports of northwest Europe in the alternative BAU-BM scenarios (Mt wood pellet equivalent/a).

	BAU-BM - Low Trade		BAU-BM -Charter Rate Low		BAU-BM -Charter Rate High		BAU-BM -Av. harbor cost		BAU-BM -TOPs		BAU-BM -low support	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Rotterdam												
Total	1.0 Mt	9.7 Mt	4.9 Mt	10.6 Mt	1.0 Mt	11.0 Mt	1.6 Mt	6.8 Mt	1.3 Mt	10.7 Mt	2.4 Mt	11.1 Mt
For use NL	**1.0 Mt**	**1.0 Mt**	**1.0 Mt**	**1.0 Mt**	**1.0 Mt**	**1.4 Mt**	**1.5 Mt**	**1.4 Mt**	**1.0 Mt**	**1.0 Mt**	**0.6 Mt**	**0.6 Mt**
	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt Amer (NL): 0.4 Mt	Maasvlakte Biomass (NL): 1.0 Mt Amer (NL): 0.5 Mt	Maasvlakte Biomass (NL): 1.0 Mt Amer (NL): 0.4 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 1.0 Mt	Maasvlakte Biomass (NL): 0.6 Mt	Maasvlakte Biomass (NL): 0.6 Mt
To other countries		**8.8 Mt**	**3.9 Mt**	**9.6 Mt**		**9.6 Mt**	**0.1 Mt**	**5.5 Mt**	**0.4 Mt**	**9.7 Mt**	**1.8 Mt**	**10.5 Mt**
		DE: 5.2 Mt	DE: 3.9 Mt	DE: 6.2 Mt		DE: 5.9 Mt CZ: 2.8 Mt	DE: 0.1 Mt	DE: 4.5 Mt FR: 1.0 Mt	DE: 0.4 Mt	DE: 6.0 Mt	DE: 1.8 Mt	DE: 6.6 Mt
Antwerpen/Gent												
Total	3.0 Mt	5.9 Mt	3.0 Mt	12.9 Mt	0.0 Mt	5.5 Mt	2.0 Mt	3.4 Mt	2.9 Mt	5.9 Mt	2.6 Mt	4.9 Mt
For use BE	**2.0 Mt**	**2.9 Mt**	**2.0 Mt**	**3.0 Mt**		**2.9 Mt**	**1.5 Mt**	**2.9 Mt**	**2.0 Mt**	**3.0 Mt**	**2.0 Mt**	**2.4 Mt**
	Genk Langerlo (BE): 1.8 Mt Awirs (BE): 0.1 Mt BE: 0.1 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.1 Mt	Genk Langerlo (BE): 1.5 Mt BE: 0.5 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.2 Mt		Genk Langerlo (BE): 1.8 Mt BE: 1.1 Mt	Genk Langerlo (BE): 1.5 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.1 Mt	Genk Langerlo (BE): 1.8 Mt Awirs (BE): 0.1 Mt BE: 0.1 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.2 Mt	BE: 2.0 Mt	BE: 2.4 Mt
To other countries	**1.0 Mt**	**2.9 Mt**	**1.1 Mt**	**9.9 Mt**	**0.0 Mt**	**2.5 Mt**	**0.5 Mt**	**0.5 Mt**	**0.9 Mt**	**2.9 Mt**	**0.6 Mt**	**2.6 Mt**
	Amer (NL): 0.5 Mt Borssele (NL): 0.5 Mt	FR: 2.0 Mt Borssele (NL): 0.5 Mt Amer (NL): 0.4 Mt	Amer (NL): 0.6 Mt Borssele (NL): 0.5 Mt	FR: 9.1 Mt Borssele (NL): 0.5 Mt Amer (NL): 0.4 Mt	Borssele (NL): 0.0 Mt	FR: 2.0 Mt Borssele (NL): 0.5 Mt	Borssele (NL): 0.5 Mt	Borssele (NL): 0.5 Mt LU: 0.0 Mt	Borssele (NL): 0.5 Mt Amer (NL): 0.5 Mt	FR: 2.0 Mt Borssele (NL): 0.5 Mt Amer (NL): 0.4 Mt	Borssele (NL): 0.4 Mt Amer (NL): 0.3 Mt	FR: 2.0 Mt Borssele (NL): 0.4 Mt Amer (NL): 0.2 Mt
Hull / Immingham / Liverpool / Tyne												
Total	0.5 Mt		0.5 Mt		0.5 Mt		2.5 Mt		0.5 Mt			
Use UK	**0.5 Mt**		**0.5 Mt**		**0.5 Mt**		**2.5 Mt**		**0.5 Mt**			
	Drax (UK): 0.5 Mt		Drax (UK): 0.5 Mt		Drax (UK): 0.5 Mt		Drax (UK): 2.5 Mt		Drax (UK): 0.5 Mt			
To other countries												
Amsterdam												
Total												
For use NL												
To other countries												

Table 22 Throughput of solid biomass in the selected sea ports of northwest Europe in the alternative SNP scenarios (Mt wood pellet equivalent/a).

	SNP - High Trade		SNP -Charter Rate Low		SNP -Charter Rate High		SNP -Av. harbor cost		SNP -TOPs		SNP -low support	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
Rotterdam												
Total	**5.5 Mt**	**14.8 Mt**	**9.4 Mt**	**15.7 Mt**	**1.3 Mt**	**15.6 Mt**	**6.8 Mt**	**14.5 Mt**	**5.5 Mt**	**16.0 Mt**	**5.2 Mt**	**16.9 Mt**
For use NL	**1.5 Mt**	**1.6 Mt**	**1.3 Mt**	**1.6 Mt**	**1.3 Mt**	**2.5 Mt**	**3.2 Mt**	**2.5 Mt**	**1.5 Mt**	**1.6 Mt**	**0.9 Mt**	**2.0 Mt**
	Maasvlakte Biomass (NL): 1.3 Mt Gelderland (NL): 0.2 Mt	Maasvlakte Biomass (NL): 1.4 Mt NL: 0.2 Mt	Maasvlakte Biomass (NL): 1.3 Mt	Maasvlakte Biomass (NL): 1.4 Mt NL: 0.2 Mt	Maasvlakte Biomass (NL): 1.3 Mt	Maasvlakte Biomass (NL): 1.4 Mt Amer (NL): 0.9 Mt	Amer (NL): 1.7 Mt Maasvlakte Biomass (NL): 1.3 Mt	Maasvlakte Biomass (NL): 1.4 Mt Amer (NL): 0.9 Mt	Maasvlakte Biomass (NL): 1.3 Mt Gelderland (NL): 0.2 Mt	Maasvlakte Biomass (NL): 1.4 Mt NL: 0.2 Mt	Maasvlakte Biomass (NL): 0.8 Mt Gelderland (NL): 0.1 Mt	NL: 1.1 Mt Maasvlakte Biomass (NL): 0.9 Mt
To other countries	**4.0 Mt**	**13.2 Mt**	**8.1 Mt**	**14.1 Mt**		**13.2 Mt**	**3.6 Mt**	**12.0 Mt**	**4.0 Mt**	**14.3 Mt**	**4.4 Mt**	**14.9 Mt**
	DE: 4.0 Mt	DE: 13.2 Mt	DE: 8.1 Mt	DE: 14.1 Mt		DE: 13.2 Mt	DE: 3.6 Mt	DE: 12.0 Mt	DE: 4.0 Mt	DE: 14.1 Mt CZ: 0.2 Mt	DE: 4.4 Mt	DE: 14.2 Mt CZ: 0.7 Mt
Antwerpen/Gent												
Total	**4.5 Mt**	**5.7 Mt**	**4.4 Mt**	**10.9 Mt**	**2.8 Mt**	**4.8 Mt**	**2.7 Mt**	**3.2 Mt**	**4.5 Mt**	**5.7 Mt**	**2.1 Mt**	**4.1 Mt**
For use BE	**2.7 Mt**	**2.8 Mt**	**2.3 Mt**	**2.8 Mt**	**2.3 Mt**	**2.8 Mt**	**2.2 Mt**	**2.8 Mt**	**2.7 Mt**	**2.8 Mt**	**0.8 Mt**	**1.6 Mt**
	Genk Langerlo (BE): 1.8 Mt Rodenhuize (BE): 0.9 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.0 Mt	Genk Langerlo (BE): 1.1 Mt Rodenhuize (BE): 0.9 Mt BE: 0.3 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.0 Mt	Genk Langerlo (BE): 1.5 Mt Rodenhuize (BE): 0.9 Mt	Genk Langerlo (BE): 1.8 Mt BE: 0.9 Mt	Genk Langerlo (BE): 1.4 Mt Rodenhuize (BE): 0.9 Mt	Genk Langerlo (BE): 1.8 Mt BE: 0.9 Mt	Genk Langerlo (BE): 1.8 Mt Rodenhuize (BE): 0.9 Mt	Genk Langerlo (BE): 1.8 Mt BE: 1.0 Mt	BE: 0.8 Mt	BE: 1.6 Mt
To other countries	**1.8 Mt**	**2.9 Mt**	**2.1 Mt**	**8.0 Mt**	**0.5 Mt**	**2.1 Mt**	**0.5 Mt**	**0.5 Mt**	**1.8 Mt**	**2.9 Mt**	**1.3 Mt**	**2.5 Mt**
	Amer (NL): 1.3 Mt Borssele (NL): 0.5 Mt	FR: 1.6 Mt Amer (NL): 0.9 Mt Borssele (NL): 0.5 Mt	Amer (NL): 1.7 Mt Borssele (NL): 0.5 Mt	FR: 6.7 Mt Amer (NL): 0.9 Mt Borssele (NL): 0.5 Mt	Borssele (NL): 0.5 Mt	FR: 1.6 Mt Borssele (NL): 0.5 Mt	Borssele (NL): 0.5 Mt	Borssele (NL): 0.5 Mt	Amer (NL): 1.3 Mt Borssele (NL): 0.5 Mt	FR: 1.6 Mt Amer (NL): 0.9 Mt Borssele (NL): 0.5 Mt	Amer (NL): 1.0 Mt Borssele (NL): 0.4 Mt	FR: 1.6 Mt Amer (NL): 0.5 Mt Borssele (NL): 0.4 Mt
Hull / Immingham / Liverpool / Tyne												
Total	**3.4 Mt**	**4.7 Mt**	**3.5 Mt**	**4.7 Mt**	**3.2 Mt**	**4.7 Mt**	**4.2 Mt**	**4.7 Mt**	**3.4 Mt**	**4.7 Mt**		**3.8 Mt**
Use UK	**3.4 Mt**	**4.7 Mt**	**3.5 Mt**	**4.7 Mt**	**3.2 Mt**	**4.7 Mt**	**4.2 Mt**	**4.7 Mt**	**3.4 Mt**	**4.7 Mt**		**3.8 Mt**
	Drax (UK): 3.4 Mt	Drax (UK): 4.7 Mt	Drax (UK): 3.5 Mt	Drax (UK): 4.7 Mt	Drax (UK): 3.2 Mt	Drax (UK): 4.7 Mt	Drax (UK): 4.2 Mt	Drax (UK): 4.7 Mt	Drax (UK): 3.4 Mt	Drax (UK): 4.7 Mt		Drax (UK): 3.8 Mt
To other countries												
Amsterdam												
Total	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**		**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.2 Mt**	**0.2 Mt**
For use NL	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.3 Mt**		**0.3 Mt**	**0.3 Mt**	**0.3 Mt**	**0.2 Mt**	**0.2 Mt**
	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt		Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.3 Mt	Hemweg (NL): 0.2 Mt	Hemweg (NL): 0.2 Mt
To other countries												

6 Discussion

6.1 Methodology

This study combined a classical transport problem, calculating lowest cost routes between all possible origins and destinations, with a linear optimization model to allocate biomass supply to demand nodes of solid biomass in such a way that all demand is being met optimized for the lowest cost. The key advantage of this approach is that the model remains relatively fast and transparent. There are however some major implications and limitations to the chosen approach and model tool used. The most important are:

- The Biomass Allocation Model only considers supply and demand on an annual basis averaging out peaks in supply and demand. Stock-and-flow modeling with time dynamics of supply and demand and required storage facilities would provide more insight in required facilities for solid biomass.
- The Biomass Allocation Model does not allow for integer variables and allocates biomass supply to demand nodes based on a linear programming problem to minimize total cost. This implies that the model cannot distinct between small or large scale supply/demand nodes or trade routes, i.e. a trade route of 1 ton biomass is considered equal to a trade route of 100,000 ton. The reason is that the introduction of integers into the model structure would increase the complexity and calculation time of the model significantly.
- Selected trade routes by the Biomass Allocation Model are based on single-year demand and supply of solid biomass. Therefore, peak demand in a certain year will be considered equal to long-term supply/demand resulting in scattered trade routes of biomass. If a forward-looking model would be used, that takes the investment costs of biomass facilities into account such as storage in ports, the model outcome is expected to look less scattered with larger, centralized trade routes.
- With supply and demand of solid biomass assumed exogenous to the Biomass Allocation model, there is no feedback between the total demand of solid biomass for renewable energy generation and the cost-supply of solid biomass. If, for example, prices of imported biomass are assumed to increase. The Biomass Allocation model will use more biomass from domestic resources. If energy demand would have been modeled endogenously, also alternative renewable energy technologies, such as wind or PV, might be more economically attractive than using domestic biomass resources in such a scenario. Also changes in fossil fuel prices will not affect the pre-defined demand of solid biomass in the model tool, because they are based on static chosen co-firing shares and load factors.

6.2 Input data

In this study, existing scenarios of renewable energy deployment have been used to quantify the demand for solid biomass in the EU-27 and applied exogenously to the Biomass Allocation model. Although recent scenario projections have been used (2011), regulatory changes and an uncertain investment climate also increase uncertainties in the energy sector. The scenarios have been updated with additional market information, but there are still many uncertainties. For example in the Netherlands, new policy decisions are expected in the 2^{nd} or 3^{rd} quarter of 2013 that could change the potential of co-firing of solid biomass significantly. Such potential changes stress the need for a flexible tool to assess these changes and the possible impact on the demand of solid biomass and related trade routes as provided in this study.

Another limitation to the current input data used in this study is that sustainability criteria are not modeled explicitly and all biomass is assumed to be produced sustainably. Sustainability criteria for solid biomass could impact the supply potential, especially of imported, primary biomass from outside the EU-27. Although the model could be extended with a greenhouse gas calculation module, other criteria, including biodiversity, could only be addressed properly when more data would be available.
Demand nodes of solid biomass in this study only include existing large power plants and power plants that are currently under construction. Demand for heat and advanced transport fuels is allocated to the geographic centers of NUTS-1 regions based on population size. Additional demand nodes could be added, but most locations, especially of future biofuel plants, are currently unknown. Furthermore, other sectors such as biobased chemicals, could have the potential to become large scale consumers of solid biomass, but are not included in the current model.

6.3 Results

Finally, the following points need to considered when interpreting the results of this study with regards to the selected sea ports. The Biomass Transport Model selects the cheapest route of getting biomass from the origin of supply to the destination of use. Sea ports are selected based on the combination of the geographic location of the intermodal sea port terminals, connections to hinterland transport networks and upfront cost (harbor dues, mooring, towage etc.). Although costs are a decisive factor of sea ports in future trade routes of solid biomass, there are many more factors that could not be modeled in this study. These include for example the availability of storage facilities for solid biomass or long term contract agreements between suppliers, terminal operators and ports and utilities. Therefore, all biomass trade flows in the contestable hinterland should be considered to assess the potential of a biomass hub concept because it could potentially go via other ports if pre-conditions are being met.
Secondly, biomass trade through the port of Rotterdam in this study is for a large extent driven by demand from other EU member states. On the one hand, this shows the strategic location of the port of Rotterdam to become a biomass hub for Europe. On the other hand, the transport model is mainly developed for northwest Europe. Projections of solid biomass throughput to EU member states outside northwest Europe is more uncertain, but still important to the results.

7 Conclusion

This study investigated the potential trade flows of solid biomass, processed into pellets, for the purpose of renewable energy generation in northwestern Europe (Belgium, Denmark, Germany, the Netherlands, and United Kingdom). Previous efforts to model biomass trade were based on geographically aggregated regions (for example countries) with simple networks representing trade routes. This study combined a geographic explicit Biomass Transport Model, including a detailed logistic transport network with a detailed representation of sea port terminals and large demand nodes (power plants) in northwest Europe with a biomass allocation model in order to create a flexible assessment tool for trade flows of solid biomass, the implications of (large) demand at specific power plants and the possible role of sea ports.

The developed tool was then used to assess biomass demand in the EU-27 under different scenarios of renewable energy (RES) support policies and scenarios of global supply of solid biomass. The three scenarios of biomass demand, discussed in detail in Report I of this study, included a business as usual scenario (BAU) assuming a continuation of current support policies in the EU-27 to 2030. Furthermore, a BAU scenario was included with mitigation of non-economic barriers resulting in increased deployment of RES. The third scenario included fine tuning and improvements of RES support policies, as well as a mitigation of current non-economic barriers to meet the RES 2020 targets of 20% renewable energy in 2020. For solid biomass supply outside Europe, three scenarios were assumed. A Reference Trade scenario that considered, although still highly uncertain, a most likely development of solid biomass supply in key regions of supply and demand. Furthermore, a High Trade 450 and Low Trade scenario assessed future alternative development pathways loosely based on the IPCC SRES A2 (Low Trade) and B1 (High Trade) scenarios and IEA World Energy Outlook 450 (with higher demands for renewable energy, to keep global temperature rises below 2 °C by limiting global concentrations of CO_2 below 450 ppm).

Based on the existing projections of renewable energy generation and primary demand in the EU-27 from the Re-Shaping project, updated with plant specific assumptions on co-firing and full conversion to biomass, total demand of solid biomass was projected to increase in all scenarios:

- Under the assumption that current support policies will continue to 2030 (BAU scenario), total demand for solid biomass in northwest Europe could almost double from 45 Mt (wood pellet equivalent, 17.6 MJ/kg) to 67 Mt in 2020 and 78 Mt in 2030. Main growth in demand was projected for residential heating (RES-H non grid), increasing from 24 Mt in 2010 to 41 Mt in 2030 and electricity generation (RES-E), increasing from 19 Mt in 2010 to 31 Mt in 2030.
- Mitigation of non-economic barriers (BAU-BM scenario), could increase the role of solid biomass significantly resulting in a total demand of 85 Mt in 2030. Compared to the BAU scenario, larger growth was mainly projected in RES-E sectors (up to 42 Mt in 2030).
- With enhanced levels of RES support and with non-economic barriers being mitigated aiming to meet the binding RES 2020 targets in 2020 (SNP scenario), total demand for solid biomass in northwest Europe was projected to increases to 87 Mt in 2020 and 109 Mt in 2030. In this scenario, solid biomass demand for residential heating was almost similar to the BAU scenario (40 Mt in 2030), but sharp increases in demand were projected for RES-E (47 Mt in 2020 and 51 Mt in 2030) and the production of advanced biofuels (up to 12 Mt in 2030). Additional plant specific assumptions made for this study, resulted in higher demand for renewable

electricity generation (RES-E) and related demand for solid biomass already in 2020 compared to the original Re-Shaping scenario projections.

Based on the projected increase in demand for solid biomass in all scenarios, a growing share of solid biomass supply in northwest Europe was also projected to come from imported resources. In 2020, imports of solid biomass range from 13 Mt (20% of the total solid biomass demand) to 36 Mt (38% of the total solid biomass demand) in the BAU and SNP scenario respectively. In 2030, total imports increase in the BAU scenario to 21 Mt, but was projected to remain relatively stable in the SNP scenario (34 Mt). Germany, currently a net exporting country of wood pellets, was projected to become the largest importing country of solid biomass in all scenarios with up to 10 Mt in the BAU scenario in 2020 to 14 Mt in the SNP scenario in 2020 and up to 18 Mt in the SNP scenario in 2030.

For imported solid biomass from outside the EU-27, sea port facilities are crucial. For selected ports that are considered important for solid biomass trade in northwest Europe, the projected amounts have been calculated in the scenarios. From comparing these projections, the following conclusions can be drawn:

- Total throughput of solid biomass (pellets) for the purpose of energy generation could become large. The projections show that up to 27 Mt (SNP scenario in 2030), driven by demand in northwest Europe, but also other EU member states could be transferred via the these selected sea ports;
- With the assumed port specific upfront cost, the port of Rotterdam could become the largest hub of solid biomass in northwest Europe (up to 16 Mt in 2030). However, throughput in the port of Rotterdam was mainly driven by demand from other EU member states (mainly Germany). In the SNP scenario, for example, total throughput of solid biomass in the port of Rotterdam increases from 5.5 Mt in 2020 to 16 Mt in 2030 with 1.5 Mt (2020) to 1.6 Mt (2030) projected to be used in the Netherlands and the remaining 4.0 Mt (2020) to 14.3 Mt (2030) re-exported.

Finally, the findings of this study indicate that solid biomass trade is likely to increase in the future as a result of demand for renewable energy generation. The scenarios assessed in this study provide insight in possible trade flows of solid biomass for conservative and more ambitious scenarios. Although the developed model tool is limited, especially with respect to time dynamics and required (storage) capacities for solid biomass or alternative biomass commodities, the chosen model approach allows for the assessment of alternative scenarios with possible updates of additional biomass conversion plants.

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Appendix I: Background data

Table 23 RES-E from solid biomass in northwest Europe in the Re-Shaping scenarios (Green-X) (Resch, 2012), Port of Rotterdam scenarios, RES-E from solid biomass and waste in the NREAPs and co-firing in the ECN planned policy scenario (ECN 2012).

	2010	2020	2030
BE			
SNP Green-X	2,835	3,232	2,709
SNP PoR	2,835	4,496	2,709
Of which allocated	54%	100%	98%
NREAP*	2,580	9,575	
DK			
SNP Green-X	2,474	5,116	5,668
SNP PoR	2,737	5,116	5,668
Of which allocated	100%	85%	50%
NREAP*	3,578	6,345	
DE			
SNP Green-X	13,324	32,026	43,655
SNP PoR	13,324	32,026	43,655
Of which allocated	0%	0%	0%
NREAP*	17,498	24,569	
UK			
SNP Green-X	4,542	12,283	18,807
SNP PoR	4,542	20,488	18,807
Of which allocated	66%	100%	51%
NREAP*	5,500	20,590	
NL			
SNP Green-X	2,989	4,887	8,042
SNP PoR	4,170	10,002	8,042
Of which allocated	100%	100%	82%
NREAP*	5,103	11,975	
Of which co-firing	3,078	8,350	
ECN Co-firing (planned policy)	3,611	8,056	5,278

*NREAPs table 11, including electricity from waste

Table 24 NUTS-1 Regions used to allocate biomass demand and supply in the EU-27 (ESRI, 2012)

NAME	NUTS-0	NUTS-1	POPULATION	GDP	SQKM
Ostösterreich	AT	AT1	3620133	126115	23337
Südösterreich	AT	AT2	1774104	51242	25728
Westösterreich	AT	AT3	3031959	106160	34108
Brussels Hoofdstedelijk Gewest	BE	BE1	1108893	65141	158
Vlaams Gewest	BE	BE2	6291935	203643	13407
Région Wallonne	BE	BE3	3517276	84036	16723
Severna i Iztochna Bulgaria	BG	BG3	3885916	15086	68377
Yugozapadna i Yuzhna Tsentralna Bulgaria	BG	BG4	3622404	19210	42755
Ceska Republika	CZ	CZ0	10541773	149298	77913
Baden-Württemberg	DE	DE1	10708797	369811	35593
Bayern	DE	DE2	12521489	450607	69780
Berlin	DE	DE3	3435855	89739	879
Brandenburg	DE	DE4	2498884	55076	29184
Bremen	DE	DE5	659706	27789	380
Hamburg	DE	DE6	1779531	88622	736
Hessen	DE	DE7	6044454	224234	20772
Mecklenburg-Vorpommern	DE	DE8	1636903	36160	22854
Niedersachsen	DE	DE9	7915518	215869	47037
Nordrhein-Westfalen	DE	DEA	17823363	554670	33658
Rheinland-Pfalz	DE	DEB	3997457	107757	19671
Saarland	DE	DEC	1015478	31458	2540
Sachsen	DE	DED	4127931	96160	18246
Sachsen-Anhalt	DE	DEE	2324185	54421	20278
Schleswig-Holstein	DE	DEF	2827441	74905	15518
Thüringen	DE	DEG	2223576	51036	15951
Danmark	DK	DK0	5560625	233402	42737
Eesti	EE	EE0	1336645	14091	45013
Noroeste	ES	ES1	4433792	91203	45509
Noreste	ES	ES2	4462479	125056	70610
Comunidad De Madrid	ES	ES3	6479492	186855	8087
Centro (E)	ES	ES4	5733824	109345	216934
Este	ES	ES5	13703238	323998	60744
Sur	ES	ES6	9979576	173743	100647
Manner-Suomi	FI	FI1	5351522	176343	339404
Åland	FI	FI2	28028	1074	1235
Île De France	FR	FR1	11865157	561027	11924
Bassin Parisien	FR	FR2	10802971	277564	145052
Nord - Pas-De-Calais	FR	FR3	4042771	99016	12382
Est	FR	FR4	5413824	136734	47924
Ouest	FR	FR5	8608743	223085	85383
Sud-Ouest	FR	FR6	6925298	181847	103995
Centre-Est	FR	FR7	7613941	219888	70871
Méditerranée	FR	FR8	7940684	208333	67783
North East (England)	GB	UKC	2606163	54975	8547
North West (England)	GB	UKD	6946833	162729	14330
Yorkshire and The Humber	GB	UKE	5330757	120282	15353
East Midlands (England)	GB	UKF	4499700	106468	15459
West Midlands (England)	GB	UKG	5480152	125146	12836
East of England	GB	UKH	5850817	149204	19079
London	GB	UKI	7914857	372720	1574
South East (England)	GB	UKJ	8547245	243677	19082
South West (England)	GB	UKK	5287295	131252	23870
Wales	GB	UKL	3022155	60796	20897
Scotland	GB	UKM	5243379	141449	78422
Northern Ireland	GB	UKN	1814755	38751	13967
Voreia Ellada	GR	GR1	3602781	66342	57220
Kentriki Ellada	GR	GR2	2494422	49754	54625
Attiki	GR	GR3	4133510	93815	3855
Nisia Aigaiou, Kriti	GR	GR4	1124855	26190	17997
Kozep-Magyarorszag	HU	HU1	2976744	47813	7287
Dunantul	HU	HU2	3031734	25279	36265
Alfold Es Eszak	HU	HU3	3986612	24646	48719
Ireland	IE	IE0	4592095	156127	69296
Nord-Ovest	IT	ITC	16123392	498637	57664
Nord-Est	IT	ITD	11647665	356485	61633
Centro (I)	IT	ITE	11989771	344053	58370
Sud	IT	ITF	14180693	242423	73746
Isole	IT	ITG	6722091	116037	50479
Lietuva	LT	LT0	3309238	27329	64082
Luxembourg (Grand-Duché)	LU	LU0	511033	40101	2566
Latvija	LV	LV0	2233098	17735	63839
Noord-Nederland	NL	NL1	1715258	65804	8480
Oost-Nederland	NL	NL2	3529362	104737	10013
West-Nederland	NL	NL3	7830155	298236	9680
Zuid-Nederland	NL	NL4	3571916	120349	7166
Centralny	PL	PL1	7766058	96669	53004

Poludniowy	PL	PL2	7933966	72398	27176
Wschodni	PL	PL3	6704841	44800	73903
Polnocno-Zachodni	PL	PL4	6116961	54255	65311
Poludniowo-Zachodni	PL	PL5	3899967	36544	28991
Polnocny	PL	PL6	5731650	44856	59753
Continente	PT	PT1	10214603	162495	89910
Macroregiunea unu	RO	RO1	5232829	26448	67808
Macroregiunea doi	RO	RO2	6500744	25881	71861
Macroregiunea trei	RO	RO3	5517136	47881	36163
Macroregiunea patru	RO	RO4	4142862	21242	60820
Östra Sverige	SE	SE1	3632050	150453	49469
Södra Sverige	SE	SE2	4092931	135720	84329
Norra Sverige	SE	SE3	1703595	56804	317648
Slovenija	SI	SI0	2053983	35518	20202
Slovenska Republika	SK	SK0	5430925	66774	48558

Appendix II: Model tools and user manual

Required software

In order to run the Biomass Allocation Model, the following software is required to be installed in addition to Microsoft Excel 2010. All software is free available. The required solver and interface (COIN-Or and Pulp) are already available in the Biomass Allocation Model directory and do not require to be installed.

Table 25 Required software to run the Biomass Allocation Model

Name		**Description**	**Link**
Microsoft Excel 2010			
Python 2.7		Programming language, used to write the model script.	http://www.python.org/download/releases/2.7/
PyXLL		PyXLL creates the opportunity to write add ins for MS Excel using Python. Used for the MS Excel based model tool interface.	http://www.pyxll.com/
Python for Windows extension		Win32 API extension	http://sourceforge.net/projects/pywin32/files/pywin32/

Appendix III: Results (digital)

All model input data and results are available in Microsoft Excel.