RE-Shaping

Shaping an effective and efficient European renewable energy market

D12 Report:

Long Term Potentials and Costs of RES

Part II: The Role of International Biomass Trade

Authors:

Ric Hoefnagels, Martin Junginger, UTRECHT UNIVERSITY
Gustav Resch, Christian Panzer, EEG / TU VIENNA

August 2011

A report compiled within the European research project *RE-Shaping* (work package 5)
www.reshaping-res-policy.eu
Intelligent Energy - Europe, ALTENER
Grant Agreement no. EIE/08/517/SI2.529243

Supported by INTELLIGENT ENERGY EUROPE

The RE-Shaping project

Year of implementation:	July 2009 – December 2011
Client:	European Commission, EACI; Intelligent Energy – Europe - Programme, Contract No. EIE/08/517/SI2.529243
Web:	www.reshaping-res-policy.eu

Project consortium:

Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research (ISI), Germany *(Project coordinator)*
Energy Economics Group	Vienna University of Technology, Institute of Energy Systems and Electric Drives, Energy Economics Group (EEG), Austria
ECOFYS	Ecofys b.v. (Ecofys), The Netherlands
DIW BERLIN	Climate Policy Initiative, DIW Berlin (DIW) Germany
LEI	Lithuanian Energy Institute (LEI), Lithuania
Universiteit Utrecht	Utrecht University, The Netherlands
Energo Banking	Energy Banking Advisory Ltd., Hungary
KEMA	KEMA, The Netherlands
Università Commerciale Luigi Bocconi	Bocconi University, Italy

The core objective of the RE-Shaping project is to assist member state governments in preparing for the implementation of Directive 2009/28/EC and to guide a European policy for RES in the mid to long term. The past and present success of policies for renewable energies will be evaluated and recommendations derived to improve future RES support schemes.

The core content of this collaborative research activity comprises:

- Developing a comprehensive policy background for RES support instruments.
- Providing the European Commission and member states with scientifically based and statistically robust indicators to measure the success of currently implemented RES policies.
- Proposing innovative financing schemes for lower costs and better capital availability in RES financing.
- Initiation of national policy processes which attempt to stimulate debate and offer key stakeholders a meeting place to set and implement RES targets, as well as options to improve the national policies fostering RES market penetration.
- Assessing options to coordinate or even gradually harmonise national RES policy approaches.

Contact details:

<< Project coordinator >>

Mario Ragwitz
Fraunhofer Institute for
Systems and Innovation Research
Breslauer Str. 48
D-76139 Karlsruhe
Germany
Phone: +49(0)721/6809-157
Fax: +49(0)721/6809-272
Email: mario.ragwitz@isi.fraunhofer.de

<< lead author of this report >>

Ric Hoefnagels
Copernicus Institute – Utrecht University

Budapestlaan 6
3584 CD Utrecht
The Netherlands
Phone: +31(0)30-2537645
Fax: +31(0)30-2537601
Email: e.t.a.hoefnagels@uu.nl

This report

aims to identify likely trade flows of biomass for energy purposes based on demand, supply and likely cost in Europe

Authors:
Ric Hoefnagels, Martin Junginger UNIVERSITY OF UTRECHT
Gustav Resch, Christian Panzer, EEG / TU VIENNA

Acknowledgement:

The authors and the whole project consortium gratefully acknowledge the financial and intellectual support of this work provided by the Intelligent Energy for Europe – Programme.

Supported by INTELLIGENT ENERGY EUROPE

with the support of the EUROPEAN COMMISSION
Executive Agency for Competitiveness and Innovation
Intelligent Energy for Europe

Table of Contents

Page

Figures

Tables

1 Introduction

With concerns regarding security of supply, global climate change and ambitious targets for renewable energy, it is expected that the European (and global) demand of biomass for energy purposes will increase. In the past years, the European Union has been the centre for biomass demand and with the new Renewable Energy Directive (RED), including the commitment to produce 20% of energy from renewables in 2020, biomass will likely play a major role.

In past years, we have seen that new sources of biomass have been mobilized to meet the European demand: these can be residue streams (two examples are palm kernel shells shipped from South East (SE) Asia to Europe, and wood pellets from sawdust carried from British Columbia to Europe) and biomass from dedicated plantations (e.g. palm oil from SE Asia and wood pellets from plantation wood in the South East of the US).

However, it is as yet unclear how much of the future demand can be supplied by untapped resources, both residues and dedicated energy crops within the EU-27, and how much is likely to be sourced from outside the EU-27. Policy makers are faced with this and other uncertainties. Similarly, different industry sectors are faced with increasing competition: for example, lignocellulosic feedstocks are nowadays already heavily utilized to produce electricity and heat, but in the future may also be sourced for 2nd generation biofuels production. Next to this, future demands for material use, such as paper, construction and particleboard industries, is also uncertain.

In order to assess the potential supply of biomass from EU and non-EU sources and expected logistic chains of biomass distribution, insight is required in the current and future options for biomass transport and the related economic and environmental performance. Such logistic chains should encompass the different transport modes (road, railway, canals and rivers and sea), changes of transport means (transhipment) and storage, barriers (e.g. borders, capacities) and physical properties of biomass (e.g. wood chips, wood pellets, and liquid). Logistic chains for biomass feedstock and derived commodities have been assessed for intercontinental chains (Hamelinck, Suurs et al. 2005), Europe (Hansson and Berndes 2009) and selected European regions and destinations (van Dam, Faaij et al. 2009). A complete assessment of the EU-27 including the cost and GHG emissions of all logistic processes (pre-treatment, storage, transhipment and intermodal transport) from supply regions to all countries within the EU-27 has, however, not been conducted yet.

For the RE-Shaping project, the aim is to update the GREEN-X model framework with international biomass trade in order to estimate the impact on RES-deployment, related cost and related biomass trade flows in the EU-27. Therefore, this work package aims to provide detailed insight in likely (intra-European) trade flows of biomass for bioenergy purposes by modelling intermodal logistic chains of solid biomass. Sub-goals of this project are:

- Identification of costs related to logistic processes of biomass, including production, pre-treatment, storage, transhipment and transport;

- Identification of GHG emissions related to logistic processes of solid biomass distribution within the EU-27;
- Identification of threshold values for biomass supply (both domestic and regional).

This report presents (i) the methodology and (ii) the results of identifying the current and future cost and GHG performance of biomass transport that are used as input to the GREEN-X model. The impact on final demand of biomass will be estimated endogenously in the GREEN-X model and results will be reported in related publications. Other deliverables within the same project include the supply potentials and likely production cost of biomass for energy purposes (D10 report of the RE-Shaping project (Junginger, Hoefnagels et al. 2011)) and the current status of international biomass trade (D8 report of the RE-Shaping project (Ragwitz, Held et al. 2011)). Furthermore, the results of the implementation of the trade model in Green-X will be further shown in the D22 Report of the Re-Shaping project: "Renewable energies in Europe – Scenarios on future European policies for RES".

The structure of this report is as follows. Section 2 provides an overview of current trade of solid biomass and related transport modes, section 3 covers the methodology of the modelling exercise. Section 4 shows the results of cost and GHG emissions related to biomass distribution and section 5 and 6 end with the discussion and conclusion respectively.

2 Trade of solid biomass and related transport chains

This section describes the current status of Intra- and Inter-European trade of solid biofuels. Solid biofuels are mainly traded across borders as wood pellets, but also wood chips, fuel wood and waste wood have been traded internationally (Junginger, van Dam et al. 2010). Due to a) data limitations and b) because wood pellets are the main traded commodity of solid biofuels (due to its relatively high calorific value and manageability (Junginger, Dam et al. 2009; Sénéchal, Grassi et al. 2009)), this section focuses on wood pellet trade and related transport chains.

2.1 Current Intra- and Inter-European wood pellet trade

From January 2009 onwards, wood pellets are recorded by EUROSTAT (CN code: 4401 30 20). Although these statistics provide insight in the production, import and export of wood pellets for intra- and extra-European markets, these statistics are not complete and inconsistencies between import and export figures are still found (Sikkema, Steiner et al. 2010). Figure 2-1 shows the trade flows of Intra- and Inter-European pellet trade. Figure 2-2 depicts the major wood pellet markets in the EU-27 in 2009. Detailed data underlying these results is provided in Appendix II.

Some countries, such as Austria and Germany, are largely self-sufficient whereas other countries, such as Belgium, Denmark and the Netherlands depend mainly on imported wood pellets. Main exporting countries include countries with large forest industry sectors such as the Baltic state and North West Russia (Ragwitz, Held et al. 2011; Sikkema, Steiner et al. 2011).

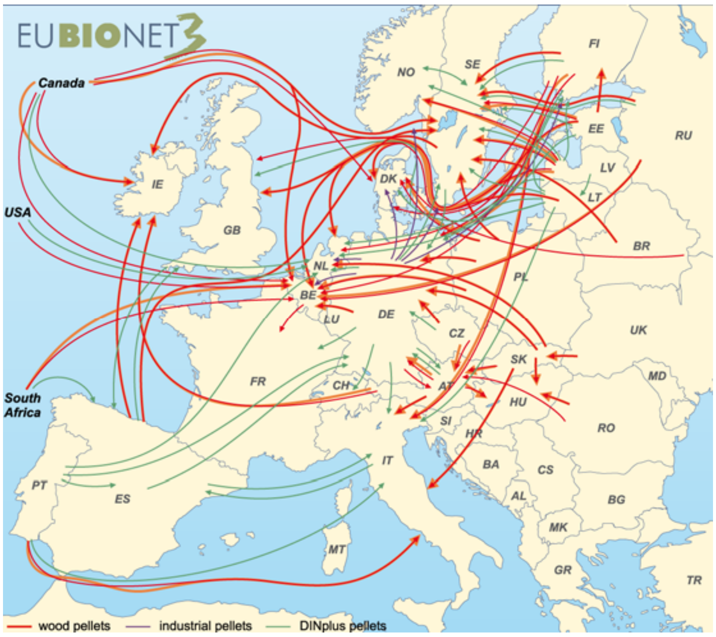

Figure 2-1 Intra- and Inter-European trade flows of wood pellets (EUBIONET3)

In quantitative terms, Germany (1560 kton) and Sweden (1576 kton) are the largest producers of wood pellets. Latvia (728 kton) and Germany (482 kton) are the largest exporters of wood pellets whereas the Netherlands (960 kton) and Denmark (756 kton) are the largest importers of wood pellets. Latvia exported wood pellets mainly to Scandinavian countries (59%) and Estonia (20%). Germany mainly exports to Scandinavian countries (27%) and Spain (23%). The Netherlands is the largest importer of non-EU wood pellets from Canada (43%) and the US (33%). Denmark mainly imports from Estonia (29%), Sweden (13%) and North-West Russia (11%) (Appendix II).

In 2009, wood pellets imported from non-EU countries are mainly covered by large imports from the USA and Canada to the Netherlands (Canada 43%, USA 33%) and Belgium (Canada 19%, USA 41%) whereas wood pellets from North-West Russia are mainly exported to Scandinavian countries. The supply of wood pellets from the USA is a newly developed market (started in 2008-2009 from the South-East), but has already become one of the major sources of wood pellets in Europe (Ragwitz, Held et al. 2011).

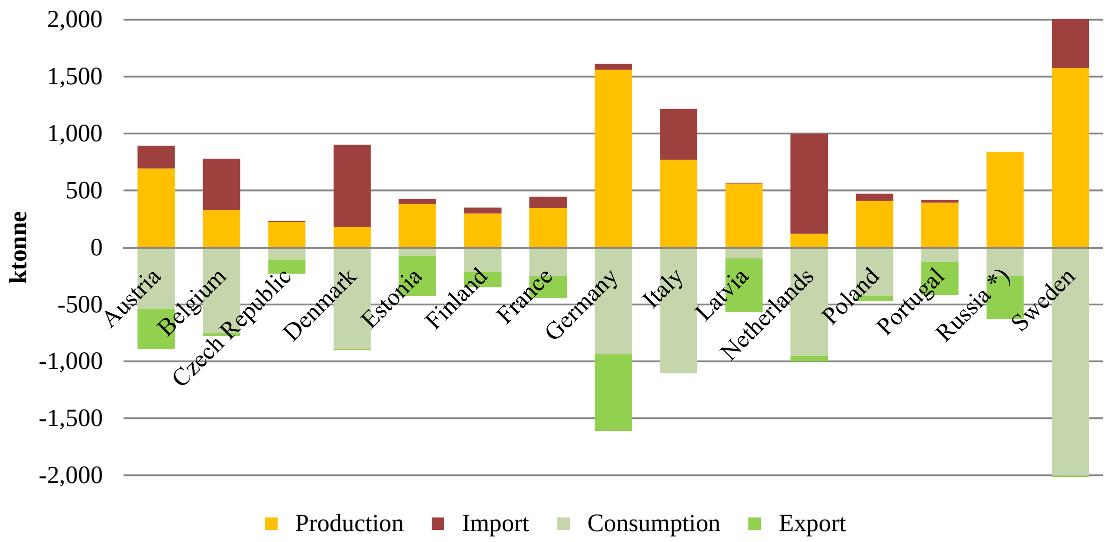

Figure 2-2 Major wood pellet markets in Europe (Sikkema, Steiner et al. 2011)

2.2 Outlook[1]

The global wood pellet production and trade has been increasing exponentially, and it is likely that strong further growth will occur in the next decade. The biggest growth areas in 2009-2010 were the South East of the USA and North West Russia, where currently wood pellet plants with capacities of 500-1000 ktonnes per year are being built. Also in other world regions, such as Latin America, Australia and southern Africa, wood pellet plants are being

1 This section was also published in Ragwitz, Held et al. (2011)

built, aiming primarily to export to Europe. However, this growth in supply will likely only occur if there is sufficient (European) demand. Estimates for the European pellet demand in various studies vary from 18 million tonnes in 2013, 16.5 million tonnes in 2015 and about 28 million tonnes in 2025. Very optimistic scenarios even expect a demand between 50 and 80 million tonnes already in 2020 (Sikkema et al. 2011). Most projections foresee the largest growth in the electricity sector, ranging from a modest 3% share for co-firing of pellets to even 20% co-firing shares in some utilities. While in theory, the EU could mobilize more of its own woody resources, in practice it is quite likely that imports from outside the EU will strongly increase in the future. Depending on the development of demand, and taking into account the current investments in production capacity, these could easily reach 5 to 10 million tonnes per year by 2020.

How much could such volumes contribute to renewable electricity production? As a rule of thumb, 1 million tonnes of wood pellets equals about 17.5 PJ primary energy, which (if co-fired in a modern coal power plant) is sufficient to produce about 2 TWh of renewable electricity. Assuming a moderate 5-10 million tonnes imports from outside the EU, which will be used almost solely for electricity production, between 10-and 20 TWh could be produced in the EU, based on imported biomass. In case the (very optimistic) 50 million tonnes EU consumption from the Aebiom scenario (Aebiom 2008) would be reached in 2020, probably more than half of this would have to be from sources outside the EU. In such a case, 30 million tonnes of wood pellets could in a best case allow up to 60 TWh of renewable electricity production. Assuming a price of 120 €/tonne (about 7 €/GJ, or 25 €/MWh) delivered to the end user (which is a typical price paid between 2007-2010 in the Rotterdam harbour), the electricity production costs are roughly 6 euro cent per kWh. This is solely based on the fuel costs, but additional investment costs in coal-fired power plants and O&M costs are relatively low. Also, the saved costs of avoided coal use and the value of CO_2 credits are not taken into account. The avoided costs of coal may be a significant factor determining the competitiveness of electricity from wood pellets – coal prices have varied between 2-4 €/GJ (7 and 14 €/MWh) in past years. Thus, electricity production costs are likely to be competitive with e.g. electricity from wind farms with medium to high wind speeds, and well below production costs from e.g. a typical off-shore wind farm.

Which countries are likely to invest in large-scale electricity production from solid biomass? In past years, these have been Belgium, Denmark, the Netherlands, Hungary and the UK. In the future, also other countries with large coal-fired power plants (such as Germany, Poland, the Czech Republic and other eastern European countries) could cover significant shares of their RES-E target by co-firing (imported) solid biomass (Hansson 2009). Whether they will do this will depend largely on their other options to reach their RES-E targets.

Looking at the option of biomass trade from the perspective of the EU target achievement, as well as regarding the need for flexibility to reach the target, it is interesting to compare the different quantitative contributions. Based on the Green-X modelling, performed within this project, the total RES deployment needed to reach the target of 20% by 2020 amounts to about 2,980 TWh. The need for flexibility measures between member states is estimated at about 110 TWh by 2020. Therefore it can be seen that biomass trade from outside the EU leading to an electricity production of 20 TWh could substantially contribute to the need for flexibility, but may not be sufficient. Also, biomass trade within the EU can further add to the flexibility for target achievement, although one should discuss whether flexibility based on statistical transfers or physical trade of biomass are superior with respect to the overall environmental and economic balance.

2.3 Supply chain and transport modes

Wood pellets are used for bulk markets such as district heating and co-firing. Furthermore, they are also and sold in big (500-1000 kg) or small (15-25 kg) bags via retailers for small scale users (Figure 2-3) (Sénéchal, Grassi et al. 2009). Note that the transport, handling and storage of raw materials before pelletizing can differ (depending on the feedstocks used and whether the pellet mill is integrated with a saw mill, or whether feedstock has to be sourced externally. Also, wood pellets are transported using different logistic chains that differ per end user (e.g. bulk electricity or small scale household heating) and region. The main markets for wood pellets differ per region (Sikkema, Steiner et al. 2010):

- Bulk power: Belgium, the UK, the Netherlands and Poland
- Bulk district heating: Denmark and Sweden
- Bulk residential heat: Austria, Germany, Slovakia
- Bags residential heating: Bulgaria, France, Hungary, Italy.

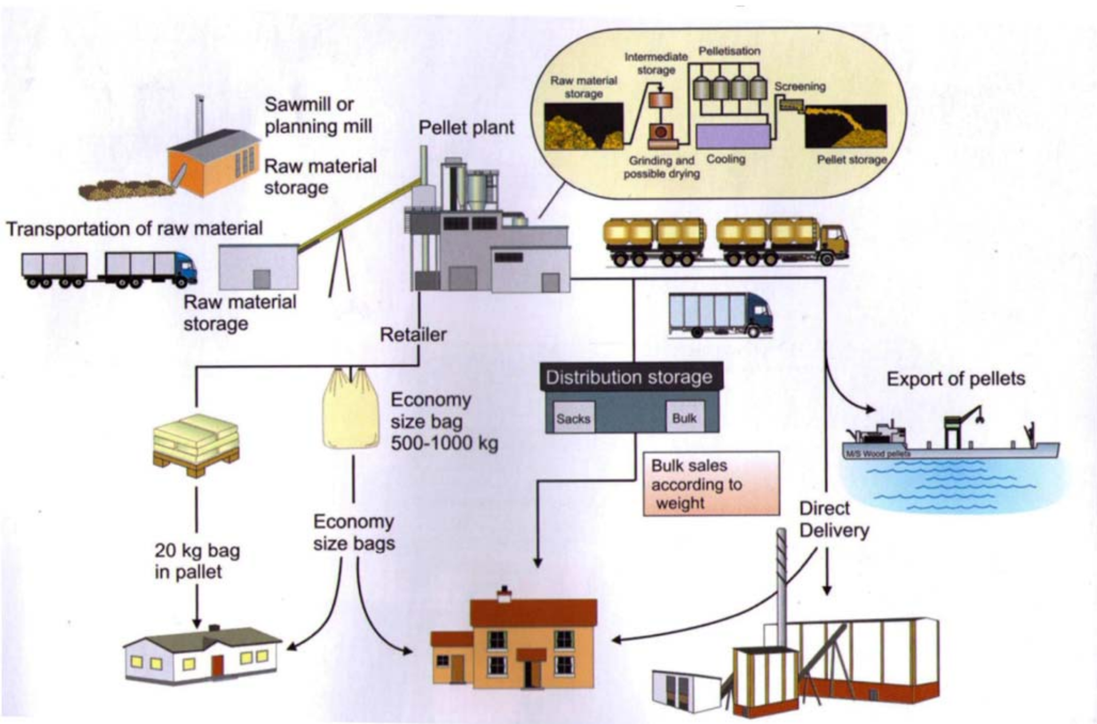

Figure 2-3 Production and trading of pellets (Source: VTT in (Sénéchal, Grassi et al. 2009)).

Road

Apart from the Baltic States, wood pellets are mainly transported by truck within Europe (Obernberger and Thek 2010; Sikkema, Steiner et al. 2011). Although it is assumed that transport of pellets for distances larger that 100 to 300 km is more cost effective by train or ship (Sénéchal, Grassi et al. 2009), pellets producers from Romania, Bulgaria, Hungary, Slovakia and Czech Republic claim that almost all pellets are transported by truck and only a small fraction is transported to Rotterdam via ship from Romania and Bulgaria (Boer, Cuijpers et al. 2010). In 2009, Slovakia transported 91 kton wood pellets to Italy by truck (Appendix II).

Rail

At this moment, pellets are not transported by rail on significant scale in Europe. The costs and lead times are considered too high for cross boundary rail transport (Boer, Cuijpers et al. 2010). Furthermore, intermodal transport and transhipment is always required due to the limitations of the railway network. In the USA, the Cottondale plant in Florida uses rail transport for transport of pellets from the production plant to the harbour (~ 100 km) (Sénéchal, Grassi et al. 2009) and also the Waycross plant, recently commissioned in Georgia, uses rail transport to transport pellets from the production facility to the harbour (Savannah) (Georgia Biomass 2011). Because the rail network is directly connected to the pellet plant, transhipment costs are avoided.

Analogue to pellets, grain is currently exported from Eastern Europe to Western Europe by rail. The price of grain transport via rail from Budapest to Rotterdam was estimated to be € 50 / tonne, but depends on many factors such as contract type, scale, distance, border crossings, rail network conditions (e.g. single tracks, electric etc.), dedicated transport and terrain types (e.g. mountains). Trade off distances between rail and road transported were estimated to be 500 km (Boer, Cuijpers et al. 2010).

Inland waterways

Barges or push-tug barges are mainly used for the transportation of round wood (Sénéchal, Grassi et al. 2009), but are also used for the supply of wood pellets and other biomass such as palm kernel waste and other residues to power plants. Wood pellets are, for example, transhipped in the Rotterdam harbour from large sea ships into 1500 dwt (dead weight tonnage) barges to supply the Amer power plant in Geertruidenberg (the Netherlands) (Loo and Koppejan 2008).

Short sea shipping

Short sea shipping includes ocean or sea shipping routes that remain in the same continent. In Europe alone, around 10,000 ships are active at sea consisting of ships between 500 GT (gross tonnage) and 10,000 GT. The average shipment size was 3,607 GT in 2009 (EUROSTAT 2010d). Short sea shipping is mainly used for wood pellets exported from Scandinavian countries and the Baltic States to Western Europe using coasters and Handysize ships with average loads of 4,000 to 6,000 t (Selkimäki, Mola-Yudego et al. 2010).

Long distance maritime shipping

Long distance intercontinental shipping, e.g. from the USA or Canada to Europe takes place by large dry-bulk Handymax and Panamax carriers. The size of the ships depends, amongst others, if it is a common transport route. For example, similar transport cost were found for transporting wood pellets from Vancouver to Rotterdam and Antwerp compared to wood pellets transported from Halifax. Although the distance is more than three times larger (SeaRates.com 2010), Halifax to Europe is not a common trade route and ships are therefore considerably smaller (Obernberger and Thek 2010; SeaRates.com 2010). The main trade routes are from North America to the Netherlands, Belgium and the UK, with average overseas shipments of 20,000 to 30,000 tonnes in Panamax freighters (Ragwitz, Held et al. 2011).

3 Modelling Intra-European biomass trade

To get insight in likely trade routes of biomass supply and the related cost and GHG premiums, a modelling tool was developed for this study. This section describes the modelling approach (3.1), related assumptions on the biomass supply chain including potentials, pre-treatment and selected destinations (3.2), a detailed description of the network model developed in ESRI's ArcGIS (3.3) and the detailed input parameter of this transport network model (3.4).

3.1 Logistic chains and modelling approach

The cost and GHG analysis of solid biomass trade includes wood chips and pellets from various sources of lignocellulosic biomass including forestry products, forestry residues, wood processing residues and dedicated energy crops (short rotation coppice or grassy crops). Figure 3-1 depicts a general supply chain of the related logistic processes included in the calculation model. Chipping is used for woody biomass whereas baling is used for grassy crops and straw. Woody biomass can be transported internationally as wood chips or wood pellets. Grassy crops and straw can only be exported over long distances as pellets due to their large specific volumes (Sultana, Kumar et al. 2010). Distribution from the selected destinations to the end users is not taken into account.

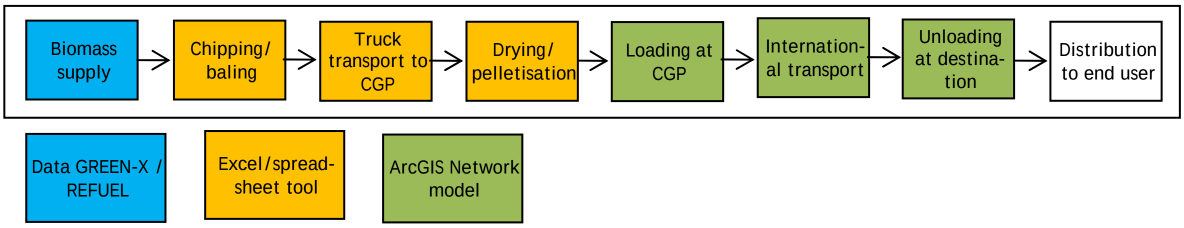

Figure 3-1 Overview of lignocellulosic biomass supply chains and modelling approach

The supply potential and cost of biomass in the EU-27 member states are derived from the Green-X database. To estimate the regional distribution of dedicated energy crops within the EU-27 countries, the REFUEL NUTS-2 level database was used as explained in section 3.2. Biomass transport from resource areas to pre-treatment plant (either chipping or pelletization) are calculated using an excel spread sheet tool (section 3.2). Transporting from regional resource areas to their destinations is specific per origin and destination and per commodity and type of modality used (e.g. truck or ship). These logistic steps are therefore calculated using an intermodal freight transport model using ESRI's ArcGIS Network Analyst extension (ESRI 2010). This model calculates the cost and GHG emissions from the supply regions (NUTS 2 level) to the destination harbours (section 3.3). Distribution to end users was not taken into account in this project.

3.2 Biomass supply and pre-treatment

3.2.1 Biomass supply

From the available biomass feedstock categories in GREEN-X, the following feedstock categories were assumed to be available for Intra-European trade of solid biomass:

Feedstock	Exported as
• AP4 (SRC willow)	Chips/pellets
• AP5 (miscanthus)[2]	Pellets
• AP6 (switch grass)[1]	Pellets
• AR1 (straw)[1]	Pellets
• FP1 (forestry products - current use (wood chips, log wood)	Chips/pellets
• FP2 (forestry products - complementary fellings (moderate))	Chips/pellets
• FP3 (forestry products - complementary fellings (expensive))	Chips/pellets
• FR2 (forestry residues - current use)	Chips/pellets
• FR3 (forestry residues - additional)	Chips/pellets
• FR5 (additional wood processing residues (sawmill, bark)	Pellets

A discussion of the potential and cost of these and other biomass categories in GREEN-X per EU-27 member state is provided in Junginger et al. 2011 (2011). The regional distribution within the EU-27 member state is based on the potentials of energy crops per NUTS-2 region from REFUEL (de Wit and Faaij 2010) a shown for woody crops (AP4) in Figure 3-2 and for grassy crops and straw (AP5, AP6 and AR1) in Figure 3-4. For biomass from forestry (FP1, FP2, FP3, FR2, FR3 and FR5), it was assumed that the potential is equally distributed to the relative share of forestry cover per NUTS-2 region (Figure 3-3) (EUROSTAT 2010c). These shares are assumed to remain constant over time (2005 – 2030).

[2]Available in GREEN-X, but not covered in the results of this report.

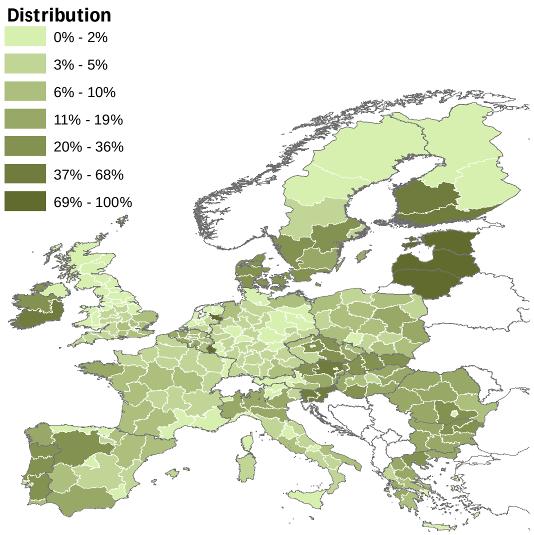

Figure 3-2 NUTS-2 distribution of SRC energy crops , based on REFUEL (de Wit and Faaij 2010)

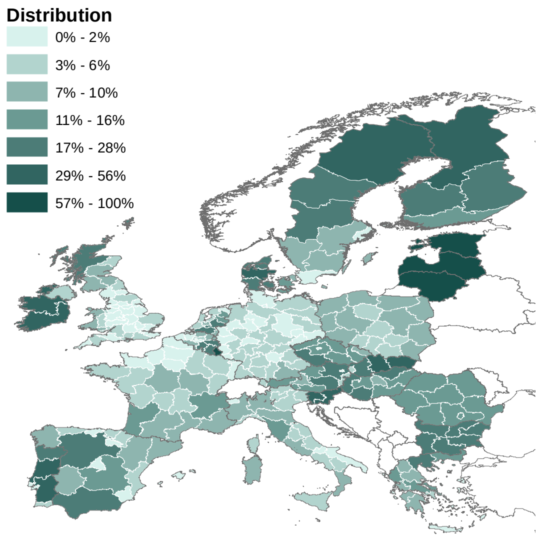

Figure 3-3 NUTS-2 distribution of forestry biomass , based on EUROSTAT woodland cover (EUROSTAT 2010c)

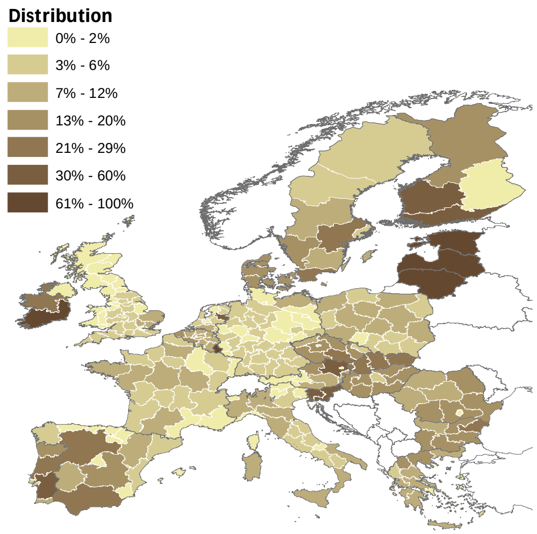

Figure 3-4 NUTS-2 distribution of grassy crops, based on REFUEL (de Wit and Faaij 2010)

3.2.2 Transport to the first processing unit

The first processing units (chipping/pelletization) are assumed to be in the centre of each NUTS3 region with the distance from the biomass source to the processing unit to be the average distance of each NUTS3 region, corrected for the layout of the road system. Since these local roads are not included in the ArcGIS database, a circuity factor (F) of 1.4 was assumed, (typical for agricultural land, based on USA data), as shown in equation 3-1 (van Dam, Faaij et al. 2009).

$$D = F * (^2/_3) * R \qquad \text{(eq. 3-1)}$$

With R:

$$R = (\sqrt{^1/_2\, A}/\pi) \qquad \text{(eq. 3-2)}$$

With D being the corrected average distance and A being the area (km^2) of each NUTS3 region.

All biomass is transported by truck to the chipping or pelletization plant. Transport is dedicated (taking empty return into account).

3.2.3 Pre-treatment

The techno-economic parameters for pre-treatment of the different feedstock categories included are depicted in Table 3-1. The cost for chipping are derived from Hamelinck, Suurs et al. (2005) whereas energy requirements are consistent with the typical values of the EC as also used in for the Well-to-Wheel study for biofuels (JEC 2008) for willow crops. The data for the pellet plant are derived from the Swedish framework conditions in (Thek and Obernberger 2004), but corrected for energy requirements (EC 2010) and inflation (Eurozone 1 $€_{2002}$ = 1.09 $€_{2006}$.

Table 3-1 Cost and performance parameters for wood pre-treatment (chipping or pelletization).

Parameter	Unit (output)	Wood chips	Wood pellets	Pellets (wood proc. residues)[1]
Scale	t/h	10	10	10
Load factor		90	0.91	0.91
Capital	M€	0.15	1.06	0.62
	€/t[2]	0.21	13.7	8.07
O&M	€/t	0.39	6.2	0.0
Electricity	MJ/t		1260	720
Diesel	MJ/t	50.4	36	36
Heat	MJ/t		4235	847
GHG emissions[3]	kg. CO_2-eq./t	4.6	9.26	9.26
Total cost[4]				
2010	€/t	1.7 - 2.2	50.8 - 53.9	42.8 - 45.9
2020	€/t	2.0 - 2.5	52.8 - 56.3	44.8 - 48.3
2030	€/t	2.2 - 2.7	54.2 - 58.0	46.2 - 50.0

1) Reduced energy requirements and capital due to the physical properties of the feedstock (mainly sawdust).
2) Discount rate = 7%, economic lifetime = 20 years.
3) Based on direct and indirect emission factors for diesel and electricity (EU mix) (JEC 2008).
4) The production cost differ per country due to variable energy prices (Appendix II).

3.2.4 Demand (destinations)

Based on the assumption that the demand for energy is higher in populated regions, per NUTS-1 region in the EU-27, the NUTS-3 regions with the highest population are selected. These regions are related to the largest cities within a country. In addition, also the most imported sea harbours are included. Figure 3-5 gives an overview of the harbours and cities that are located in the selected NUTS-3 regions.

Figure 3-5 Destinations for Intra-European biomass trade in the EU-27

3.3 Geospatial Intermodal biomass logistic model

The logistic model is created by use of a hub-spoke network approach similar to (Winebrake, Corbett et al. 2008) using ESRI's ArcGIS Network Analysis tool. The model exists of an interconnected set of links (arcs) and nodes. These links represent real roads, waterways, railways and shipping routes. The tribute tables of these links include, apart from length (km), also attribute data on speed, capacity (e.g. maximum ship sizes), toll costs, rail charges etc. Each node in the network represents intersections, rail terminals, harbours or ports. These nodes are connected to other transport modes via intermodal transport hubs. These hubs are artificially assumed to be in the geographical centre of each NUTS-3 region (centroids). Figure 3-6 shows an example of an intermodal transport hub that connects to all transport modes in the network. Most transport hubs are however only connected to road and railway nodes. The attributes of the connectors include loading/unloading and storage costs depending on the connector type (e.g. from truck to ship).

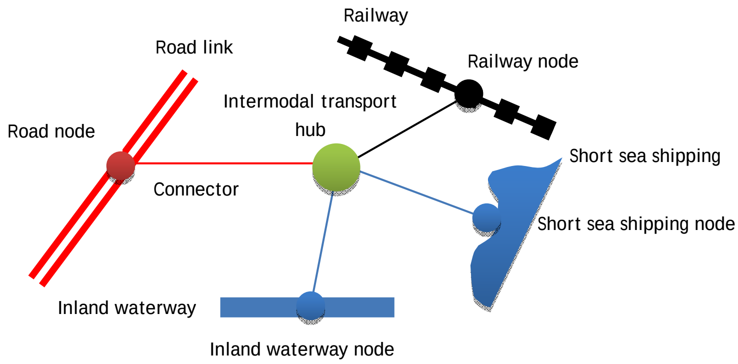

Figure 3-6 The network model approach, based on Winebrake et al. (2008)

The network for road, rail and inland waterways were created using the TransTools ("TOOLS for TRansport Forecasting ANd Scenario testing") shapefiles (JRC 2009). Sea harbours were derived from the EC GISCO database (EUROSTAT 2010e). Links between sea harbours were created in ArcGIS, distances between harbours were derived from the WN Network database (WN 2010) and SeaRates.com (SeaRates.com 2010).

The origins of biomass production include the centroids (geographical centre) of all NUTS3 regions in the EU-27 (1270 centroids). The selected destinations include the largest sea harbour per country if available. Otherwise, the capital city was assumed to be the main destination hub (Figure 3-5).

3.4 Transport modes, cost and performance

For intermodal transport of biomass, four transport modes are available: road (truck), rail, inland navigation or short sea shipping. The cost and environmental performance of these transport modes are covered in this section.

3.4.1 Fuel consumption

Fuel consumption is calculated based on the capacity utilization of each transport mode as follows (Knörr, Seum et al. 2010):

$$ECF = ECF_{empty} + \left(EFC_{full} - ECF_{empty}\right) * CU$$

In which:

EFC = final energy consumption

ECF_{empty} = final energy consumption empty

EFF_{full} = final energy consumption full load

CU = capacity utilization (weight load / load capacity)

3.4.2 Volume (stowage factor)

Wood pellets, but especially wood chips, have relative low densities compared to some other bulk goods that are transported (e.g. iron ore or cement). The specific cargo volume per weight (stowage factor) in m^3/t is the key factor in design optimization of transporting particular cargo (Obernberger and Thek 2010).

In this study, similar transport truck/ship/rail types are assumed for transport of wood pellets and wood chips. The stowage factor of pellets and wood chips is used to correct for the volumetric limitations of the transport modalities.

Stowage factors used (m^3/t) (Hamelinck, Suurs et al. 2005):

- Wood chips: 4.17 (610 kg/m^3)
- Wood pellets: 1.64 (240 kg/m^3)

3.4.3 Transport modes

3.4.3.1 Road transport (truck)

Transport by truck is one of the most used and fasted growing modes for transport of freight (EC 2010). For transport of pellets and other solid biomass, different truck types are being used depending on the end consumer type, region and lose or in bags (Obernberger and Thek 2010; Sikkema, Junginger et al. 2010). The techno-economic performance data for truck transport are based on background data from Smeets et al. (2009) and NEA (NEA 2004). The fuel requirement for trucks is consistent with EcoTransit (Knörr, Seum et al. 2010) for trucks >24-40 t (0.30 l/vkm) for 50% load and slightly lower than the estimated fuel consumption by JRC for the typical and default values in for truck transport of solid and gaseous biofuels (0.35 l/vkm and assuming empty returns) (EC 2010).

For the future, an annual efficiency improvement of 0.9% was assumed which results in an efficiency improvement of 20% between 2010 and 2030 based on the average efficiency improvement of trucks of 0.8 to 1% per year in the last 40 years. It should be noted however that much of the efficiency gains were made in the 1970s and 1980s and from the 1990s onwards, the improvement rate was much lower, mainly due to strict emission limit values (e.g. NOx, PM) and related measures. Still, the IEA (2010) expects that trucks can be made 30 to 40% more efficient by 2030 due to improved engines, weight reduction and larger pay loads, tyre improvements and aerodynamics.

Table 3-2 Input parameters for road and rail transport

Parameter	Truck Truck (dry bulk) 2010	 2020	 2030	Rail	References
Load (t)		27		1625	Smeets et al. 2009
Load (m3)		120		4550	
Load factor (during laden trips) ()		0.93		1.00	NEA 2004
Laden trips of total trips ()		0.56		0.50	
Fixed cost (excl labour) (€/vh)		18			
Variable cost (excl.fuel) (€/vkm)		0.11			Smeets et al. 2009
Required labour (person/v)		1.00			
Fuel consumption full (l/vkm)	0.37	0.34	0.31		TML 2005, IEA 2009, Smeets et al. 2009, Knörr, Seum et al. 2010
Fuel consumption empty (l/vkm)	0.23	0.21	0.20		
Fuel consumption average (l/vkm)	0.31	0.28	0.26	5.8	
Fuel type		Diesel		Diesel	
Total GHG emissions (g. CO_2-eq/tkm)	68	62	57	22	JEC 2008

3.4.3.2 Rail freight transport

The operation cost and environmental performance of rail transport is difficult to estimate due to various reasons. Due to competitiveness in these sectors, cost data per component is not publicly available. Secondly, the costs are not separated for freight and passenger transport and thirdly, subsidies and country specific rail charges make a significant share of the total transport tariffs (TML 2005). Therefore, we derived the transport tariffs for bulk freight transport by rail from TML (2005) available for 21 countries in Europe. For the other countries, region specific averages were assumed. Based on the energy requirement from bulk transport by diesel freight trains, the fuel fraction was estimated to be 8%. This fraction was used to correct for the fossil fuel prices in the model.

Because the rail network segments in the TransTools model do not include data on electric and non-electrified railway infrastructure in Europe, we assumed all trains to use diesel locomotives. It should be noted that the share of freight transport by diesel locomotives varies significantly per country. In the UK, 90% of freight per tkm are hauled by diesel locomotives (McKinnon 2007), but these figures might be lower in other countries.

In Germany, the average emissions for freight transport by rail were estimated to be 22.6 g. CO_2-eq./tkm for 2009 (DB 2010). These are slightly higher than the estimations in this study for Europe (22.3 g. CO_2-eq./tkm). The estimations in this study do also include indirect emissions for the production of Diesel and other GHG emissions (CH_4, N_2O).

3.4.3.3 Inland waterways

Inland waterways are subdivided into six classes. In the transport model, Class I waterways, typically suitable for pits-Péniche type of barges, were excluded as they are not cost-effective compared to trucks if biomass is transported. For Class II through Class VI waterways, different suitable barges are included in the model (Table 3-3). Class V and Class VI are combined in the model as they are both possible for large push-convoys that can carry up to 12,000 tonnes. In the model, Class II ships, such as a Kempenaar, can navigate on all waterways (Class II – Class VI), whereas large push-convoys can only navigate on Class V and VI waterways such as the Waal in the Netherlands (UN 2006). The model calculates if it is economically more attractive to use smaller ships or to use larger ships when possible and tranship to smaller ships when required on smaller waterways depending on navigation and transhipment costs.

The techno-economic performance data for inland waterway navigation was derived from Smeets et al. (2009) updated with load factors and laden trip data from NEA (2004). All barges for inland navigation are assumed to use Marine Diesel Oil (MDO) as transport fuel.

Future improvements in cost and performance depend on three important parameters: larger ships or higher load factors (larger ships are more fuel efficient), technological improvements and the use of alternative fuels. For this project, we assumed that the energy requirement of ships remains constant to 2030 as no realistic estimations were found in literature on the improvement potential and substitution rate of existing ship fleets.

Table 3-3 Input parameters for inland navigation

	Inland navigation				
	Class 2	Class 3	Class 4	Class 5/6	
Parameter	Kempenaar	Rhine-Herne Canal ship	Large Rhine ship	Four-barges convoy set	References
Load (t)	550	950	2500	10800	NEA 2004, Smeets et al. 2009
Load (m3)	642	1321	3137	14774	
Load factor (during laden trips) ()	0.71	0.85	0.77	0.83	NEA 2004
Laden trips of total trips ()	0.73	0.81	0.75	0.65	
Fixed cost (excl .labour) (€/vh)	10	22	72	214	NEA 2004, Smeets et al. 2009
Variable cost (excl. fuel) (€/vkm)	0.0	0.0	0.7	17.8	
Required labour (person/v)	1.28	1.44	2.62	3.76	
Fuel consumption full (l/vkm)	6.1	8.8	13.1	20.0	NEA 2004, JEC 2008, Smeets et al. 2009
Fuel consumption empty (l/vkm)	4.9	7.6	11.8	18.4	
Fuel consumption average (l/vkm)	5.6	8.4	12.6	19.3	
Fuel type	MDO	MDO	MDO	MDO	
Total GHG emissions (g. CO_2-eq./tkm)	61	40	28	10	JEC 2008

3.4.3.4 Short Sea Shipping

Despite the longer distances, short sea shipping is an attractive alternative to road transport due to the relatively low costs and fuel requirements. However, within Europe, only the Baltic States prefer short sea shipping over road transport at this moment (4000 to 5000 tonnes). The ships used have on board cranes for loading and unloading (Sikkema, Steiner et al. 2011). We assumed ship types for near shore navigation with a load of 5700 ton dry bulk based on NEA (NEA 2004). Note that the environmental performance of these ships is comparable with ships for inland navigation (Class IV). For the future, we assumed that larger ships will be used with an average load of 9600 ton from 2015 onwards. The IEA estimates that maritime transport energy requirements could improve up to 40% by 2030, however some of these measures would limit flexibility and speed (IEA 2009).

Table 3-4 Input parameters for short sea shipping

Parameter	Short Sea Shipping Dry bulk 2010	2020-2030	References
Load (t)	5700	9600	NEA 2004, Smeets et al. 2009
Load (m3)			
Load factor (during laden trips) ()	0.79	0.79	NEA 2004
Laden trips of total trips ()	0.94	0.94	
Fixed cost (excl. labour) (€/vh)	123	225	NEA 2004, Smeets et al. 2009
Variable cost (excl. fuel) (€/vkm)	5.7	11.2	
Required labour (person/v)			
Fuel consumption full (l/vkm)			
Fuel consumption empty (l/vkm)			NEA 2004, JEC 2008, Smeets et al. 2009
Fuel consumption average (l/vkm)	35.3	53.1	
Fuel type	HFO	HFO	
Total GHG emissions (g. CO_2-eq./tkm)	23	20	JEC 2008

3.4.4 Transhipment

The transhipment cost depicted in Table 3-5, are based on estimates from a transhipment firm in Rotterdam, the Netherlands (Smeets, Lewandowski et al. 2009), but corrected for differences in labour cost per country (section 3.4.5). Appendix I presents the data for all countries included in the model. The cost for storage are not included here and could add 0.08 €/t*day^{-1}. Prices of storing in ports and loading onto ships were found to be 4.17 €/t to 4.87 €/t including 14 days of storage for the port of Riga (Jong, Tselekis et al. 2010). For Romania, transshipment cost of 2.4 €/t were found (Boer, Cuijpers et al. 2010).

Table 3-5 Transhipment cost (in €/t)

Fuel type	Truck Av.	Truck Range	Rail Av.	Rail Range	Ship Av.	Ship Range
Loading	1.83	1.14 - 2.74	2.97	1.86 - 4.46	1.83	1.14 - 2.74
Unloading	1.83	1.14 - 2.74	2.97	1.86 - 4.46	1.83	1.14 - 2.74

The energy requirement and related greenhouse gas emissions are based on Ecotransit (Knörr, Seum et al. 2010) based on transhipment of corn (1.3 kWh/t corn). We used this figure for all transhipment options in the model. The required energy was assumed to be generated by diesel generators with an efficiency of 36%, based on the engine efficiency of inland shipping (Schilperoord 2004). Although it is a rough assumption that all modalities have similar (primary) energy requirements and GHG emissions for transhipment, the impact on the total GHG balance is relatively small.

3.4.5 Country specific parameters: fuel, tolls and labour cost

3.4.5.1 Fuel cost

The cost of fuel (diesel, marine diesel, heavy fuel oil) including excise duties and taxes are country specific. To estimate the cost of diesel, the relationship between diesel prices (ARA Spot price FOB) and crude oil prices (EU Brent), excluding excise duty and VAT, were derived from Meerman et al. (2011) with a correlation of R^2 = 0.96 and assumed to be similar for all countries. Excise duties and VAT were derived from the EU energy and transport in figures (EC 2010).

All ships for inland navigation were assumed to use marine diesel oil (MDO). Prices of MDO were based on diesel prices, but exclude excise duties. Short Sea Shipping was assumed to use heavy fuel oil (HFO). Prices of heavy fuel oil were based on the correlation between European high sulphur fuel oil and UK Brent blend (R^2 = 0.94).

Table 3-6 shows the cost of fuel included in the model. The projections are based on PRIMES crude oil projections increasing from €$_{2008}$46/bbl. in 2005 to €$_{2008}$73/bbl. in 2020. The ranges represent ranges of the minimum and maximum impacts of excise duties and VAT tax in the different countries.

Table 3-6 Fossil fuel prices (€2006), based on PRIMES crude oil price projections, diesel and MDO : (Meerman 2011), excise duties and tax: (EC 2010), HFO: (IEA, 2010).

	2005				2010				2020				2030			
Fuel type	Av.	Range			Av.	Range			Av.	Range			Av.	Range		
Crude fuel (before tax)				0.29				0.32				0.46				0.57
Diesel	0.90	0.73	-	1.13	0.93	0.77	-	1.16	1.16	0.97	-	1.36	1.34	1.13	-	1.52
Marine diesel oil (MDO)	0.46	0.41	-	0.49	0.50	0.44	-	0.53	0.72	0.64	-	0.77	0.90	0.80	-	0.95
Heavy fuel oil (HFO)	0.27	0.26	-	0.28	0.29	0.28	-	0.30	0.42	0.40	-	0.44	0.52	0.50	-	0.54

3.4.5.2 Toll cost

Toll charges include vignette countries and road toll per km and type (e.g. amount axles, weight, environmental performance). For this study, the toll cost charges per road segment for freight transport were derived from the TransTools model. The toll cost charges for freight transport also include ferry cost. These were also used for this project.

3.4.5.3 Labour cost

Labour cost for transport and storage per country (in €/h) are based on EUROSTAT labour market statistics, for transport and storage 2008 (EUROSTAT 2010a). It should be noted that these data were only available for 17 countries in Europe. For other countries, the regional averages were assumed. For example, Finland was assumed to have similar labour cost to North-West Europe (based on Belgium, Denmark, Germany, United Kingdom and Switzerland).

4 Results

The results presented in this section show the impact of biomass transport on the total cost and GHG balance of solid biofuel production and supply. The results, as provided here, are converted into origin – destination matrices per feedstock and year. These are implemented in the energy model GREEN-X, but not further discussed in this report. Implications of the cost premiums to future biomass demand and trade flows are addressed in the deliverables of WP4 of the RE-Shaping project.

4.1 Overview

The costs of biomass supply (including cultivation, harvesting and storage (farm gate), transport to the pelletization unit and transport to the final destination) are depicted in Table 4-1. For long distance transport, biomass is either transported as wood chips or wood pellets. It depends on the distance and transport route if pelletization is cost-effective compared to transport of wood chips over long distances.

Feedstock cost range from 7 €/MWh[3] (forestry residues, Finland in 2010) to 51 €/MWh (willow crops produced in southern Europe in 2030). It should be noted however, that alternative SRC crops that are not included in GREEN-X (e.g. eucalyptus), could be produced for lower costs in these regions (Fischer, Prieler et al. 2010). The additional cost for processing and transport to the final destination add substantially to the total supply cost. Forestry residues could be delivered for 10 €/MWh in 2010 (Luxembourg, domestic source), but the cost could increase to 39 €/MWh if imported from the North of Sweden. Wood pellets from the same feedstock and region supplied to Luxembourg would also cost 39 €/MWh.

3 In this report, primary energy is reported in MWh when reporting costs, to be consistent with the Green-X model, but in MJf (MJ primary fuel) when reporting GHG emissions. 1 MWh equals 3600 MJ, or 0,086 toe.

Table 4-1 Cost of biomass supply (€/MWh)

Feedstock	Transported as	Year	Feedstock (farm gate)[1]		Transport to CGP (truck) and processing[2]		Transport to destination[3]	
			Av.	Range	Av.	Range	Av.	Range
AP4 (SRC willow..)	Chips	2010	33	29 - 35	1.6	0.6 - 4.9	47	31 - 68
		2020	42	37 - 44	1.7	0.7 - 5.2	56	40 - 79
		2030	48	42 - 51	1.8	0.7 - 5.4	64	46 - 88
	Pellets	2010	33	29 - 35	12.1	10.7 - 15.7	51	37 - 66
		2020	42	37 - 44	12.7	11.2 - 16.4	61	42 - 77
		2030	48	42 - 51	13.1	11.6 - 17.0	68	45 - 85
FP1 (forestry products - current use (wood chips, log wood) and FP2 (forestry products - complementary fellings (moderate))	Chips	2010	22	18 - 25	1.6	0.6 - 4.9	37	22 - 57
		2020	26	22 - 29	1.7	0.7 - 5.2	41	26 - 62
		2030	29	24 - 32	1.8	0.7 - 5.4	45	29 - 67
	Pellets	2010	22	18 - 25	12.1	10.7 - 15.7	41	32 - 56
		2020	26	22 - 29	12.7	11.2 - 16.4	45	36 - 61
		2030	29	24 - 32	13.1	11.6 - 17.0	49	39 - 65
FP3 (forestry products - complementary fellings (expensive))	Chips	2010	31	27 - 34	1.6	0.6 - 4.9	45	31 - 65
		2020	37	32 - 40	1.7	0.7 - 5.2	52	36 - 71
		2030	40	35 - 44	1.8	0.7 - 5.4	56	40 - 77
	Pellets	2010	31	27 - 34	12.1	10.7 - 15.7	49	37 - 63
		2020	37	32 - 40	12.7	11.2 - 16.4	56	42 - 70
		2030	40	35 - 44	13.1	11.6 - 17.0	60	45 - 75
FR2 (forestry residues - current use) and FR3 (forestry residues - additional)	Chips	2010	13	7 - 19	1.6	0.6 - 4.9	27	10 - 50
		2020	15	9 - 22	1.7	0.7 - 5.2	30	12 - 54
		2030	16	10 - 24	1.8	0.7 - 5.4	32	13 - 57
	Pellets	2010	13	7 - 19	12.1	10.7 - 15.7	31	20 - 48
		2020	15	9 - 22	12.7	11.2 - 16.4	34	23 - 52
		2030	16	10 - 24	13.1	11.6 - 17.0	36	24 - 56
FR5 (additional wood processing residues (sawmill, bark)	Pellets[4]	2010	17	14 - 20	10.5	9.1 - 14.1	34	26 - 48
		2020	20	17 - 23	11.1	9.6 - 14.8	38	30 - 52
		2030	22	19 - 26	11.5	10.0 - 15.4	41	32 - 55

1) Farm gate cost including cultivation and harvesting. The feedstock costs vary per country.
2) Processing (chipping and or pelletization) and transport to CGP by truck.
3) Intra-European transport, based on lowest cost routes between countries. Emissions and cost depend on distance and transport modes used (ship, rail, truck).
4) No chips available (part of this stream exists of saw dust).

The GHG performance of woody crops is substantially better than most 1st generation bioenergy crops produced as feedstock for biofuels, mainly due to lower inputs of utilities (fertilizers) and higher yields (Hoefnagels, Smeets et al. 2010). The emissions for cultivation of willow crops are based on the default values of the European Commission for European short rotation forestry (EC 2010) of which the input parameters are based on willow crops[4]. For residues, all emissions for cultivation and harvesting are allocated to the main output. The

4 Also available online: http://ies.jrc.ec.europa.eu/uploads/media/Input_data_BIO%20181108.xls

GHG emissions for transport to the CGP and pre-treatment (chipping and pelletization) add up between 0.4 g CO_2-eq./MJf (MJ primary fuel) (chipping only) to 10.5 g CO_2-eq./MJf (chipping (3%), pelletization (8%) and transport to the CGP (89%)). For pelletization of FR5 biomass, the GHG emissions are lower due to the lower energy requirements (electricity and heat) for pelletization of saw dust.

Table 4-2 Greenhouse gas emissions of biomass supply (g CO_2 -eq./MJf)

Feedstock	Transported as	Year	Cultivation and harvesting[1]	Transport to CGP (truck) and processing[2]				Total at destination			
				Av.	Range			Av.	Range		
AP4 (SRC willow)	Chips	2010	2.0	0.6	0.4	-	1.2	11.1	2.4	-	27.0
		2020	2.0	0.6	0.4	-	1.1	10.3	2.4	-	24.6
		2030	2.0	0.6	0.4	-	1.1	9.9	2.4	-	23.8
	Pellets	2010	2.0	9.9	9.7	-	10.5	15.3	11.7	-	21.4
		2020	2.0	9.8	9.6	-	10.4	15.0	11.7	-	20.5
		2030	2.0	9.8	9.6	-	10.3	14.8	11.7	-	19.8
FP1 (forestry products - current use (wood chips, log wood) and FP2 (forestry products - complementary fellings (moderate)), FP3 (forestry products - complementary fellings (expensive))	Chips	2010	1.0	0.6	0.4	-	1.2	10.0	1.4	-	25.9
		2020	1.0	0.6	0.4	-	1.1	9.2	1.4	-	23.6
		2030	1.0	0.6	0.4	-	1.1	8.8	1.4	-	22.7
	Pellets	2010	1.0	9.9	9.7	-	10.5	14.2	10.6	-	20.3
		2020	1.0	9.8	9.6	-	10.4	13.9	10.6	-	19.5
		2030	1.0	9.8	9.6	-	10.3	13.7	10.6	-	18.7
FR2 (forestry residues - current use) and FR3 (forestry residues - additional)	Chips	2010	0.0	0.6	0.4	-	1.2	9.0	0.4	-	24.9
		2020	0.0	0.6	0.4	-	1.1	8.3	0.4	-	22.6
		2030	0.0	0.6	0.4	-	1.1	7.9	0.4	-	21.7
	Pellets	2010	0.0	9.9	9.7	-	10.5	13.2	9.7	-	19.3
		2020	0.0	9.8	9.6	-	10.4	12.9	9.7	-	18.5
		2030	0.0	9.8	9.6	-	10.3	12.8	9.7	-	17.7
FR5 (additional wood processing residues (sawmill, bark)	Pellets[3]	2010	0.0	5.6	5.4	-	6.2	9.0	5.4	-	15.1
		2020	0.0	5.6	5.4	-	6.1	8.7	5.4	-	14.2
		2030	0.0	5.6	5.4	-	6.1	8.5	5.4	-	13.5

1) Processing (chipping and or pelletization) and transport to CGP by truck.
2) Intra-European transport, based on lowest cost routes between countries. Emissions and cost depend on distance and transport modes used (ship, rail, truck).
3) No chips available (part of this stream exists of saw dust).

4.2 Detailed cost and GHG supply curves, example of SRC willow

To provide a detailed view on the build-up of the cost and GHG balance of biomass supply, one feedstock (SRC willow) and two destinations (the Netherlands, a main importing country of solid biomass and Austria, a land locked country without direct connections to sea harbours) are selected as illustrative examples.

4.2.1 Cost

Figure 4-1 and Figure 4-2 depict the cost-supply curves of SRC willow crops supplied to the Netherlands and Austria respectively. The graphs on the left show the cost-supply curves if the willow crops are chipped in the stacked area diagram whereas the lines show the cost-supply curve for willow pellets. The graphs on the right show the cost-supply curves of willow pellets in stacked area diagrams whereas the lines show the cost-supply curves for willow chips.

The results in Figure 4-1 and Figure 4-2 show that the additional cost for pelletization (the purple area) which results in a higher specific caloric values and lower stowage factors, does only pay off for the far right of the supply curves for Austria, but similar results were found for other crop types and most destination countries in the EU-27. It should be noted though that the model does not take into account that wood pellets have better fuel handling and combustion properties than wood chips which could result in higher conversion efficiencies. The results could therefore be different if conversion to final energy carriers (electricity or heat) would be taken into account.

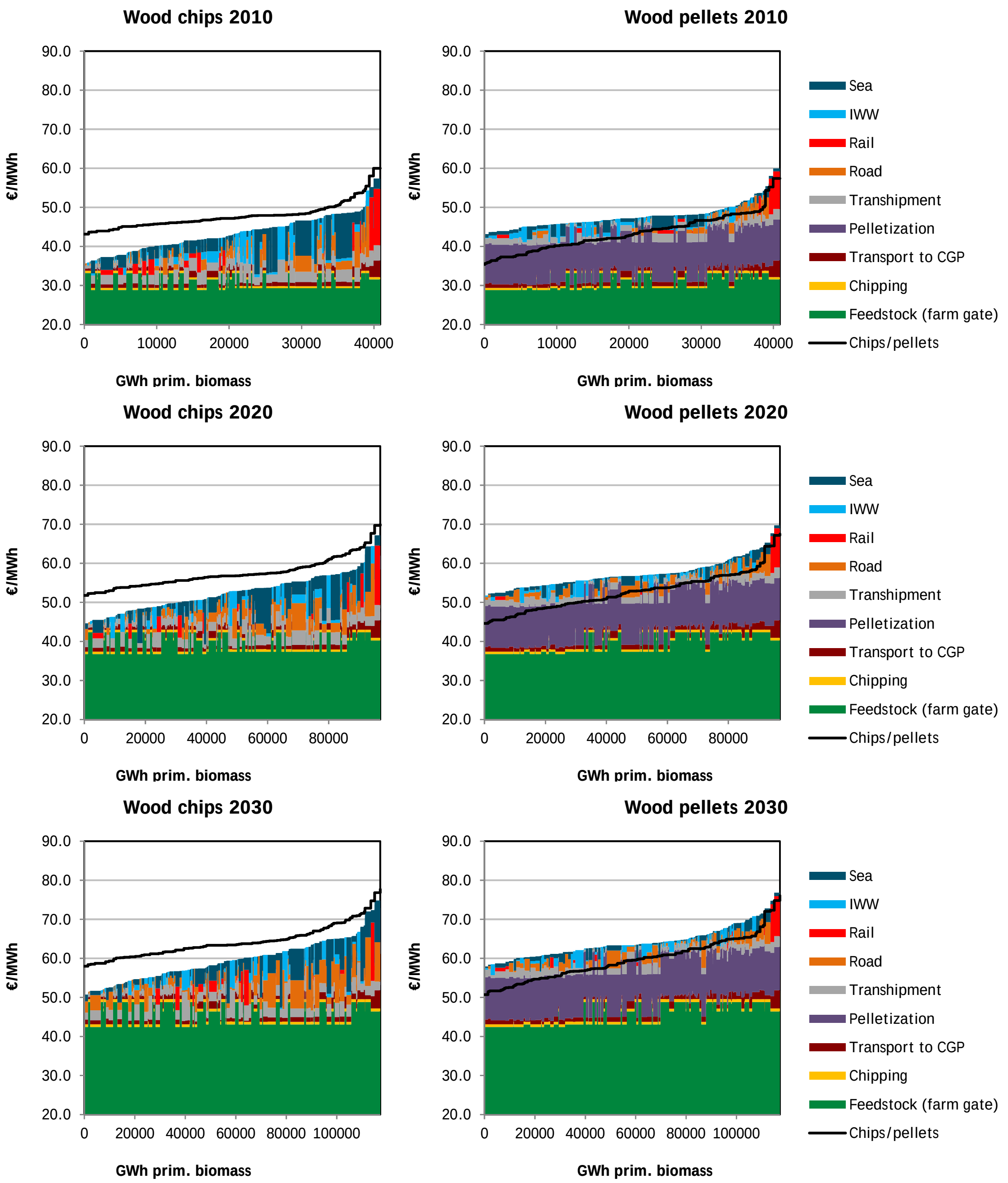

Figure 4-1 Cost supply curves of wood chips and pellets, illustrative case of willow crops supplied to the Netherlands

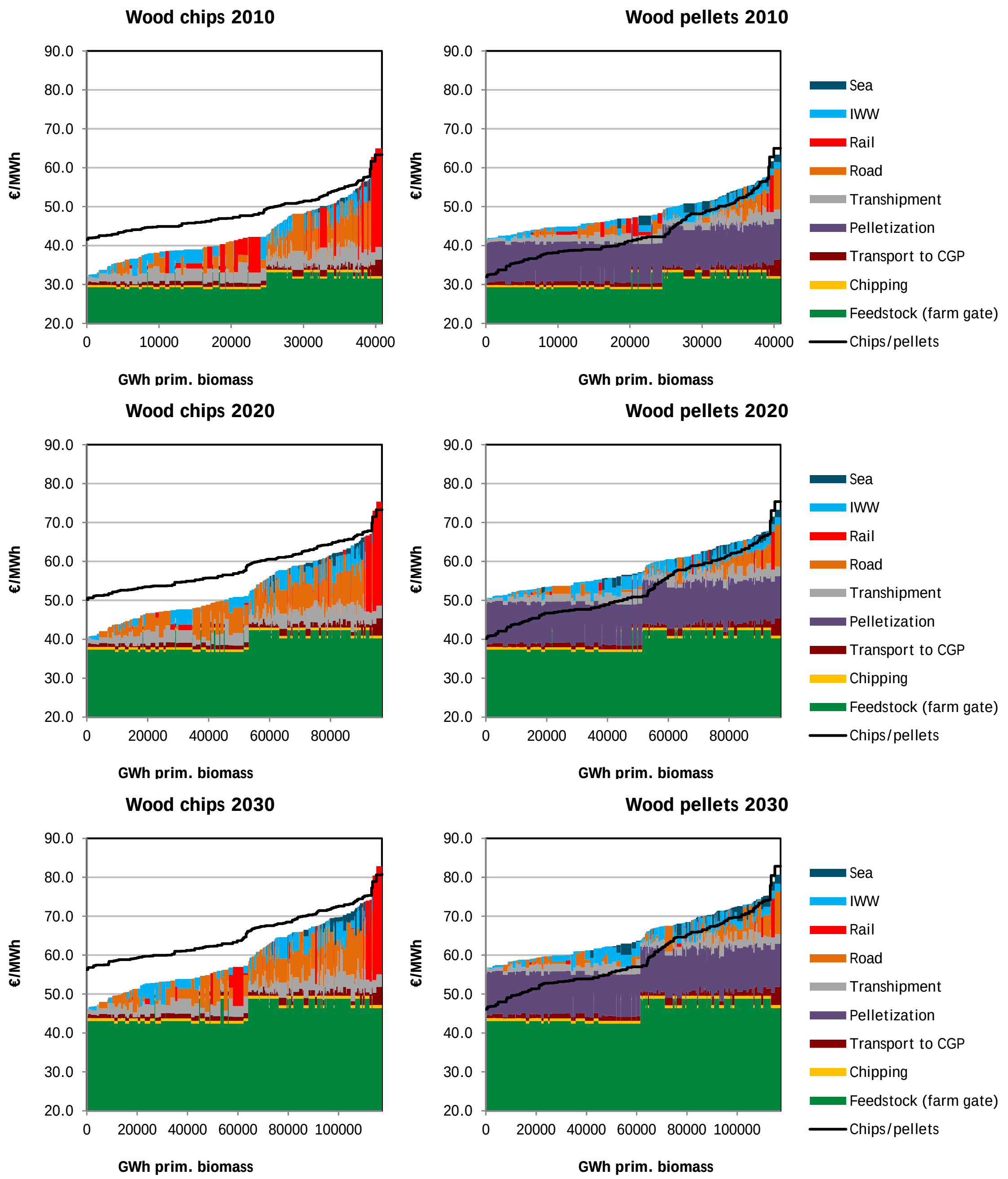

Figure 4-2 Cost supply curves of wood chips and pellets, illustrative case of willow crops supplied to Austria

4.2.2 Greenhouse gas emissions

Figure 4-3 and Figure 4-4 show the GHG-supply curves of willow chips and pellets produced in the EU-27 and supplied to the Netherlands and Austria respectively. The supply chains are similar to the cost supply chains as shown in Figure 4-1 and Figure 4-2 (optimized for cost), but are sorted to the total GHG balance.

The results for the Netherlands show that for 80% (2010) to 91% (2030) it is more effective to transport wood chips over long distances than wood pellets. For Austria, the GHG balance of wood chips is always better than the GHG balance of wood pellets, regardless of the source of origin. It should be noted though that these results are sensitive to the conservative assumptions on the fossil energy requirements of the pelletization plant (section 3.2.3).

To illustrate the impact of the assumptions of GHG emission from processes other than transport, the results for the Netherlands and Austria are also shown for wood processing residues (FR5) for the year 2010 (Figure 4-5 and Figure 4-6 respectively). For this feedstock categories, there are no emissions for cultivation. Furthermore, it was assumed that the heat and electricity requirement is lower for pre-treatment (Table 3-1). For FR5 biomass, 35% of the total supply (the Netherlands) to 16% (Austria), it is effective to pelletize before long distance transport compared to transport of wood chips.

The strong increase in emissions of short sea shipping, especially for supply of wood chips to the Netherlands, are the result of cost optimization in combination with relatively low fuel prices for short sea shipping (heavy fuel oil, Table 3-6). It is therefore often more cost-effective to ship biomass over long distances via sea to the harbour of Rotterdam, despite the high stowage factor of wood chips.

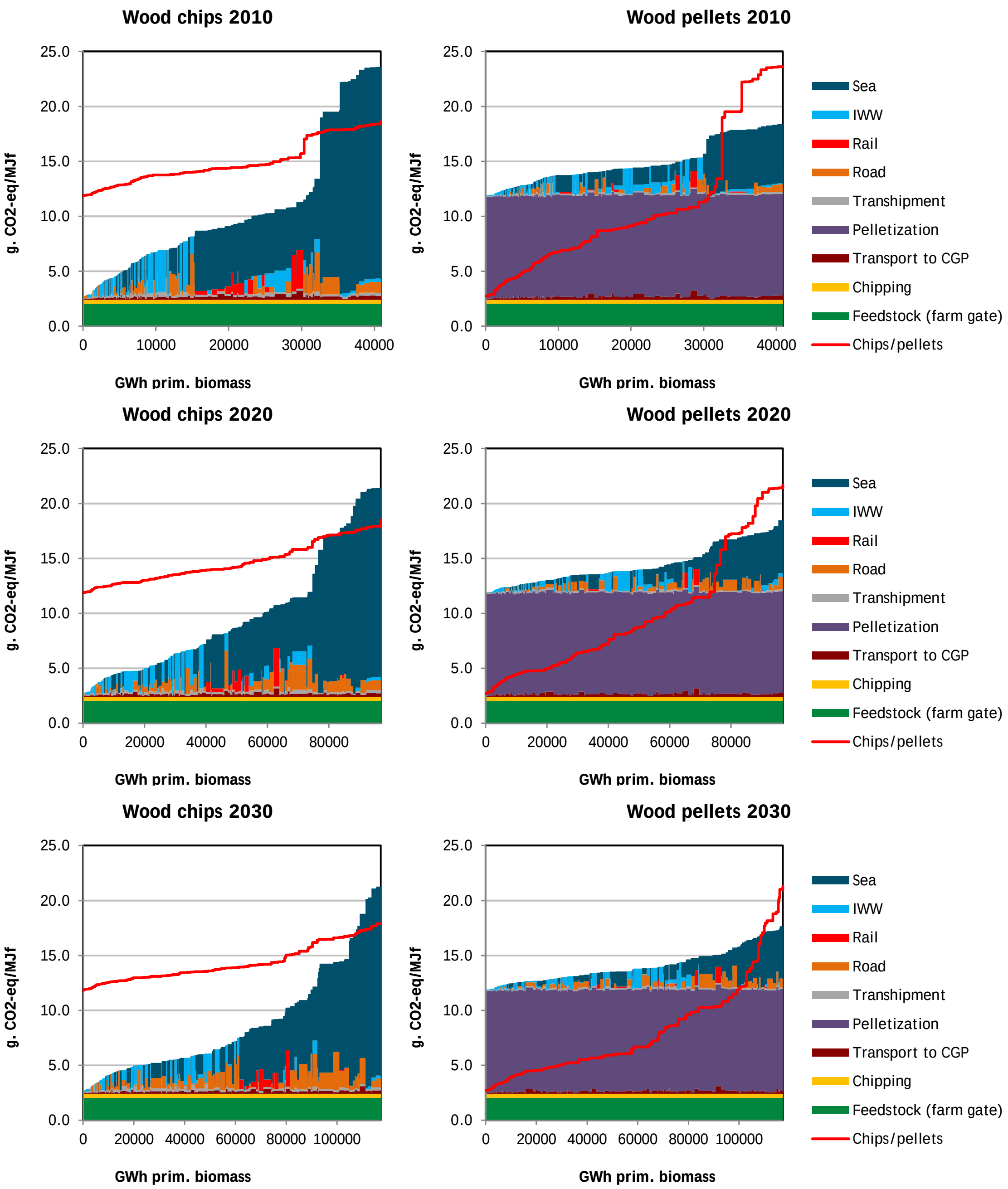

Figure 4-3 GHG supply curve chips and pellets, illustrative case of willow crops supplied to the Netherlands

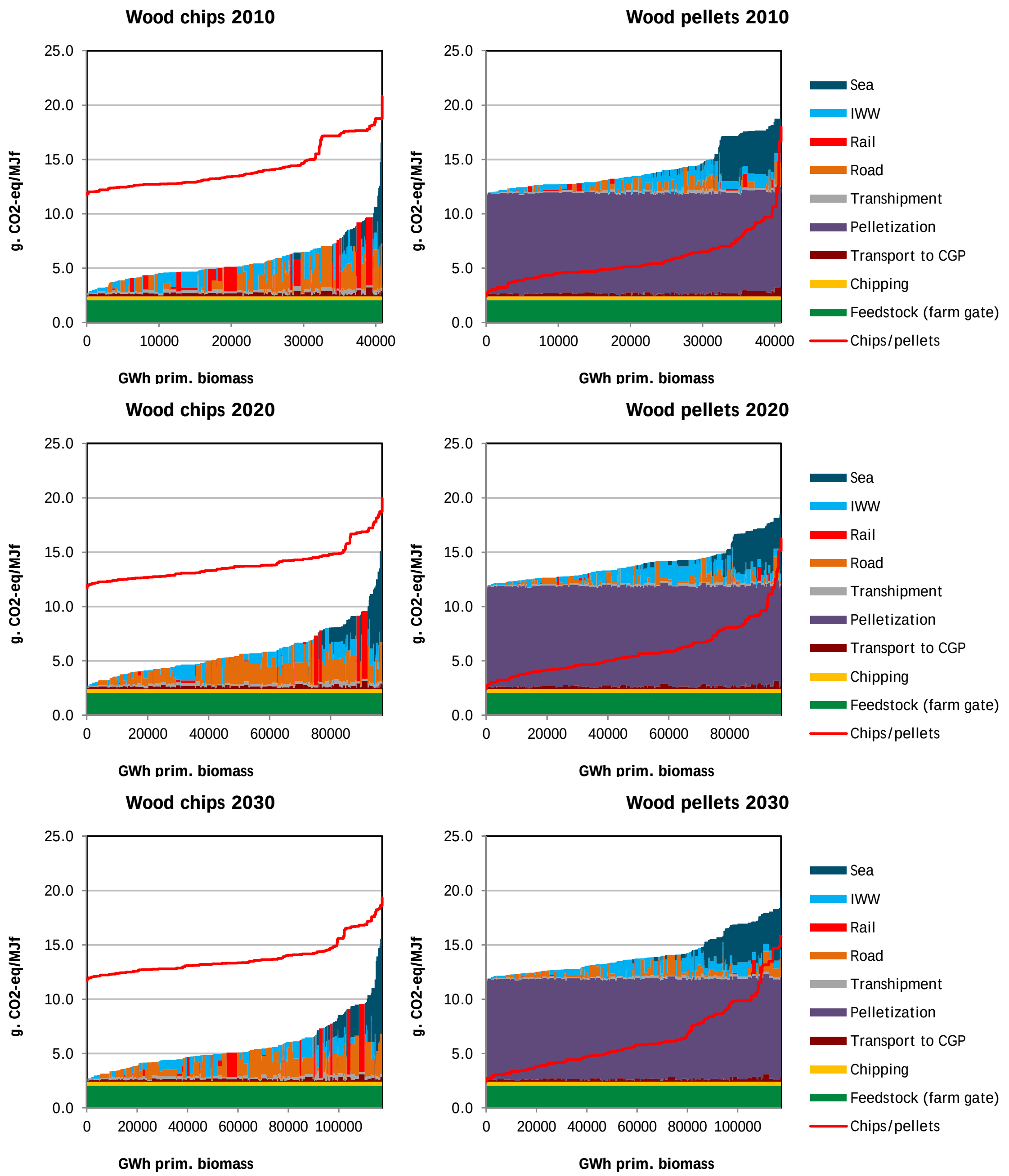

Figure 4-4 GHG supply curve chips and pellets, illustrative case of willow crops supplied to Austria

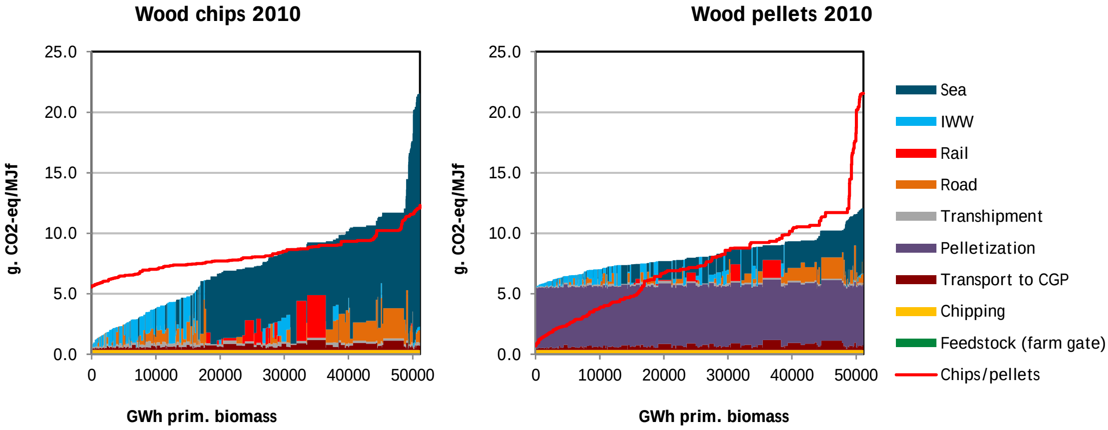

Figure 4-5 GHG supply curve chips and pellets, illustrative case of wood processing residues supplied to the Netherlands

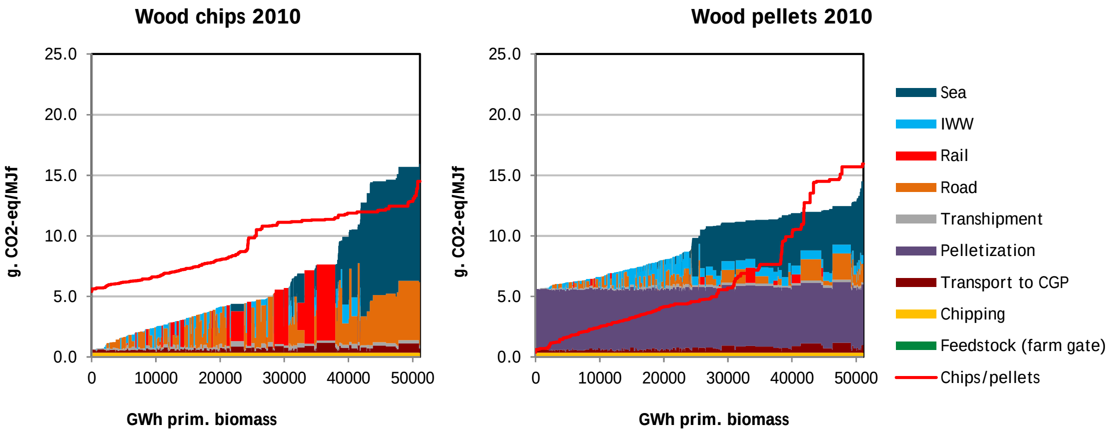

Figure 4-6 GHG supply curve chips and pellets, illustrative case of wood processing residues supplied to the Austria

4.3 Modal shares

Figure 4-7 shows the distance share of modalities used per importing country for 2010 to 2030. The results show a clear distinction between land locked countries without direct access to sea harbours (Austria, Czech Republic, Hungary, Luxembourg and Slovakia) and countries that have sea ports. For Slovenia, however, transport via land routes appear to be more cost effective than most sea routes due to the location of the sea harbour (Koper, Figure 3-5).

Short sea shipping is the most used transport modality for both wood chips and wood pellets with shares ranging from 37 to 94% for wood chips and 41 to 91% for wood pellets. Land locked countries, such as Austria, Czech Republic, Hungary and Slovakia include lower shares of sea transport. For these countries, the Danube is an important transport corridor resulting in higher shares of inland navigation. Pellet transport to Austria for example, includes 43% transport via inland navigation. Note that also island countries (Malta and Cyprus) include significant shares of land transport as biomass has to be transported to a sea harbour first before it can be shipped to these islands.

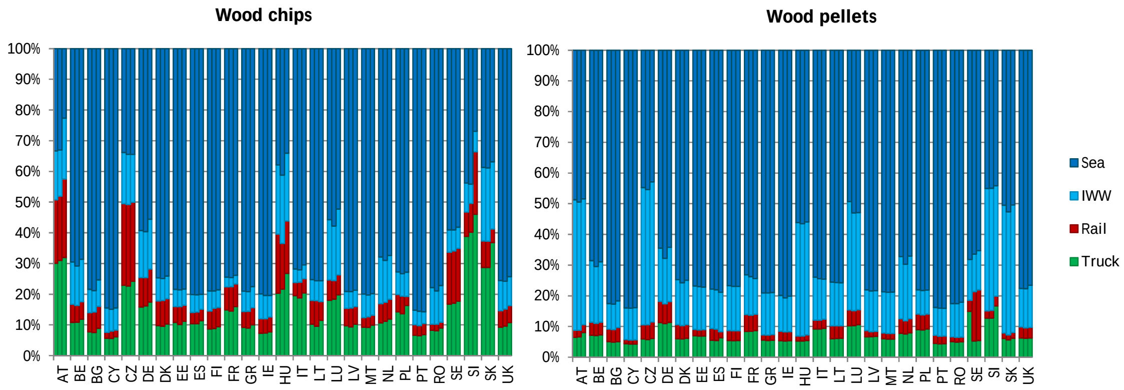

Figure 4-7 Modal shares of international transport of wood chips and wood pellets

5 Discussion

This report investigated the potential cost and GHG impact on the total supply chain of bulk solid woody biofuels by means of geospatial explicit modelling of intermodal logistic chains in ArcGIS. The results in this study are based on lowest cost routes between origin and destination. Although alternative optimization options are available, e.g. shortest path, lowest GHG emissions or lowest transportation time, cost optimization is the most consistent with the energy modelling approach of GREEN-X.

If optimized for cost, the model shows cost ranges of biomass supply of 10 to 88 €/MWh and GHG emissions ranging from 0.4 to 27 g. CO_2-eq./MJf depending on the source of origin, type of biomass, destination, year and pre-treatment process (chipping or pelletization). It is important to note that these results include all possible transport chains between origins and destinations in the EU-27. Some of these supply chains will not become economically feasible. However, analysis of likely trade routes is beyond the scope of this report because it only describes the methodology and input parameters used in the GREEN-X model. The results, including implications of Intra-European biomass trade, will be published as part of the final outcomes of WP4 of the RE-Shaping project.

The cost, as calculated in this study, is the result of different input assumptions of which the most important are: feedstock cost, cost and performance of pre-treatment processes (chipping or pelletization), cost of transport and cost of transhipment. The most important factors for the GHG balance are pre-treatment (especially pelletization) and the performance (energy requirements) of the different transport modes. The discussion will therefore focus on these parameters, the related impacts on the results and potential improvements to the model.

Feedstock cost in the results of study is derived from the country database of GREEN-X. These cost estimations are, in some cases, higher than projected by other studies for similar feedstock types as discussed in D10 of the RE-Shaping project (Junginger, Hoefnagels et al. 2011). This could result in an overestimation of total supply cost of Intra-European biomass supply. For example, Sikkema, Junginger et al.(2010) estimate the cost of externally purchased feedstock for the production of wood pellets was to be 13.6 €/t (and an additional 24 €/t for local transport to the pellet mill), and estimate total wood pellet delivery costs to an industrial end-user to be about 109 €/t. This study estimates the supply cost of wood pellets from similar feedstocks (wood processing residues) in the EU-27 delivered to Sweden to be 25 to 45 €/MWh (127 to 235 €/t). If, however, similar feedstock prices would be assumed to Sikkema, Junginger et al. (2010) (37.6 €/t pellets), the range of supply cost (89 to 182 €/t) would be in line with the 109 €/t found by Sikkema, Junginger et al.

For **pre-treatment** of biomass feedstock, two options for long distance transport were included in the model: wood chips or wood pellets. The advantage of wood pellets over wood chips are the increased calorific value (18 MJ/kg pellets, 12.6 MJ/kg chips), better handling, increased density (610 kg/m^3 pellets, 240 kg/m^3 chips) and lower moisture content (10% pellets, 30% chips). An oversimplified approach was used to calculate the cost of pelletization and chipping. Thek and Obernberger (2004) found differences of pellet production cost of 62 €/t in Sweden to 90 €/t in Austria, mainly due to economies of scale, personal cost, co-generation benefits and electricity prices. This study assumes the same scale for all countries (based on the Swedish case). Furthermore, only fuel cost (diesel and biomass for conditioning and drying) were country specific. All other factors, including the GHG performance and cost of electricity supply per country were based on European averages. This study assumes 467 g. CO_2-eq./kWh, based on the low voltage EU mix (JEC 2008). We used the methodology to be (more) consistent with the values as reported by the European Commission (EC 2010). However GHG emissions of electricity production range strongly between European countries: emission factors of 88 (Sweden, 29% nuclear, 44% hydro) to 1000 g. CO_2-eq./kWh electricity (Estonia, 55% lignite, 31% natural gas) were reported for Europe in 2010 by GEMIS (GEMIS 2010). This implies that the GHG performance for pelletization is overestimated in countries such as Sweden and underestimated in countries such as Estonia. Given the very high contribution of GHG emission due to electricity use for the pelletisation step (see figures 4-3 to 4-6), the choice of a single EU-wide emission factor has a major influence on the results. Especially in the case of exporting countries with low electricity emission factors, pelletisation before transport might reduce overall GHG emissions significantly more than calculated under the current methodology.

Related to **transport**, the assumption whether a truck, train or ship **returns empty** is important to the overall cost balance. In this study, these values were based on empirical data for the Netherlands (NEA 2004). For short distance transport of pellets by **truck**, cost ranges of 12 to 18 €/t (16 €/t for 200 km) were found (Sikkema, Steiner et al. 2011). If the same distance are applied to the model in this study, it results in average cost of 15.3 €/t in 2010 (range: 11.4 – 20.5 €/t) to 16.1 €/t in 2030 (range: 12.3 – 21.3 €/t) excluding toll charges. For long distance transport however, the result of this study are overestimated compared to real cost estimates. The European Transport organization LKW Walter was asked for cost estimates from Warsaw to Rotterdam and from Warsaw to Trieste. They estimated cost of 850 € (Warsaw to Rotterdam) and 1150 € (Warsaw to Trieste) per full load truck (Jong, Tselekis et al. 2010) which would equal 34 and 46 €/t pellets respectively for the same full load factor. If we allow the model to use truck transport only, the cost would be 69 and 59 €/t pellets for Rotterdam and Trieste respectively in 2010. The main reason that cost are higher in this study is the empty return factor used (loaded trips of total trips = 55%). The amount of empty returns for long distance truck transport might therefore be overestimated in this study. Note however, that most transport chains in the result of this study include only short distance transport by truck and a combination of more transport modes. On the other hand, for rail transport, it was found that currently empty **trains** are going from Eastern to Western Europe which could be an opportunity for cost-efficient transport of (solid) biofuels in Europe (Verweij, Zomer et al. 2009; Boer, Cuijpers et al. 2010).

Regional variations including climate were not taken into account in this model, but could influence the results significantly. For St. Petersburg to Denmark, the cost of transport are around 5 €/t more expensive (25 €/t pellets) compared to transport from Riga to Denmark (20 €/t pellets), mainly due to seasonal ice coverage and related cost for icebreakers (Sikkema, Steiner et al. 2011). For routes from the black sea to Western Europe, cost of 29 to 31 €/t were found. For this project, interviews with stakeholders by Jong, Tselekis et al. (2010) resulted in cost ranges of 21 to 23 €/t for transport routes of the Baltic Sea to Western Europe. The bottom-up cost calculations in this study are significantly lower for short distance transport and in range for longer distances. For Riga to Rotterdam, the costs range from 6.1 €/t in 2010 to 7.4 €/t in 2030 (compared to 17.5 €/t pellets found by Jong, Tselekis et al. (2010) for the same route). For Constanta to Rotterdam (6200 km), the costs were, in range with empirical data, estimated to be 23 €/t (2010) to 29 €/t (2030) (excluding stevedoring, unloading and storage).

Apart from assumptions related to transport modes, also further improvements could be made in the model regarding **the network structure** of the different transport modes (road, railways, inland water ways and sea harbour connections). For example, inland waterways such as the Danube river, includes many strategic bottlenecks, as identified by the Inland Transport Committee (UN 2006) that were not all included in the TransTools network database. An update of the network in the ArcGIS database, including current bottlenecks and future developments of the inland waterway network in Europe would therefore improve the model.

6 Conclusion

This report investigated the impact of international transport on the total cost and greenhouse gas balance of solid woody biomass. For this purpose, a geospatial intermodal biomass transport model was developed in the ArcGIS 10.0 Network Analyst extension. This model has been complemented with data on the cost of shipment using road (truck), water (ocean ships and inland navigation ships) and rail and the cost of transhipment between these modalities.

With respect to the methodology applied in this study, we conclude that the modelling tool developed for this study using the ArcGIS Network Analyst extension, provides useful insights in country-to-country cost of biomass distribution. The results will be used as input to the energy model GREEN-X to estimate future supply and demand of biomass without being limited to national biomass sources or distribution of international supply of biomass applied exogenously to the GREEN-X modelling framework. Furthermore, related GHG emissions of the total biomass supply chain provide insight in the GHG reduction performance and optimal use of biomass sources.

Main results from the modelling tool are:

- Transport cost can add substantially to the total cost balance of supplying solid biofuels to the demand region. The cost for transporting biomass processed into wood chips from the supply region to the final destination could add up to 48% (33 €/MWh) of the total supply cost (68 €/MWh) in the case of SRC crops and up to 75% (32 €/MWh) of the total cost (43 €/MWh) in the case of forestry residues. The cost for transporting biomass processed into pellets from the supply region to the final destination could add up to 52% (24 €/MWh) of the total supply cost (45 €/MWh) in the case of forestry residues and 30% (20 €/MWh out of 60 €/MWh) in the case of SRC crops.
- When only looking at the cost of GJ delivered to the end-user, the cost for pelletization do not pay off against the lower transport cost from increased energy density, lower moisture content and lower stowage factor. However, the model does not take into account possible end-user requirements and preferences.
- Because no GHG emissions are assumed for the feedstock of primary and secondary forestry residues, pre-treatment and transport constitute the major part of the total GHG balance of these supply chains. Emissions for transport add up to 99% (22 g CO_2-eq./MJf) for wood chips from forest residues and up to 64% (10 g CO_2-eq./MJf) for wood pellets from wood processing residues. For pellets, the share of transport is considerably lower due to the higher energy density and reduced volume compared to wood chips. Pelletization adds also significantly to the total GHG balance though.
- For SRC crops, the share of transport emissions is lower due to emissions for cultivation and harvesting (up to 91% or 25 g CO_2-eq./MJf for SRC chips and 45% or 10 g CO_2-eq./MJf for SRC pellets). Different from cost, from a GHG perspective, it can be effective for many supply chains to pelletize the biomass first before long distance transport instead of transporting wood chips.

Finally, it is concluded that further development of the modelling tool is required to improve consistency between different biomass feedstocks in GREEN-X that were not addressed in this modelling exercise. These include:

- Improvement of parameters related to biomass logistics. For example, specific transhipment and storage cost (€/t) for pellets and wood chips are now assumed to be similar, but could differ substantially in reality.
- The same holds for the amount of empty returns per transport mode. The knowledge that trains return empty from Eastern European countries to Western European countries could support optimized supply routes. More insight is required in these logistic processes that requires more information on transport sectors and related activities.
- The addition of more non-EU supply regions such as North-West Russia (forestry potential) and Ukraine (agricultural biomass potential) and inter-continental linkages to e.g. Canada and the USA. Europe is already importing large amounts of wood pellets for bioenergy production from these regions and it is expected to increase in the future.
- The addition of other biomass commodities such as liquid biofuels (e.g. FT-diesel or ethanol) and other solid biofuels such as torrefied pellets. Torrefied pellets have higher energy densities than wood pellets and could therefore decrease transportation costs, but on the other hand, they require additional process energy for the torrefaction process. Thus, a triple trade-off between wood chips, wood pellets and torrefied pellets could be evaluated. For liquid biofuels, especially 2nd generation biofuels would be interesting to include as they compete with similar biomass sources (e.g. grassy crops or woody biomass) to electricity and heat production.
- The model results in this study do not include the final transport step to the conversion plant. Modelling biomass distribution including the locations of large scale users, such as pulverized coal plants with potentials for biomass co-firing, would improve the understanding of the total biomass supply cost. Since the locations of these plants are known, these could be added relatively easy as demand nodes in the ArcGIS model based on x/y coordinates. Furthermore, adding these conversion plants would show end-user requirements and benefits such as lower handling cost of wood pellets compared to wood chips. Also, coal power plants can basically only co-fire wood pellets – significant additional investments would be necessary to enable them to co-fire wood chips.

References

Boer, S. d., M. Cuijpers, et al. (2010). Logistics of biomass in Europe - Costs and environmental performance of biomass transport from the Danube region to the ports of Rotterdam, Marseille and Trieste. R. Hoefnagels and M. Junginger. Utrecht, Copernicus Institute, Utrecht University.

DB (2010). Annual Report 2009 - Deutsche Bahn.

de Wit, M. and A. Faaij (2010). "European biomass resource potential and costs." Biomass and Bioenergy **34**(4): 188-202.

EC (2010). EU energy and transport in figures - Statistical pocketbook, European Commission.

EC (2010). REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT - on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. SEC(2010) 65. Brussels, European Commission (EC).

ESRI. (2010). "ArcGIS Network Analyst - Overview." Retrieved July 2011, 2011, from http://www.esri.com/software/arcgis/extensions/networkanalyst/index.html.

EUBIONET3 Biomass trade for the European market, IEE, EUBIONET3.

EUROSTAT (2010a). lc_an_costh_r2-Hourly labour costs - Nace Rev. 2, Transport and storage.

EUROSTAT (2010c). Land cover and land use, soil, and landscape – Land covered by woodland (lan_lcv_woo).

EUROSTAT. (2010d). "Maritime transport statistics - short sea shipping of goods." from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Maritime_transport_statistics_-_short_sea_shipping_of_goods.

EUROSTAT. (2010e). "EUROSTAT GISCO (the Geographical Information System at the COmmission) Database." from http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/introduction.

Fischer, G., S. Prieler, et al. (2010). "Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part I: Land productivity potentials." Biomass and Bioenergy **34**(2): 159-172.

GEMIS (2010). Globales Emissions-Modell Integrierter Systeme (GEMIS) Version 4.5, Öko-Institut.

Georgia Biomass. (2011). "Georgia Biomass - The Project." Retrieved July, 2011, from http://www.gabiomass.com/projects#.

Hamelinck, C. N., R. A. A. Suurs, et al. (2005). "International bioenergy transport costs and energy balance." Biomass and Bioenergy **29**(2): 114-134.

Hansson, J. and G. Berndes (2009). "Future bioenergy trade in the EU: modelling trading options from a cost-effectiveness perspective." Journal of Cleaner Production **17**(Supplement 1): S27-S36.

Hoefnagels, R., E. Smeets, et al. (2010). "Greenhouse gas footprints of different biofuel production systems." Renewable and Sustainable Energy Reviews **14**(7): 1661-1694.

IEA (2009). TRANSPORT, ENERGY AND CO2 - Moving Toward Sustainability. Paris, International Energy Agency (IEA).

IEA (2010). Energy Technology Perspectives 2010 - Scenarios and Strategies to 2050. Paris, International Energy Agency (IEA).

JEC (2008). Well-to-Wheels Study Version 3, European Council for Automotive R&D (EUCAR), European association for environment, health and safety in oil refining and distribution (CONCAWE), the Institute for Environment and Sustainability of the EU Commission's Joint Research Centre (JRC/IES).

Jong, B. d., K. Tselekis, et al. (2010). Logistics of biomass in Europe - Economic and environmental performance of transporting biomass from Central and Eastern to Western European countries. R. Hoefnagels and M. Junginger. Utrecht, Copernicus Institute - Utrecht University.

JRC. (2009). "TRANS-TOOLS." from http://energy.jrc.ec.europa.eu/transtools/.

Junginger, H., J. v. Dam, et al. (2009). Solutions to overcome barriers in bioenergy markets in Europe - D2.2 - Resources, use and market analysis. VTT-R-01700-10, EUBIONET3.

Junginger, M., R. Hoefnagels, et al. (2011). Long Term Potentials and Costs of RES Part I: Potentials, Diffusion and Technological learning - RE-Shaping D12 Report, RE-Shaping, Supported by Intelligent Energy Europe, European Commission.

Junginger, M., J. van Dam, et al. (2010). Solutions to overcome barriers in bioenergy markets in Europe – Resources, use and market analysis, EUBIONETIII **Report D2.2**.

Knörr, W., S. Seum, et al. (2010). Ecological Transport Information Tool for Worldwide Transports - Methodology and Data IFEU (Heidelberg), Öko-Institut (Berlin), IVE / RMCON (Hannover).

Loo, S. v. and J. Koppejan (2008). The handbook of Biomass Combustion and Co-firing. London, UK, Earthscan.

McKinnon, A. (2007). CO2 Emissions from Freight Transport: An Analysis of UK Data.

Meerman, M. (2011). "Diesel and oil prices, article B."

NEA (2004). Comperative Frameworkfor Modalities 1.4b. Zoetermeer, Netherlands, NEA.

Obernberger, I. and G. Thek (2010). The Pellet Handbook, Earthscan Ltd.

Obernberger, I. and G. Thek (2010). The Pellet Handbook - The production and thermal utilisation of biomass pellets, BIOS BIOENERGIESYSTEME GmbH.

Ragwitz, M., A. Held, et al. (2011). Review report on support schemes for renewable electricity and heating in Europe - RE-Shaping D8 Report, RE-Shaping, Supported by Intelligent Energy Europe, European Commission.

Schilperoord, H. A. (2004). Environmental Performance of Inland Shipping. Amsterdam, Royal Haskoning.

SeaRates.com. (2010). "Sea Rates - Sea Freight Exchange." Retrieved 2010, December 2010, from http://www.searates.com/.

Selkimäki, M., B. Mola-Yudego, et al. (2010). "Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland." Renewable and Sustainable Energy Reviews **14**(9): 3068-3075.

Sénéchal, S., G. Grassi, et al. (2009). Logistic management of wood pellets: Data collection on transportation, storage and delivery management. Brussels, EUBIA - European Biomass Industry Association.

Sikkema, R., M. Junginger, et al. (2010). "Erratum: The international logistics of wood pellets for heating and power production in Europe: Costs, energy-input and greenhouse gas balances of pellet consumption in Italy, Sweden and the Netherlands." Biofuels, Bioproducts and Biorefining **5**(2): 226-226.

Sikkema, R., M. Steiner, et al. (2010). "The European wood pellet market 2009 and feedstock prospects 2020."

Sikkema, R., M. Steiner, et al. (2011). "The European wood pellet markets: current status and prospects for 2020." Biofuels, Bioproducts and Biorefining **5**(3): 250-278.

Smeets, E. M. W., I. M. Lewandowski, et al. (2009). "The economical and environmental performance of miscanthus and switchgrass production and supply chains in a European setting." Renewable and Sustainable Energy Reviews **13**(6-7): 1230-1245.

Sultana, A., A. Kumar, et al. (2010). "Development of agri-pellet production cost and optimum size." Bioresource Technology **101**(14): 5609-5621.

Thek, G. and I. Obernberger (2004). "Wood pellet production costs under Austrian and in comparison to Swedish framework conditions." Biomass and Bioenergy **27**(6): 671-693.

TML (2005). TREMOVE-II - Freight Cost. Leuven, Belgium, Transport & Mobility Leuven (TML). **3**.

UN (2006). INVENTORY OF MAIN STANDARDS AND PARAMETERS OF THE E WATERWAY NETWORK ("BLUE BOOK") - Revision 1. New York and Geneva, United Nations.

van Dam, J., A. P. C. Faaij, et al. (2009). "Options of biofuel trade from Central and Eastern to Western European countries." Biomass and Bioenergy **33**(4): 728-744.

Verweij, K., G. Zomer, et al. (2009). Retrack - Improving European Railways, European Commission, DG TREN.

Winebrake, J. J., J. J. Corbett, et al. (2008). Intermodal Freight Transport in the Great Lakes: Development and Application of a Great Lakes Geographic Intermodal Freight Transport Model. Rochester, NY, Great Lakes Maritime Research Institute.

WN. (2010). "WN Network database " Retrieved March, 2010, 2010, from www.distances.com.

Abbreviations

CGP	Central gathering point
CH_4	Methane
CHP	combined heat and power
CO_2	Carbon dioxide
EC	European Commission
EU-27	European Union comprising 27 member states
g. CO_2-eq.	gram CO_2 equivalent
GJ	Giga Joule
HFO	Heavy Fuel Oil
IWW	inland waterway
MDO	Marine Diesel Oil
MJf	Mega Joule fuel (final fuel, either pellets or wood chips)
MS	member state
MWh	Megawatt hour (3.6 GJ)
N_2O	Nitrous oxide (laughing gas)
NREAP(s)	National Renewable Energy Action Plan(s)
RES	renewable energy source(s)
RES-E	electricity generation from renewable energy sources
RES-H	heat from renewable energy sources
RES-T	transport fuels from renewable energy sources
SRC	Short rotation coppice
SSS	short sea shipping
t_{fw}	Tonne (1 Mg) fresh weight

A.1 Country specific input parameters

Table 0-1 Country specific parameters

	Diesel (€/l)				MDO (€/l)				HFO (€/l)				Labour (€/h)	Transhipment cost (€/t fw)		
														Truck	Ship	Rail
Period/country	2005	2010	2020	2030	2005	2010	2020	2030	2005	2010	2020	2030	2005-2030	2005-2030	2005-2030	2005-2030
Crude fuel (before tax)	0.29	0.32	0.46	0.57	0.29	0.32	0.46	0.57	0.29	0.32	0.46	0.57				
Refined fuel before tax	0.39	0.42	0.61	0.76	0.39	0.42	0.61	0.76	0.22	0.24	0.35	0.43				
EU-27																
Austria	0.88	0.92	1.15	1.33	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	28.04	2.48	2.48	4.03
Belgium	0.92	0.96	1.19	1.37	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	28.35	2.49	2.49	4.05
Bulgaria	0.84	0.88	1.10	1.28	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	2.86	1.14	1.14	1.86
Cyprus	0.73	0.77	0.99	1.16	0.45	0.49	0.70	0.88	0.26	0.28	0.40	0.50	7.42	1.38	1.38	2.25
Czech Republic	0.95	0.99	1.21	1.39	0.46	0.50	0.73	0.91	0.27	0.29	0.42	0.52	9.24	1.48	1.48	2.41
Denmark	0.96	1.00	1.24	1.43	0.49	0.53	0.77	0.95	0.28	0.30	0.44	0.54	33.03	2.74	2.74	4.46
Estonia	0.91	0.95	1.18	1.36	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	7.46	1.39	1.39	2.25
Finland	0.95	0.99	1.22	1.41	0.48	0.52	0.75	0.93	0.27	0.30	0.43	0.53	28.04	2.48	2.48	4.03
France	0.98	1.02	1.24	1.42	0.47	0.51	0.73	0.91	0.27	0.29	0.42	0.52	28.04	2.48	2.48	4.03
Germany	1.04	1.08	1.31	1.49	0.46	0.50	0.73	0.91	0.26	0.29	0.41	0.52	26.20	2.38	2.38	3.87
Greece	0.75	0.79	1.00	1.16	0.42	0.46	0.67	0.83	0.27	0.30	0.43	0.53	14.60	1.76	1.76	2.87
Hungary	0.96	1.00	1.23	1.42	0.49	0.53	0.77	0.95	0.28	0.30	0.44	0.54	7.48	1.39	1.39	2.25
Ireland	0.91	0.94	1.16	1.33	0.44	0.48	0.70	0.87	0.27	0.29	0.42	0.52	28.04	2.48	2.48	4.03
Italy	0.98	1.01	1.24	1.42	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	14.60	1.76	1.76	2.87

Table 0-2 Country specific parameters (continued)

	Diesel (€/l)				MDO (€/l)				HFO (€/l)				Labour (€/h)	Transhipment cost (€/t fw)		
														Truck	Ship	Rail
Period/country	2005	2010	2020	2030	2005	2010	2020	2030	2005	2010	2020	2030	2005-2030	2005-2030	2005-2030	2005-2030
Latvia	0.87	0.91	1.14	1.32	0.47	0.51	0.74	0.92	0.27	0.29	0.43	0.53	5.76	1.30	1.30	2.11
Lithuania	0.86	0.90	1.12	1.30	0.46	0.50	0.73	0.91	0.27	0.29	0.42	0.52	6.35	1.33	1.33	2.16
Luxembourg	0.74	0.77	0.97	1.13	0.41	0.45	0.65	0.81	0.26	0.28	0.40	0.50	28.04	2.48	2.48	4.03
Malta	0.87	0.91	1.14	1.32	0.46	0.50	0.72	0.90	0.26	0.28	0.41	0.51	11.17	1.58	1.58	2.57
Netherlands	0.95	0.99	1.22	1.40	0.46	0.50	0.73	0.91	0.26	0.29	0.41	0.52	28.04	2.48	2.48	4.03
Poland	0.89	0.93	1.16	1.34	0.48	0.52	0.75	0.93	0.27	0.30	0.43	0.53	7.75	1.40	1.40	2.28
Portugal	0.79	0.83	1.03	1.18	0.41	0.44	0.64	0.80	0.27	0.30	0.43	0.53	14.60	1.76	1.76	2.87
Romania	0.80	0.84	1.07	1.25	0.46	0.50	0.73	0.91	0.28	0.30	0.43	0.54	4.55	1.23	1.23	2.00
Slovak Republic	1.04	1.07	1.30	1.48	0.46	0.50	0.73	0.91	0.27	0.29	0.42	0.52	7.86	1.41	1.41	2.29
Slovenia	0.99	1.03	1.26	1.44	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	14.86	1.78	1.78	2.89
Spain	0.84	0.87	1.10	1.27	0.45	0.49	0.71	0.89	0.26	0.28	0.41	0.51	18.03	1.95	1.95	3.16
Sweden	1.04	1.09	1.32	1.51	0.49	0.53	0.77	0.95	0.28	0.30	0.44	0.54	28.04	2.48	2.48	4.03
United Kingdom	1.13	1.16	1.36	1.52	0.41	0.44	0.64	0.80	0.27	0.29	0.42	0.52	21.60	2.13	2.13	3.47
Non-EU countries (region)																
South East	0.79	0.83	1.05	1.23	0.46	0.50	0.72	0.90	0.27	0.29	0.42	0.52	7.42	1.38	1.38	2.25
North West	0.96	1.00	1.22	1.40	0.46	0.50	0.72	0.90	0.27	0.29	0.42	0.52	28.04	2.48	2.48	4.03
North East	0.88	0.92	1.15	1.33	0.47	0.51	0.74	0.92	0.27	0.29	0.42	0.52	6.52	1.34	1.34	2.17
Central	0.96	1.00	1.22	1.40	0.46	0.50	0.72	0.90	0.27	0.29	0.42	0.52	28.04	2.48	2.48	4.03

A.2 Pellet trade 2009

Table 0-3 Overview of Intra- and Extra-European pellet trade (EUROSTAT: CN 4401 40 20)

Country	Import (kton/yr)	From	Intra-EU	Extra-EU	Export (kton/yr)	To	Intra-EU	Extra-EU	Production (kton/yr)	Consumption (kton/yr)	Main market*
Austria	201	Germany: 49%, Czech Republic: 22%, Romania: 19%, Others: 10%	99%	1%	357	Italy: 82%, Germany: 15%, Switzerland: 2%, Others: 1%	98%	2%	693	537	bulk RH
Belgium	453	USA: 41%, Canada: 19%, Netherlands: 14%, Others: 26%	28%	72%	29	Netherlands: 62%, Germany: 17%, France: 13%, Others: 8%	100%	0%	326	750	large scale power
Bulgaria	0	Romania: 98%, Netherlands: 1%, Germany: 1%, Others: 0%	100%	0%	2	Italy: 95%, Greece: 4%, Turkey: 1%, Others: 0%	99%	1%	27	24	bags RH
Cyprus											no market
Czech Republic	7	Slovakia: 59%, Germany: 19%, Ukraine: 9%, Others: 13%	81%	19%	124	Austria: 53%, Germany: 22%, Italy: 20%, Others: 4%	100%	0%	224	106	export
Germany	54	Austria: 25%, Czech Republic: 23%, Russia: 14%, Others: 38%	66%	34%	728	Spain: 23%, Denmark: 14%, Sweden: 13%, Others: 51%	96%	4%	1560	886	bulk RH
Denmark	756	Estonia: 29%, Sweden: 13%, Russia: 11%, Others: 46%	83%	17%	15	Germany: 66%, Sweden: 14%, UK: 12%, Others: 8%	99%	1%	180	921	bulk DH
Estonia	45	Latvia: 89%, Russia: 11%, Ukraine: 0%, Others: 0%	89%	11%	354	Denmark: 72%, Sweden: 18%, UK: 8%, Others: 2%	100%	0%	381	72	export
Spain	2	France: 48%, Germany: 41%, Italy: 6%, Others: 5%	99%	1%	3	Italy: 75%, Portugal: 13%, France: 7%, Others: 5%	100%	0%	100	99	export
Finland	50	Russia: 82%, USA: 11%, Sweden: 5%, Others: 2%	7%	93%	136	Sweden: 60%, Denmark: 38%, UK: 2%, Others: 0%	100%	0%	299	213	export
France	103	Belgium: 55%, Germany: 21%, Spain: 20%, Others: 5%	100%	0%	202	Germany: 30%, Belgium: 27%, Italy: 26%, Others: 16%	92%	8%	345	245	bags RH
UK	45	Estonia: 41%, Finland: 15%, Portugal: 14%, Others: 30%	93%	7%	12	Netherlands: 74%, Sweden: 23%, Spain: 1%, Others: 2%	99%	1%	138	171	large scale power
Greece	1	Bulgaria: 80%, UK: 13%, Germany: 7%, Others: 1%	100%	0%	0	Macedonia: 70%, Cyprus: 29%, Bulgaria: 1%, Others: 0%	30%	70%	33	33	no market
Hungary	27	Slovakia: 64%, Romania: 31%, Ukraine: 3%, Others: 2%	97%	3%	8	Austria: 69%, Italy: 24%, Slovenia: 3%, Others: 3%	100%	0%	36	55	bags RH
Ireland	4	UK: 90%, Malaysia: 8%, Vietnam: 2%, Others: 0%	90%	10%	9		100%	0%	27	21	bulk RH
Italy	465	Austria: 31%, Germany: 16%, Slovenia: 14%, Others: 40%	77%	23%	1	France: 28%, Spain: 18%, Portugal: 13%, Others: 41%	74%	26%	772	1236	bags RH
Lithuania	69	Belarus: 82%, Russia: 8%, UK: 5%, Others: 5%	8%	92%	249	Denmark: 68%, Italy: 12%, Sweden: 6%, Others: 13%	100%	0%			export

Table 0-4 Overview of Intra- and Extra- European pellet trade (EUROSTAT: CN 4401 40 20) (continued)

Country	Import (kton/yr)	From	Intra-EU	Extra-EU	Export (kton/yr)	To	Intra-EU	Extra-EU	Production (kton/yr)	Consumption (kton/yr)	Main market*
Luxembourg	5	France: 52%, Belgium: 30%, Germany: 17%, Others: 0%	100%	0%	15	Germany: 50%, Belgium: 27%, Netherlands: 13%, Others: 10%	100%	0%			bulk RH
Latvia	5	Lithuania: 49%, Estonia: 19%, Belarus: 15%, Others: 17%	69%	31%	482	Denmark: 31%, Sweden: 28%, Estonia: 20%, Others: 20%	100%	0%	562	85	export
Malta											no market
Netherlands	960	Canada: 43%, USA: 33%, Portugal: 7%, Others: 17%	17%	83%	58	Belgium: 64%, Germany: 21%, Denmark: 6%, Others: 9%	99%	1%	120	1021	large scale power
	61	Hungary: 47%, Germany: 22%, Ukraine: 15%, Others: 16%	83%	17%	48	Denmark: 63%, Sweden: 19%, Germany: 17%, Others: 2%	100%	0%			
Poland	61	Hungary: 47%, Germany: 22%, Ukraine: 15%, Others: 16%	83%	17%	48	Denmark: 63%, Sweden: 19%, Germany: 17%, Others: 2%	100%	0%	410	423	large scale power
Portugal	22	Spain: 100%, Italy: 0%, Germany: 0%, Others: 0%	100%	0%	291	Netherlands: 30%, UK: 27%, Belgium: 17%, Others: 26%	100%	0%	394	125	export
Romania	0	Germany: 60%, Ukraine: 20%, Hungary: 18%, Others: 2%	80%	20%	95	Austria: 46%, Italy: 41%, Hungary: 5%, Others: 7%	100%	0%	157	63	export
Sweden	535	Russia: 30%, Finland: 16%, Latvia: 14%, Others: 40%	62%	38%	82	Denmark: 82%, Norway: 8%, Germany: 7%, Others: 3%	90%	10%	1576	2029	bulk DH
Slovenia	57	Bosnia and Herzegowina: 46%, Croatia: 46%, Serbia: 3%, Others: 5%	4%	96%	61	Italy: 99%, Austria: 0%, France: 0%, Others: 0%	100%	0%	154	150	export
Slovakia	3	Czech Republic: 59%, Ukraine: 37%, Croatia: 3%, Others: 1%	60%	40%	14	Italy: 77%, Austria: 9%, Denmark: 6%, Others: 8%	99%	1%	118	107	bulk RH
Euro area	2375	USA: 21%, Canada: 21%, Germany: 10%, Others: 48%	43%	57%	1891	Italy: 25%, Belgium: 11%, Sweden: 10%, Others: 54%	97%	3%	4668	5166	
EU15	3654	USA: 15%, Canada: 14%, Russia: 10%, Others: 61%	55%	45%	1938	Italy: 21%, Denmark: 13%, Belgium: 11%, Others: 55%	97%	3%	6562	8288	
EU25	3928	USA: 14%, Canada: 13%, Russia: 10%, Others: 64%	55%	45%	3279	Denmark: 26%, Italy: 17%, Sweden: 13%, Others: 44%	98%	2%	8446	9286	
EU-27	3928	USA: 14%, Canada: 13%, Russia: 10%, Others: 64%	55%	45%	3376	Denmark: 26%, Italy: 17%, Sweden: 12%, Others: 44%	98%	2%	8630	9373	

*) RH = Residential Heat, DH = district heating, **) No pellet market

This report

aims to identify likely trade flows of biomass for energy purposes based on demand, supply and likely cost

A report compiled within
the European research project

RE-Shaping

Shaping an effective and efficient
European renewable energy market

For further information on the project please visit www.reshaping-res-policy.eu