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DOI

[10.1016/j.rser.2017.04.108](https://doi.org/10.1016/j.rser.2017.04.108)

Publication date

2017

Document Version

Final published version

Published in

Renewable & Sustainable Energy Reviews

Citation (APA)

Dafnomilis, G., Hoefnagels, R., Pratama, Y. W., Schott, D. L., Lodewijks, G., & Junginger, M. (2017). Review of solid and liquid biofuel demand and supply in Northwest Europe towards 2030: A comparison of national and regional projections. *Renewable & Sustainable Energy Reviews*, 78, 31-45.
<https://doi.org/10.1016/j.rser.2017.04.108>

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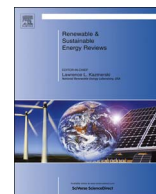
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Review of solid and liquid biofuel demand and supply in Northwest Europe towards 2030 – A comparison of national and regional projections



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ARTICLE INFO

Keywords:

Biomass
Bioenergy
Biomass trade
Biomass imports
Northwest Europe

ABSTRACT

Biomass is the largest source of renewable energy carrier in the European Union (EU) contributing to over 60% of renewable energy, with the majority of supply coming from domestic sources. However, an increasing significant amount of feedstock is imported, either due to domestic undersupply or higher production costs within the country. This article provides an up-to-date view of bioenergy supply, demand and trade in Northwest Europe to 2030. Projections of the energy system model Green-X are compared to recent national studies concerning bioenergy imports. The results show that there is a sizeable gap of the projection bandwidths after the 2020 horizon. Projections might under- or overestimate biomass potential in certain cases, depending on whether they are derived from national reports or regional models, whether future policy developments were taken into account etc. The ranges of biomass consumption are multiple times apart by 2020 already, and the gap increases by 2030. Total biomass imports in the region can range between 14 and 44.3 Mt by 2020 and 18.5–60 Mt by 2030.

1. Introduction

1.1. Background

In a pathway towards sustainable energy supply with deep reductions in greenhouse gas (GHG) emissions and decreased dependency on fossil fuels, biomass used for energy purposes (bioenergy) is expected to play a substantial role by all Member States (MS). In 2013, bioenergy consumed in European Union (EU) amounted to 64% of the total renewable energy consumption; mainly in the heating sector, but with significant contributions to electricity production and transport fuels [1]. Although this share is expected to decrease by 2020, due to the development of other renewable sources such as wind and photovoltaics (PV), the actual amount of biomass for heating, electricity and transport is expected to rise by up to 1400 PJ [2].

Mandates and support policies to increase the share of renewable energy to 20% in 2020 as agreed on by EU MS in the Renewable Energy Directive (RED) 2009/28/EC have been the main driver of the increased supply of renewable energy including bioenergy in the EU.

Between 2000 and 2013, bioenergy supply more than doubled. According to EU MS, renewable energy production from biomass should increase by 33% in 2020 compared to 2013 as reported in the National Renewable Action plans (NREAPs) [3].

Under the 2030 climate & energy framework, the EU has agreed to achieve 40% reduction in GHG emissions (compared to 1990), 27% energy consumption from renewable sources, and at least 27% increase in energy efficiency by 2030. A major challenge for the 2030 horizon is how this 27% share will be distributed through the EU, considering there are still no binding national targets. MS action plans will need to be drawn up, allowing for different national capacities for RE production, while expanding upon the already achieved targets of 2020 [4].

The publication of the ILUC directive (Directive EU 2015/1513), amends the Fuel Quality Directive (2009/30/EC) and RED by imposing a cap on food based biofuels. Similar to the RED, at least 10% of energy consumption in transport should come from renewable energy sources, with a maximum of 7% biofuels made from food crops. The imposed cap on food based transport biofuels might further shift biomass demand towards non-food lignocellulosic sources.

Abbreviations: GHG, Green House Gas; MS, Member State; EU, European Union; PV, Photovoltaics; RED, Renewable Energy Directive; FQD, Fuel Quality Directive; NREAP, National Renewable Action Plan; NW, Northwest; EC, European Commission; RES, Renewable Energy Source; DE, Deutschland (Germany); DK, Denmark; BE, Belgium; UK, United Kingdom; NL, Netherlands; BAU, Business As Usual; QUO, Quotas; UNFCCC, United Nations Framework Convention on Climate Change; DECC, Department of Energy and Climate Change; PJ, peta Joule; Mt, million tonnes

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<http://dx.doi.org/10.1016/j.rser.2017.04.108>

Received 20 July 2016; Received in revised form 2 December 2016; Accepted 28 April 2017

Available online 02 May 2017

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With the growing demand for biomass in the last decade, international trade of liquid biofuels and solid biomass has grown substantially, particularly in the EU. Extra-EU imports of biodiesel were practically zero before 2005 but peaked in 2012 at 118 PJ (19% of transport biofuel consumption in the EU in 2012) and declined to 34 PJ in 2014.

The largest part of EU biomass supply is and will be based on domestic sources; currently, 4% of the total biomass used for energy purposes is imported. However by 2020, and especially by 2030, this amount could increase by a significant amount, taking into account potential supply gaps, especially in the industrial sector (electricity production, closing down of coal power plants) [5]. Inequalities in forested area, waste biomass streams, differences in the amounts of supply and demand for bioenergy from one MS to another, open up opportunities for bioenergy trade. In the case of surplus of supply, countries may export bioenergy products to other countries, where bioenergy demand cannot be fulfilled from local resources (the Netherlands, Belgium).

Production costs of bioenergy feedstock (e.g. wood pellets) are also an important factor driving bioenergy trade. These costs can be lower if raw materials are pre-treated, in the form of wood pellets, torrefied wood pellets, intermediate or final form of biofuels in the case of liquid biomass. The higher costs for producing bioenergy feedstock within the EU (labor cost, supply of raw materials), make the option of importing bioenergy feedstock from countries where raw materials are abundant and production costs are cheaper, a more reasonable option [6]. This situation supports the growth of global bioenergy trade since availability of raw materials and cheap production cost are usually found in countries outside EU (United States, Canada, Brazil, and Indonesia) that can cater to several diverse end markets of biomass.

Especially in the US, which is by far the biggest exporter of wood pellets to the EU, independence of mills from the sawmill industry has allowed a focus on the export of pellets. Raw material is more readily available as a result of the lower demand from a declining paper and pulp industry and increasing forest productivity. A combination of factors such as a large availability of feedstock at competitive prices, as well as a sound and sustainable forest management system, relatively easy logistics, and cheap transport has rapidly attracted investment in the southeast USA from American as well as European companies. Much of the additional US capacity installed since 2010 is aimed at producing industrial pellets for export to the EU [7–10].

Biomass use is expected to grow in specific sectors, such as co-firing in coal power plants in the short-term future, possible high quality industrial heat in the long-term future and residential heating. The resource for the two first aforementioned sectors is wood pellets, while residential is traditionally achieved through the use of wood logs. However, use of higher quality wood pellets for heating has been getting traction the last several years. Moreover, in light of the conservation or unavailability of domestic resources, imports of solid biomass may increase across the EU region [11–13].

1.2. Problem definition and objectives

Despite the importance of biomass in the renewable energy landscape in the medium to long term future (2020–2030), there is a great deal of uncertainty on how the development of bioenergy will be like. While scenarios show a growth in bioenergy if renewable energy and climate policy targets are pursued [2,12], subsequent policy progress and political conviction seem to be lacking in respect to bioenergy support.

Bioenergy development projections, while attempting to take policy progress into account, do not always directly reflect the effects of policy measures, as it can usually be difficult to predict behavior (including the behavior of markets). As an example, the latest National Energy Outlook of the Netherlands under the ‘existing policy’ variant refers to specific, officially published measures and measures that are as binding

as possible, such as the European Emissions Trading System (ETS) and subsidies for renewable energy. The ‘intended policy’ variant is based on existing policy plus published intended measures that, as of May 1st, 2015, were not yet officially implemented but were specific enough to incorporate in the calculations [14]. Latest developments show that the utility companies in the country have submitted four applications for co-firing under the spring SDE+ auction [15].

The bioenergy situation in Northwest Europe is generally characterized by highly erratic short term developments, diverse sustainability criteria between MS, complex logistics and hesitation for long term investment in dedicated infrastructure. Actual economic growth, demographic development, technology costs and other developments in and outside the MS are not always in line with these projections [14]. There is a knowledge gap concerning biomass's future presence in the sectors of electricity, heating and transport, as well as the supply potentials of EU – which region will need to import biomass, to what amounts and what will be the source region.

This work's objective is to quantify the uncertainties of the future status of bioenergy supply in NW Europe. An effort is made to provide, in as much detail as possible, developments in the bioenergy field on a regional level initially and on a MS level additionally. The main path to achieve that is to accurately supplement previous regional (EU level) model projections related to the bioenergy future with up-to-date national (MS level) plans for the short to long term energy sector evolution.

All of the above mentioned uncertainties are translated into ‘bandwidths’ (ranges) for the projections, relating to indicators such as final and primary energy demand and, more importantly, future supply, as imports of feedstock will heavily influence sector growth and international trade of biofuels, especially in the MS that have small potential of domestic supply. The results of this work can be used to visualize the needs for future infrastructure development, as well as logistics and policy support in the bioenergy sector.

In order to achieve this objective the following steps need to be undertaken:

- 1) Review of current status of bioenergy by end use sector
- 2) Review of national and regional projections of renewable energy deployment
- 3) Industry, market announcements, expert interviews, existing and future policies and sustainability criteria relevant to bioenergy in NW Europe, stakeholder participation in workshops
- 4) Comparison of projections of solid and liquid biomass demand and supply in Northwest Europe
- 5) Quantification of future bandwidths of biomass imports

1.3. Scope of work

The focus is largely set on lignocellulosic biomass, as heat and electricity needs consist by far the biggest percentage of biomass use. According to Sikkema and Fiorese [16], EU has become the largest importer of woody biomass for energy purposes in the form of wood pellets. Import of woody biomass, especially for electricity generation, will likely continue beyond 2020. In 2035, the authors remark that the import of biomass may reach up to 16 Mt of wood pellets, in order to fulfill the demand in the electricity sector alone.

Liquid biofuel prospects are also explored, as the use of second generation (advanced) biofuels is expected to grow beyond 2020 in order to prevent conflict between energy supply and food security issues [17].

Production of biochemicals, plastics and novel biomaterials through biomass were excluded from this research. According to expert opinions and industry representatives as well as macro-economic outlooks of sustainable energy and biorenewable innovations the use of biomass for energy purposes (heat, electricity and transport fuels) is still expected to be dominant over biobased materials up to 2030.

Moreover, in case the market for bio based materials arises, production is more likely to take place outside the EU, close to the feedstock source regions [18].

Five MS from the NW EU region are looked into detail, based on the biomass status in each respective country. The UK, the Netherlands, Denmark, Belgium and Germany (along with Sweden and Italy) are the largest consumers of solid biomass for energy purposes. The importance of solid, liquid or gaseous biofuels varies between countries, mainly due to typical concepts and capacities of production and utilization plants, and support schemes [6]. The Netherlands, Belgium and Denmark are characterized by limited forested areas and land that is better used for other purposes. Germany, while a net exporter of solid and liquid biomass, imports feedstock for the production of biofuels from across the globe, mainly Argentina and Indonesia [19]. The UK is by far the largest importer of solid biomass in the form of wood pellets in the EU, reaching up to 7.3Mt in 2015 [15]. At the same time, all five MS have highly ambitious targets for the future, especially considering industrial uses of biomass, which may play the most significant role for these technologies in low-carbon energy systems [12,20,21]. With the available internal production peaking in most EU countries, it follows that these states will also be among the biggest biomass importing EU members by 2030 and will play a major role in intra- and extra-EU biomass trade [22].

2. Method

2.1. Current status of bioenergy

The current role of solid and liquid biofuels in NW Europe is investigated through data collection from statistical offices, government organizations and literature review. As a starting point, Eurostat statistical data is used, complemented with statistical data from national organizations such as Statistics Netherlands (CBS), Department of Energy and Climate Change (DECC) etc. However, a detailed breakdown in type of feedstock or source of the biomass is not available from these data sources. The main reason is that biomass uses (e.g. wood chips, wood pellets, vegetable oil, agriculture residues) are complexly intertwined with non-energy sectors and that stocks of renewable products for non-energy purposes are not part of energy balances. Furthermore, lack of detailed resource monitoring, unregistered uses (e.g. household consumption) and cascaded uses, i.e. process of biomass into a final product which is used at least one more time for materials or energy [23,24], make it difficult to monitor and analyse biomass use for energy. In particular direct and indirect trade of biomass used for energy purposes is weakly covered in statistics for similar reasons [25]. In addition, significant differences have been observed while comparing import and export quantities in the same or different statistical data sources [26].

A major source of information, was the IEA Bioenergy Task 40 national reports. Task 40 is an international working group under the IEA Bioenergy Implementing Agreement, aiming to support the development of a sustainable, international, bioenergy market by providing high quality information and analyses, as well as overviews of bioenergy developments. Data from government agencies and organizations were used as well to complement information not currently present in the Task 40 national reports.

In order to get a more detailed overview on a national level it is necessary to supplement the official statistics from Eurostat and the other available national data with anecdotal information and reports.

2.2. Projections to 2030

The publication of the national renewable action plans in 2011 and progress reports that are published biannually provide quantified insight in how EU MS expect to meet the 2020 national binding renewable energy targets as agreed on in the RED. Regarding the 2030

goals mentioned in Section 1.1, while the EC has published several reports, they focus more on establishing a policy framework for the renewable energy progress rather than quantifying specific targets.

Industry and market announcements concerning future demand and imports of biomass were also taken into account. Presentations in conferences, workshops and personal interviews with representatives from the energy sectors assure that both empirical and research data are incorporated to ensure a more thorough outcome on bioenergy development.

Results of studies that take a national perspective on renewable energy deployment are compared to scenarios of renewable energy deployment at the EU level. To this purpose, projections of RES deployment of the DiaCore project are considered [12].

2.2.1. Projections of renewable energy deployment at the European level

The review of national data is compared and combined with results from the Intelligent Energy project DiaCore which aims to facilitate and coordinate an efficient and sustainable deployment of renewable energy, including biomass, to 2020 and 2030. The DiaCore results were developed using the energy system model Green-X.¹ Green-X is a partial equilibrium model of the European energy sector developed by the Energy Economics Group of Vienna University of Technology and has been widely used within the European Commission for facilitating renewable energy strategies.

Two main scenarios of policy support from the DiaCore study were selected:

- The Baseline (BAU) scenario assumes a continuation of current support policies for renewable energy to 2020. Beyond 2020, a carbon price will remain, but support for renewable energy is assumed to be phased out.
- The QUO-27 scenario assumes that the target of at least 20% renewable energy share in gross final energy consumption and 10% in transport by 2020. Furthermore, at least 27% renewable energy is assumed to be achieved by 2030 without country specific targets. National policies to meet 2020 targets are assumed to be replaced with a more harmonized policy concept with EU-wide quotas (QUO) to meet the renewable energy target of 27% by 2030. The efficiency target (27% increases in energy efficiency compared to 2007) and GHG target (40% reduction compared with 1990) are not taken into account.

A more detailed description of these scenarios is provided in Resch et al. [27,28]. A detailed assessment of bioenergy in these scenarios is provided in Hoefnagels et al. [12].

2.2.2. Policy review and sustainability criteria

Policies related to renewable energy generation in each respective country were also reviewed. The objective was to investigate to which level governmental policy support is substantial when considering energy production from biomass, and to what extent these policies affect (or may affect in the future) bioenergy development.

Policies in all three sectors were reviewed (Table 2). Policies in the heat and electricity sector focus mainly in feed-in tariffs, tax exemptions and investment support across all countries. The transport sector is mainly governed by a blending quota obligation. However, according to personal interviews and discussions of the author with stakeholders in the industry, it is the lack of long-term stability and guarantee of support that creates such uncertainty in the biomass market, as well as hesitation for long-term investments of any kind. The results are presented in Section 3.2.

¹ A detailed description of the Green-X model is available online: www.green-x.at.

2.2.3. Input from stakeholders

Discussions were held with experienced and active stakeholders in the (bio)energy industry in the Netherlands, via interviews and focus group discussions. The purpose of these activities was to obtain information from an industrial perspective and to gain insight in possible situations regarding the bioenergy deployment beyond 2020. The Copernicus Institute of Sustainable Development from Utrecht University organized a workshop that aimed to identify, qualify, and quantify the demand for energy, traditional and new material purposes to 2030. Representatives from the power, transport fuels, chemicals and domestic and international imports (US) forestry sectors presented their views on the bio based economy and gave their respective opinions in the shaping of these scenarios.

The authors also had personal contact with experts from the other MS under examination in this work: professors from universities focused on bioenergy research, government officials from respective Ministries of Energy and/or Environment and researchers from institutes or organizations dealing with biomass development. A list of the interviewees can be found in [Appendix B](#) – Personal communication.

3. Bioenergy in Northwest Europe – state of play and respective policies

The current share of renewable energy sources to the final energy consumption of each country is shown in [Fig. 1](#). By examining the respective stipulated targets for 2020, it can be seen that Germany and Denmark are well on their way to meet their renewable targets while Belgium, the UK and the Netherlands are lagging behind.

3.1. Bioenergy breakdown per country and sector

A more detailed, per sector view of the renewable energy state of play takes place in this section. In [Table 1](#), the share of renewable energy sources in the sectors of electricity, heat and transport is presented. In the electricity and heat sectors, variations are significant between countries. The share of biomass in the renewable electricity production varies from 20% in the UK to 50% in the Netherlands. Biomass is by far the greatest contributor in the renewable heat sector with more than 75% share in the whole region. In the transport sector, percentages of biofuel hover around the 5% mark (in total final consumption) for all investigated countries.

The distinct bioenergy sectors in the individual countries are presented in detail in the following section.

3.1.1. Germany

Electricity from biomass (all types of feedstock) accounts for 31% of the total renewable electricity generation in the country [30]. The majority of bio-electricity comes from biogas plants, mostly small-scale installations on farms, larger plants for bio-waste digestion and in larger landfill and sewage gas plants. The main biomass resources used are animal manure and renewable raw materials as maize silage. Solid

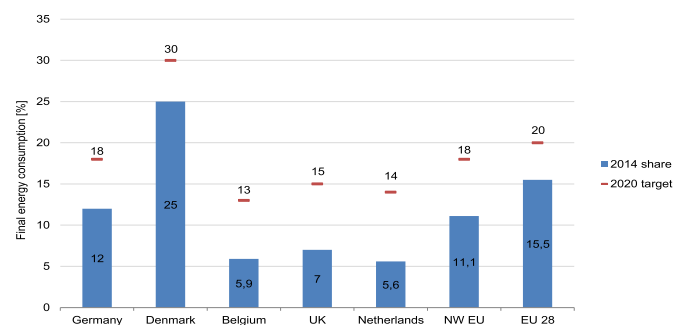


Fig. 1. Current share of RES in final energy consumption vs 2020 targets [1,19,29].

bioenergy is the second main biomass source for electricity generation in Germany through more than 640 CHP plants.

Bioenergy provides the largest renewable heat contribution, as is the case in all MS under examination ([Table 1](#)). The largest share comes from solid biomass, followed by heat from biogas (mainly through cogeneration) [30]. Solid biomass for domestic heating is wood-based and predominantly applied in small- to medium-scale systems in private households. Major fuels for the decentralized heat supply in buildings are primarily wood logs, followed by a small share of pellets, chips and briquettes [31].

The current share of biofuels is 5.5% based on energy content, with the major contributors being biodiesel and bioethanol [30].

3.1.2. Denmark

The consumption of biomass has increased significantly the last years and in 2014 it contributed to 15% of the electricity generation from RE in Denmark. A total of 39 CHP plants used biomass as fuel in 2014 corresponding to a total consumption of approx. 2.7 Mt biomass [32].

Biomass is used in stand-alone heating applications as well. The use of biomass in the industry sector was mainly for heating purpose in farms and minor industries, while wood pellets are used in private and district heating boilers [30,33].

Concerning biofuels, at present, there is small scale production of biodiesel from animal waste and an ethanol pilot plant. Other than that, the entirety of the biofuels needs is imported, consisting of biodiesel and bioethanol [32].

3.1.3. Belgium (Flanders)

The share of solid biomass in the total net green power production in 2013 was 35% [34,35]. The gross green power production from biogas had a share of 9.6% in the total Flemish gross renewable power production in 2013 as well.

77% of the total green heat production in 2013 is produced by biomass installations using solid biomass. The main heat production is from wood combustion installations (stoves, open fires) in households (73% of the total heat production by solid biomass). Industry is contributing a 12.6% share. Only a few installations are using other biomass streams for heat production (sludge, olive pits/pulp and coffee waste) [34,35].

All liquid biofuels consumed in the transport sector in 2013 consist of biodiesel (81%) and bio-gasoline (19%) [34,35].

3.1.4. UK

In 2014, electricity generation from bioenergy reached 20% of the total renewable electricity generation. Bioenergy in the above context consisted of landfill and sewage gas, energy from waste, plant and animal biomass, anaerobic digestion and co-firing with fossil fuel. The majority of the bioenergy generation came from plant biomass, which includes enhanced co-firing (> 85% biomass) [36].

Renewable sources accounted for 4.9% of total heat consumption during 2014. The main form of renewable heat production in the UK is direct combustion of various forms of biomass (94% of the total). Domestic wood is the main contributor to renewable heat production – around 57% of the total renewable heat. Nondomestic use of wood and wood waste, and plant biomass are the following largest contributors, around 17% and 14% respectively [37].

In 2014 biodiesel represented 60.2% of biofuel consumption and bioethanol the remaining 39.8% for a cumulative of 3.9% of total road fuel consumption [36].

3.1.5. The Netherlands

Data for 2014 show a slight decline in production, mainly stemming from the previous subsidy scheme coming to an end causing the power plants to fall back on co-firing. However, latest RES applications under the 2016 spring SDE+ auction reached more than double the €4bn

Table 1

Final energy consumption, overall RES and biomass in 2014 [1,19,29].

	Biomass-e		Biomass-h		Biomass-t		Biomass/Total final energy	Biomass/RES
	% RE-e	PJ	% RE-h	PJ	% RE-t	PJ	%	%
Germany	31	169	87.4	425	88.6	112	7.8	61
Denmark	27	12.5	98	43.5	100 ^a	10	8.7	65.6
Belgium	35	10.5	77	20.5	100 ^a	9	2.7	61
UK	20	47	94	107	100 ^a	52	3.4	51.3
Netherlands	50	18.5	86	46.5	100 ^a	15	4.6	75.4
NW EU	32.6	258	88.5	642.5	97.7	198	5.5	62.9
EU28	17.7	565	89	3282	100 ^a	548	9.5	61.3

^a Not including renewable electricity in transport.

budget – with 4 co-firing applications, and another auction following in autumn 2016 [15].

Biomass had a much greater participation in the production of renewable heat than electricity, with 86% of the total renewable heat production. Municipal waste (24%) and industrial biomass boilers (15%) were the leading sources, while a big percentage of biomass heat came from small residential or farm installations [38].

Consumption of biofuels consisted solely of biogasoline (35%) and biodiesel (65%) [38].

3.2. Renewable energy policies and biomass sustainability criteria

A summary of policies supporting bioenergy (and RE in general) production can be found in Table 2 below.

Schemes for RES are a key mechanism to help achieve the renewables goal, but also attract high levels of interest in relation to the differences between EU MS and the overall costs to consumers. Their objective is to promote and support large scale take-up and deployment of renewable energy generation and energy efficiency amongst consumers. The above policies and support schemes are the major drivers for bioenergy development in Northwest Europe.

The policies presented in Table 2 are in support of renewable development in general. Adequate financial incentives alone, however, do not guarantee the success of a support scheme, but must be combined with attractive framework conditions, for instance regarding spatial planning, grid connection, and other barriers in order to unfold their full potential [39]. In reality, policies specifically relating to bioenergy may be less or more favorable, depending on the specific MS. Moreover, these policies are often driven by oil prices. As oil prices increase, more policies are put in place to advance the use of renewable energy, and as oil prices drop, these projects are put on hold. Therefore, higher fossil fuel prices reduce the cost of renewable energy policies and consumer energy bills [40].

Regarding electricity production from biomass, both costs and the support level may vary strongly for the many different types of biomass resources. However, there are considerable differences in generation costs, partly due to the fact that the support systems of countries with comparatively low minimum generation costs allow the application of cost-efficient co-firing. Moreover, it should be added that the generation costs in the biomass sector are also heavily dependent on plant size.

Currently, less than half of the MS deployed more biomass electricity than what they planned and this situation is not changing in the medium term. At EU level a sizeable underachievement is expected on the path to 2020 compared to the NREAP trajectory. The deployment is slowed down especially by non-cost barriers, which are not immediately solved in the short term [39]. van Stralen et al. [20] researched the importance of biomass in the EU's 2020 energy mix for electricity, heat, and transport and concluded that the NREAP targets are ambitious and questioned whether they can be reached, especially under strict sustainability criteria. However, later research by Lamers

et al. [41] indicates that while stricter criteria will increase the overall supply (and thus policy) costs, the EU will still be able to supply sufficient solid biomass to meet its targets in the electricity and heating sector plus second generation transport fuel. The key question will be how cost-effective the 2020 targets can be achieved and how policy makers will incentivize the mobilization of biomass.

In Germany, for example, the newly reduced feed-in tariffs and the “cap” on eligible new capacity led to a massive decrease in new plants in 2014 – the German Biogas Association calculates that less than 50 MW_{el} of newly-built plants came online, and has a pessimistic view on future electricity produced from biomass. The German Bioenergy Association expects that no new plants for solid biomass will be built. Overall, it is expected that some of the existing companies will go bankrupt in the near future due to lack of markets [30]. In the Netherlands, support is provided through the SDE+ scheme until 2023, and there is an established cap on promoting the use of biomass by coal-fired power stations that will not exceed the level of 25 PJ [42], linked to the shut-down of five coal-based power plants built in the 1980s. The further scope for expanding the share of (liquid and solid) biofuels will however depend on the final outcome of the EU agreement on sustainability criteria for biomass [43]. Up to the time this work was accepted for publication, the cap on co-firing was assumed to remain in place beyond 2023 as well. In Belgium, the generous green certificates systems, together with a drop in deployment costs (especially for solar PV), led to overcompensation, excess demand for installations and increased distribution tariffs for electricity. Consequently, the support levels were reduced several times by the different regions and at the federal level in 2012–14 [44].

In contrast, in Denmark, while the level of support has changed many times, support for bioelectricity producers applies for the lifetime of the production unit, along with exemption from taxes. As a result, there is a high level of certainty about future support at the time of investment. [32,45].

It should be however noted, that, due to economic downturn in many countries, electricity demand has grown less in recent years than projected when the NREAPs were first developed. So while it currently appears that the European Union as a whole – and several countries in particular – may undershoot their NREAP trajectories in terms of TWh generated, in fact, the contribution as a share of electricity demand and final energy demand may still be on track [21].

The biomass heating sector shows a comparatively smaller gap than the biomass electricity one. Centralized (district heating, large biomass plants) and decentralized (heat plants which use pellets, wood chips, or log wood as fuel and which are not connected to a heat grid) heat production from biomass seems to have adequate or even higher than necessary support levels across the MS through tax exemptions and/or investment subsidies among other schemes. Based on the attractive remuneration levels – both for centralized and decentralized biomass heating – the deployment of biomass heat at EU level is higher than expectations based on the NREAPs which is not projected to change in the medium term.

Table 2
Renewable energy policy overview per MS [39].

	Germany	Denmark	Belgium	UK	Netherlands
Electricity	Renewable Energy Sources Act (EEG): feed-in tariffs for renewable electricity	Feed-in premium tariffs for renewable power; support for bioelectricity production is given for lifetime	Quota system: Green power certificates	Renewables Obligation (RO): quota system, obligation on electricity suppliers for renewable supply	Tax regulation mechanisms I (reduction of environmental protection tax)
	Market Premium: Premium tariff I Investment loans for private individuals and domestic and foreign companies	No energy or CO ₂ -tax on biomass	Investment support	Tax exemption mechanisms Contracts for Difference (CfD): contract between the generator and government - increases investor certainty	SDE+ scheme: a feed-in premium, depending on the technology, the amount of energy produced and phase of application
	New buildings: Renewable Heat Act - requirement for owners to get a certain share of their heat from renewable energy Existing buildings: Market Incentive Program (MAP) - investment grants and low-interest loans and repayment subsidies	Tax exemption on heat production under certain conditions	Quota system: CHP certificates	Renewable Heat Incentive (RHI): tariffs for use of renewable heat in buildings	SDE+- feed-in premium, supports installations for the production of renewable heat via biomass
Heat		Grants for research/development in bioenergy	Investment subsidies for industry and households	Green Deal: investment loans, incentive scheme for energy-efficiency improvements in buildings	Tax regulation mechanisms: enables entrepreneurs based in the Netherlands to write off investments in renewable energy plants against tax
		Blending obligation of 5.75% biofuels for transportation fuels (on energy content)	Quota obligation	Renewable Transport Fuel Obligation (RTFO): biofuel quota, legal requirement on transport fuel suppliers to ensure that 4.75% v/v of their overall sales are from a renewable source	Biofuel quota: imported or produced fuels need to include a defined percentage of biofuels
	Biofuel quota- > GHG emissions reduction quota: imported or produced fuels need to include a defined percentage of biofuels. From 2015, a greenhouse gas reduction quota is introduced. Tax regulation mechanism (reduced tax rate for biofuels)	CO ₂ and energy tax exemption	Tax regulation mechanisms		Tax regulation mechanism II (MIA/VAMIL scheme): opportunity for private companies to deduct an extra amount of the investment cost from the taxable profit

Until 2020, it can be expected that the targets will be achieved on an EU level, by a slight margin. Large members states though, like France and the UK are expected to fail in delivering the planned deployment which has a major impact on overall target achievement at an EU level since significant gaps arising in few large MS can hardly be compensated by surpluses in comparatively small countries [39]. Fewer MS can maintain their progress achieved by 2014 and several MS are at risk of achieving their indicative 2020 targets for biomass heat production, also with new policy initiatives being implemented in forthcoming years. Most noteworthy, the United Kingdom bears the risk of losing its frontrunner position and falling apart of all other MS.

Policy regarding biofuel stimulation can be described as quite "effective" [39], as there are strong drivers to deploy biofuels. Mandates (also called obligation) are not just a cost-neutral instrument for the government, but also an efficient driver for the stimulation of biofuels usage. In case of a mandate, there can be a buy-out price, or there is no escape option (penalty).

However, a high buy out price it is not a guarantee that targets are met. Belgium and Germany have reasonable high buy out prices set, but did not manage to reach their 2012 target. Similar to other sectors and technologies, it can be expected that the situation will become worse until 2020. There are only few planned measures described in the MS' progress reports that may positively impact the deployment of biofuels in the transport sector. According to scenarios assessed, only five countries are expected to end up with a higher deployment of biofuels in 2020 than their planned one. Denmark is the only one of the MS examined in this work that is expected to do so. The strongest deficits can be expected for the United Kingdom and Germany – all facing projected deficits larger than or of about 40%. The Netherlands and Belgium are expected to have a deficit between 15–25%.

It is clear that although each MS has a clear ambition of tackling the 2020 targets, there is still progress to be made. Harmonization and optimization of policies and regulations help in this respect, and more gains can be made by using the cooperation mechanisms of the RED, e.g. joint projects – tools not yet used by most MS, but with longer term potential [46].

In addition to policy indecisiveness and lack of long term support, sustainability criteria also add to the layer of complexity and uncertainty that bioenergy development faces. For the largest importers of solid biomass for heat and power production in the EU (the UK, Belgium, Denmark and the Netherlands), sustainability of biomass supply is imperative. Therefore, each MS has developed its own governance frameworks such as legislation or voluntary agreements with the industry to safeguard sustainable production of solid biomass. This had led to varying sustainability requirements between these countries, which may potentially cause market barriers and impede international trade. European suppliers and generators of wood pellets and wood chips have been calling for a consistent, harmonized set of sustainability criteria at the EU level to avoid trade barriers [47,48]. Lack of EU level sustainability criteria for solid biomass leads to concerns about the overall benefits of the RES target in some countries [46].

According to Scarlat [49], EU-wide harmonized sustainability criteria are necessary to provide reliable evidence to the general public on the sustainable use of biomass in order to increase public acceptance. Sustainability criteria should cover all types of biomass, with the same criteria for different uses of biomass (food, feed, bio-based products, bioenergy and biofuels) to avoid leakage, cover the entire supply chain and include various aspects such as GHG emissions or resource efficiency. The Roundtable on Sustainable Biomaterials (RSB) made some significant steps in this direction and expanded its scope in 2013 to cover bioenergy and bio-based products [50].

4. Results – future outlook in the region

In this section, future developments of bioenergy in the selected

countries are examined. The final bioenergy consumption of each MS is presented, as reported by each respective country. The subsequent primary energy demand is calculated, based on the Energy Efficiency Indicators of the International Energy Agency (IEA) [51]. Feedstock sources, both domestic and imports are then determined, taking into account information of types of biomass needed per sector, domestic supply potential and future energy sector needs and import trends.

The results are then set side by side with existing model projections that have been performed on an EU level concerning biomass consumption, demand and supply, to obtain a comprehensive report of bioenergy development in the region [12].

The uncertainty of bioenergy development, especially after 2020 is showcased in the limited information available for each sector, spread among different types of reports from different organizations. Most notable effort on that front is the Task 40 reports undertaken by the IEA Bioenergy organization. In this work, a complete overview of the following periods of bioenergy deployment is given: (1) short-term bioenergy development aimed at policies and trends in order to comply with RED 2009/28/EC and FQD 2009/30/EC; and (2) long-term bioenergy development beyond 2020, more uncertain due to lack of clear (bioenergy) policies.

While each EU member has committed to achieving the RED and FQD targets, the path to that end varies significantly between them. The state of technology in each sector, pre-existing industrial installations, (un)availability of domestic biomass supply, sustainability criteria and political as well as economical aspirations are just several of the factors influencing the development of bioenergy.

4.1. Northwest Europe

4.1.1. Biomass consumption and demand

An overview of the bioenergy development in terms of final energy consumption for the whole Northwestern Europe can be seen in Fig. 2.

While a sizeable increase from the current level of bioenergy production can be observed by 2020, the national reports project a decline in production by 2030. The most important factor are respective governmental policies and the respective energy systems changes in the two biggest MS under examination, Germany and the UK. A detailed explanation is provided in each MS' respective Section (4.2 for Germany, 4.5 for the UK).

The model outcomes do not exactly reflect these future expectations. Their results closely follow the national outlooks for the short-term horizon of 2020. As expected the BAU scenario is follows the national projections closer, since it assumes a continuation of current renewable policies. However, the results diverge when assessing the long-term future of bioenergy. The biomass development scenarios based on the national reports incorporated up-to-date renewable energy policies, recent energy sector development and outlooks from

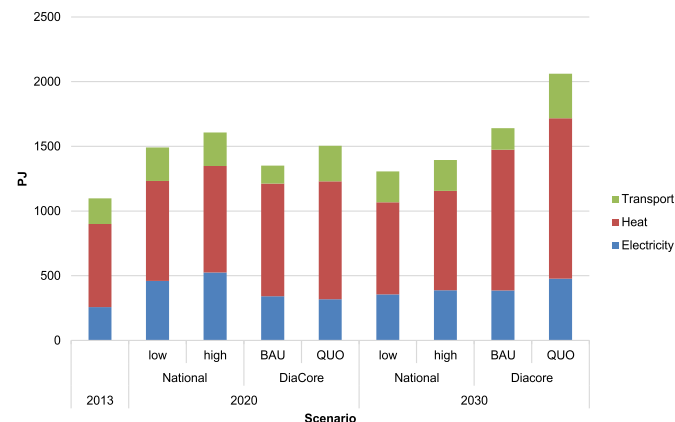


Fig. 2. Northwest EU final biomass consumption by end use sector.

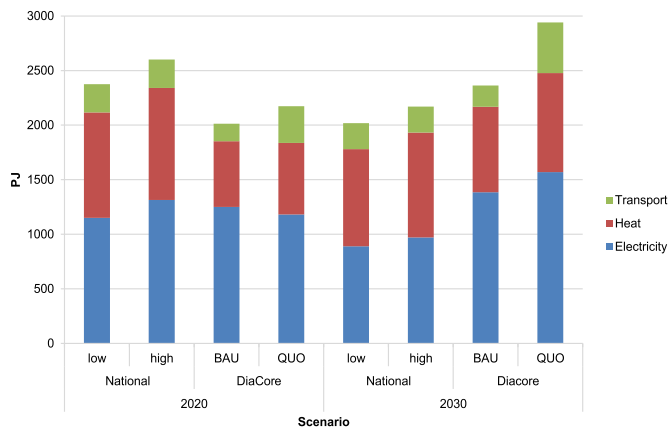


Fig. 3. Northwest EU primary biomass demand by end use sector.

2014 and 2015. They are developed by each MS individually, focusing on its energy sector and market and they naturally mimic the national policies and follow the political ‘spirit’ of each respective MS.

The DiaCore work operates on an EU level, analyzing the impact of the global biomass markets on the EU RES supply until 2030. DiaCore scenarios are partly based on projections of final energy demand, conventional (fossil) generation mix and related primary fossil energy demand and CO₂ emissions taken from the PRIMES Reference scenario (2012) [52]. Their main goal is ‘splitting’ available biomass streams (domestic supply or imports) among all EU MS in an effort to reach the 2020 and 2030 targets.

The different scope and the uncertainty of the field itself, lead to greater deviations in the scenarios for the 2030 horizon.

A similar overview can be given for the primary energy demand in Fig. 3.

4.2. Germany

4.2.1. Final consumption

Total final biomass consumption in all forms is projected to peak in 2020, but will decline significantly by 2030 according to the country's national report (Fig. 4) [30]. Primary reason behind this drop in biomass consumption is the desire of the German government against further growth, but restructure towards more efficient use of residues and wastes, and less land-intensive production [30]. In contrast, the DiaCore energy model projects a sizeable increase in the use of biomass in all sectors.

Preliminary analysis of the current policy scheme (EEG 2.0) effects on new net electricity generation indicate that between 2020 and 2030 the overall capacity will shrink due to retirement rates of existing plants being higher than the rate of newly added capacity [52]. The

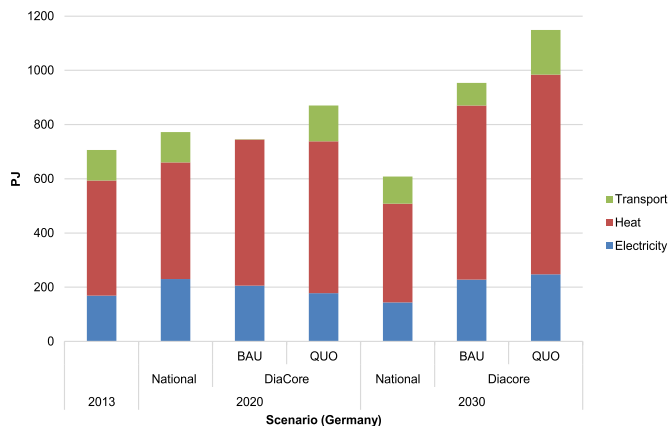


Fig. 4. Final biomass consumption by end use sector (DE).

cumulated installed bioelectricity capacity under the EEG 2.0 scenario would reach a maximum of 236 PJ (8.2 GWel) by the end of 2015, and would then be reduced to 230 PJ (8 GWel) by 2020, and to 144 PJ (5 GWel) by 2030, i.e. it would reach the level of 2010.

In the heat sector, the development of lower oil (and natural gas) prices until 2020 implies that less biomass will be used unless more favorable incentives will be available. Nitsch [53] shows that instead of a 15% renewable heat share by 2020 (and 25% by 2030), the current policies would result in only 11% (2020) (11.5% in 2030) shares respectively. Bioenergy is expected to remain on the 2015 level until 2020, and then be reduced to a lower level than in 2010 [30].

The current share of biofuels is not expected to increase much until 2020. Uncertainties concerning both the future EU regulation on biofuels (“cap” on 1st generation biofuels, minimum quota for 2nd generation biofuels) and post-2020 energy and climate policy of the EU reinforce that projection. Moreover, German renewable transport policies currently favour electric cars running on renewable electricity over biofuels [19]. The transport sector will most probably be characterized by low fossil fuel prices and missing targets for advanced biofuels, which, coupled with the uncertainty on post-2020 regulations – may lead to a similar outcome as in the other sectors: overall levelling-off, and even net reductions by 2030 [30].

So far, all financial incentives offered by the government in Germany are for R&D activities. There are no definite policies or regulations addressing biorefineries or the bioeconomy. There is, however, a growing debate about incentives for bio-based materials, and “advanced” biomass conversion systems such as biorefineries [30].

4.2.2. Primary demand and biomass supply

Primary demand and related biomass imports are shown in Fig. 5. Primary biomass demand follows the consumption projections; however expected imports vary significantly between the energy models projections and the national outlook.

Germany has been increasingly relying on domestic supply for the majority of the electricity and heat production from biomass. A certain amount of wood pellets and waste wood is expected to be imported, but there will only be a small participation of solid biomass in the electricity sector and domestic supply in the heating sector. This further illustrates the desire of the German government to restructure towards more efficient use of residues and wastes and reduce the imports between 2020 and 2030.

Liquid biofuel imports are expected to remain constant.

4.3. Denmark

4.3.1. Final consumption

The Danish Energy Agency (DEA) has defined different scenarios for a fossil free energy supply by 2050 and with fossil free production of heat and electricity by 2035. The share of renewable energy in

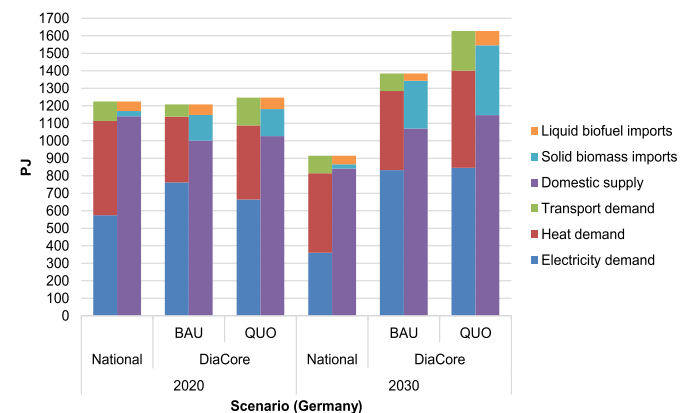


Fig. 5. Primary biomass demand and supply (DE).

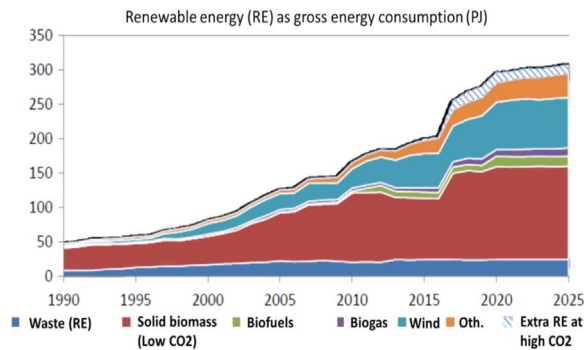


Fig. 6. Renewable energy development (DK) [32].

Denmark is expected to amount to approximately 35% by 2020, and thereby exceed the targeted obligation of 30%. More than half of this renewable energy will be produced from biomass. The use of all types of biomass is expected to steadily increase until 2030 comparatively to 2014 levels, supported by a no energy or CO₂ tax policy and financial support through feed-in tariffs (see section 3.2).

Key driver in this increase is the use of solid biomass in the electricity and district heating system, mainly through a growth in the use of woody biomass. Consumption of biomass increases in central power stations as well, which are, or will be converted to 100% biomass or a combination of coal and biomass. Overall it is estimated that the central power consumption of solid biomass for electricity production grows from about 23 PJ in 2012 to about 41 PJ in 2020 (Fig. 6).

As mentioned above, biomass consumption exhibits a significant increase in the district heating sector by 2020 as well. Households are estimated to have an almost unchanged consumption of wood in 2020 for heating purposes.

From a report by the Danish Centre for Environment and Energy (DCE), there are two scenarios for biofuel demand, in road transport, up to 2020 and 2030 [54]. Scenario 1, which follows the major European biofuels policy and scenario 2, which is aimed at more aggressive policy to achieve bioenergy deployment (Table 3) Fig. 7.

4.3.2. Primary demand and biomass supply

In Denmark, biomass is imported in considerable amounts, compared to the Danish production and consumption of biomass. In 2013, 34% of the biomass utilised for energy was imported in the country. Import of wood pellets are dominant, mainly for replacing coal in large scale CHP plants [32]. As mentioned in Section 3.1, liquid biofuels are almost exclusively imported as well Fig. 8.

4.4. Belgium

4.4.1. Final consumption

Electricity production from biomass and waste in Belgium is expected to increase by 2030. The contribution of biomass increases in absolute terms, though its share in electricity production from renewable sources decreases, mainly due to an increase in wind power and PV contribution [55].

Conversion of biomass and waste to distributed heat in the industrial sector increases slightly from 7% to 10% in 2020 and

Table 3
Future biofuel scenarios (DK) [54].

Demand [PJ]	Scenario 1		Scenario 2	
	2020	2030	2020	2030
Biodiesel	14.9	17.7	22.3	44.2
Ethanol 1st generation	2.5	2	2.75	2.9
Ethanol 2nd generation	3	3.8	5.6	11.7

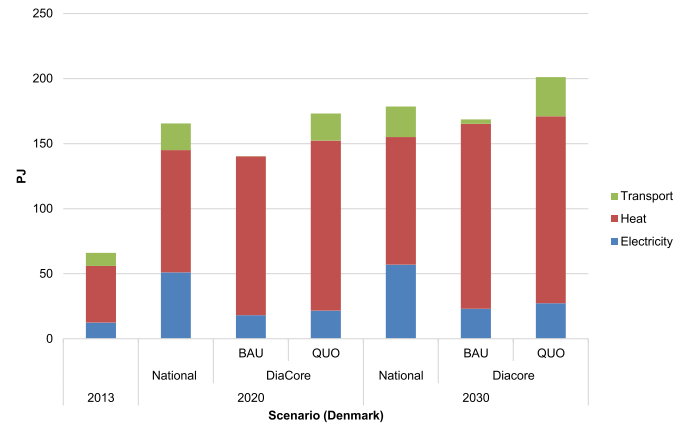


Fig. 7. Final biomass consumption by end use sector (DK).

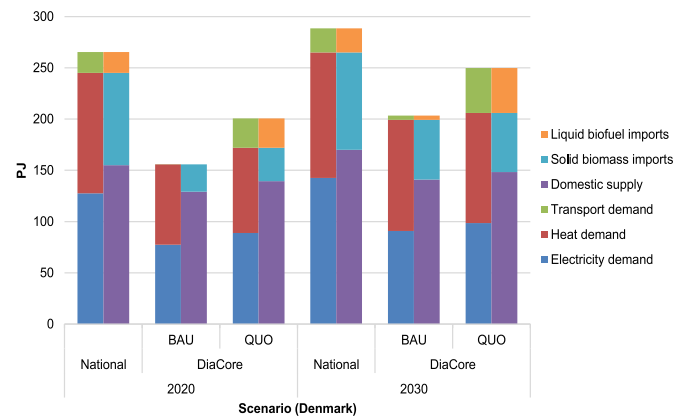


Fig. 8. Primary biomass demand and supply (DK).

remains the same up until 2030. Residential heating remains at the same levels throughout the time period to 2030, partly due to increased energy efficiency measures in the sector [56].

Biofuel consumption between 2010 and 2020 doubles (from 4% to 8% of total transport energy needs), exclusively due to bioethanol and biodiesel demand [56] Fig. 9.

4.4.2. Primary demand and biomass supply

Belgium has limited domestic biomass potential; as such, biomass imports play a major role in reaching the national targets. Wood is the main imported biomass source from inside and outside the EU, while agricultural crops are also imported from the EU. The main biomass feedstock for energy that is traded are wood pellets.

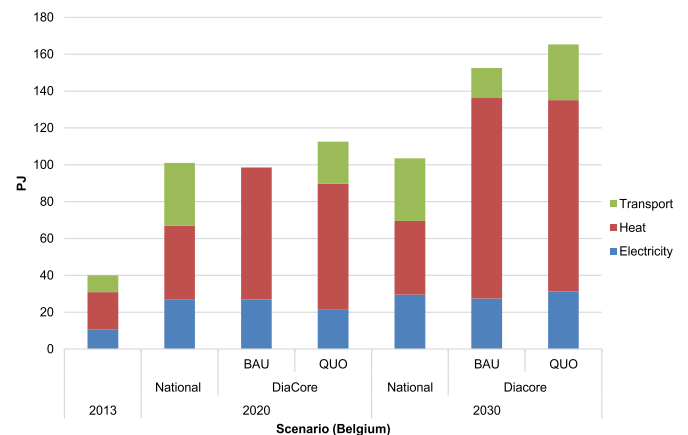


Fig. 9. Final biomass consumption by end use sector (BE).

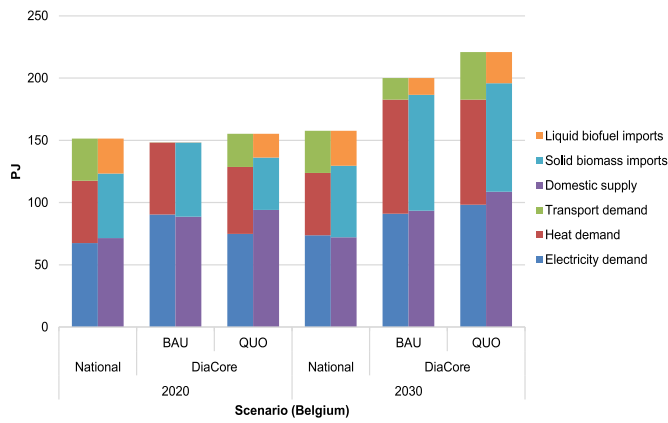


Fig. 10. Primary biomass demand and supply (BE).

31% of the biomass used in 2013 is estimated to have been imported: 19% outside Europe and 12% from other European countries [34]. Belgium will be importing almost a third of the country's solid biomass needs in the form of wood pellets (and to a lesser extent wood logs) in the future, mainly for use in electricity production; only 20% of the total Belgian pellet consumption was produced locally [34]. Liquid biofuels, as in the case of Denmark, are almost exclusively imported Fig. 10.

4.5. United Kingdom

4.5.1. Final consumption

The United Kingdom's Department of Energy and Climate Change (DECC) submitted 2 different scenarios for the bioenergy future in the UK, ranging between 350 and 466 PJ in 2020 and 288–327 PJ in 2030 [57]. The absolute amounts of bioenergy in all forms are reduced by 2030, due to the competitive development of other forms of renewable energy and alternative uses of biomass.

It is estimated that between 10 and 18 Mt/y of solid biomass will be required for electricity generation in the UK in 2020; this biomass will be used in power stations which have converted from being coal-fired to biomass-fired, as well as in new, dedicated biomass plants (including CHP plants) [57].

Bioelectricity slightly decreases in 2030, mainly due to landfill gas resource availability decline and the rising share of other forms of renewable electricity such as wind and tidal energy [58].

In earlier reports, the UK government's goal was to achieve 205 PJ of heat production from biomass by 2020 [59]. According to more recent publications, the projected delivered heat from biomass in the UK in 2020 ranges between 155 and 205 PJ, requiring approximately 4.3 to 8.3 Mt/y of solid biomass for heat by 2020 [57].

Key transitions to 2030 are the use of boilers, domestic or not, and industrial heat. Use of biomass in domestic boilers increases slightly, but the share of boilers in non-domestic buildings and in the process industry greatly decreases, due to more widespread use of heat pumps, the phasing out of boilers at the end of their life, and bioresource diversion to alternative uses. Use of biomass in heat production ranges between 100 and 137 PJ [58].

In a research commissioned by British Petroleum regarding the role of biofuels up to and beyond 2020, scenarios were developed to represent a range of possible biofuels futures. According to the 'middle' scenario, demand for biofuels will be around 80 PJ in 2020 and will drop down to 66 PJ in 2030, as the overall gasoline consumption drops, a result of improvements in vehicle fuel efficiency [60]. More recent reports project a wider range (43–118 PJ) of biofuel demand for 2020 [57] Fig. 11.

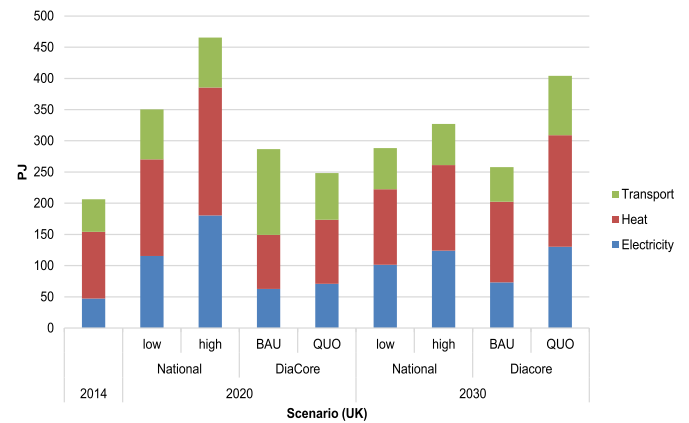


Fig. 11. Final biomass consumption by end use sector (UK).

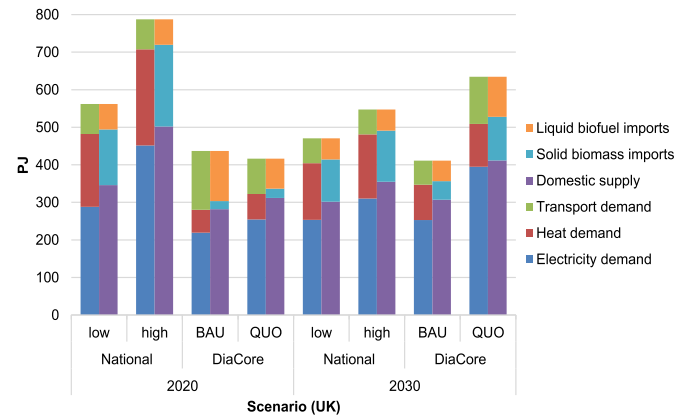


Fig. 12. Primary biomass demand and supply (UK).

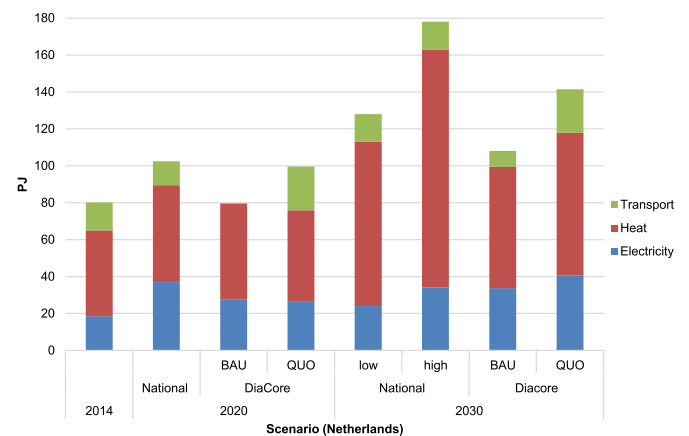


Fig. 13. Final biomass consumption by end use sector (NL).

4.5.2. Primary demand and biomass supply

Fig. 12 showcases the importance of the UK's biomass landscape in the EU's biomass imports. In 2011, 41% of the solid biomass used for electricity generation in the UK were in the form of imported wood pellets (mainly from North America). This percentage is projected to increase to 48% by 2020 (31% respectively for heat production) and remain relatively stable until 2030. This makes the UK the main importer of solid biomass in the region by far, and a key country in shaping the development of bioenergy in the region.

Reports from 2016 proclaim that almost 71% of the liquid biofuels used in the country were imported [61]. For the purposes of this work,

this amount was assumed to remain the same until 2030 Fig. 13.

4.6. The Netherlands

4.6.1. Final consumption

Final energy consumption from biomass increases by 2020, supported through the co-firing of solid biomass in coal power plants and small to medium scale heating. Despite a projected reduction of co-firing amounts, bioenergy consumption in 2030 is expected to increase in the heating sector, where industrial heat could pick up a sizeable share. Liquid biofuel consumption is expected to remain relatively stable from 2020 to 2030.

The deployment of bioenergy in the Netherlands to 2020 will most likely be in line with the energy agreement, including a 25 PJ cap on co-firing and the decommissioning of coal power plants that were built in the 1980s. There is much more uncertainty for the 2030 horizon: the energy agreement concerning the co-firing capacity in power plants is assumed to remain the same, but the actual amount of final consumption of biomass for co-firing is reduced due to a lower utilization of the power plants and the increasingly larger share of wind and PV power production. Combined demand for biomass electricity and heat ranges from 138 to 168 PJ for 2030 [14,62].

As mentioned in Section 3.1, four applications for co-firing have been submitted already, reaffirming the move towards meeting the Energy Agreements' targets [46].

Heat from biomass might still grow in order to meet the gap in meeting the renewable energy target, though this is unlikely for the 2020 horizon. Biomass use is not expected to be a major contributor to heating for residential and services sector in the Netherlands, however industrial heat production from wood pellets, in light of the SDE+ subsidy scheme and the Energy Agreement support, will become competitive by 2030. Waste incineration and small-scale energy production from biomass will grow, as will biogas production through gasification of waste, manure and slurry streams [14]. Final energy demand from solid biomass sources can be seen in Fig. 14.

The demand of biofuels will largely depend on policies, such as blending obligations, double counting and technological development. According to projections by different sources taking into account competing technologies and increased efficiency in fossil fuel use biofuel demand in the Netherlands can range from 15 to 40 PJ in 2030 [14,63].

4.6.2. Primary demand and biomass supply

Despite the increase in use in the heating sector, the actual imports of biomass are projected to decrease (low scenario) or remain even from 2020 to 2030. While co-firing will be supported by imported wood pellets, large part of the heat share is covered by domestic sources. Industrial heat may require higher quality feedstock that can offset the

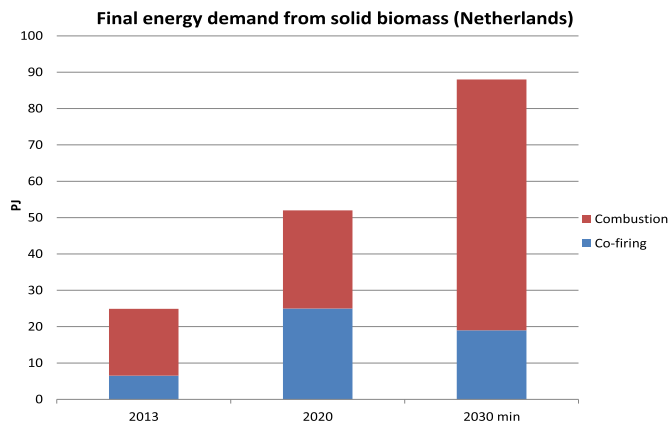


Fig. 14. Final energy demand from solid biomass (NL) [64].

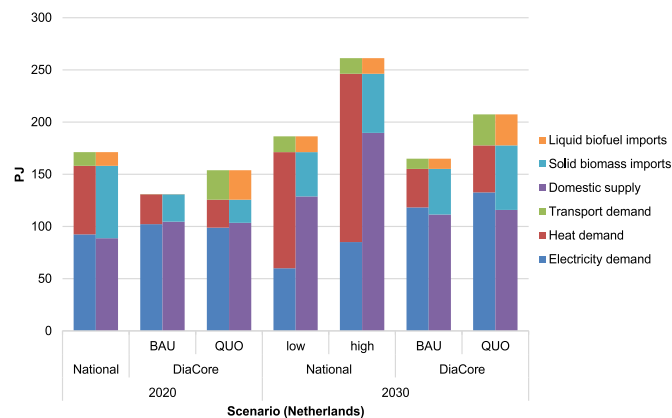


Fig. 15. Primary biomass demand and supply (NL).

decrease in the electricity sector in the high scenario Fig. 15.

4.7. Biomass import trends

Based on the information presented in the previous sections, an overview of the future bioenergy status in Northwest Europe can be visualized. When we juxtapose the results from the regional models with the national projections, we can see that in most cases the final bioenergy demand deviates within reasonable limits (5–15%) for the 2020 horizon. Required imports however are either overestimated (Germany, the Netherlands) or underestimated (Denmark, UK). Bigger divergences between sources are observed on the 2030 horizon, highlighting the uncertainty of biomass development on a national level on the one hand, and the inability to include future policy of the previous projections on the other.

Although most of the biomass will be supplied from domestic resources, especially in the cases of Germany and the UK, an increase in imports is also expected (Table A1). Import amounts are based on current and future trends, technological developments and sector needs.

Solid biomass is imported in the selected countries for use in the electricity and heat sector. It is assumed that the feedstock is first processed into pellets, the main traded commodity of solid biomass, at the source region. Industry indicates that the majority of the biomass feedstock used for electricity or heat generation in Denmark, Belgium, the UK and the Netherlands will be imported mainly from North (or South) America, Russia and the Baltic region. Notable exception is Germany, where waste wood (from construction and demolition activities, municipal solid waste etc.) is imported mainly from the Netherlands (> 50% of total imports) or other neighboring countries for use in electricity and heat production [30].

Liquid biomass is imported in the already processed form of biodiesel or bioethanol mainly from Brazil, the US, and Southeast Asian countries. Liquid biofuels are predominantly used in the transport sector, blended with fossil fuels.

Solid biomass use for electricity and heating purposes is expected to increase by 35–49% to 1213–1348 PJ by 2020 (from 900 PJ in 2014) and reach 1068–1717 PJ by 2030. Imported biomass may consist 8–25% of the above in 2020, and 13–32% in 2030, taking into account the least to most optimistic projections (see also Table A2).

Taking into account only national report data, bioenergy consumption will decrease to some extent by 2030 (1068–1157 PJ), mainly due to the decreased participation of bioenergy in the German energy system offsetting the slight increases in the rest of the region (Table A1).

Consumption of biofuels is also projected to rise to 243–348 PJ in 2020 (a 21.5–74% increase from 2014) and slightly more (231–464

PJ) by 2030. Imports of biofuels are expected to range between 62–70% of the primary demand up to 2030.

Once again, national reports show more moderate projections, with a sizeable increase to 260 PJ by 2020, but a leveling off of consumption by 2030 (239 PJ) due to decreased use in Germany and the UK.

In general, despite the net trade of biomass more than doubling compared to the current levels, overall solid biomass imports, while quite high, are not as impressive as expected a few years ago. Whereas imports in the smaller MS under investigation (Denmark, Belgium and the Netherlands) will increase, the total imports might even decrease due to reorganizations of the renewable energy field, more efficient use of existing resources, or competition from other forms of renewable energy – as explained in each countries respective Sections, 4.2–4.6.

Liquid biofuels are expected to be predominantly imported in their final form for all MS under consideration (the UK is the lowest among them with projected imports around 85% of the primary demand), except Germany, whose projected domestic production lowers the total percentage of imports, as presented above.

5. Discussion

A multitude of data sources (see section 2) were used to supplement previous existing model projections that assess bioenergy deployment in the EU. While energy models taken into consideration approximate the final consumption in the region quite accurately, there are some divergences between them and the national projections. Future development in particular is shaped by an ever-shifting policy landscape and political decisions that may (or not) change in rapid succession. The models cannot completely incorporate these parameters into its function. Careful analysis is needed of up-to-date governmental decisions in order to successfully supplement previous bioenergy projections.

At the time of this work, the most up-to-date relevant data were taken into account. However, there are also parallel developments that may influence them significantly, but that did not have a quantifiable effect in published media until this point. As an example, the UK government's decision that the support rate under the Renewables Obligation (RO) for future biomass co-firing and conversion projects should no longer be covered by the government's grandfathering policy could pose a hindrance to the development of a biobased economy in the respective countries.

The recent Brexit decision may have even greater ramifications on the bioenergy future of the UK and the EU as a whole. On the short term, the post-referendum empowerment of the dollar against the sterling has left Europe supplying most of the UK's marginal and spot demand for wood pellets in recent months as the cost competitive advantage of European pellet suppliers relative to the North Americans has increased [65,66]. On the long term, statements coming from the U.K. government have confirmed that the commitment to increasing renewable energy generation remains [67]. Contracts between the UK government and UK utilities for closing down (or retrofitting) the country's coal power plants by 2023 are still in place. Brexit, in whatever form, is unlikely to change the UK's climate change goals; these are established at a national level under the Climate Change Act 2008. But, there will nevertheless be important issues to settle. For example, at an international level the UK's emissions reduction commitment would need to be disentangled from the EU target under the United Nations Framework Convention on Climate Change (UNFCCC) and the recent Paris agreement. Regarding renewable and low carbon energy policy, following Brexit, the UK would be released from its renewable energy targets under the EU Renewable Energy Directive and from EU state aid restrictions, potentially giving the government more freedom both in the design and phasing out of renewable energy support regimes. However, given that the UK would

still be bound by national and international decarbonization obligations, it is anticipated that renewable and low carbon energy development would continue to form part of UK Government climate change policy [68].

In the Netherlands, the SDE+ scheme supports above all cost-efficient technologies, but it cannot immediately cater for all innovative and costly technologies by 2020. The existing subsidy or support schemes are the main means of achieving the renewable energy targets in the MSs. However, they alone might not be enough [43]. In addition several key non-economic barriers have to be addressed: the time needed to bring new installations to operation and to connect it to the grid, the protection of the environment (permitting procedures) and public acceptance by the legitimately concerned citizens [69]. As renewables deployment advances, policies have to adapt over time, moving from clear targets and regulations to adapting market design and ensuring public acceptance.

Also on EU-level, the forthcoming updated directive on the promotion of the use of energy from renewable sources is currently causing uncertainty. For example, if and how first- and second generation biofuels will receive policy support, and whether solid biomass for heat and electricity production will have to adhere to EU-wide mandatory or voluntary sustainability criteria will largely determine future biomass trade flows towards the EU as well.

The above examples and developments only further serves to showcase the uncertainty and volatility of the sector. Developments in policy are rapid and may be significant enough to warrant an overhaul of existing or ongoing work in the field, in order to have a current, detailed picture of the biomass state in the EU at all times. The effectiveness and efficiency of almost all the RED provisions can be enhanced by putting a stable post-2020 policy in place that includes a continuation of these measures as well as a clear governance system. This conclusion holds for all provisions. Moiseyev et al. [70] studied the impact of subsidies on the production of wood-based electricity and heat under different levels of carbon emission prices. Even a relatively modest subsidy or bonus of 30 €/MWh for electricity generation used in just a few EU member countries leads to a substantial increase in the use of industrial wood use for energy, even under a modest carbon price. A stable longer term outlook will enhance investor certainty as well as increase the incentive for stakeholders and government authorities to put in the effort needed. The initial effort and cost of setting up the procedures and processes is then offset by much more long term and therefore overall higher benefits [52].

Being open economies, the MSs of NW EU benefit from trade, but at the same time, they are impacted by global energy market trends as well as by the energy policy choices of their neighboring countries. There is a high risk of increased market distortion from nationally focused subsidies of renewables and capacity mechanisms in neighboring countries. Global price differences in gas, coal and raw materials between the MSs and their major trading partners can have a significant impact on the competitiveness of the bioenergy industry [43,69].

6. Conclusions

In the previous sections, the uncertainties of future bioenergy development in NW Europe were quantified and reported. The variability of bioenergy development is made evident by the sizable gap of the projection bandwidths after the 2020 horizon. Depending on whether the projections are derived from national reports or regional models, whether future policy developments were taken into account, the ranges of biomass consumption are multiple times apart by 2020 already, and the gap increases by 1.4 times more by 2030.

Total imports (solid and liquid biomass) for the NW EU region, taking into account the lowest and highest scenarios, range between

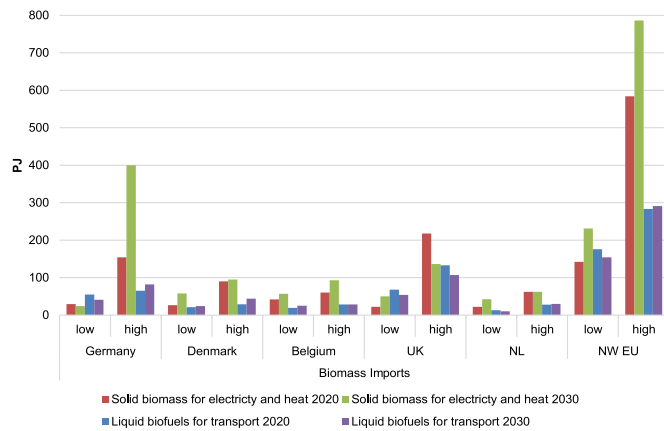


Fig. 16. Projected biomass imports for Northwest Europe.

318 and 875 PJ by 2020 and 386–1076 PJ by 2030 (Fig. 16). A more moderate view, taking into account mostly the national outlook for each respective country suggests imports of 389–528 PJ for 2020 and 331–369 PJ for 2030.

Imports of solid biomass could reach up to 276–458 PJ by 2020, supported by the need for preprocessed biomass in the form of wood pellets in the electricity and heat sector which cannot be produced domestically in the reviewed countries (except Germany which has a positive wood pellet trade balance). Biomass imports will increase, due to more power plants turning into co-firing or dedicated biomass use, [14,32,34], concerns regarding domestic land use and food production [19] or a combination of the above. Assuming an energy content of 17.6 GJ/ton for processed wood pellets and 14 GJ/ton for wood logs and waste wood (in the case of Germany) the required import amounts for the whole region leads to 8.5–35 Mt of solid biomass in 2020. Imports may fluctuate between 13.5 and 49 Mt in 2030. Detailed numbers are provided in Table A2, Appendix A of this report.

The summation of the national projections lead to 22–30 Mt (390–530 PJ) of solid biomass imports by 2020, and a decrease (321–370 PJ) by 2030, following the decreasing trend in biomass consumption for electricity and heat, leading to 19–21 Mt of imports.

Biofuel imports could reach up to 283 PJ by 2020 and will likely plateau around this level (291 PJ) until 2030, mainly due to low fossil fuel prices and increases in vehicle efficiency [30,57], but also depending on the future EU policy towards 1st and 2nd generation biofuels. Taking into account the energy content of biodiesel and bioethanol and assuming that the percentages of each biofuel will remain more or less steady, imports can reach 6 Mt in 2020 (7 million liters) and 4.6 Mt in 2030 (6.4 million liters).

On the whole, a modest growth is expected in biomass trade

volumes. As explained in Section 4.7, due to numerous inter-connected and complicated factors, even while the trade numbers double, the overall imports are expected to fluctuate in a lower spectrum than previously assumed.

Implications of the above could mean little to massive infrastructure development by 2030, mainly by developing new biobased industries, opening up new markets for bio-based products and creating new business and innovation opportunities in all European regions, in areas such as agriculture, forestry and industry [71]. Depending on the expected throughput to NW EU, supply, handling and storage chains will need to be adapted as well in order to cope with the physical and biological properties of the respective feedstock. Ranging from modification of the equipment in import terminals up to the need for constructing new, dedicated facilities (biomass terminals or biorefineries) to efficiently process the volume of imports.

6.1. Future research

The results presented in this paper are important in order to quantify the acute uncertainties regarding future biomass imports of the whole Northwest European region, as this will largely affect the respective infrastructure development.

The next step towards that goal will be the creation of in-depth scenarios, in order to examine infrastructure needs and optimization under different pathways.

Solid biomass may be a viable intermediate feedstock for the production of liquid (mainly 2nd generation) biofuels in facilities located within the EU. Extensive research, technological development, investment, and upgrading bio refineries and logistic facilities have to be prioritized to support the bio-based economy in EU beyond 2020. Since bioethanol and 2nd generation biofuels are prioritized, production and logistic facilities can be developed in order to produce these two bioenergy products [72]. Therefore, bioenergy trade flows will be focused on importing feedstock for the production of advanced biofuels. According to Sanna [73], advanced biofuel assessments indicate that between 3 and 25 EJ of energy on an annual basis could be produced in Europe by 2030, which could represent 5–50% share of transport energy.

Acknowledgements

This work is part of the BioLogiK NL project, which aims to develop knowledge of the logistics chains of biomass from abroad to the Netherlands [74]. It was made possible by the financial support from the ‘Subsidiering Energie en Innovatie Biobased Economy: Kostprijsreductie Elektriciteit en Warmteproductie’ (Grant No. TEBE213008).

Appendix A. – Tables

see: Tables A1 and A2.

Table A1

Bioenergy demand and respective imports required [PJ].

		Germany	Denmark	Belgium	UK	Netherlands	NW EU
Final consumption							
<i>Electricity and heat</i>	2020	661–744	140–152	67–99	149–386	76–90	1212–1348
	2030	508–984	155–171	70–136	202–309	99–163	1068–1717
<i>Transport</i>	2020	112–132	21	23–34	75–138	13–24	243–348
	2030	83–165	24–30	16–34	55–95	9–24	187–348
Primary demand							
<i>Electricity and heat</i>	2020	1088–1138	156–245	118–148	280–482	126–158	1837–2341
	2030	815–1401	199–265	124–183	347–509	155–246	1780–2477
<i>Transport</i>	2020	112–159	21–29	27–34	80–157	13–28	252–406
	2030	99–227	24–44	34–38	64–126	10–30	231–464
Biomass supply							
<i>Domestic</i>	2020	994–1084	129–163	66–97	312–490	89–117	1629–1883
	2030	791–1177	144–189	66–119	292–478	115–190	1448–2097
<i>Imports solid bioenergy</i>	2020	30–154	27–90	42–60	22–218	22–69	142–591
	2030	24–400	58–95	57–93	50–136	42–62	232–786
<i>Imports liquid bioenergy</i>	2020	55–65	21–29	19–28	68–133	13–28	176–284
	2030	41–82	24–44	25–28	54–107	10–30	154–290
Total imports	2020	85–219	47–119	61–88	90–351	35–98	318–875
	2030	65–481	82–139	82–121	104–243	52–91	
		386–1076					

Table A2

Biomass imports in NW EU [Mt].

Sector	Biomass imports Germany	Denmark	Belgium	UK	Netherlands	NW EU
Electricity & heat						
2020	2–10.5	1.5–5.1	2.4–3.4	1.3–12.4	1.3–3.5	8.4–35
2030	1.6–27.5	3.3–5.4	3.2–5.3	2.8–7.7	2.4–3.5	13.4–49
Transport						
2020						
Mt	1.7–2	0.7–0.9	0.6–0.8	2.4–4.6	0.4–0.9	5.7–9.3
ML	2–2.3	0.8–1	0.6–1	2.8–5.6	0.5–1	6.7–11
2030						
Mt	1.3–2.5	0.7–1.4	0.7–0.8	2–3.7	0.3–0.9	5–9.4
ML	1.5–2.9	0.9–1.6	0.8–1	2.3–4.5	0.4–1.1	5.8–11

Appendix B. – Personal communication

The list of the contacts providing information mentioned in [Section 2.2.3](#) includes:

- Peter - Paul Schouwenberg, Head Environment - Stakeholder Management - New Energy, RWE Essent
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- Richard Peberdy, Vice President - Sustainability, Drax Biomass
- Wolfgang Stelte, Project Manager, Danish Technological Institute - Centre for Biomass and Biorefinery
- Anders Evald, Chief Consultant, HOFOR A/S
- Christiane Hennig, Senior Research Associate - Sustainable energy supply, German Biomass Research Centre
- Guisson Ruben, Project Manager - Biobased Economy, VITO
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- Rocio Diaz-Chavez, Research Fellow, Centre for Environmental Policy, Imperial College London
- André de Haan, Corporate Scientist - Process Technology, Corbion Purac
- Rob Groeliker, Technical Director, Biopetrol Industries
- Robert C. Abt, Professor of Natural Resource Economics and Management, North Carolina State University
- Jan Oldenburger, Senior Consultant - Forest Products and Statistics, Probos Foundation

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