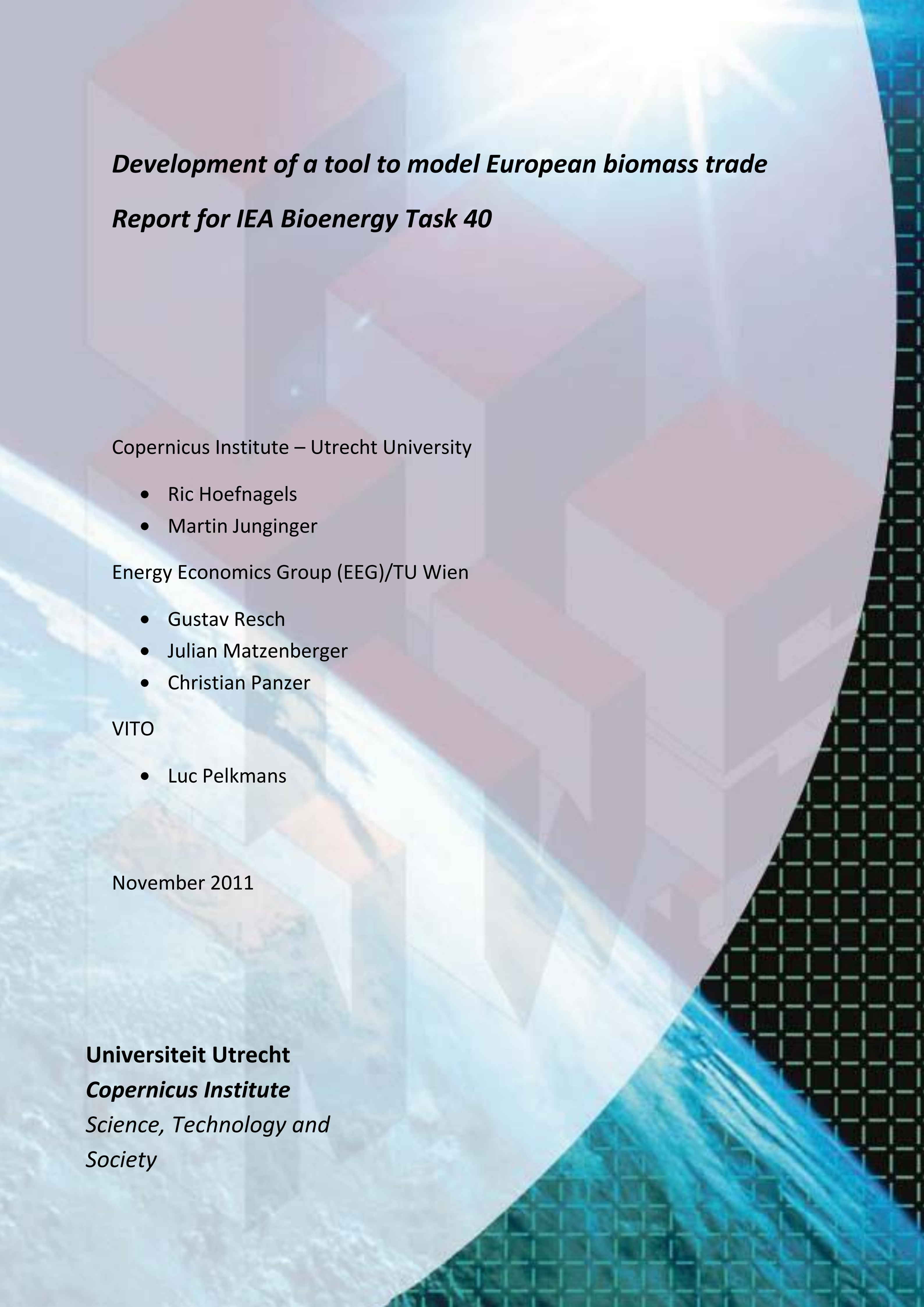

Development of a tool to model European biomass trade

Report for IEA Bioenergy Task 40

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Foreword

This report presents the results of an effort for IEA Bioenergy Task 40 to develop a modelling tool for international biomass trade. Part of this work has also been done in the frame of the RE-Shaping project, and parts of the methodology and the results have also been published as a RE-Shaping deliverable (Hoefnagels, Junginger et al. 2011). In addition, the scenarios for International solid biomass imports were originally developed for the European Commission (Junginger, 2011).

The main aim of this report is to illustrate the approach to include logistic cost of biomass in an energy model and implications to supply and demand of biomass for bioenergy. The costs, as presented in this report, are not intended to and do not always reflect actual (fluctuating) prices of feedstocks, pre-processing and transport of bulk freight.

Contents

Abbreviations

AP	Agricultural products
AR	Agricultural residues
BAU	Business as usual
bbl	Oil barrel (159 l)
BC	British Columbia
CH_4	Methane
CHP	Combined heat and power
CIF	Cost Insurance Freight
CO_2-eq	Carbon dioxide equivalent
CU	Capacity Utilization
EC	European Commission
ECF	Final energy consumption
EU-27	European Union
FOB	Freight on board
FP	Forest products
FR	Forest residues
GHG	Greenhouse gases
GJ	Gigajoule ($10^{\wedge 9}$ joule)
GTAP	Global Trade Analysis Project
h	hour
HFO	Heavy Fuel Oil
IEA	International Energy Agency
JRC	Joint Research Center
KJ	Kilojoule ($10^{\wedge 3}$ joule)
km	kilometer
ktoe	Kilo tonne of oil equivalent (41.868 TJ)
kWh	kilowatt hours
l	Liter
MDO	Marine Diesel Oil
MJ	Megajoule ($10^{\wedge 6}$ joule)
MS	Member states
Mtoe	Million tonne of oil equivalent (41.868 PJ)
N_2O	Nitrous oxide
NOx	Nitrogen oxide
NREAP	National Renewable Action Plan
PJ	Petajoule ($10^{\wedge 15}$ joule)
PM	Particulate matter (fine dust)
PV	Photovoltaic
RED	Renewable Energy Directive
RES	Renewable energy systems
SNP	Strengthened national support
t	Metric tonne
TJ	Terajoule ($10^{\wedge 12}$ joule)
tkm	tonne kilometer
UK	United Kingdom
VAT	Value added tax
vh	Vehicle hour
vkm	Vehicle kilometer

1 Introduction

1.1 Background information and problem definition

In the past few years, the European Union has been the centre for solid biomass demand and with concerns regarding security of supply, global climate change and ambitious targets for renewable energy, it is expected that the European and global demand for biomass for energy will increase. The new Renewable Energy Directive (RED) (EC 2010), and the ensuing national Renewable Energy Action Plans (NREAPs) that are published for all EU-27 member states since February 2011, provide insight in the future demand for biomass up to 2020 (ECN 2011) confirming increasing trends of biomass use for bioenergy in Europe.

In the past years, we have seen, that new sources of biomass have been mobilized to meet the European demand, including residue streams (two examples are palm kernel shells shipped from SE Asia to Europe, and wood pellets from sawdust shipped from British Columbia to Europe) and biomass from dedicated plantations (e.g. palm oil from SE Asia, ethanol from Brazil and wood pellets from plantation wood in the SE of the US).However, it is as yet unclear how much of the future demand can be supplied by untapped resources within the EU-27, and how much is likely to be sourced from outside the EU. Policy makers have to deal are faced with this and other uncertainties. Similarly, different industrial sectors are faced with increasing competition, e.g. lignocellulosic feedstocks are already heavily utilized to produce electricity and heat, but in the future may also be a sourced for 2nd generation biofuels production. Next to this, demand by the paper, construction and particleboard industries, is also uncertain (Mantau, Saal et al. 2010).

With the publication of the NREAPs, on-going modelling work and statistical analysis such as the PELLETS@TLAS project (PELLETS@TLAS 2009), REFUEL (REFUEL 2009), GREEN-X (RE-Shaping 2011) and scenario development of future biomass trade (LUT), insight in the current and future demand and supply of biomass for bioenergy is growing. However, no model exists that can even remotely capture on-going biomass energy trade flows, data availability for both current and future supply and demand of biomass is such that efforts can be justified to devise a modelling tool to describe on-going and possible future trade flows.

Such a modelling tool would be very helpful to provide clarification on the role of biomass for meeting renewable energy targets to policy makers. Similarly, such scenario analysis could also be very helpful for the industry to compare these visions with their own global sourcing strategies.

1.2 Aim of this study

The aim of this study is therefore to i) get a comprehensive overview of expected biomass production and demand for the EU-27 member states, and the resulting biomass deficits/surplus which may be covered by international bioenergy trade, and ii) to develop a modelling tool linked to the Green-X model to simulate biomass trade flows in the EU-27 up to 2020.

1.3 Approach

To assess likely trade flows of biomass for bioenergy in context of supply and demand, this study is divided into three parts. Part 1 covers an analysis of the NREAPs, in part 2, an intermodal transport model is developed and in part 3, results of the transport model are integrated in the renewable energy model GREEN-X and scenarios on bioenergy trade are modelled.

The analysis of the NREAPs focuses on final energy produced from biomass that is expected to contribute to the total share of renewables in the NREAPs and the amount of biomass EU MS expected to mobilize from domestic sources and how much is required from import for electricity and heat. The results of the NREAPs for bioenergy are compared with the supply potentials, as available in the GREEN-X model and with existing model projections. Biomass used for transport fuels are beyond the scope of this study. In addition, a detailed analysis on the quality of the NREAPs has been conducted for selected member states (MS).

To model trade flows of solid biomass within Europe, a geospatial explicit intermodal transport model has been developed in the Network Analyst extension of ESRI's ArcGIS (ESRI 2010). The model includes four transport modalities (truck, train, inland ship and short sea shipping) that are connected via transhipment terminals. The origins and destinations of biomass supply and demand regions are connected via lowest cost routes.

The resulted cost and greenhouse gas (GHG) emissions are implemented as origin – destination specific cost and GHG premiums in the renewable energy model GREEN-X and combined with Low Import and High Import scenarios of non-EU biomass. For these scenarios, combined with the EU targets on renewable energy, likely trade flows are modelled in GREEN-X.

This report describes the results of the assessment of the NREAPs (Section 2) and provides a description of the modelling framework developed for Intra-European trade flows (Section 3). Inter-European trade flows, i.e., biomass imported from non-EU regions are described in section 4. Section 5 discusses the model outcomes of GREEN-X, including the implications of biomass trade, and section 6 and 7 ends with the discussion and conclusion respectively.

2 The National Renewable Energy Action Plans and expected supply and demand of biomass for bioenergy

This section discusses the information available in the NREAPs on the planned share of biomass for electricity and heat to meet the binding renewable energy targets of the EC. Although planned to be published in June 2010, all NREAPs were finally available and processed by ECN (2011) by February 2011. Additional answers and clarifications provide by member states to the EC were published in July 2011 on the NREAP website of the EC. This section uses the information available from July 2011 onwards by the EC (2011) and ECN (2011). In addition, detailed information on the NREAPs provided by IEA Bioenergy Task 40 partners for selected member states has been included.

2.1 Electricity and heat from biomass in the NREAPs

Table 2-1 shows the total contribution of RES electricity, RES heating/cooling[1] and RES transport. RES-heat is projected to remain the largest contributor to total renewable energy production in Europe and including mainly heat from biomass (92% in 2005 to 80% in 2020 of total RES-heat). Because RES-electricity from biomass competes with other alternatives such as hydro, wind and PV, the current and future total share of biomass electricity is low compared to heat (6% in 2005 to 8% in 2020 of total renewable energy and 14% in 2005 to 19% in 2020 of total RES-electricity). RES-transport consists almost 90% of ethanol and biodiesel from biomass in 2020 followed by RES-electricity in transport (10%) and others (2%). Transport fuels are not covered in this study.

Table 2-1 Total contribution from renewable energy sources (RES) for all EU-27 member states (ECN, 2011) and contribution of biomass to total RES production.

		Final energy (Mtoe)				Share total renewable energy (%)			
		2005	2010	2015	2020	2005	2010	2015	2020
RES electricity	**Total**	41.1	55.0	76.2	103.1	42%	40%	42%	42%
	Of which biomass	5.9	9.8	14.5	19.9	6%	7%	8%	8%
RES-heating/cooling	**Total**	54.7	67.9	84.8	111.6	55%	50%	47%	46%
	Of which biomass	50.1	59.8	72.3	89.5	51%	44%	40%	37%
RES-transport	**Total**	3.9	15.1	21.3	32.0	4%	11%	12%	13%
Total RES	**Total**	98.7	137.0	180.9	244.5	100%	100%	100%	100%

2.1.1 Electricity from biomass

The amount of electricity from biomass is projected to double between 2010 and 2020. Germany, the UK, France and Italy project the largest absolute growth between 2010 and 2020, but also smaller countries such as Belgium, the Netherlands project significant growth in bioelectricity generation (Figure 2-1). Solid biomass remains the largest feedstock for electricity generation, whereas liquid biomass has the lowest share (Table 2-2). Note that liquid biomass includes mainly electricity generation from black liquor from pulp and paper industries (e.g. in Finland). It is unclear if also other liquid biofuels that might be subject to sustainability issues (e.g. palm oil) are included.

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[1] Note that biomass cooling is not used in any of the NREAPs and is therefore only mentioned in table 2-1.

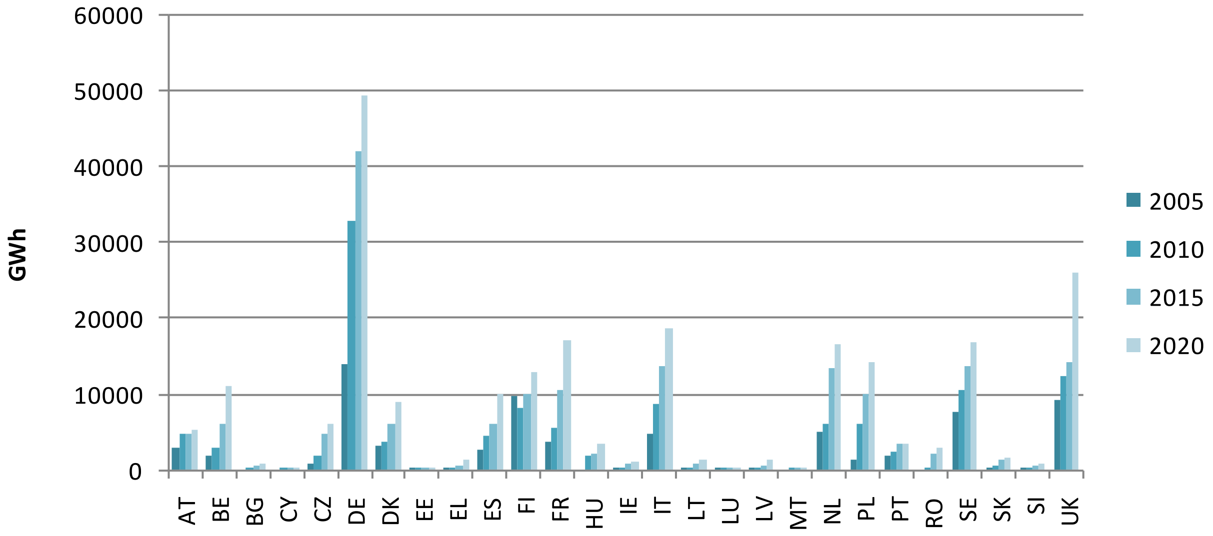


Figure 2-1 Projected total electricity generation from biomass (solid, liquid and biogas) (ECN, 2011)

Table 2-2 Gross electricity generation from biomass (GWh), based on table 10a and 10b from the NREAPs (adjusted from ECN, 2011)

	Biomass electricity generation								Biomass electricity generation per feedstock type											
	Biomass electricity				Of which CHP (%)				Solid biomass				Biogas				Liquid biomass			
Country	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
AT	2823	4720	4826	5147	61%	68%	69%	70%	2507	4131	4223	4530	283	553	567	581	33	36	36	36
BE	1791	3007	5952	11039	NA	NA	NA	NA	1521	2580	5145	9575	235	393	777	1439	35	34	30	25
BG	0	2	656	871	NA	100%	100%	100%	0	0	387	514	0	2	269	357	0	0	0	0
CY	0	30	84	143	NA	NA	NA	NA	NA	NA	NA	NA	0	30	84	143	NA	NA	NA	NA
CZ	721	1930	4819	6165	66%	100%	100%	100%	560	1306	3065	3294	161	624	1754	2871	0	0	0	0
DE	14025	32777	42091	49457	NA	16%	28%	42%	10044	17498	21695	24569	3652	13829	18946	23438	329	1450	1450	1450
DK	3243	3772	6034	8846	100%	100%	100%	100%	2960	3578	5312	6345	283	194	721	2493	0	0	1	8
EE	33	241	346	346	100%	100%	100%	100%	33	241	346	346	NA	NA	NA	NA	NA	NA	NA	NA
EL	94	254	504	1259	NA	29%	14%	12%	NA	73	73	364	94	181	431	895	NA	NA	NA	NA
ES	2652	4518	5962	10017	28%	32%	31%	25%	2029	3719	4660	7400	623	799	1302	2617	0	0	0	0
FI	9660	8090	9880	12910	88%	99%	95%	96%	9640	3930	5300	7860	20	40	50	270	NA	4120	4530	4780
FR	3819	5441	10495	17171	88%	100%	100%	100%	3341	4506	8366	13470	478	935	2129	3701	0	0	0	0
HU	0	1955	2250	3324	NA	6%	32%	90%	NA	1870	1988	2688	NA	85	262	636	NA	NA	NA	NA
IE	116	348	887	1006	11%	11%	7%	56%	8	28	567	687	108	320	320	319	0	0	0	0
IT	4675	8645	13712	18780	51%	31%	31%	31%	3477	4758	6329	7900	1198	2129	4074	6020	0	1758	3309	4860
LT	7	148	761	1223	100%	99%	100%	100%	3	98	533	810	4	50	228	413	0	0	0	0
LU	46	69	200	334	59%	94%	94%	95%	19	25	77	190	27	44	123	144	NA	0	0	0
LV	41	72	664	1226	98%	97%	86%	76%	5	8	271	642	36	64	393	584	NA	NA	NA	NA
MT	0	9	140	135	NA	NA	NA	NA	NA	0	86	86	NA	9	54	50	NA	NA	NA	NA
NL	5041	5975	13350	16639	31%	48%	38%	50%	4758	5103	11189	11975	283	872	2161	4664	0	0	0	0
PL	1451	6028	9893	14218	100%	31%	32%	36%	1340	5700	8950	10200	111	328	943	4018	0	0	0	0
PT	1976	2392	3359	3516	66%	64%	59%	56%	934	1092	1468	1468	34	130	368	525	1008	1170	1523	1523
RO	0	67	2050	2900	NA	101%	100%	100%	0	48	1450	1950	0	19	600	950	0	0	0	0
SE	7570	10631	13692	16753	100%	100%	100%	100%	7452	10513	13574	16635	53	53	53	53	65	65	65	65
SK	32	610	1349	1710	100%	100%	100%	100%	27	540	725	850	5	70	624	860	NA	NA	NA	NA
SI	114	298	623	676	100%	100%	100%	100%	82	150	272	309	32	148	351	367	0	0	NA	NA
UK	9109	12330	14290	26160	NA	0%	6%	7%	4347	5500	7990	20590	4762	6830	6300	5570	NA	NA	NA	NA
EU-27	69039	114359	168869	231971	47%	44%	50%	54%	55087	76995	114041	155246	12482	28731	43884	63978	1470	8633	10944	12747

2.1.2 Heat from biomass

Biomass heat in the EU-27 is projected to increase with almost 50% from 59.8 Mtoe in 2010 to 89.5 Mtoe in 2020. Main contributors to the absolute growth are France (64% growth), Italy (141% growth), the UK (112% growth) and Germany (25% growth) as depicted in Figure 2-2. Especially heat from CHP plants is projected to contribute more in 2020 (32%) compared to 2010 (22%) whereas the absolute contribution of households remains relatively constant (Table 2-3). Although heat from biogas is estimated to grow rapidly (e.g. in Germany) (Table 2-4), in absolute terms, heat from the combustion of solid biomass generation remains the largest (89% in 2020).

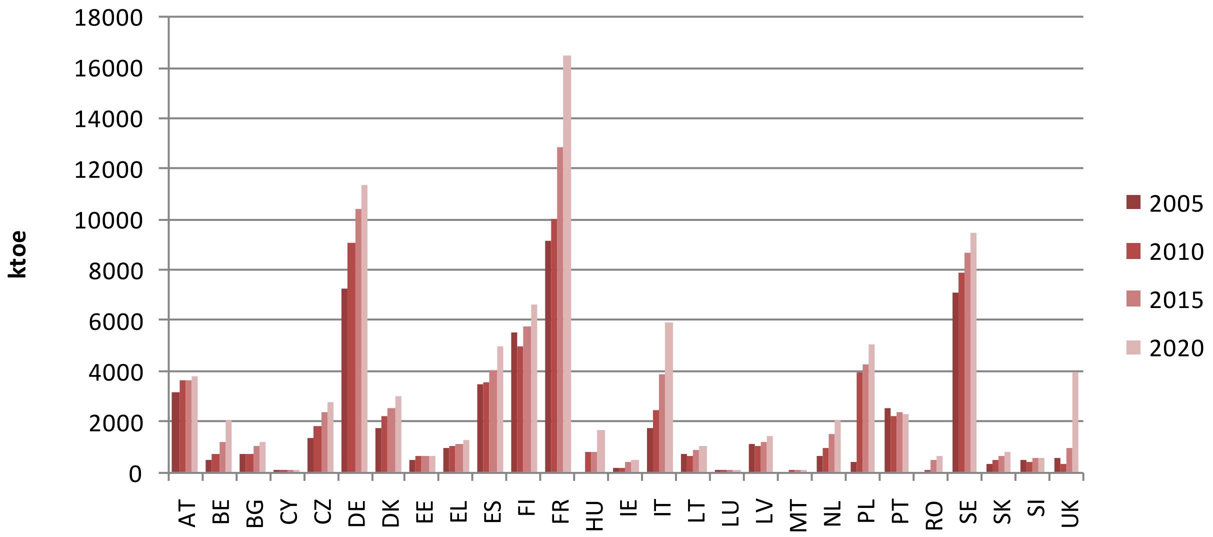


Figure 2-2 Heat generation from biomass including heat from biomass CHP (solid, liquid and biogas) (ECN, 2011)

Table 2-3 Heat generation from biomass per sector (ktoe), based on table 11 from the NREAPs (adjusted from ECN, 2011).

					Of which (%):											
	Total biomass heat generation				Heat from CHP				Stand alone (industrial/residential)				Households			
Country	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
AT	3162	3625	3656	3805	15%	24%	23%	24%	0%	0%	0%	0%	85%	76%	77%	76%
BE	477	682	1178	2034	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%	0%	0%
BG	724	736	1056	1200	0%	0%	14%	16%	0%	0%	0%	0%	100%	100%	86%	84%
CY	4	18	24	30	0%	0%	0%	0%	58%	62%	61%	61%	42%	38%	39%	39%
CZ	1374	1805	2407	2781	9%	26%	46%	47%	27%	14%	3%	4%	64%	61%	51%	49%
DE	7261	9092	10389	11355	0%	13%	25%	38%	39%	26%	19%	9%	61%	61%	56%	53%
DK	1760	2245	2545	2991	51%	46%	61%	68%	9%	11%	1%	0%	40%	43%	38%	32%
EE	505	612	626	607	2%	11%	15%	15%	98%	89%	85%	85%	0%	0%	0%	0%
EL	951	1020	1138	1238	0%	1%	1%	2%	38%	38%	46%	50%	62%	60%	53%	48%
ES	3477	3591	4060	4950	6%	11%	11%	12%	36%	32%	38%	45%	58%	57%	51%	43%
FI	5490	4980	5800	6610	44%	45%	44%	48%	35%	35%	38%	35%	20%	20%	19%	17%
FR	9153	10018	12828	16455	10%	14%	20%	25%	18%	18%	24%	30%	72%	68%	55%	45%
HU	0	813	830	1637	NA	4%	22%	44%	NA	21%	5%	0%	NA	75%	73%	56%
IE	183	198	388	486	1%	3%	4%	26%	90%	85%	90%	69%	9%	12%	6%	5%
IT	1755	2464	3879	5933	35%	27%	26%	22%	0%	13%	15%	17%	65%	60%	60%	61%
LT	686	665	886	1035	0%	5%	20%	26%	91%	86%	75%	70%	8%	9%	5%	4%
LU	22	32	62	103	26%	41%	61%	66%	3%	0%	0%	0%	71%	59%	39%	34%
LV	1119	1023	1191	1409	1%	1%	10%	14%	31%	30%	29%	30%	69%	69%	62%	56%
MT	0	1	2	2	NA	0%	0%	0%	NA	100%	100%	100%	NA	0%	0%	0%
NL	657	961	1487	2071	67%	79%	86%	92%	8%	5%	3%	0%	24%	17%	11%	8%
PL	403	3911	4227	5089	100%	13%	19%	23%	0%	87%	81%	77%	0%	0%	0%	0%
PT	2508	2182	2349	2329	15%	19%	22%	21%	39%	50%	51%	53%	46%	30%	27%	26%
RO	0	16	484	654	NA	100%	100%	100%	NA	0%	0%	0%	NA	0%	0%	0%
SE	7078	7883	8686	9491	31%	38%	43%	46%	55%	49%	44%	41%	15%	14%	13%	12%
SK	358	454	636	759	2%	36%	46%	46%	88%	57%	48%	46%	9%	8%	6%	7%
SI	449	438	549	580	6%	15%	23%	23%	20%	9%	6%	9%	73%	76%	70%	68%
UK	560	323	961	3914	0%	0%	19%	12%	100%	90%	71%	70%	0%	10%	10%	18%
EU-27	50116	59791	72325	89548	18%	22%	29%	32%	33%	33%	31%	32%	49%	45%	40%	36%

Table 2-4 Heat generation from biomass per feedstock type, based on table 11 from the NREAPs (adjusted from ECN, 2011)

	Total heat generation per feedstock type											
	Solid biomass				Liquid biomass				Biogas			
Country	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
AT	3128	3558	3589	3738	6	7	7	7	28	60	60	61
BE	476	669	1138	1947	0	4	14	32	2	9	26	55
BG	724	736	1015	1147	0	0	0	0	0	0	41	54
CY	4	18	24	30	0	0	0	0	0	0	0	0
CZ	1351	1706	2137	2350	0	0	0	0	23	99	270	431
DE	6794	7516	8389	8952	313	664	688	711	154	912	1312	1692
DK	1714	2178	2426	2609	0	8	8	8	46	59	111	374
EE	505	612	626	607	0	0	0	0	0	0	0	0
EL	951	1012	1128	1222	0	0	0	0	0	8	10	16
ES	3441	3550	3997	4850	0	0	0	0	36	41	63	100
FI	5450	2710	3300	3940	0	2240	2470	2610	40	30	30	60
FR	9067	9870	12500	15900	0	0	0	0	86	148	328	555
HU	0	812	800	1552	0	0	0	0	0	1	30	86
IE	176	188	362	453	0	0	0	0	7	10	26	33
IT	1655	2206	3404	5254	0	153	279	397	100	105	196	282
LT	685	657	851	973	0	0	0	0	1	8	35	62
LU	19	25	44	83	0	0	0	0	3	6	18	21
LV	1113	1013	1139	1343	0	0	0	0	6	10	52	66
MT	0	0	0	0	0	0	0	0	0	1	2	2
NL	588	850	1313	1722	0	0	0	0	69	111	174	349
PL	385	3846	3996	4636	0	0	0	0	18	65	231	453
PT	1785	1514	1515	1484	713	655	801	801	10	13	33	44
RO	0	13	392	511	0	0	0	0	0	3	92	143
SE	6992	7800	8607	9415	65	65	65	65	21	18	14	11
SK	357	443	540	630	0	0	0	0	1	11	96	129
SI	401	415	483	497	43	0	12	28	5	23	54	55
UK	493	305	904	3612	0	0	0	0	67	18	57	302
EU-27	48254	54224	64618	79456	1140	3796	4344	4659	723	1771	3363	5434

2.1.3 Biogas injected into the grid

The Netherlands includes also an additional category for biomass injected into the natural gas grid. The Netherlands assumes that this will increase from 31 ktoe in 2010 to 202 ktoe in 2015 and 582 ktoe in 2020. This category has not been included in the estimations of biomass requirements in this study.

2.2 Biomass supply and expected demand

2.2.1 Biomass supply (EU-27 domestic sources)

Figure 2-3 depicts the estimated amount of biomass in the NREAPs (left columns) and the amount of biomass potentially available for energy production used in the Green-X model. It should be noted that the total amount of biomass available in Green-X also includes biomass from expensive resources such as expensive complementary fellings (forestry direct). The price of these biomass types are more expensive than forestry imports from abroad and are therefore likely only used in scenarios with high biomass demand (Figure 2-4).

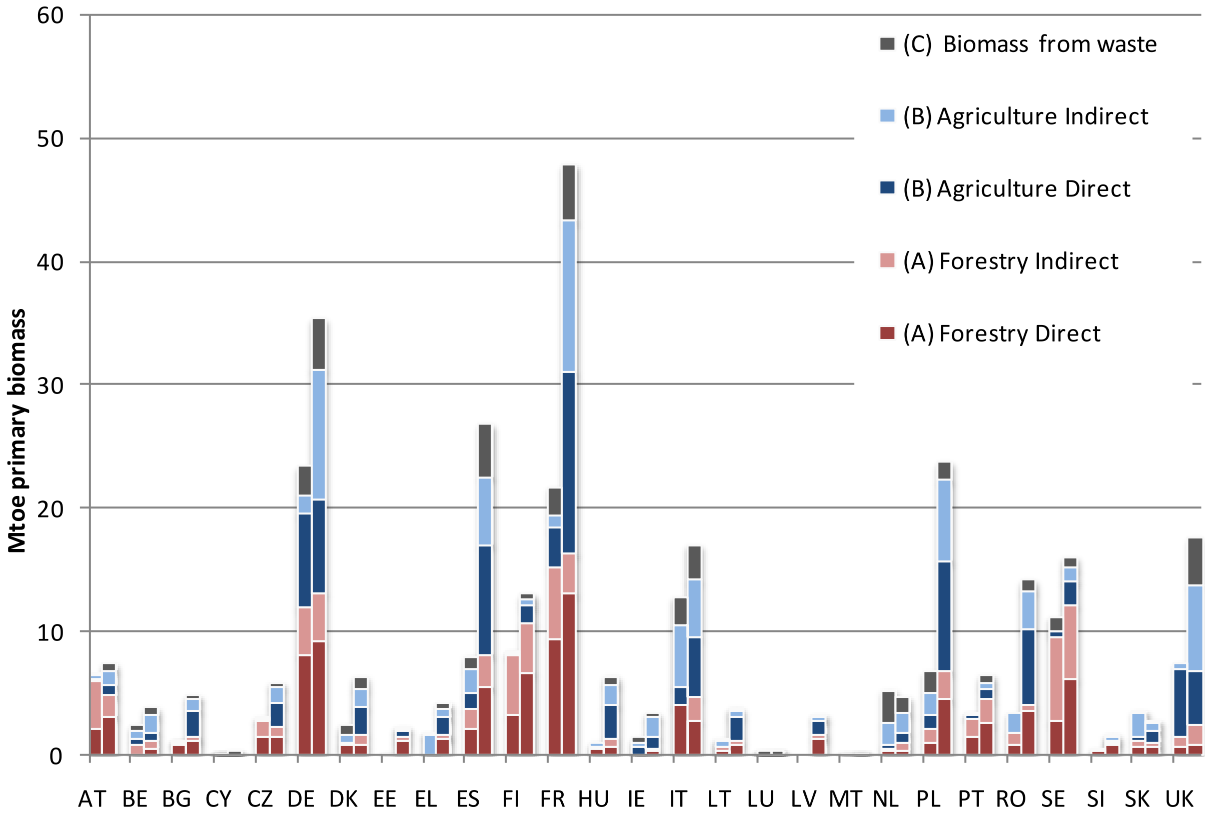


Figure 2-3 Biomass supply in the NREAPS and Green-X for the EU27 from primary, secondary and tertiary resources in 2020. The left columns are based on table 7a of the NREAPS (partly based on ECN 2011), the right columns show the potentials that are used in the Green-X model (Resch 2011).

For most countries that include estimations of biomass in table 7a of the NREAPS for 2020, the supply of primary biomass is higher in the Green-X database than in the NREAPS apart from Slovakia (SK), the UK and the Netherlands (NL). In absolute terms, the largest difference between the NREAPs and Green-X are in the estimated potentials of direct biomass from agriculture in France (FR) and Spain (ES), Poland

(PL), Romania and Germany (DE). The Green-X projections of biomass demand, i.e. the total potential that will be used, for Spain, France and Poland are much lower than the total technical potential and in range with the projected demand and supply of biomass in the NREAPs (Figure 2-4). For Germany, the demand for primary biomass in the NREAPs is in range with Green-X whereas the supply in the NREAPs is significantly lower. This would imply that imports of biomass are required to meet the demand in Germany in 2020.

The main differences between the domestic supply of biomass in the NREAPs and Green-X are found in relatively expensive biomass categories including direct forestry products and direct products from agriculture (mainly energy crops). Expensive complementary fellings, that are included in the potentials of Green-X under direct products from forestry, could explain part of the difference between the NREAPs and Green-X for this category (mainly in Finland, France, Poland and Spain). Energy crops in the NREAPs are significantly lower in France (12 Mtoe), Spain (9 Mtoe), Poland (9 Mtoe), Romania (7 Mtoe) and Italy (4 Mtoe). As shown in Figure 2-4, the potentials in Green-X are not fully used because not all biomass resources will become economically available in the scenarios. Some of these expensive biomass resources might already have been excluded from the NREAP tables.

Indirect products from agriculture in Green-X mainly exists of straw, but excludes biogas from animal manure. For France (11 Mtoe difference), the potential of indirect products from agriculture is linked to the conservative estimates for direct agricultural biomass. Italy includes large potentials for biogas from animal manure in this category.

The exclusion of certain categories in the estimated supply of biomass in the NREAPs for 2015 and 2020 (table 7a), as described below, also explains some of the differences between the NREAPs and Green-X.

2.2.2 Biomass demand

The blue columns in Figure 2-4 show the total potential supply of biomass from the NREAPS, similar to Figure 2-3 and the estimated demand based on the projections of final bioenergy for electricity, heat and transport fuels in the NREAPs from table 10, 11 and 12 in 2020. The red columns show the potential for biomass as implemented in Green-X and projection ranges of demand for 2020 for three scenarios including Business As Usual (BAU), BAU barriers mitigated and Strengthened National Support (SNP). This figure shows that not all of the technical potentials in Green-X are projected to be used for bioenergy as some of these biomass categories are not projected to become economically available in the scenarios. This is in particular true for countries that show large differences between the NREAPs and Green-X (Spain, France and Poland).

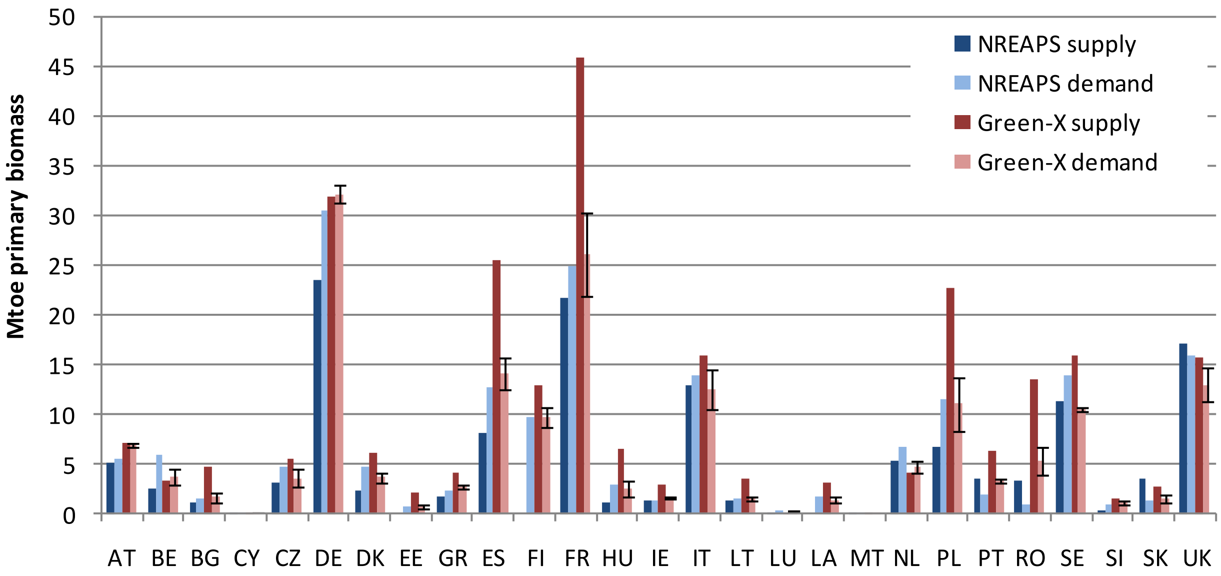


Figure 2-4 Primary biomass supply and demand for electricity, heat and biofuels in the National Renewable Action Plants (table 7a) and Green-X supply and demand ranges for the scenarios Business as Usual (BAU), BAU Mitigated barriers and Strengthened National Support for 2020 (Resch, 2011).

2.3 Issues related to the biomass supply estimates in the NREAPS

This section is mainly based on input from the IEA Bioenergy Task 40 partners in Austria (EEG/TU Wien), Denmark (Technologisk Institut), Finland (Lappeenranta University of Technology) and Germany (Oeko Institute/DBFZ).

2.3.1 Missing data and tables

A major part of the NREAPs do not include all categories of biomass in Table 7 (supply in 2006) and 7a (supply in 2015 and 2020) of biomass from forestry; direct (A1) and indirect (A2), biomass from agriculture: direct (B1) and indirect (B2) and biomass from the biodegradable fraction of waste: MSW (C1), industry (C2) and sewage sludge (C3). Finland and Latvia exclude the expected supply of biomass for 2015 and 2020 whereas Estonia and Greece only provides estimates on direct forestry products (A1) and additional information in text. Note that additional information in appendices or resubmitted NREAPs are now available online. Finland, for example, added the missing tables (7a and 8) in the appendices of the resubmitted NREAP.

Other countries that only include part of the biomass categories in table 7a are Bulgaria (only B1 and 2), Denmark (excludes B1), Estonia (excludes B1, B2 and C1 and C2) and Slovenia (includes only A1 and C2).

2.3.2 Units

The data in table 7 and 7a of the NREAPS are presented in various units of volume m^3, weight (ton wet or dry basis) or calorific value: ktoe, PJ/yr. For data presented in volume (m^3), the main issue is to combine volumes of solid biomass and liquid biomass in category A2 (indirect supply of wood biomass). Black liquor, from the pulp and paper industry, cannot directly be added to solid biomass categories. The liquid volume is different from the solid volume and secondly, the energy density of black liquor (9.0

MJ/kg wb (wet basis)) is lower than most indirect woody biomass sources (e.g. waste wood 15.8 MJ/kg wb) (ECN, Phyllis). Also, it is sometimes unclear if data presented in weight is on wet or dry basis.

In some cases, the specific energy content of the expected amount of domestic resources can be derived from the column primary energy production (ktoe). However, this column is interpreted differently by the MS. The UK, for example, provides the total estimated renewable energy (heat and electricity) produced in this column. Luxembourg considers the total primary production in table 7a to be the total primary demand for biomass and provides the total domestic supply in the column for total primary energy production.

Also inconsistencies were found in the units used. Greece appears to provide biomass from direct agriculture (B1) in Mtoe rather than the reported units (ktoe). A similar error was found for Malta. For Slovenia, it is most likely that the domestic supply of direct forestry should be 333 ktoe instead of 1333 ktoe.

2.3.3 Categories

Also for other categories, adding up volumes or weight units can result in errors and is not always meaningful. Especially when it is unclear what is covered by the biomass categories included (e.g. rapeseed or rapeseed oil). Secondly, some categories are specific to certain conversion systems and have various calorific values such as manure (anaerobic digestion) and straw. Soybean oil could also be problematic as it is a by-product from soybean meal production (feed industry) and should therefore be included in category B2, secondary products.

Furthermore, adding imported refined fuels to primary biomass feedstocks results in balance errors. For example, the NREAP of Austria includes a small consistency in category B (direct biomass from agriculture) of table 7 regarding imported biodiesel that is added to primary feedstocks.

2.3.4 Realisability of the estimated potentials

The future biomass supply potentials that are included in the NREAPs to meet the demand for electricity, heat and transport fuels is uncertain and depends on many factors including competitive use of other sectors or by-products created by other sectors (e.g. pulp and paper industries, biorefineries, sawmill industries). For **Finland** it was assumed that the volume of these industries, based on forestry products, remains at its peak. However, a study by the Finnish forest research institute, has estimated that the production of forest products in Finland will decrease towards 2020.

The NREAP of **Denmark** estimates that the unexploited biomass potential is 130 PJ including municipal solid waste. This potential has been criticized. A report of the Danish Institute of Agricultural Sciences (2008) argues that the unexploited potential of biomass in Denmark is around 90 PJ or more. Some resources require additional development of handling and conversion such as grass, while straw and woody energy crops can be used directly. Still the potential is 40 PJ lower than estimated in the Danish NREAP and according to some Danish experts, even the 90 PJ is too optimistic (Ryberg and Nikolaisen 2009).

The **Netherlands** expect to be able to produce a large share of its renewable energy target from biogas from (co-)digestion of manure which is likely too optimistic.

3 Modelling intermodal transport chains of biomass for bioenergy in Europe

In order to identify likely trade routes of solid biomass and to quantify the specific costs and GHG emissions of the logistic chains of solid biomass trade, a geospatial network model has been developed in the ArcGIS Network Analyst extension (ESRI 2011). The model includes an intermodal network with road, rail, inland waterways and short sea shipping in Europe. The networks are connected via transhipment hubs where biomass can be transferred to other transport modalities (e.g. from truck to ship). The model optimizes for least cost or GHG emissions from demand to supply regions by transport costs and transhipment costs. Total cost and GHG emissions depend on the routes taken, transport modes used and number of transfers between different transport modes.

3.1.1 The transport network

The transport model uses a hub-spoke method similar to Winebrake, Corbett et al. (2008) that connect different transport nodes via connectors (the spokes) to transhipment hubs. The nodes represent existing harbours, road exits and rail terminals. Links connecting these nodes represent existing roads, railways and canals or rivers. The centroids are connected to the nearest road, rail and waterway nodes via connectors. Cost evaluators were applied to these connectors representing the cost for transhipment (loading/unloading and storage) between different transport modes. Figure 3-1 depicts an example of a transhipment hub in a region including all transport modalities, e.g. Rotterdam. Note that in most regions only road and rail networks are available. Figure 3-2 provides an overview of the destinations used in the model. Network data for road, rail and inland waterways (Figure 3-3) were based on the TRANS-TOOLS V2 model (JRC 2009), a decision support model for transport impact analyses. Sea harbours were derived from the EC GISCO database. 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). Cost and GHG evaluators specific to biomass logistics were added to the TRANS-TOOLS freight network. The performance parameters (cost and emissions) were based on literature review and expert interviews and added as evaluators to the logistic network in ArcGIS.

Because biomass supply potentials in GREEN-X are available on country level, the spatial distribution of energy crops within countries of the EU-27 were derived from the results of the REFUEL project (de Wit and Faaij 2010) that provides the supply potential on NUTS-2 level. Relative availability of forestry residues and products were assumed to be similar to the forestry cover on NUTS-2 level (EUROSTAT 2010). The potentials per NUTS-2 region within a country were combined with the biomass potentials and farm-gate costs on country level of the GREEN-X model.

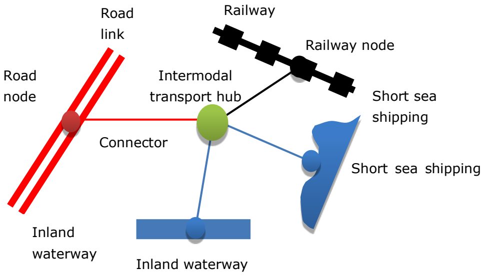


Figure 3-1 the network model approach (hub-spoke) following Winebrake et al. (Winebrake, Corbett et al. 2008; JRC 2009)

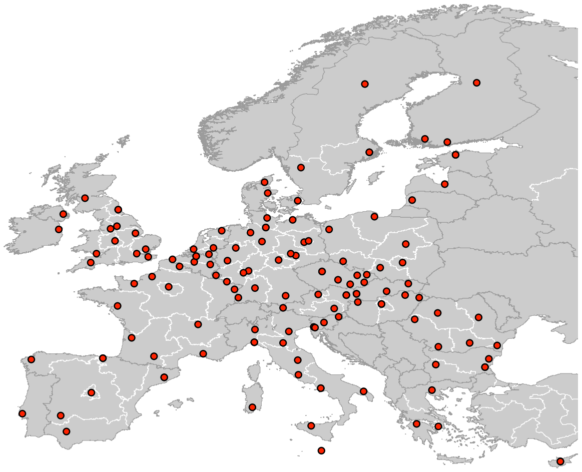
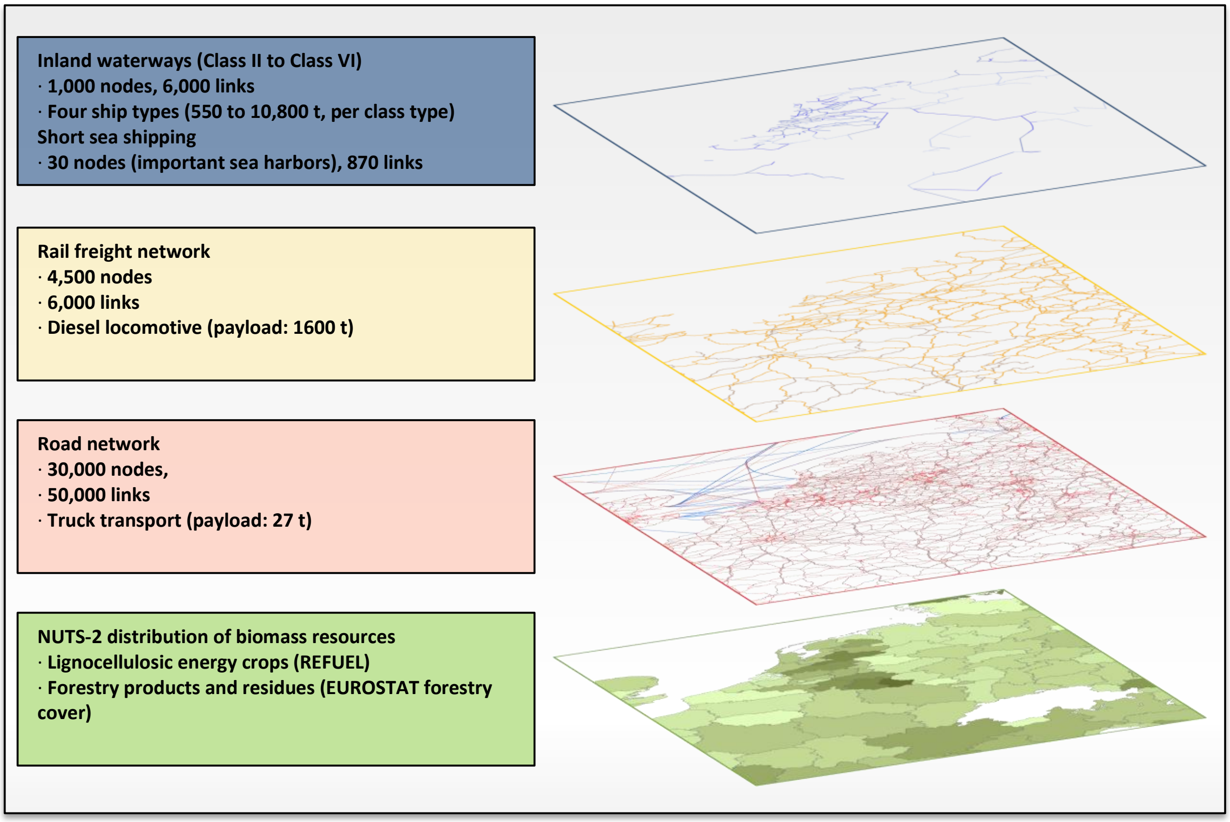


Figure 3-2 EU-27 destinations (largest cities per NUTS-1 region and/or important harbours in the EU-27)



Inland waterways (Class II to Class VI)
- 1,000 nodes, 6,000 links
- Four ship types (550 to 10,800 t, per class type)

Short sea shipping
- 30 nodes (important sea harbors), 870 links

Rail freight network
- 4,500 nodes
- 6,000 links
- Diesel locomotive (payload: 1600 t)

Road network
- 30,000 nodes,
- 50,000 links
- Truck transport (payload: 27 t)

NUTS-2 distribution of biomass resources
- Lignocellulosic energy crops (REFUEL)
- Forestry products and residues (EUROSTAT forestry cover)

Figure 3-3 depiction of biomass distribution (NUTS-2 level) and network link layers for part of the biomass logistics model.

3.2 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.

3.2.1 Fuel consumption

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

$$ECF = ECF_{empty} + \ \ EFC_{full} - ECF_{empty} \ \ * CU$$

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)

3.2.2 Freight 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 amount of volume that a specific type of cargo holds per specific weight (m^3/t) in a ship is called the stowage factor. The stowage factor 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 (Hamelinck, Suurs et al. 2005):

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

3.2.3 Transport modes

3.2.3.1 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 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 (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 3-1 Input parameters for road and rail transport

Parameter	Truck			Rail	References
	Truck (dry bulk)				
	2010	2020	2030		
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			Smeets et al. 2009
Variable cost (excl.fuel) (€/vkm)		0.11			
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

3.2.3.2 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) released during the fuel lifecycle.

3.2.3.3 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 3-2). 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 (empty returns) 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 3-2 Input parameters for inland navigation

Parameter	Inland navigation				References
	Class 2	Class 3	Class 4	Class 5/6	
	Kempenaar	Rhine-Herne Canal ship	Large Rhine ship	Four-barges convoy set	
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

3.2.3.4 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 3-3 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

3.2.4 Transhipment

The transhipment cost depicted in Table 3-4, 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 0). 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, transhipment cost of 2.4 €/t were found (Boer, Cuijpers et al. 2010).

Table 3-4 Transhipment cost (in €/t)

Fuel type	Truck Av.	 Range	Rail Av.	 Range	Ship Av.	 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 of the supply chain is relatively small.

3.2.5 Country specific parameters: fuel, tolls and labour cost

3.2.5.1 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 3-5 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 3-5 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

3.2.5.2 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 costs in the TransTools database. These were also used for this project.

3.2.5.3 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.

4 Scenarios for Inter-European solid biomass trade[2]

4.1 Introduction and aim

In the past decade, the trade of solid biomass has increased strongly, as described in many Task 40 reports, see e.g. (Junginger et al, 2011). Especially the trade of wood pellets for both small-scale heating applications and large scale use for electricity / CHP production has reached a volume of several million metric tonnes per year.

However, the GREEN-X model is unable to endogenously model imports of biomass from third countries. Therefore, imports from outside the EU represent an exogenous input to the modelling exercise. The aim of this chapter is to describe how this input is developed.

4.2 Approach and scope definition

In principle, two approaches are possible to determine the international trade flows of solid biomass. The first one would be to employ macro-economic trade models such as GTAP based models[3]. However, this option was discarded because of several reasons:

- These models are unable to model specific biomass trade flows (e.g. wood pellets)
- The model data is often several years old, thus unable to take into account recent developments. For example, he latest GTAP database (GTAP 7), used in most CGE models, covers 2004 as a base year when international trade of bioenergy commodities was still relatively small.
- Integration of such a model with the Green-X model would have exceeded the available time and resources within this project

Therefore, it was decided to primarily carry out a bottom-up scenario analysis. It was decided to develop two scenarios:

1. A "business as usual / low import" scenario. The main basis for the expected import flows for the short term (2011-2015) are based on **industry expectations** as presented in the first half of 2011 (e.g. Schouwenberg, 2011; de Wolff, 2011), announcement in trade journals (such as Bioenergy International) and on recent literature, such as the latest UNECE Forest products report (UNECE/FAO 2011). These sources already take into account the ongoing investments in e.g. new pellet plants in many parts of the world, and take into account the maximum speed with which wood pellet production and trade can realistically grow in the coming years. In our opinion, they represent the most realistic outlook for the next 4 years. For the period of 2015-2020, potential further development is based on the (projected) availability of woody biomass (e.g. by Pöyry (2010)), and the specific availability of woody biomass in the main sourcing regions (e.g. van den Bos, 2010; De Wit et al. 2011 for Eucalyptus/Brazil, and Gerasimov and Karjalainen (2011) for NW Russia). The assumptions have also been presented to and checked by several experts from Canada and the US.

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[2] This section is based on Junginger (2011).

[3] For a full overview of models that are (partially) able to model international bioenergy trade, see e.g. Dornburg et al (200x)

2. An “optimistic / high import” scenario. This scenario basically builds forth on the conservative scenario, but assumes that from 2014 onwards, a number of world regions will use land for energy crops to produce additional wood pellets

Furthermore, we only consider **woody solid biomass imports** towards the EU-27, as we deem solid biomass exports extremely unlikely. This is based on the fact that overall, the EU-27 is projected to have a deficit of solid biomass, as follows by an own internal review of the national renewable energy action plans (Section 2), and is also projected by the recent EUwood study (Mantau, Saal et al. 2010). Even if individual countries may have surpluses, they often cannot compete with the prices of solid biomass imported from other world regions. Possible exceptions are exports to Switzerland and Norway, but it is expected that these trade flows remain marginal (as was the case in 2010 (Eurostat, 2011)).

Also, in all scenarios presented in recent months (and years), (almost) only woody biomass trade is considered. Also currently, no meaningful imports of any agricultural residues for energy use from outside the EU occur to our knowledge. Therefore, we do not consider imports of agricultural biomass for energy. Finally, the preferred type of traded (refined) biomass are wood pellets, as they have a relatively high (volumetric) energy density, are less prone biological activity than e.g. wood chips, and can be blended with coal with less effort than wood chips. As all industry scenarios found only consider wood pellets, this study also assumes that (with one exception) all inter-continental trade will occur as wood pellets[4].

The **available and predominant types of feedstock** (either woody residues such as sawdust, discarded wood, bark, etc.) or roundwood (such as eucalyptus or pine trees from dedicated plantations) will be discussed in more detail in the following sections.

Regarding the expected **prices** CIF[5] Europe, we base our assumptions on observations for the market price for industrial wood pellets delivered CIF Rotterdam, which fluctuated between 2007 and 2010 between 110-140 €/tonne, with a typical average of 120 €/tonne. This price was used as basis for the calculation for the prices across the EU. In addition, we used current prices for short sea shipping to derive prices at other European harbours. For example, if wood pellets would be shipped from St. Petersburg to Stockholm, this price would be lower than 120 €/tonne, as the transport cost would be lower than transporting the pellets to Rotterdam.

Finally, there are a number of important limitations/assumptions to the scenarios:

1. The projected supply of wood pellets in the sourcing regions is **100% dependent on sufficient demand in the EU**. If this demand is not met, no new investments will be made. In the Green-X model, we take this into account by using the following constraint: if in year x the supply potential from a specific supply region is not fully utilized, then the supply in year x+1 will not

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[4] Note that inter-European trade may occur in the form of wood chips, especially in the Baltic sea region, mainly due to the shorter transport distances and the ability of many medium-sized end-users to use wood chips as fuel. Furthermore, we do take one specific project of Vattenfall into account, which annually plans to import 1 million bone-dry metric tonnes of wood chips from Liberia to Scandinavia.

[5] Cost, Insurance and Freight, i.e. delivered to a specific destination.

be projected as in the main scenario, but will remain stable, up to the year where the potential is fully utilized. Only then, further growth of the supply potential is possible.

2. The scenarios assumes that **all biomass produced in the sourcing areas is available for the European wood pellet market**. In reality, this does of course not need to be the case. For example, if the US would decide to stimulate the use of wood for co-firing, or (perhaps more likely) 2nd generation biofuel technology using lignocellulose as feedstock become commercially available, the amount of resources available for the EU may decline severely. Also, it is quite possible that the South East Asian markets (E.g. Japan and especially South Korea) may boom in the future, and may significantly reduce the imports from especially Western Canada (Murray, 2011)
3. The scenario does **not take into account** ongoing developments in the field of **torrefaction**. Torrefaction technology is currently developed by a large number of individual initiatives, but at the time of writing, not a single, operational large-scale plant has been realized. Nevertheless, it could well be that by e.g. 2015, torrefaction technology is widely commercially available. This could have implications for a) the costs (which may be higher or equal to those of wood pellets), b) the GHG balance (especially for long-distance shipping, torrefied pellets have a lower GHG emission due to the higher energy density), and c) the available potential (as due to the pretreatment step, biomass feedstocks may become available, which were previously 'stranded' (e.g. due to too high transport costs). However, it is still uncertain whether torrefaction technology will break through (and when), and the limited amount of time available, we did not include torrefaction in the analysis.

Based on the above-mentioned scenario, the available biomass potential will be added to the supply curves in Green-X.

4.3 The business as usual / low import scenario

Based on past and current import trends, press releases of individual companies, expert opinions and (especially) on scenario studies by Schouwenberg (2011) and de Wolff (2011), we identified a number of main future sourcing areas. In the following sections, the following data is described for each of the sourcing regions:

a) a short description of the current production capacity and anticipated growth in the next 10 years,
b) the main current feedstocks used for wood pellet production, and an outlook on future feedstock availability
c) a short descriptions of the main modes of transport used for feedstock and wood pellet transport

4.3.1 East and West Canada

The total capacity of the existing 34 wood pellet mills is 2.6 million tonnes (Murray 2011). About 71% of the Canadian capacity is located in the west, mainly British Columbia (BC). There are 16 plants, with an average capacity of 118 ktonnes per year, and the largest is 400 ktonnes/year. The total western capacity is 1 889 000 tons. While the largest part of the feedstock is still based on wood residues form wood processing, it is notable that in past years, wood of trees killed by the Mountain Pine Beetle (MPB) has also become an important source of feedstock for wood pellet production. Currently, this share is about 30, but in 2020, it was estimated that up to 50% of the feedstock used for wood pellet production may be from MPB wood (Murray, 2011). As there are (currently) only two integrated wood pellet mills, also sawdust needs to be transported to the wood pellet mills (on average 100 km by truck). Transport from the mills to the two main ports (Vancouver and St. Rupert) takes places by train. Average transport distances from the BC hinterland (and its main logistic hub Quesnel) tot Vancouver and Prince Rupert are 660 km and 850 km respectively (Verkerk 2008). Pellets are then stored for a short time at the port, loaded onto a dry bulk carrier, and shipped through the Panama Canal to Europe, or over the Pacific Ocean to East Asia.

The eastern part Canada currently contains 29% of the total wood pellet production capacity. The 18 plants have an average of 43 000 tonnes and the largest is 120 000 tonnes (Murray, 2011). The feedstock consists of basically 100% residues from the wood processing industry, and is transported (on average) 100 km from the saw mills to the pellet mills. The wood pellets are transported on average 200 km by truck to the main export harbours of Belledune (New Brunswick) or Halifax (Nova Scotia).

Almost all Canadian production is exported: in 2010, this amounted to about 1.35 Mtonnes to Europe, 0.9 Mtonnes to the US (mainly from the land-locked plants in the centre of Canada), and 60 ktonnes from BC to Japan. Domestic use is about 100 ktonnes (Bradley 2011). For 2011, expectations are that imports will increase to 1,75 MT and 100 ktonnes to the EU and Japan respectively, and will remain stable for the US (Murray, 2011).

Regarding capacity and export developments, Bradley (2011) estimates that production capacity might increase from 2.6 to 3.5 million tonnes in 2014, and to 5.5 million tonnes/year in 2018. An estimated maximum export potential is 4.7 million tonnes, of which about 55% from British Columbia (Western Canada), and the remainder from Central and Eastern Canada. This scenario is based on the expectation that demand in South Korea will grow strongly to allow for the expansion in BC, but in theory, this amount could also become available for Europe, depending on sufficient demand and economic feasibility.

The feedstock base for this expansion is likely partially going to be further residues from sawmills, but possibly also increasingly forest residues (collected at the roadside) and (in BC) also MPB wood, which would require an additional collection effort. Verkerk estimates for BC that in BC alone, a total of 1.3 oven-dry tonnes of sawmill residues may be available, which would in theory suffice to supply roughly half of all wood pellets produced in BC in 2018. The remainder may likely be produced from MPB trees (Murray, 2011). For eastern Canada, we assume that production for export may increase to 920 ktonnes in 2020, but the feedstock source will remain 100% sawdust.

4.3.2 South East USA

The ‘fibre-basket’ in the South-East of the USA encompasses (parts of) the states of Georgia, North Carolina, South Carolina, Alabama and Florida. This area has been a major producer of wood for the pulp and paper and construction sector for decades. Due to the housing crises and decreasing demand for roundwood for construction, large amounts of wood are currently un(der)utilized in this region.

According to Bioenergy International (2011) the total capacity in this area was about 1.1 Mtonnes at the end of 2010 (Bioenergy International 2011). Capacities of individual plants ranged between a few small ones (<50 ktonnes), several medium sized ones (50-160 ktonnes), and one very large plant (500 ktonnes, GreenCircle, Florida). These plants typically utilize wood residues from the existing saw mills, except for the GreenCircle plant which utilizes roundwood from southern pine. In May 2011, one of the largest wood pellet plants in the world has started operation in Waycross, Georgia, with a capacity of 750 ktonnes per year – solely using SFM-certified southern pine roundwood as feedstock, and utilizing the bark to produce the required heat for drying. Also for the years to come, further plants are planned using southern yellow pine as feedstock, e.g. a 250 ktonnes plant planned to open early in 2012 in Western Alabama, expandable to 500 ktonnes, destined for export and domestic use (Westerveld 2011). Nevertheless, it is also likely that further woody residue streams will be utilized for wood pellet production as well. The US-based consultancy Forisk (Forisk Consulting 2011) estimates that in the coming 5 years, the total demand for wood as raw material for wood pellet production may rise from about 20 million (short & wet) tonnes in 2011 to about 30 million short tonnes in 2015. While the projected demand for 2011 is higher than current capacities, this still supports the projected rapid increase in production as assumed by Schouwenberg (2011) and de Wolff (2011).

Transport distances of the feedstock can be very low or not applicable (in case of integrated sawmill/wood pellet plants), but are probably typically 50 km on average. Wood pellets destined for export are mainly transported by (diesel powered) train to the harbour, in some cases also by boat. For example, the biggest plant in Waycross is about 160 km away from export harbour Savannah, where the pellets are transferred to ocean-going vessels at a dedicated terminal. Similarly, wood pellets are transported approximately 80 kilometres from the GreenCircle plant to the harbour of Panama city (Kortba, 2010). However, it is unlikely that future plants will also be situated so close to export harbours, so on average, a transport distance of 200 km by train is assumed.

4.3.3 North-West Russia[6]:

In the past years, the Russian wood pellet market was rather turbulent and erratic. Pioneer companies, which started the development of pellet production withdrew from the market several years ago. A second generation of pellet mills are also on the stage of closing or business diversification. The third generation of pellet plants, which are constructed on a base of big woodworking factories work stable.

Two big Russian wood pellet producers have about one third or even half of wood pellet export from Russia to Europe. These companies are “Dok Enisey” (from Krasnoyarsk region, Siberia) and Lesozavod-25 (from Archangelsk region, North-West Russia). Both companies export about 120-130 ktonnes per year. The third Russian operative big pellet mill is “STOD” (“Tallion-Terra”) from Tver region, with a production capacity of about 80 ktonnes per year of wood pellets. A number of companies from Karelia, Vologda and Leningrad regions produce each about 20-40 ktonnes per year and export the major part of it. Other pellet producers export less than 20 ktonnes per year and some mills sell only several tons of fuel pellets per year abroad. “Vologdabioexport” from Vologda region was one of the main pellet

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[6] Unless indicated otherwise, this section is based on Rakitova (2011).

producers in Russia and one of the biggest pellet exporters from Russia to Europe, but it stopped production in 2010, due to lack of raw materials.

New projects, such as “Swedwood Tikhvin” with a capacity of 75 ktonnes of pellets, are about to launch production in 2011. Also other large projects have been announced in the Leningrad region as well as in other regions. For example, the new company Russian Wood Pellets (RWP) plans to construct several pellet mills with a total capacity of 3 million tons of pellets per year.

For these wood pellet plants, it was assumed that sawdust is the (main) feedstock, that the average transport distance to a port (e.g. St. Petersburg for export to the EU) is 250 km, and that total exports volumes may reach 630 ktonnes before 2020.

However, the biggest plant by far (in fact the biggest plant in the world) is the recently commissioned Vyborgskaya wood pellet plant, situated close to the Finnish border, in the vicinity of St. Petersburg. This plant has a capacity of 900 ktonnes of wood pellets. According to Lesprom (2010), the raw material for pellets consists primarily of logs from Russia and Belarus, which is partly FSC-certified. The timber will be supplied to the plant by rail. The main port for export will be the Port of Vyborg and pellets will be transported the short distance from the factory by rail and truck. The raw material for pellets consists primarily of logs from Russia, and to a very small extent from Belarus, which is partly FSC-certified. The timber will be supplied to the plant by truck (about 50%, average transport distance assumed 250 km) and by barges (also 50%, average transport distance 300 km) (Granath, 2011, Lesprom, 2010). From the plant, the wood pellets can be shipped to the EU over the Baltic Sea.

4.3.4 North-East Brazil

Production capacity and feedstock: Up till 2011, no meaningful wood pellet production capacity in Brazil exists, and no wood pellets have been exported so far. However, according to several press releases (Sultana, Kumar et al. 2010; Suzano 2011), Suzano Papel e Celulose is negotiating with the Brazil's Alagoas state authorities about the construction of one million tonne wood pellet plant, requiring about 30,000 ha of eucalyptus plantations to deliver the feedstock. In the state of Alagoas, investments in eucalyptus plantations have been ongoing in recent years. Downey (2011) reports that two more plants may follow in 2018-2019. This is in contrast with the scenario given by de Wolff (2011), which assumes 3 million tonnes of wood pellet production from 2015 onwards. As the plant sites are not clear yet, it is difficult to estimate transport distances. Distances from plantations to the pellet mill are likely 50 km on average. The distance to a port is difficult to estimate, but as the state of Alagoas is not reaching further inland than 300 km and has a well-developed road-network, it seems reasonable to assume that average transport distances will not exceed 200 km.

4.3.5 Liberia

Next to the wood pellet imports described above, we also take into account imports of wood chips from western Africa. In April 2011, Swedish utility company Vattenfall AB has agreed to buy 1 million tons of woodchips sourced from Liberian rubber trees in a five year agreement. The company has estimated that it will need between 7 million and 8 million tons per year of biomass by 2020 to reach the target of a 40 reduction in hard coal usage. Vattenfall has sourced woodchips from Russia and the Baltic States that are primarily pine, but has expressed that the woodchips from the Liberian rubber trees will be more efficient. The company has made an agreement with Buchanan renewables. Buchanan works with rubber tree plantation owners in Liberia to clear old, unproductive rubber trees and replant with new stock. The cleared trees are then used for the production of high quality, low moisture wood chips. Current production levels are about 400,000 tons of wood chips per year, but it is estimated that Liberia has the potential to provide between 2 million and 3 million tons of wood chips every year. The wood chips are destined for Berlin, Germany, where Vattenfall intends to co-fire them in coal-fired power plants (Vattenfall 2011).

For the import scenarios, we assumed that up until 2020, one million tonnes of wood chips could become available for import to the EU. Based on the distribution of rubber tree plantations, we assumed that the trees are chipped on site, and then transported by truck to the harbour of Buchanan (average transport distance was assumed to be 150 km), and then shipped to the EU using Handy-size vessels. Norden (2011) reports that (part of the) shipping will take place in 24 cargoes of 25,000 tonnes each, with 4, 8 and 12 Handymax cargoes in 2011, 2012 and 2013, respectively.

As can be seen in Figure 4-1, the total potential available for import to the EU under the business as usual scenario may increase drastically from about 42 PJ in 2010 to over 270 PJ in 2020 – under all conditions as stated above. This scenario is based on existing projects, project currently being built and announced projects. Naturally, especially assumptions regarding the 2nd half of the decade become increasingly uncertain. For example, it is very uncertain whether the large-scale production of pellets from eucalyptus in Brazil will occur, and if the anticipated continued growth in wood pellets from pine wood can actually be sustained until 2020.

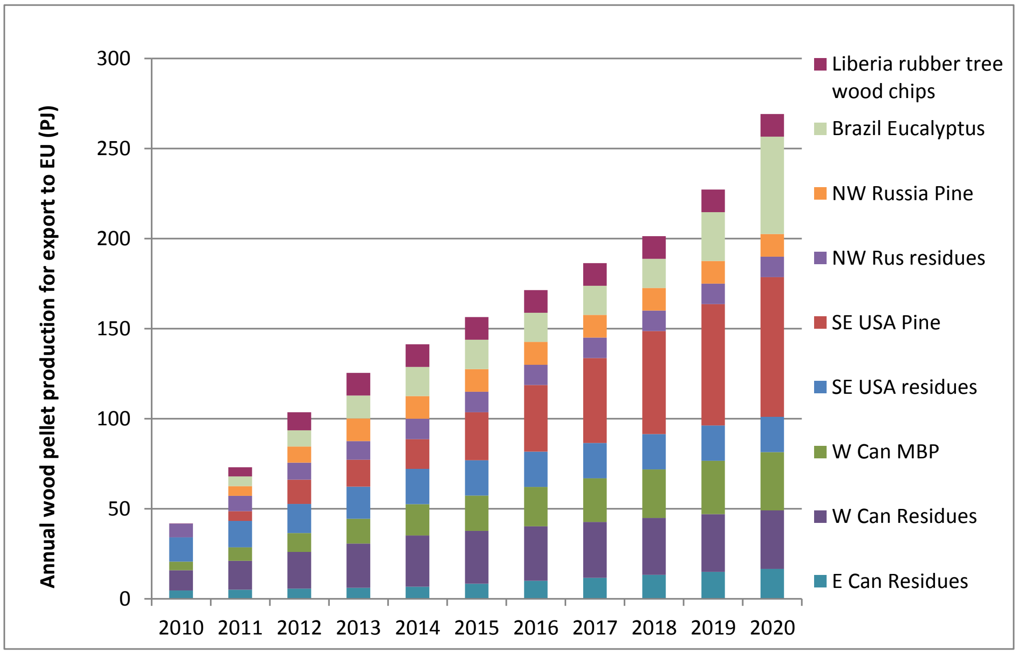

Figure 4-1 anticipated growth in available solid biomass supply from the various sourcing regions. residues = woody industry residues (e.g. sawdust), MPB = Mountain pine beetle affected wood.

4.4 The high import scenario

The scenario developed in the previous section is mainly based on industry expectations. The large utilities, which currently consume and (partially also produce) industrial wood pellets, are either obliged by national laws to adhere to sustainability criteria (e.g. utilities in Belgium, and recently also the UK), or already adhere to voluntary sustainability criteria (e.g. RWE Essent). It can be argued that the scenario described in the previous section is a "Business as Usual" scenario, but it can also be argued that these developments will only happen under the general expectation that mandatory sustainability criteria will be introduced.

In this section, we describe an alternative (or better complementary) high import scenario, in which we assume that demand for wood pellets in the EU and abroad increases rapidly, triggering investments in additional wood pellet plants based on feedstock from new plantations using short rotation crops. We base this high import scenario on the following assumptions:

- We assume that short rotation woody energy crops will likely be established in the same regions as currently pulp plantations are established. Based on the selection criteria mentioned in the previous bullet point, Brazil is by far the country with the largest expanding pulp sector. At the end of 2009, the forecasts expected a capacity expansion of almost 8 million tonnes per year (Pulpmill watch 2011). Other countries would be Uruguay (3 million tonnes/year) and South Africa (almost 600,000 tonnes/year).
- Additionally, it is quite possible that new plantations will be established in the western cost countries of Sub-saharan Africa such Liberia, Sierra Leone and Ghana. These regions have been in the news lately mainly with regard to projects for biofuel production (e.g. a 57,000 ha project in Sierra Leone for the production of ethanol (Johnson 2011), it is deemed reasonable to assume that these countries may also produce woody biomass for export (see also AfricaInvestor (2011)).
- Finally, it is also possible that (given the geographic vicinity) additional roundwood from Russia may be used for energy purpose. Especially under the current export tax system, it is plausible that additional roundwood is harvested for wood pellet production.
- We do not assume any imports from Asia. Up until 2020, a deficit of woody biomass (for timber, pulp and paper and energy) is mainly expected in the EU and in South East Asia (Gizot 2010). We furthermore assume that within the next decade all regions/countries bordering the Atlantic will export mainly to the EU, whereas all regions bordering the Indian and Pacific Ocean will export to East Asia, mainly Japan and Korea (Gizot 2010). Also, according to 2009 statistics, CEPI countries (i.e. 17 EU countries and Norway) exported a net amount of 1.6 million tonnes of pulp (CEPI 2011), so it is deemed rather unlikely that in the future, wood for energy would be traded from South East Asia to the EU.

Based on these assumptions, we postulate the following import flows:

- Brazil rapidly increases production of (additional) short-rotation (i.e. 2-3 years) eucalyptus plantations from 2014 onwards to produce 2 million tonnes of wood pellets in each of the following states: Bahia, Rio Grande do Sul and Minas Gerais.
- Similarly, in Uruguay, 2 million additional tonnes are produced from eucalyptus plantations.

- In the Western African countries of Liberia, Sierra Leone, Cote d'Ivoire and Ghana, it is assumed that a total of 3 million tonnes of wood pellets will be produced by 2020 from fast growing plantations.
- Finally, it is assumed that up to 3 million tonnes of wood pellets may be sourced from (managed or unmanaged) forests in North-west Russia.

These assumptions lead to an additional amount of 14 million tonnes of wood pellets in 2020, bringing the total to 28 million, i.e. roughly twice as much as assumed in the low-import BaU scenario. Figure 4-2 shows the anticipated growth in available solid biomass supply from the various sourcing regions in the high import scenario from 2010 (1) tot 2020.

Note that the assumptions of the amounts is to some extent arbitrary, but reflects the current dominant position of Latin America, the expected rise of Sub-Saharan production potential, and the large (existing) potential from standing forests is North-West Russia. While all developments are not deemed unrealistic, they are *highly speculative*, and would depend amongst others on a strong demand for solid biomass in the EU, and (very) rapid investments in the sourcing areas.

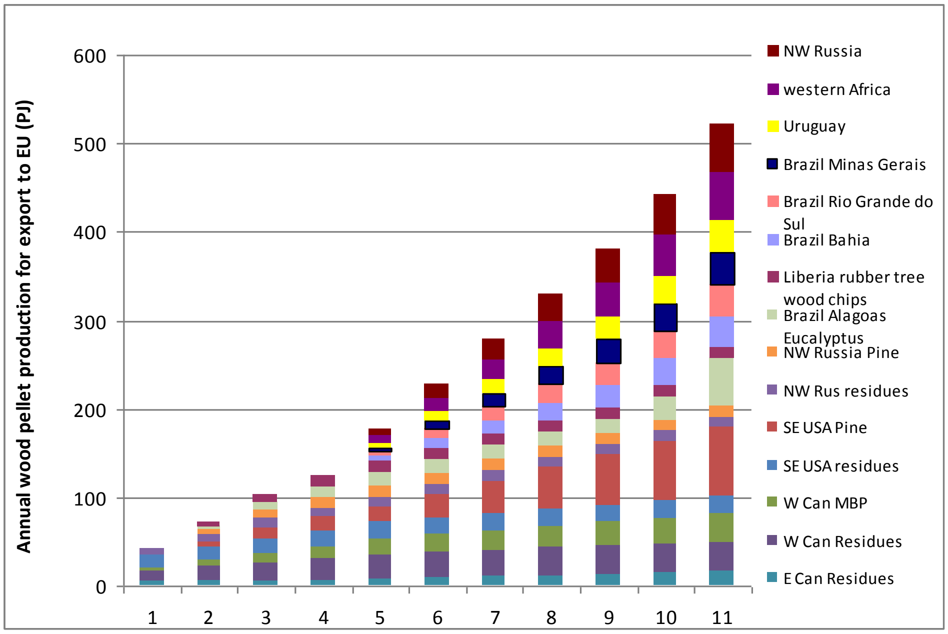

Figure 4-2 Anticipated growth in available solid biomass supply from the various sourcing regions in the high import scenario from 2010 (1) tot 2020 (11).

5 Results

This section covers a discussion of the results of the transport model (0) and the impact of the transport model assumptions and exogenous assumptions on non-EU imports on total inter- and intra-European future trade flows of biomass for bioenergy purposes as projected with GREEN-X (5.2). The emphasis in this section is on biomass trade rather than transport costs because these are already discussed in more detail in the Re-Shaping D12 report (Hoefnagels et al. 2011).

5.1 Transport cost

The results of the biomass logistics model include country to country tables for all 27 EU member states and all tradable solid biomass commodities for every 5 years up to 2030. These results are integrated in the GREEN-X model. To provide an indication of the cost premiums in the GREEN-X model, Table 5-1 shows the averages cost and the ranges for all EU member states. To demonstrate the detailed results of the transport model and the cost implications of biomass pre-treatment and transport, Figure 5-1 through Figure 5-4 show the total supply cost to supply either wood chips or wood pellets from short rotation willow crops for the largest importing countries in the scenarios (Germany, the UK, the Netherlands and Austria) (Figure 5-6).

Cost ranges for tradable, lignocellulosic biomass commodities range from 3 €/GJ for forestry residues transported as wood chips to 24 €/GJ for wood pellets from short rotation coppice (willow) in 2020. These large differences are the result of feedstock cost at farm gate (3 €/GJ for forestry residues in 2010 to 13 €/GJ for SRC willow crops in 2030) and the additional cost for transport over long distances and/or pelletization. The extremely expensive supply chains are, however, unlikely to be used in any scenario.

The results in Table 5-1 and Figure 5-1 and Figure 5-2 show that it is the additional cost for densification of wood chips to pellets, is not economically effective if biomass is transported within Europe. As all biomass imported to the UK has to be transported via sea, most of the additional cost are related to short sea shipping, but also a major part has to be shipped to a sea port first, mainly via road or inland waterways. For Germany, its relatively short distance to large export countries such as Poland result in a less steep cost-supply potential of European resources compared to the UK. Because Austria is a land-locked country, the main transport modes include road and inland waterways (the Danube River) (Figure 5-4). The Netherlands (Figure 5-3) and the UK (Figure 5-2) show similar cost supply curves as both countries are able to import a large quantity via short sea shipping routes.

Table 5-1 Aggregated ranges of the total supply cost (€/GJ) for the EU-27, based on the detailed tables integrated in the GREEN-X model.

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	9	8 - 10	0.4	0.2 - 1.4	13	9 - 19
		2020	12	10 - 12	0.5	0.2 - 1.4	16	11 - 22
		2030	13	12 - 14	0.5	0.2 - 1.5	18	13 - 24
	Pellets	2010	9	8 - 10	3.4	3.0 - 4.4	14	10 - 18
		2020	12	10 - 12	3.5	3.1 - 4.6	17	12 - 21
		2030	13	12 - 14	3.6	3.2 - 4.7	19	12 - 24
FP1 (forestry products - current use (wood chips, log wood) and FP2 (forestry products - complementary fellings (moderate))	Chips	2010	6	5 - 7	0.4	0.2 - 1.4	10	6 - 16
		2020	7	6 - 8	0.5	0.2 - 1.4	11	7 - 17
		2030	8	7 - 9	0.5	0.2 - 1.5	12	8 - 18
	Pellets	2010	6	5 - 7	3.4	3.0 - 4.4	11	9 - 15
		2020	7	6 - 8	3.5	3.1 - 4.6	13	10 - 17
		2030	8	7 - 9	3.6	3.2 - 4.7	14	11 - 18
FP3 (forestry products - complementary fellings (expensive))	Chips	2010	9	7 - 9	0.4	0.2 - 1.4	13	9 - 18
		2020	10	9 - 11	0.5	0.2 - 1.4	14	10 - 20
		2030	11	10 - 12	0.5	0.2 - 1.5	16	11 - 21
	Pellets	2010	9	7 - 9	3.4	3.0 - 4.4	14	10 - 18
		2020	10	9 - 11	3.5	3.1 - 4.6	16	12 - 20
		2030	11	10 - 12	3.6	3.2 - 4.7	17	12 - 21
FR2 (forestry residues - current use) and FR3 (forestry residues - additional)	Chips	2010	3	2 - 5	0.4	0.2 - 1.4	7	3 - 14
		2020	4	2 - 6	0.5	0.2 - 1.4	8	3 - 15
		2030	5	3 - 7	0.5	0.2 - 1.5	9	4 - 16
	Pellets	2010	3	2 - 5	3.4	3.0 - 4.4	9	6 - 13
		2020	4	2 - 6	3.5	3.1 - 4.6	9	6 - 15
		2030	5	3 - 7	3.6	3.2 - 4.7	10	7 - 15
FR5 (additional wood processing residues (sawmill, bark)	Pellets[4]	2010	5	4 - 5	2.9	2.5 - 3.9	9	7 - 13
		2020	6	5 - 6	3.1	2.7 - 4.1	10	8 - 14
		2030	6	5 - 7	3.2	2.8 - 4.3	11	9 - 15

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).

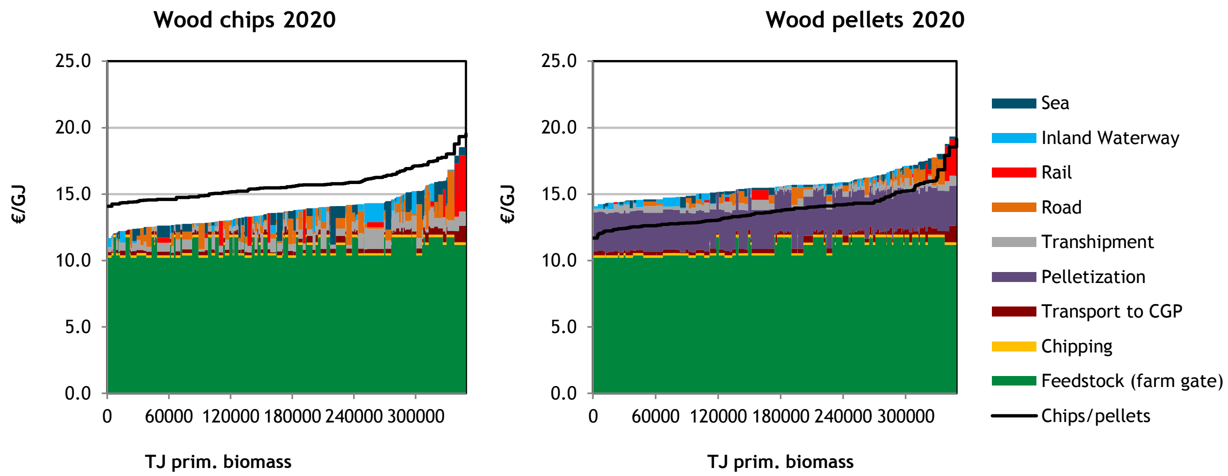

Figure 5-1 Total supply cost of SRC willow crops from EU countries supplied to Germany in 2020.

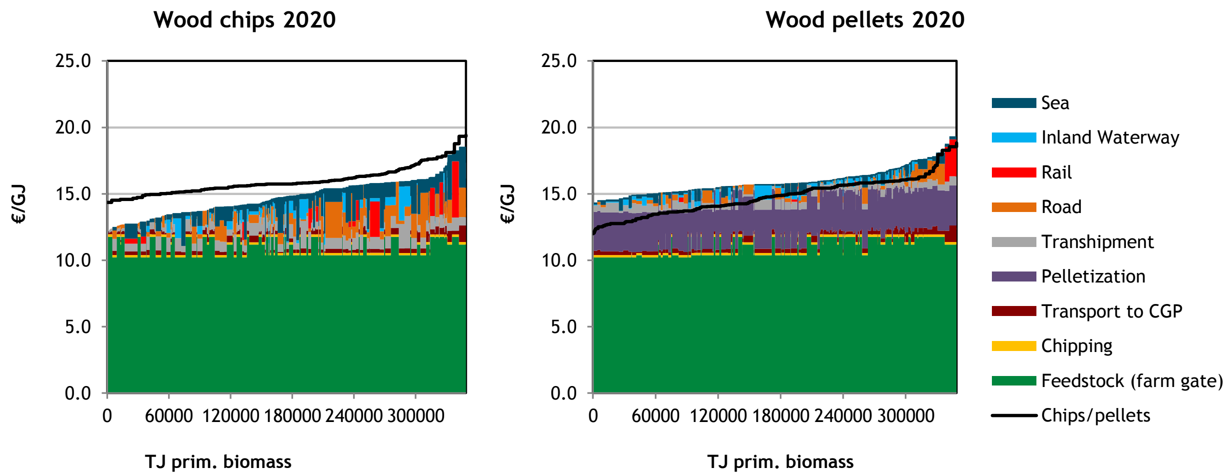

Figure 5-2 Total supply cost of SRC willow crops from EU countries supplied to the United Kingdom in 2020.

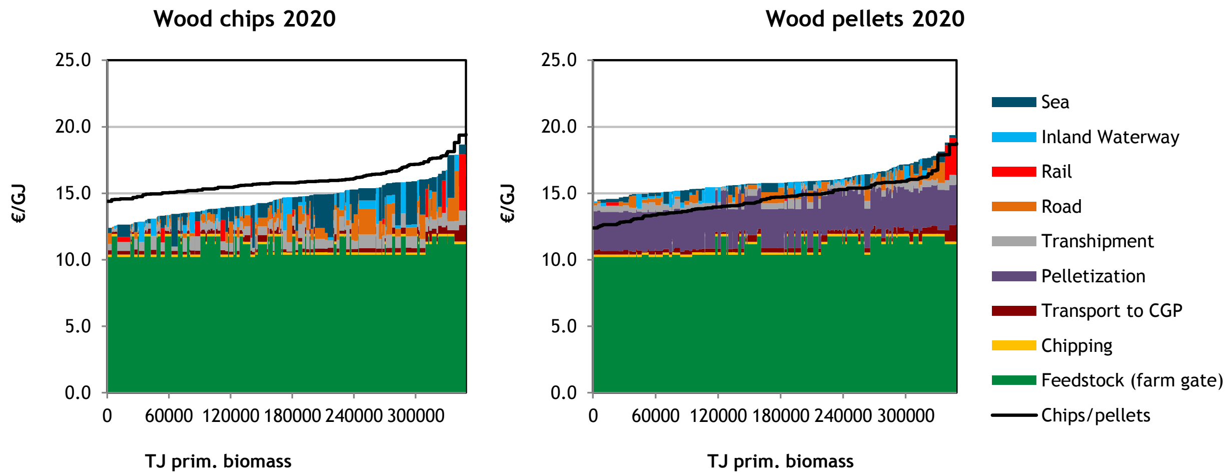

Figure 5-3 Total supply cost of SRC willow crops from EU countries supplied to the Netherlands in 2020.

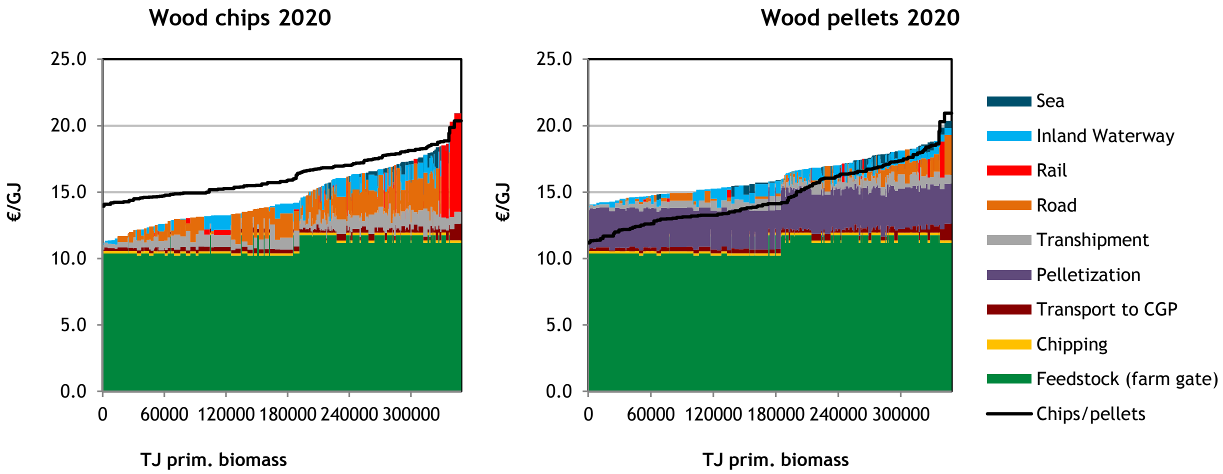

Figure 5-4 Total supply cost of SRC willow crops from EU countries supplied to the Austria in 2020.

5.2 Impact of transport cost on trade flows

Figure 5-5 shows the net domestic consumption and the sources of bioenergy used per country for electricity, heat and biofuels in the Low Import and High Import scenario in 2020 whereas Figure 5-6 shows the same results only for biomass that is traded beyond borders. Exports to other EU-countries are shown as negative bars. Domestic consumption is largest in France (25.9-26.4 Mtoe) followed by Germany (22.7-23.6 Mtoe) and Poland (13.0-13.1 Mtoe). Of these countries, only Poland is a net exporter of bioenergy commodities (2.6 to 2.9 Mtoe in the High Import and Low Import scenario respectively) (Figure 5-6). Other major exporting countries include Estonia (0.6 - 0.8 Mtoe in the High Import and Low Import scenario respectively), Hungary (0.4-0.5 Mtoe) and Slovakia (0.4 Mtoe). Countries with the largest intra-European biomass imports include Germany, the UK, the Netherlands and Austria. Countries with the largest inter-European biomass imports include Germany, followed by Italy, the UK and the Netherlands. In the Low Import scenario, Germany is projected to import 3.8 to 5.2 Mtoe of biomass, of which 47% and 30% is soured from other EU countries in the Low Import and High Import scenario respectively. Despite the reduced import potential of non-EU biomass, domestic production in Germany increases with 14 % relative to the High Import scenario, resulting in an overall increased use of biomass in the Low Import scenario. In countries that have limited domestic potential to compensate for reduced non-EU imports, e.g. the Netherlands or the UK, the total demand for bioenergy decreases relative to the High Import scenario.

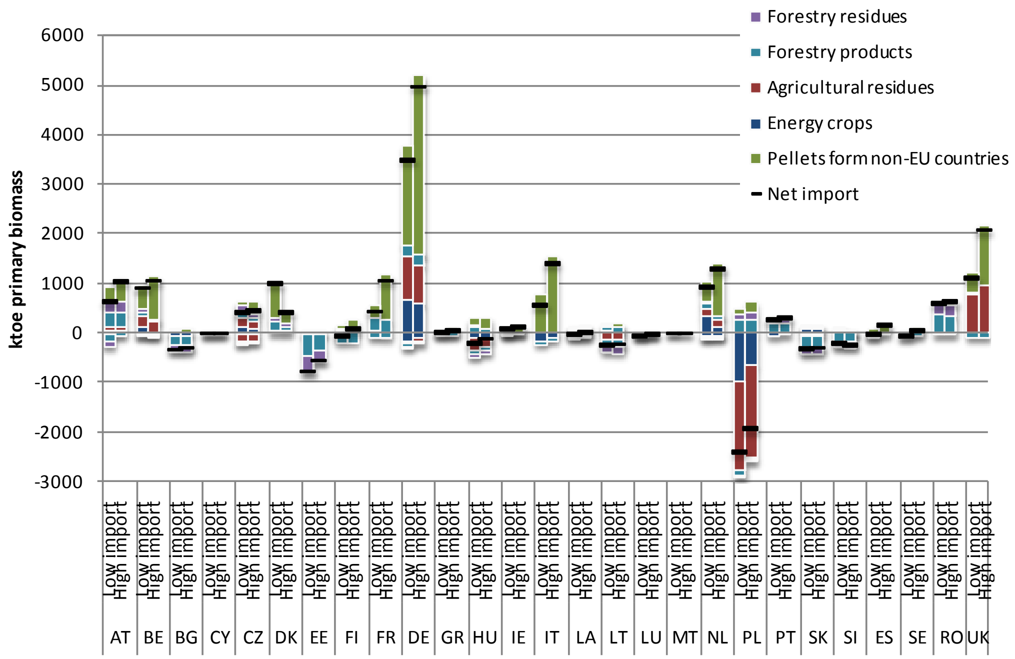

Figure 5-5Net import, export and domestic consumption of biomass for heat, electricity and biofuels in the Low Import and High Import scenario in 2020. Excluding non-tradable commodities (waste, black liquor, biogas). Export is shown as negative.

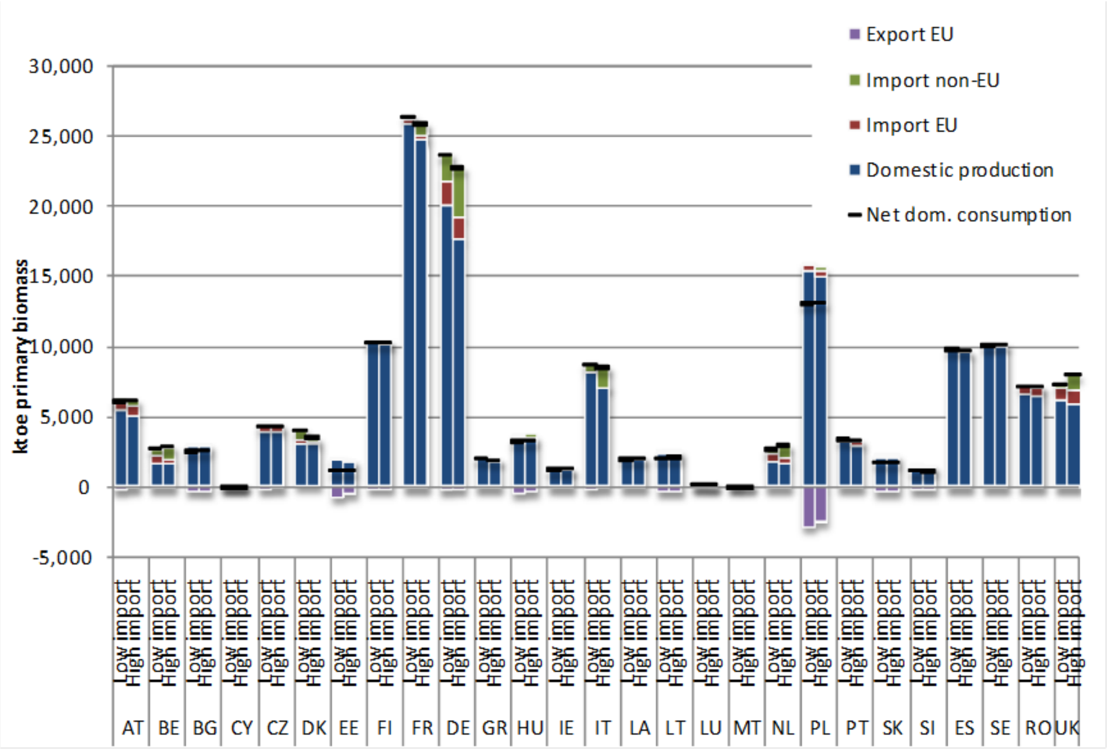

Figure 5-6 Import, export and net import of biomass from EU and non-EU countries in the Low Import and High Import scenario for 2020 per commodity type. Export is shown as negative.

The trade flows of all lignocellulosic biomass commodities in the scenarios are also visualized for the Low Import scenario in Figure 5-7 (2015) and Figure 5-8 (2020). The same graphs are provided for the High Import scenario in Figure 5-9 (2015) and Figure 5-10 (2020). Because Inter-European trade is relatively large compared to intra-European trade flows in these scenarios, the results are also shown for intra-European trade flows only in Figure 5-11 (Low Import, 2020) and Figure 5-12 (High Import, 2020). Note that the absolute size of these trade flows cannot be compared to Figure 5-7 through Figure 5-10 because the absolute amounts of trade are not consistent with the flow sizes in the other figures. For visual reasons, some countries are grouped into trade regions in these figures (Table 5-2).

Table 5-2 Grouped and individual countries in the trade flows depicted in Figure 5-7 to Figure 5-12.

Grouped countries		Individual countries	
1	Austria, Slovenia	12	Finland
2	Baltic States (Estland, Latvia, Lithuania)	13	France
3	Benelux (Belgium, the Netherlands, Luxembourg)	14	Germany
4	Czech Republic, Slovakia	15	Hungary
5	Greece, Cyprus	16	Poland
6	Ireland, United Kingdom		
7	Italy, Malta		
8	Romania, Bulgaria		
9	Spain, Portugal		
10	Sweden, Denmark		
11	non-EU countries (inter-EU imports)		

The results of biomass trade, as depicted in Figure 5-7 to Figure 5-12, show that even in the Low Import scenario, for most countries imports of wood pellets from non-EU imports dominate the trade markets. Nevertheless, there are some major intra-European trade flows in the results of both scenarios. These include exports from Poland to Germany, the UK and the Benelux countries. A significant difference between the Low Import Scenario and the High Import scenario is that Poland will export less biomass to the Benelux in the Low Import scenario, but more biomass to Germany and the UK. Germany, France and Spain, on the other hand, import more biomass to the Benelux countries in the Low Import scenario (Figure 5-11 and Figure 5-12).

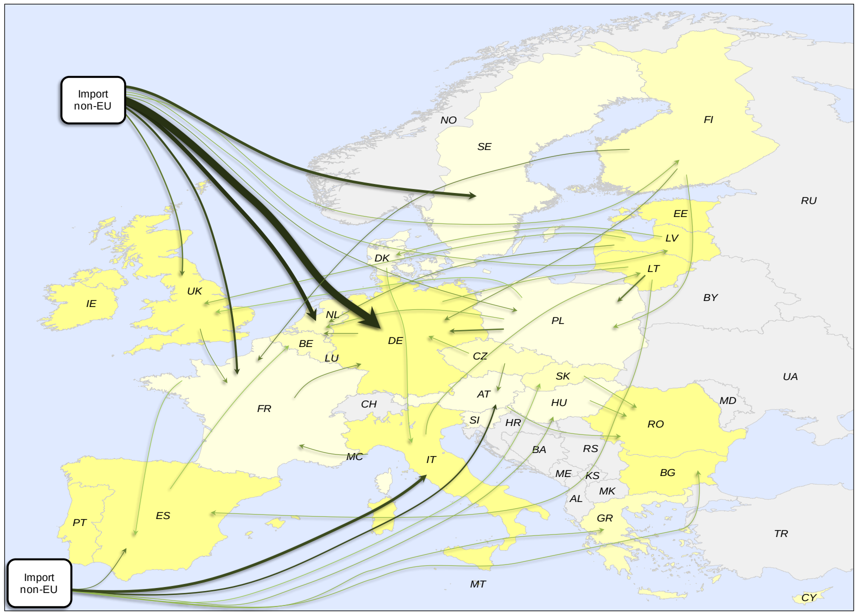

Figure 5-7 Biomass trade flows in the Low Import scenario 2015.

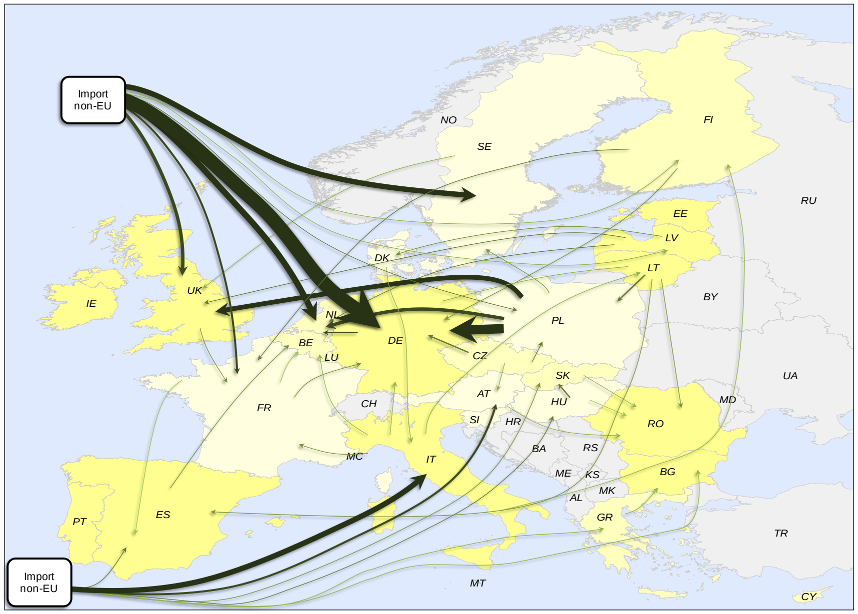

Figure 5-8 Biomass trade flows in the Low Import scenario 2020.

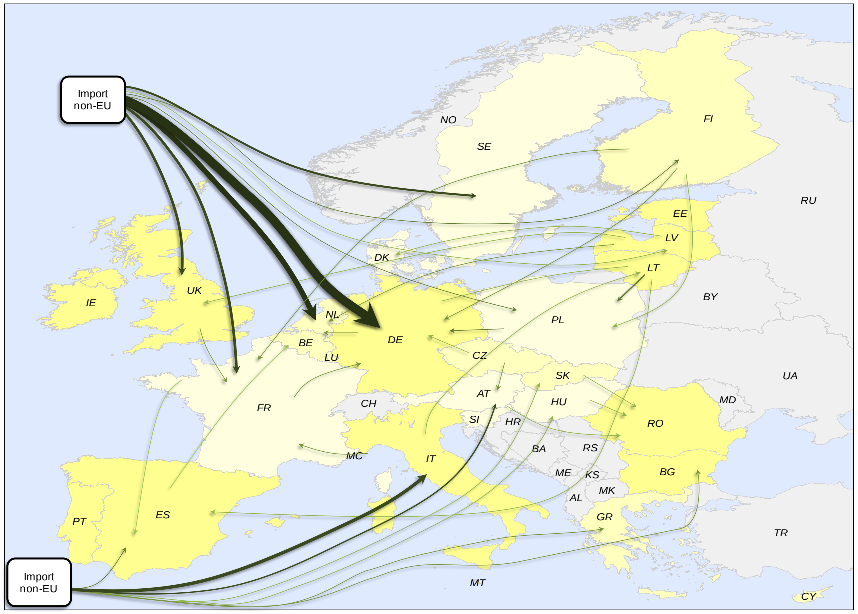

Figure 5-9 Biomass trade flows in the High Import scenario 2015

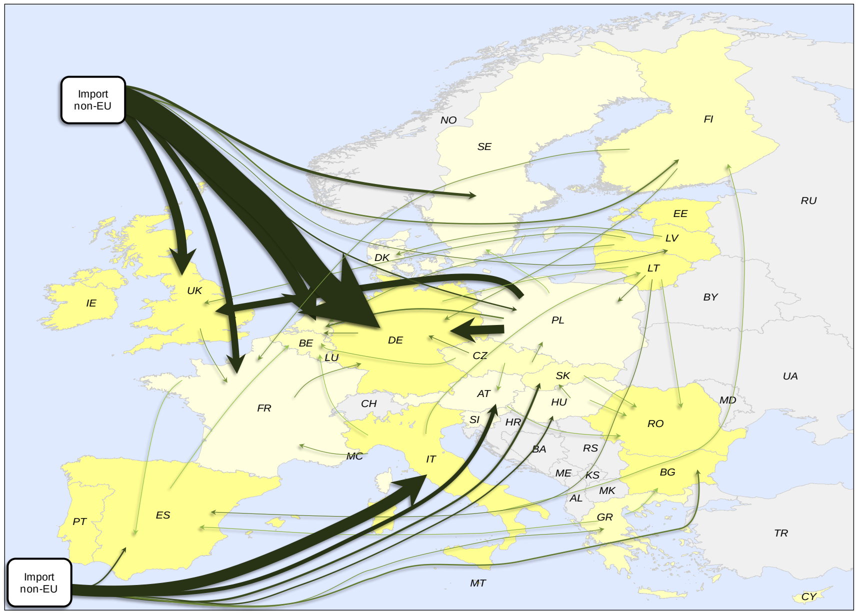

Figure 5-10 Biomass trade flows in the High Import scenario 2020

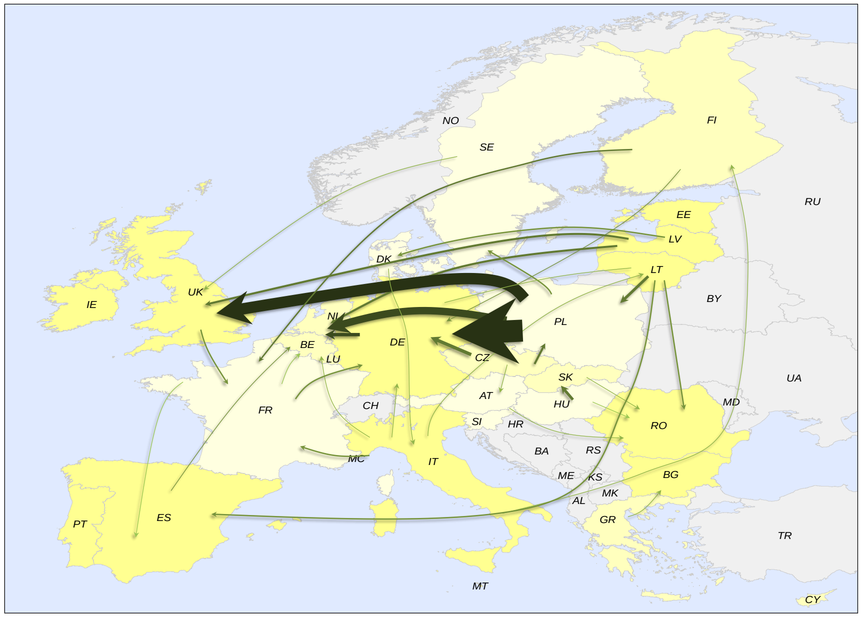

Figure 5-11 Biomass trade flows in the Low Import scenario 2020, only showing intra-European trade flows.

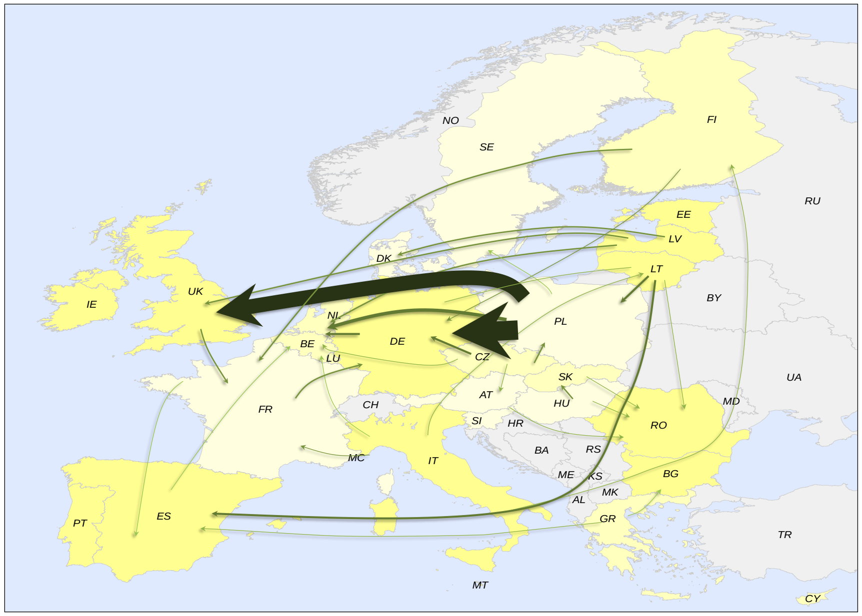

Figure 5-12 Biomass trade flows in the Low Import scenario 2020, only showing intra-European trade flows.

6 Discussion

This report investigated the potential economic implications of logistic supply chains and impact on potential future trade flows for bioenergy including forestry products, forestry residues, short rotation coppice and agricultural residues (straw). This has been done by means of geospatial explicit modelling of intermodal logistic chains in ESRI ArcGIS combined with scenario assumptions on Inter-European imports of wood pellets. The results were integrated in the renewable energy model GREEN-X to assess the impact of biomass supply cost on the potential of biomass for electricity, CHP and heat in context of a competitive renewable energy portfolio including wind, PV and hydropower and the renewable energy targets of the European Commission up to 2020.

The results of this assessment show major increases in trade flows of bioenergy commodities in the scenarios up to 2020. Because most EU member states did not include imported trade flows in their National Renewable Action Plans, it is not possible to compare the results of this study directly to the projections in these documents. If the total demand for bioenergy and the estimated gap between domestic supply and demand (Figure 2-4) are taken as a proxy for biomass imports, key importing countries in the NREAP projections would include countries that are also key importing countries in the Low Import and High Import scenarios of this study such as Belgium, Germany and the Netherlands. Other countries, including the Romania and the UK that are importing countries in the GREEN-X projections, would be able to use domestic biomass for the total demand of biomass for bioenergy. The most important difference between the NREAPs and the GREEN-X scenario projections in this study is the supply potential and estimated demand for Poland. In the GREEN-X scenario projections, Poland is the largest exporting region of biomass within Europe (44-45% of intra-European biomass trade in 2020) including mainly pellets from agricultural residues. In the NREAP of Poland, the demand for bioenergy is higher than the estimated supply potential which would imply that Poland would have to import biomass. Recent unconfirmed market signals in Poland also indicate that it might become a large importing country of wood pellets. The supply potential in the GREEN-X database might therefore be too optimistic.

The trade flows, as projected by the energy model GREEN-X, are mainly determined by the supply cost of bioenergy commodities. These cost estimates are 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 discussion therefore focuses on these parameters, the related impacts on the results and potential improvements to the model.

Feedstock costs in the results of study are 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, supply of wood pellets for district heating in Sweden (from domestic sources) was estimated to be 12% (of 109 €/t) (Sikkema, Junginger et al. 2010). This study estimates the supply cost of wood pellets from similar feedstocks (wood processing residues) in the EU-27 delivered to Sweden to be 6.9 to 12.5 €/GJ (127 to

235 €/t). If, however, similar feedstock prices would be assumed to Sikkema, Junginger et al. (2010) (37.6 €/t pellets), the supply cost would be in similar ranges (89 to 182 €/t in this study).

Apart from feedstock cost, also fluctuating **currency exchange rates** between e.g. Euros and Canadian or US dollars, Swedish Krona and Russian Rouble result in differences in import prices. These relative variations were not considered in this study because all cost parameters in GREEN-X are expressed in 2006 euros. Note however that recent changes in exchange rates had a major impact on pellet prices and transport cost (Sikkema, Steiner et al. 2011). Extensive sets of sensitivity analysis in the transport model and GREEN-X could provide insight in the impact of exchange rates. This was, however, beyond the scope of this study.

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 assumed to be country specific. All other factors, including the GHG performance and cost of electricity supply per country were based on European averages.

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.

7 Conclusion

This report investigated the potential of future intra- and inter-European trade of solid biomass for bioenergy purposes taking country to country specific intermodal transport routes into account and matching supply and demand for energy crops, forestry products and residues and agricultural residues. 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 transshipment between these modalities. The results of the ArcGIS model were integrated in the transport extended renewable energy model GREEN-X and combined with two scenarios on import potential scenarios of biomass from non-EU countries, a Low Import and High Import scenario.

The approach applied provides useful insights in potential trade routes, key supply regions and key demand regions in Europe and potential cost implications for bioenergy production taking logistic implications of biomass from farm gate to supply destinations into account. Because biomass is becoming a major tradable energy commodity, representing bioenergy trade is of key importance to energy models that include renewable energy as no (European) country is limited to national resources.

Main results of the transport model 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% (9 €/GJ) of the total supply cost (19 €/GJ) in the case of SRC crops and up to 75% (9 €/GJ) of the total cost (12 €/GJ) 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% (7 €/GJ) of the total supply cost (13 €/GJ) in the case of forestry residues and 30% (6 €/GJ out of 17 €/GJ) 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. It should be noted however that the model does not take possible end-user requirements and preferences into account.

Based on this assessment of the NREAPs for bioenergy production and supply of biomass to meet the required inputs for heat and electricity, we conclude that it was not possible to directly translate the NREAP roadmap data into scenarios for GREEN-X for the following reasons:

- The quality of the NREAPs varies between MS. Whereas MS states provide thorough overview of the roadmap to 2020, some other MS provide too little information or include too many inconsistencies in the data and information provided to translate in modelling scenarios;
- Some of the choices might be political and do not reflect optimal or realistic pathways for the deployment of RES-technologies.

Therefore, supply potentials of biomass were based on the GREEN-X database combined with High Import and Low Import scenarios of non-EU biomass to meet the EU renewable energy targets up to 2020.

With respect to the results of the GREEN-X Low Import and High Import scenario, the main results are:

- Total bioenergy intra-European biomass trade increases to 6,560 ktoe in 2020 in the Low Import scenario and 5,640 ktoe in the High Import scenario. This would be equivalent to 13 to 15 million tonne wood pellets (18 GJ/tonne).
- Inter European imports of wood pellets and wood chips are almost used to their full potential in 2020 with 5,990 ktoe in the Low Import scenario and 11,740 ktoe in the High Import scenario which is more than double the amount of Intra European biomass trade in this scenario and equivalent to 27 million tonne pellets.
- Key exporting regions within Europe are in both scenarios Poland, Estonia, Hungary and Slovakia. Poland is projected to export 2,565 (High Import) to 2,880 ktoe (Low Import) which covers 44 to 45% of total intra-European trade flows in 2020. Estonia (10%-12% of total intra-European trade), Hungary and Slovakia (7-8% of total intra-European trade) export significantly less compared to Poland in both scenarios in 2020. Key importing regions of intra-European biomass trade include Germany, the UK, the Netherlands and Austria. Key importing regions of inter-European biomass trade include Germany, Italy, the UK and the Netherlands.
- The difference between the Low Import and High Import scenario shows the impact of inter-European trade on intra-European trade. If lower imports are assumed, the increased marginal cost of domestic European resources results in increased production of energy crops in Germany and reduced imports. Other countries, such as the UK and Benelux countries, import more biomass from EU countries (mainly Poland).

These results demonstrate the potential of the modelling framework developed to model biomass trade flows. It should be noted however that the two scenarios modelled in this project are for demonstration of the models only and are not sufficient to draw any conclusions on implications of policy processes or export potentials of different countries. Such analysis would at least require a broader set of scenarios and sensitivity runs that were not conducted within this project. It is therefore also not possible to draw reasonable conclusions by comparing the results of this study with the results of the NREAPs.

Finally, it is concluded that further development of the modelling tool is required. These include:

- Improvement of input parameters to the transport model including logistic processes such as transhipment and the amounts of empty returns and capacity loads of transport modalities. For example, trains do return empty from Eastern European countries to Western European countries and could support optimized supply routes for bioenergy (from East to West). More insight is however required in these logistic processes that requires more information on transport sectors and related activities.

- 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 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 model is currently being updated to include long distance maritime shipping and links to other continents (North America). These updates will allow for consistent modelling of both inter and intra-European trade flows.

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Appendix I

Estimation of primary bioenergy requirements based on final energy projections for heat and electricity in the NREAPs

The total primary biomass requirement for electricity and heat is calculated as the sum of solid, gaseous and liquid biomass requirements for electricity, heat and combined heat and power (CHP) (eq. A-1):

$$B_{req} = B_e + B_{CHP} + B_H \qquad \text{eq. A-1}$$

Where:

- B_{req} : total primary biomass requirement (electricity, heat)
- B_e : total primary biomass requirement for electricity plants
- B_{CHP} : total primary biomass requirement for CHP plants (all biomass allocated to electricity generation)
- B_H : total primary biomass requirement for heat plants (district heating, industry and households)

In which the total biomass requirement for electricity from electricity and CHP plants is calculated as follows:

$$B_e = E_{e,\,solid} / \eta_{e,\,solid} + E_{e,\,liquid} / \eta_{e,\,liquid} + E_{e,\,biogas} / \eta_{e,\,biogas} \qquad \text{eq. A-2}$$

$$B_{CHP} = E_{CHP,\,solid} / \eta_{CHP,\,solid} + E_{CHP,\,liquid} / \eta_{CHP,\,liquid} + E_{CHP,\,biogas} / \eta_{CHP,\,biogas} \qquad \text{eq. A-3}$$

Where:

- $E_{e,\,solid}$: gross electricity generation electricity plants (solid, liquid or biogas)
- E_{CHP} : gross electricity generation CHP plants (solid, liquid or biogas)
- η_e : electric efficiency electricity plant (solid, liquid or biogas)
- η_{CHP} : electric efficiency CHP plant (solid, liquid or biogas)

All biomass required for CHP plants is allocated to electricity generation. The amount of heat from CHP plants is calculated as shown below (formulas A-4 to A-6):

$$H_{CHP,\,solid} = E_{CHP,\,solid} * \eta_{H,\,CHP,\,solid} \qquad \text{eq. A-4}$$

$$H_{CHP,\,liquid} = + E_{CHP,\,liquid} * \eta_{H,\,CHP,\,liquid} \qquad \text{eq. A-5}$$

$$H_{CHP,\,biogas} = E_{CHP,\,biogas} * \eta_{H,\,CHP,\,biogas} \qquad \text{eq. A-6}$$

Where:

- H_{CHP} : heat produced from CHP plants (solid, liquid or biogas)
- $\eta_{H,\,CHP}$: heat efficiency CHP plants (solid, liquid or biogas) (unit of heat/unit of primary biomass)

Heat from commercial stand-alone plants (industry and district heating) is calculated with formulas A-7 through A10:

$H_{DH+ind,\ solid} = H_{gross,\ solid} - H_{households,} - H_{CHP,\ Solid}$ eq. A-7

$H_{DH+ind,\ liquid} = H_{gross,\ liquid} - H_{CHP,\ liquid}$ eq. A-8

$H_{DH+ind,\ biogas} = H_{gross,\ biogas} - H_{CHP,\ biogas}$ eq. A-9

If $H_{DH+ind,\ solid/liquid\ or\ biogas} < 0$, $H_{DH+ind,\ solid/liquid\ or\ biogas} = 0$ eq. A-10

Where:

- H_{DH+ind} : heat from district heating and industry (solid, liquid or biogas)
- H_{gross} : gross heat generation (solid, liquid or biogas) (from table 11)
- $H_{households}$: gross heat generation households (assumed all solid biomass) (from table 11)

Biomass required for all stand-alone heat plants (district heating, industry, households) is calculated with formulas A-11 through A-15:

$B_{H,\ DH+ind,\ solid} = H_{DH+ind,\ solid} / \eta_{H,\ DH+ind,\ solid}$ eq. A-11

$B_{H,\ DH+ind,\ liquid} = H_{DH+ind,\ liquid} / \eta_{H,\ DH+ind,\ liquid}$ eq. A-12

$B_{H,\ DH+ind,\ biogas} = H_{DH+ind,\ biogas} / \eta_{H,\ DH+ind,\ biogas}$ eq. A-13

$B_{H,\ households} = H_{households} / \eta_{H,\ households}$ eq. A-14

$B_{H} = B_{H,\ DH+ind,\ solid} + B_{H,\ DH+ind,\ liquid} + B_{H,\ DH+ind,\ biogas} + B_{H,\ households}$ eq. A-15

Where:

- $B_{H,\ DH+ind}$: biomass required for district heating and industry (solid, liquid or biogas)
- $B_{H,\ households}$: biomass required for heating in households (assumed all solid biomass)
- $\eta_{H,\ DH+ind}$: heat efficiency district heating and industry
- $\eta_{H,\ households}$: heat efficiency households

The efficiencies assumed in Table 0-1 are based on the efficiency ranges of the technology characterization in GREEN-X. For this report, it was simply assumed that the lower bound of the efficiencies represents 2005 and the highest represents 2020. The efficiencies for 2010 and 2015 are interpolated from the assumed efficiencies of 2005 and 2020. Note that in GREEN-X, the efficiencies of biomass conversion depends on the scenarios and related substitution speed and replacement types of biomass electricity, heat and CHP plants.

Table 0-1 Assumed efficiencies for 2010 - 2020 (based on Green-X technology database)

Year	$\eta_{e\text{ (stand alone), solid}}$	$\eta_{e\text{ (stand alone), biogas}}$	$\eta_{e\text{ (CHP), solid}}$	$\eta_{e\text{ (CHP), biogas}}$	$\eta_{\text{CHP solid}}$	$\eta_{\text{CHP biogas}}$	$\eta_{\text{H,DH+ind}}$	$\eta_{\text{H, households}}$
2010	28%	31%	19%	29%	63%	54%	87%	81%
2015	29%	32%	20%	31%	63%	56%	87%	84%
2020	30%	34%	21%	33%	64%	57%	87%	87%

Appendix II

Country specific parameters in the biomass transport model

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