Master thesis Energy Science

Biomass demand in the Port of Rotterdam hinterland and the effect on port logistics

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Abstract

The ongoing greening of the European energy supply leads to ever growing demand of renewable energies. Solid biomass is currently the largest source of renewable energy in NW-EU contributing 45% of total renewable energy in 2014. Presently, there are some new developments making the future development of solid biomass use uncertain. Firstly; solid biofuels have to compete on costs not only with cheap fossil fuels but also with other renewable energy options such as wind and solar whose costs are rapidly declining. And for small scale heat demand, traditional a sector with a high share of solid biofuel use, new heating options are coming available such as heat humps and geothermal heat. Finally, the sustainability of (imported) solid biomass supply has become a topic of public debate which has influenced the governmental support for solid biomass.

Therefore, Port of Rotterdam Authority wants to improve their insight in how solid biomass demand in its contestable hinterlands (Belgium, Denmark, Germany, The Netherlands and the UK) could develop in the future so as to be as competitive as possible with other NW-EU harbors seeking to provide this contestable hinterland with access to overseas solid supply markets. Therefor PoR want to update their outdated capacity study incorporating the latest developments influencing future NW-EU solid biofuel demand.

Three solid biomass demand markets were identified which have the potential to import (additional) extra-EU biomass (in the near future). Centralized users, small scale heat and biorefining. To cope with the uncertainties regarding future solid biomass demand, four scenarios were created, varying the three main factors of uncertainty; namely solid biomass price competitiveness, total final energy demand and governmental support for solid biomass.

The scenarios showed little perspective for PoR for additional centralized demand import flows, since there is both little growth in this sector and logistics tends to be locally handled. Biorefining is still in its infancy and only for two of the four scenarios imports flows (1 - 7 Mt/y) are expected. Small scale heat however showed significant growth in three out of the four scenarios, growing from 2015's 34,4 Mt/y wood pellet equivalent (wp-eq.) to 61,8 – 89,3 Mt wo-eq. in 2030. However, since the European solid biomass supply will also grow in this same period it is still unclear if extra-EU imports are needed. Moreover, the three demand markets (could) have different pretreatment preferences (wood pellets vs. wood chips) and shipping methods (mostly bulk but possibly prepackaged wood pellets in containers for small scale heat) will could lead to fragmented logistics.

Content

1 Introduction

1.1 Background

The last few decades there has been an increasing awareness of climate change. This has led to worldwide climate agreements such as the United Nations Framework Convention on Climate Change (UNFCCC) of which the most important treaties are the 1997 Kyoto Protocol and the 2015 Paris Agreement. The main objective of these treaties is to "stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"[1].

To meet that goal the European Union (EU) Member States (MS) have agreed to a number of directives that will reduce GHG. The most important of these directives is the 2009 Renewable Energy Directive (RED) 2009/28/EC, which key objective is to reduce carbon dioxide (CO_2) emissions with 20%, to increase the share of renewable energy to 20%, and to achieve energy savings of 20% or more by 2020, compared to 1990, by setting individual targets for each MS [2]. The 2015 ILUC directive amended the RED, similar to the RED, in 2020 there should be a minimum of 10% of renewable energy consumption in transport, however, only a maximum of 7% may be made from food crops [3] . And finally, there is the 2030 climate & energy framework in which MS of the EU have among other things agreed to realize a 40% reduction in GHG emissions and a 27% increase in energy efficiency (both compared to 1990 levels) and to archive at least 27% share of renewable sources in energy consumption by 2030 [4]. In contrast to RED, no binding national targets for renewable energy are set.

1.1.1 Current and future demand for biomass

The trajectories by which MS project to achieve these binding RED targets have been published in the National Renewable Action Plans (NREAP) in 2011. As can be seen in Figure 1 in 2014 solid biofuels were the most important EU28 renewable energy source and according to these NREAPs in 2020 electricity production from biomass will be doubled from 2010 and heat production will increase with 50%, which results in a strong growth of biomass demand. This means that with a use of 5.8 EJ biomass in 2020 [5], over half of renewable energy (projected in NREAPs at 10.2 EJ [5]) is projected to be generated from biomass resources [6] providing almost a tenth of gross final energy consumption in the EU [5] meaning bioenergy will remain the largest source of renewable energy in the EU till at least 2020.

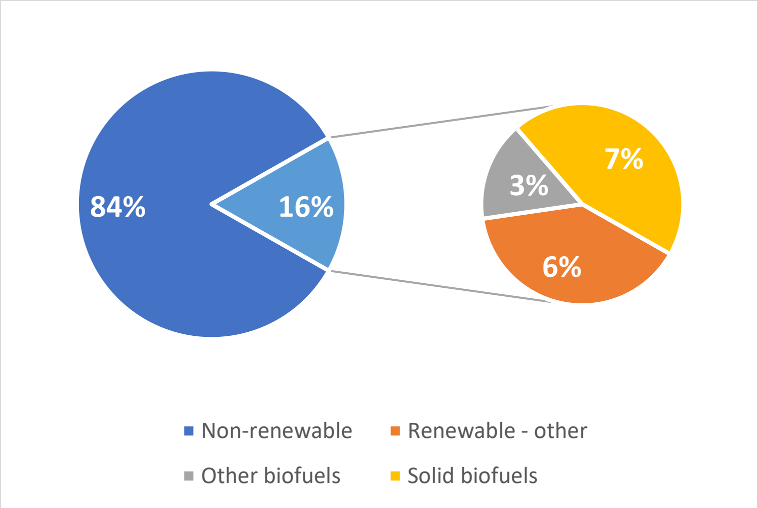


Figure 1 – 2014 EU28 gross final energy consumption [8], [9], [10], [11]

These NREAP only cover the use of biomass for energy purposes, biomass use for products (such as furniture or paper) is not covered. Bioenergy is presently mainly used in the transformation sector, i.e. by power plants transforming solid biofuels and biogas into electricity and/or heat, the residential sector where households use solid biofuels for room and water heating, the transportation sector where liquid biofuels are blended with fossil transport fuels and the industrial sector, mainly in industrial subsectors who use wood as an production material (e.g. for paper, furniture etc.) and use their waste as fuel for room heating and/or to drive industrial processes.

The precise 2015 EU28 bioenergy use per sector are shown in Table 1. Table 1 also makes immediately clear that the transformation and residential sectors are the most important demand sectors, combined covering two thirds of total 2015 EU28 biomass demand, while solid biofuels are the most important form of biomass covering three-quarters of total 2015 EU28 biomass demand.

Sector	Solid biofuels	Biogas	Liquid biofuels	Total bioenergy
Transformation input	1.207	521	46	1.774
Residential	1.762	2	0	1.764
Industry	853	14	4	871
Transport	0	5	587	593
Services	94	74	7	175
Agriculture/Forestry/Fishing	66	15	2	82
Non-specified	5	0	0	5
Total	**3.987**	**631**	**646**	**5.264**

Table 1 – 2015 EU28 bioenergy use (in PJ) per biomass type and sector [8]

1.1.2 Biomass supply regions

Presently, the largest part of biomass supply needed to meet EU MS biomass demands comes from domestic sources. In 2014, only 4% (236 PJ) of total biomass used for energy purposes is imported from outside the EU [12]. Reviewing extra-EU import data shows that in 2014 the EU28 net imported 6,4 Mt of wood pellets, or a third of total 2014 EU28 wood pellets consumption. In contrast, for liquid biofuels in the last years EU28 net imports have constantly decreased to 44 Ml for ethanol in 2014, which is less than 1 % of total 2014 EU28 consumption and 450 Ml for biodiesel and renewable diesel (HVO) which is 3% of total 2014 EU28 consumption. For both these liquid biofuels net imports are projected to decrease even further in to coming years [44]. Making it clear that solid biofuels are now and in the near future the most important form of biomass concerning imports.

A closer examination of extra-EU imports identifies Northwest Europe[1] as key region importing extra-EU solid biofuels. In this region, the share of imports in the gross inland consumption of solid biofuels has almost doubled between 2004 and 2014, from 9% to 17% and in absolute values almost quadrupled from 42 PJ in 2004 to 151 PJ in 2014 [8], showing that imports are becoming increasingly more important for NW-EU. In 2015, in NW-EU wood pellets accounted for 10 Mt of the 13 Mt NW-EU's fuel wood imports [13]. These extra-EU imports are mainly due to biomass co-firing and large scale dedicated power plants in Belgium, Denmark, The Netherlands and the United Kingdom, countries where domestic supply is of low quality and/or more expensive than foreign supply. These power plants need year-round access to large volumes of cheap wood pellets or chips. These wood pellets or chips are thus sourced mainly from the US, Canada, or the Baltics, countries with large forestry industry and thus abundant availability of cheap, raw materials. Since transport is an important cost component of biomass these countries are also favored since shipping is a cheap form of transport. For small scale use, where due to the smaller scale, year-round access to large volumes of biomass is less important, domestic or intra-EU biomass is still the cheapest option due to the additional transportation cost of extra-EU biomass. However, when total NW-EU demand for biomass grows, additional extra-EU imports could be needed if domestic production could no longer meet demand, or when the cost of additional domestic biomass production is higher than imported biomass.

In a study done by Duscha et al. [14] two scenarios of extra-EU supply of solid biomass have been developed: a Conservative scenario and an Optimistic scenario. These scenarios estimated the total potential of extra-EU supply of solid biomass between 73 Mt in the Conservative scenario and 137 Mt in the Optimistic scenario in 2030. These numbers make it clear that there is still enough extra-EU supply potential for extra-EU solid biomass import growth.

1.1.3 Capacity study

The potential for NW-EU solid biomass imports for both electricity and heat demand was already recognized by the Port of Rotterdam Authority (PoR) in the early 2010's. These solid biofuel imports could mean significant extra throughputs for the port, and where therefore of interest for PoR. However, supply, handling and storage chains could need adaptation, or new

[1] Comprising of BE, DE, DK, NL and UK

chains could need to be designed, to cope with the physical and biological properties of biomass feedstocks. [12]. And, while the biomass co-firing power plants at the Rotterdam Maasvlakte fall within PoRs captive hinterland, for additional extra-EU biomass imports into their contestable hinterland PoR has to compete with other Le Havre-Hamburg range habors. Early investment in solid biofuels logistics could give the Port of Rotterdam a decisive advantage over these other NW-EU harbors. However, when solid biomass demand would fall short of expectations, these investments could turn out to be unrecoverable. On the other hand, not or to late investing in solid biofuel logistics when solid biomass demand does take off, could lead to missed out opportunities and lost business to other NW-EU harbors.

To reduce these risks, the best possible insight is needed in how solid biofuel demand could develop in PoRs hinterland. Therefore, in 2012 PoR ordered a study by the Copernicus Institute of Sustainable Development which would assess scenarios of global supply, demand and trade of solid biofuels for NW-EU [15], [16].

In the capacity study two models were linked; namely a biomass transport model and a biomass allocation model. The biomass transport model calculates the lowest cost transport routes between biofuel supply and demand locations. The biomass allocation model takes these transport cost together with the costs for biofuels at the supply regions and then calculated the lowest total cost to meet demand at biofuel demand locations. Biomass trade flows could then determined. Solid biofuel demand for electricity generation and centralized and residential heat generation in NW-EU for the period 2010 – 2030 was modeled using different scenarios taken from the Re-Shaping project. Solid biofuel demand data for these scenarios came from the TU Wien Green-X model with the addition of power plant specific assumptions on electricity generation. The Green-X model is a partial general equilibrium model of the energy sector and was used to among other things calculate the deployment of solid biofuels for the selected Re-Shaping scenarios. The capacity study projected that NW-EU demand of solid biofuels would grow from 44.6 Mt wood pellet equivalent (wp-eq.) in 2010 to 67.3 - 93.3 wp-eq. in 2020 and 77.8 - 109.1 wp-eq. in 2030. Extra-EU imports would grow from 1.9 Mt wp-eq. in 2010 to 0 - 20.2 Mt wp-eq. in 2020 and 16.8 - 33.9 Mt wp-eq. in 2030. Thereof 0 - 5.5 Mt wp-eq. would be transported via PoR in 2020 and 10.7 - 16.0 Mt wp-eq. in 2030 [16].

1.1.4 Need for update of capacity study

Due to rapidly changing development in the bioenergy sector the 2013 capacity study is by now fast becoming outdated. Four major sources of uncertainty that could influence future NW-EU solid biofuel demand can be recognized that could result in different future NW-EU solid biofuel demand compared to the results found by the capacity study.

Firstly, the price competitiveness of solid biomass versus other form of (green) fuels. Among others due to the large scale exploitation of cheap US shale oil and shale gas, fossil fuel prices are currently low and are expected to stay low for the foreseeable future. [17] And for green electricity solid biofuels have to compete with mainly wind power, which recently experienced large costs price drops, especially for wind on sea. For example, a recent tender for Dutch wind park on sea (Hollandse Kust Zuid) is now expected to not need subsidies at al [18]. Both these reasons make solid biomass use for electricity less attractive to invest in, since both cheaper fossil fuels as renewable options exist.

Secondly, the rise of viable alternatives for renewable heat. In the capacity study, solid biofuel was expected to cover the majority of renewable heat demand in the residential sector. However, recently other options for green heat have become viable, such as heat pumps, geothermal heat and solar thermal. In Germany in 2015 for example, in newly build houses both heat pumps and geothermal energy have a larger share as biomass as the primary used energy source for heating [19]. These developments could diminish the future share of solid biofuels in residential green heat, compared with the original capacity study, since these other options also will take a share of the residential green heat market.

Thirdly, the is an ongoing public debate about the sustainability of imported solid biofuels. Currently, solid biofuel use in the NW-EU transformation sector is largely dependent on policies, such as subsidy schemes, without these policies there is no future for biomass in this sector. This dependence on policy is exemplified by for instance the Dutch demand for wood pellets, which halted after 2013 when an RES subsidy scheme came to an end, causing the power plants to stop co-firing pellets. The public debate about the sustainability of imported solid biofuels could lead to less governmental support for solid biofuels, resulting a smaller demand for solid biofuels. An example of this uncertainty is the late stage discontinuation of two advanced plans for biomass firing powerplants (in Gent and Langerloo) in Belgium.

Fourthly, the expected use of biofuels for biorefining. In the (near) future, biomass can also be used for non-energy uses by replacing fossil fuels in the production of chemicals and materials. This is often referred to as biorefining and the resulting products as biochemicals, bioplastics and such. In biorefining processes, solid biomass can be broken down by for example gasification into syngas or via fermentation into carbon dioxide and ethanol. These intermediary products can then be processed further into biofuels, biochemicals, bioplastics and such. The Netherlands has a large petrochemical sector and is, through the port of Rotterdam, a key importing country of fossil fuels and key exporting country of intermediates and end products. Moreover, large parts of the chemical industry in both Belgium and Germany are supplied though the port of Rotterdam, by for example the Rotterdam Rhine Pipeline, capable of transporting 22 Mt of crude oil and 12 Mt of oil products a year to Germany and the Rotterdam Antwerp Pipeline capable of transporting 30 Mt of crude oil a year to Belgium [20]. Therefore, PoR, would be a logical location for a biorefinery. Although biorefining is still in its infancy, the Association of the Dutch Chemical Industry (VNCI) has an ambition to replace 15% of fossil feedstocks in the production of chemicals and materials with biomass in 2030 [21] and the European Biobased Industries Consortium (BIC) has an even higher strategic goal of 20% in 2020 and 30% by 2030 [22]. In a strategic vision of the Dutch Ministry of Economic Affairs the ambitions of VNCI to replace 15% of fossil feedstock in 2030 in the Netherland with biomass was calculated at approximately 3,5 Mt of biomass [21]. Using BIC's even more ambitious goal of replacing 30% of these fossil feedstocks with biomass would double this number. This number is comparable with roughly halve the current EU28 extra-EU imports. This extra source of solid biomass demand for biobased materials was not included in the capacity study. Depending of the type of feedstock needed for biorefining, this could lead to additional biomass imports. However, these seem to be very ambitious ambitions since presently no biorefining using solid biofuels takes place, and will not till a least the early 2020's.

Therefor PoR wants an update of the capacity study, to be able to assess whether future solid biofuel demand could still lead to extra-EU imports. In this update, these new variables for uncertainty of NW-EU solid biofuel demand should be taken into account. At the same time, PoR wants to expand the capacity study with new solid biomass demand sectors, not covered in the original capacity study, namely biorefining, services heat demand and industrial heat demand. The NW-EU industrial heat demand was responsible for 3.3 EJ final energy consumption in 2015, while the NW-EU services sector had a 1.6 EJ final energy consumption in 2015, together covering 56% of total final NW-EU final energy consumption for heat and together bigger than the NW-Eu final energy consumption for residential heat, which was 3.6 EJ in 2015 [10].

1.1.5 NW-EU solid biofuels demand development

Within the timeframe of this study, it is too complex to update the entire capacity study, therefor this study solely focused on how solid biofuel demand could develop in the PoR hinterland.

Therefor a provisional literate study was done, searching for studies which could be used as source for future NW-EU solid biofuel demand. Recently a DiaCore study [23] has been published exploring the size of (future) extra-EU solid biomass imports. This study modelled the supply, demand and trade of solid biomass for bioenergy till 2030 for the entire EU. With the increased demand for biomass, the extra-EU solid biomass imports in this study grow from 20 - 25 Mt in 2020 to a range of 45 - 75 Mt in 2030. The gap in the 2030 range make it immediately clear that there is still a lot of uncertainty surrounding the future of biomass in Europe.

Recognizing the unique position of Northwest Europe concerning extra-EU biomass imports, Dafnomilis et al. [12] provided an up-to-date view of bioenergy supply, demand and trade in this region for bioenergy till 2030. This study identified not the power sector, but the further development of the (residential) heat sector as the main driver for extra-EU imports. Germany's (residential) heat demand could need up to 10,5 Mt wood pellets in 2020 and 27,5 Mt in 2030. This study models the total extra-EU biomass imports for Northwest Europe from 14 - 44,3 Mt in 2020 to 18,5 - 60Mt in 2030.

In the end is was decided that these existing studies had to many limitations to be of use when exploring or modeling future NW-EU solid biofuel demand. Not only could no studies be found which modeled future solid biomass demand for biorefining, above all, in the studies found covering the other solid biofuel demand sectors it is often not clear how the four main sources for uncertainty of future solid biofuel demand, covered in paragraph 1.1.4, were taken into account. This would make later updates of the new capacity study, when these uncertainties are better understood difficult. Therefor the choice was made to develop new scenarios for future NW-EU solid biofuel demand. In these scenarios, these uncertainties covering future solid biofuel demand in NW-EU have been translated into parameters which were used to build the different scenarios, capturing the different paths of future NW-EU biofuel demand.

1.1.6 NW-EU solid biofuel demand effect on PoR logistics

In the end, PoR is not so much interested in how future solid biofuel demand in NW-EU could develop as well in how this development could affect PoR. PoR is therefore interested in how much of the future NW-EU solid biofuel demand could be imported via Rotterdam and how this could affect port logistics. Since a complete update of the capacity study, with both updated biomass supply regions, biomass supply prices and a transport model is needed to calculate from which solid biofuel supply region solid biofuel demand in fulfilled, only a estimate can be made of extra-EU solid biomass imports while the effect on port logistics will be investigated by interviewing Rotterdam stevedores, already or expecting to handle solid biofuels.

1.1.7 Aim:

Since there has been fast, unexpected developments in the NW-EU solid biofuel demand sectors the 2013 capacity study is fast becoming outdated. Therefor PoR want to update this study. To effectively deal with recent bioenergy developments an in-depth analysis of the factors influencing the future demand for solid biomass in the port of Rotterdam hinterland is needed. These factors have to be translated into parameters which can be used to build scenarios, capturing the different paths of future biomass demand. This will then lead to a better understanding of these possible paths NW-EU solid biofuel demand can take and can thereby reduce the risks in policymaking for PoR.

This leads to the following research question:

How will the demand for solid biofuels in the Port of Rotterdam hinterland develop till 2030, what are the main sources of uncertainty influencing this and how can this effect port logistics?

To answer this question two sub-questions have to be answered first:

1. How can the demand for solid biofuels in the Port of Rotterdam hinterland develop till 2030?

2. How can solid lignocellulosic biofuel import flows affect port logistics?

1.2 Scope

This study will focus on the period 2015 till 2030. 2015 Is chosen as starting year since historical data, on which the scenarios have been built, is available till 2015. 2030 Is chosen as ending since no new policies are known after the 2030 climate & energy framework.

This study, just as the original capacity study, will focus on solid (lignocellulosic) biofuel. Solid (lignocellulosic) biofuel is not only currently the most important form of imported biomass in NW-EU, but also has the highest potential for additional demand till 2030. As described before, biomass also comes in the form of liquids (e.g. biofuels, vegetable oils) and biogas, these types of biomass are however excluded from this study, due to time constrains.

The study will focus on biofuel demands markets that have the possibility of affecting Port of Rotterdam logistics. Therefor the study will focus on biomass demand markets which use solid biomass feedstocks that are imported through the Port of Rotterdam or have the possibility of being imported through the Port of Rotterdam in the future. These demand market were chosen based on the currently most important sectors identified in Table 1 and input from expert of PoR. These demand market are bioenergy (residential and commercial heat, industrial heat and steam and electricity) and biorefining (biofuels, biomaterials and biochemicals). These demand markets (can) use solid woody biomass such as woodchips and black and white pellets for bioenergy, which have the possibility of being imported through the Port of Rotterdam.

The in this study included demand regions are five countries in the hinterland of the Port of Rotterdam which were also include in the original capacity study; namely Belgium, Denmark, Germany, The Netherlands and the United Kingdom. Previous studies and experts at PoR identified these five countries as the most probable countries for which solid biomass demand could be imported through the Port of Rotterdam. These five countries will in this study be referred to as Northwest Europe.

2 Background

2.1 Solid biomass definition

Since data series from Eurostat are used not only to analyses historic and current final energy consumption, but also to model expected future demand, for this study the Eurostat definition of solid biofuel is adopted; "Solid biomass covers organic, non-fossil material of biological origin which may be used as fuel for heat production or electricity generation. It comprises of purpose-grown energy crops (poplar, willow etc.), a multitude of woody materials generated by an industrial process (wood/paper industry in particular) or provided directly by forestry and agriculture (firewood, wood chips, wood pellets, bark, sawdust, shavings, chips, black liquor etc.) as well as wastes such as straw, rice husks, nut shells, poultry litter, crushed grape dregs etc." [24]

2.2 Solid biomass pretreatment options

When solid biomass has to be transported over long distances, such as for example US or Canadian solid biomass transported to NW-EU power plants, pretreatment is used to clean and densify solid biomass. This will not only enhance handling, it also reduces transport cost, and for some uses, (e.g. co-firing with pulverized coal) even required.

2.2.1 Chipping and pelletization

Chipping and pelletization are common pretreatment methods for wood resources. Both methods reduce the size of the feedstock. By chipping, feedstock is cut or chipped to small pieces, while pellets are dried, ground, compressed and extruded in screw or piston presses. Pellets are, typically more than chips, of uniform size, moisture and heat content, further enhancing handling. European and North-American pellet plants purchase their feedstock from nearby of adjacent sawmills, of from the logging industry, whereas wood chips are generally produced from wood waste, as a byproduct from the logging industry. [25] For this study a value heating content of 17,6 GJ/t for wood pellets and 14,0 GJ/t for wood chips is used. [12]

2.3 Solid biomass conversion technologies

Below, a short summary of relevant biomass conversion technologies available for solid woody biomass is given.

2.3.1 Heat and power

The main use of solid biomass in NW-EU is still for heat and power, which can take place though multiple conversion technologies. The two most import technologies are given below:

2.3.1.1 Dedicated combustion

Dedicated combustion only uses solid biofuels as feedstock. The leading technologies are pellet boilers and chip burners, which are used to produce hot water and/or steam. The main applications are for residential heating and electricity and CHP generation. Presently, typical capacities are 5 - 100 kW_{th} for residential heating, 0.5 - 5 MW_{th} for district heating and 2.5 - 100 MW_e for electricity and CHP generation. Thermal efficiencies for residential and district heating are 79-88% and the electric efficiency of power and CHP is 18-28%. [25]

2.3.1.2 Cofiring

Cofiring is the combined use of biomass together with another fuel, most often pulverized coal. It is applied in existing coal power plants for power and CHP production. Recent projects use injection of milled biomass into the pulverized coal pipes, allowing high proportions of biomass to be cofired, up to 100%. [26] Typical scales of these plants range from 2.5-100 MW_e. Electric efficiency of these plants is 26% for CHP and 36-41% for power. [25]

2.3.2 Biorefinery

IEA Bioenergy task 42 on biorefineries defines biorefining as “the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)”. [27] In biorefineries different conversion technologies (such as gasification, fermentation and hydrolysis) are combined to maximize the use of all the biomass feedstocks components. Moreover, the combined production of high volume, but low value products with low volume but high value products improves the cost effectiveness of these biorefineries. New second solid biofuel based biorefinery concepts are expected to be commercialized in the medium term. These biorefineries are expected to be economically feasible in 10-15 years. [25] Biorefineries are expected to be less uniform in process configurations compared to fossil fuel based refineries. This is due to the fact that biorefineries can use multiple different biomass feedstock types and conversion technologies. [25]

A study by Laser et al. found that for the conversion of lignocellulosic feedstocks, biorefineries in which the feedstock is first biochemically converted to ethanol, and then the lignin-rich residue is converted thermochemically, can achieve overall process efficiencies of 70 – 80%. Biorefineries which combine biochemical biofuel production with power and/or protein production, can achieve overall process efficiencies of 61 – 73% [28]. Finally, for biorefineries which combine thermochemical biofuel production with power generation overall process efficiencies of 55–64% can be achieved [28]. Furthermore, biorefineries using production processes that involve biochemical production of ethanol are found to be most profitable. [28]

2.4 Gross solid biofuels use trends

In Figure 2 the trend of gross inland solid biomass consumption per NW-EU country for the period 1990 till 2015 is shown.

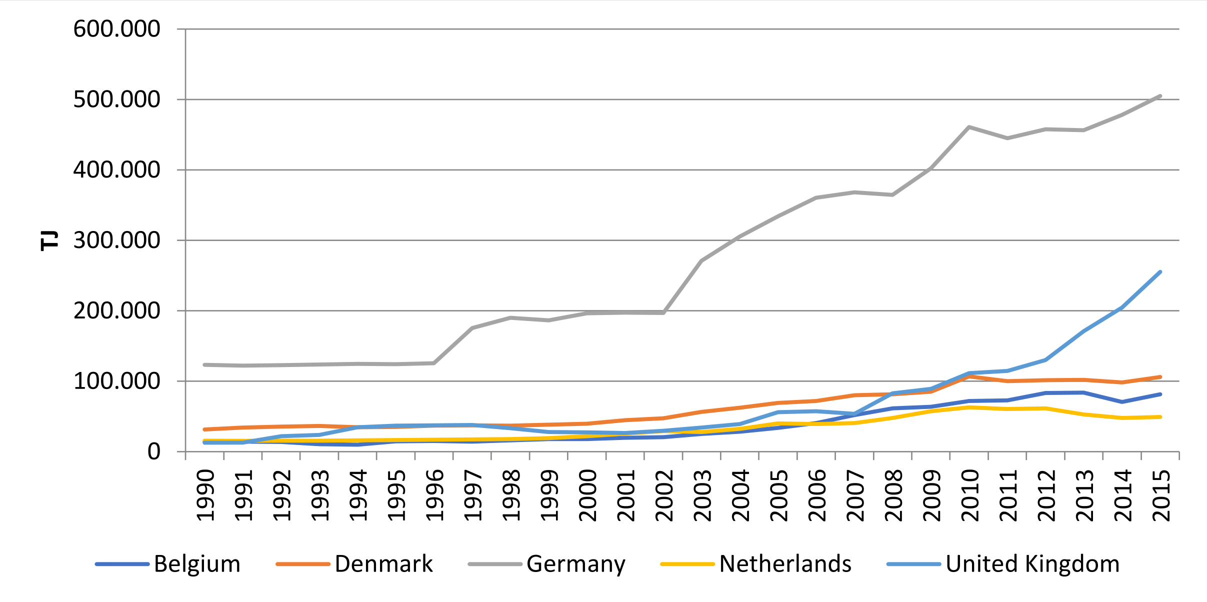


Figure 2 – NW-EU gross inland solid biofuels consumption [8]

When NW-EU's gross inland solid biomass consumption is broken per sector as shown in Figure 3, the rapid rise of transformation input (solid biofuels used to produce electricity and/or heat in power plants) clearly stands out, surpassing the residential use of solid biomass in 2014. Residential solid biofuel use has grown constantly from 1996 – 2010, roughly remaining on that level in recent years. Industrial demand has grown almost constantly from 2002, while Other use (mainly services) has grown since 2013.

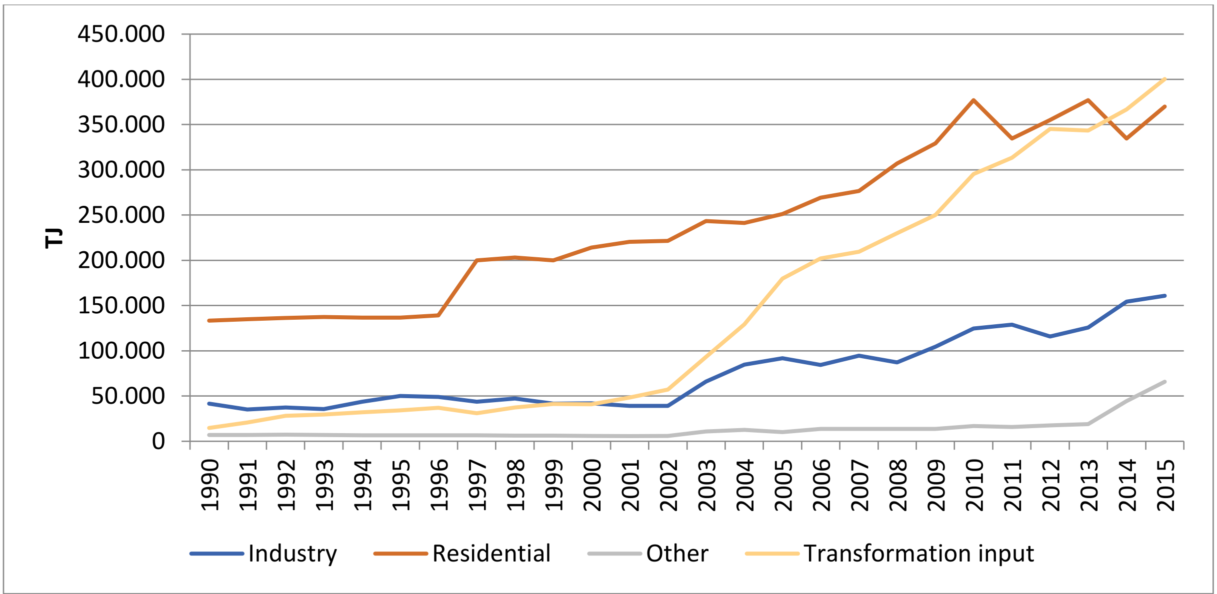


Figure 3 – NW-EU's gross inland solid biofuel consumption per use [8]

2.5 Solid biomass demand sectors

Based on the current sectors using solid biomass (Figure 3, Table 1) and input from experts of PoR, three biomass demand sectors are defined, namely:

- Centralized users (transformation sector, for solid biomass currently only power plants)
- Services, industrial and residential heat (small scale heat demand)
- Biorefining

This excludes some smaller sectors namely; the agriculture-, forestry-, fishing-, small scale power production and the transportation sector. All these sectors only use none or very small amounts of solid biofuels as can be seen in Table 1. Moreover, cursorily literature review showed that data on these sectors was hard to find, and above all, all these sectors are very unlikely to need extra-EU solid biomass imports.

2.5.1 Centralized Users

Large scale power plants (50 MW+) that produce electricity and/or heat. This is done in dedicated power plants solely firing solid biomass, in power plants co-firing solid biomass with coal or in power plants capable of running on multiple fuel sources.

Presently such power plants are operating in Belgium, Denmark and the United Kingdom, while additional (co)firing power plants are expected to come online in all these countries and the Netherlands.

2.5.2 Services, industrial and residential heat (small scale heat)

All heat demand not covered by large scale installations in the services, residential and industrial sector. Main usage is for heating rooms and water in the residential and services sector and heating of facilities and heat used in production processes in the industrial sector.

2.5.3 Biorefining

The third sector is biorefining with solid biomass. This is defined as the replacement of fossil fuels by solid biomass in the production of 2nd generation biofuels, biochemicals, biomedicine and biomaterials. This demand sector was added based on the expectation that 2nd generation biorefining will take over (part of) the share of 1st generation biorefining for biofuels, biochemicals and biomaterials since this generation are made from sugar, starch, or vegetable oils, which are all also food supplies and the EU will further tighten the share of biofuels produced from food supply sources.

2.6 Solid biomass breakdown per sector per country

There are significant differences in solid biomass use between the Northwest-European countries. This is studied by breaking solid biomass consumption down per sector and analyzing the differences.

2.6.1 Centralized users - electricity demand

Figure 4 shows the total gross electricity generation from solid biofuels. The United Kingdom has become the largest producer of solid biofuel electricity in 2014, surpassing Germany. Germany's solid biofuel electricity production has grown from 2002 till 2012, stalling on that level. In 2015 in NW-EU 3,2% of total gross electricity production was produced using solid biomass as a source, as can be seen in Figure 5. Germany and The Netherlands had a lower than average share, mainly because these two countries had no cofiring of solid biomass in 2015. Belgium and the United Kingdom both have shares around 5%, both countries have one or more cofiring powerplant and Denmark has a share of almost 10%, mainly due to the large scale utilization of CHP plants.

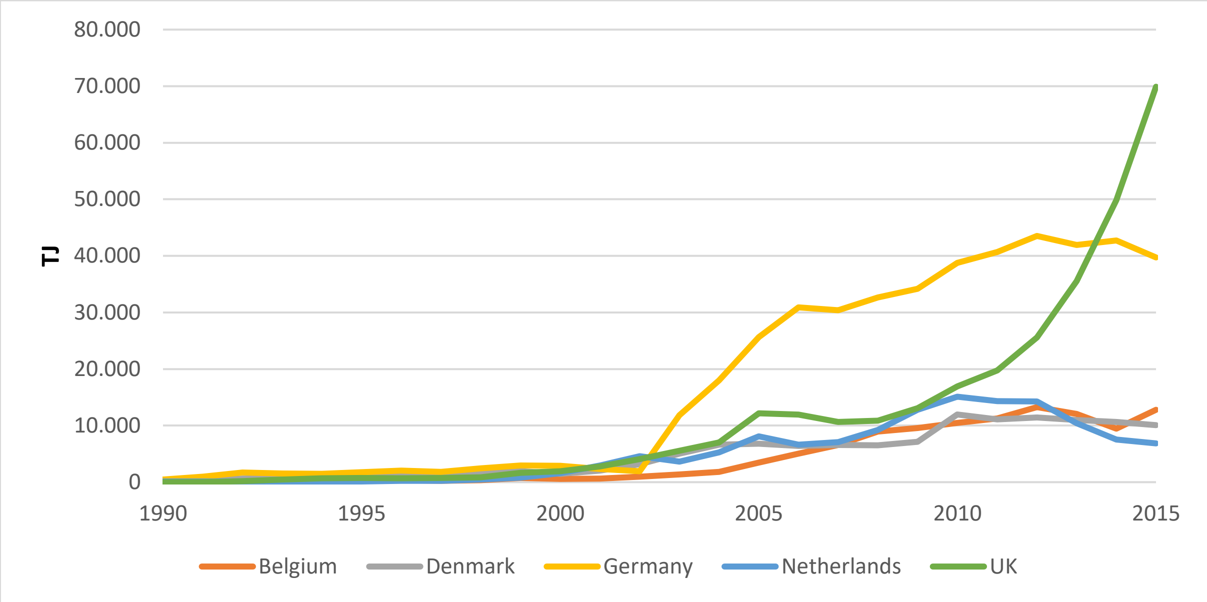


Figure 4 – Gross electricity generation from solid biofuels [9]

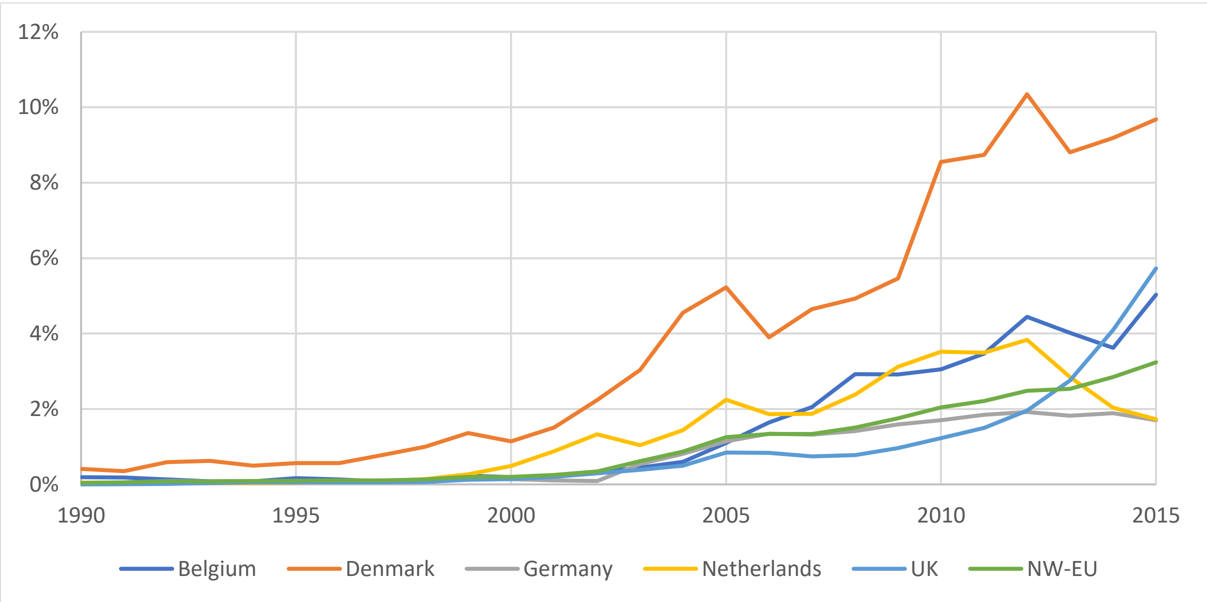


Figure 5 – Share of solid biofuels in gross electricity generation [9]

2.6.2 Centralized users - derived heat demand

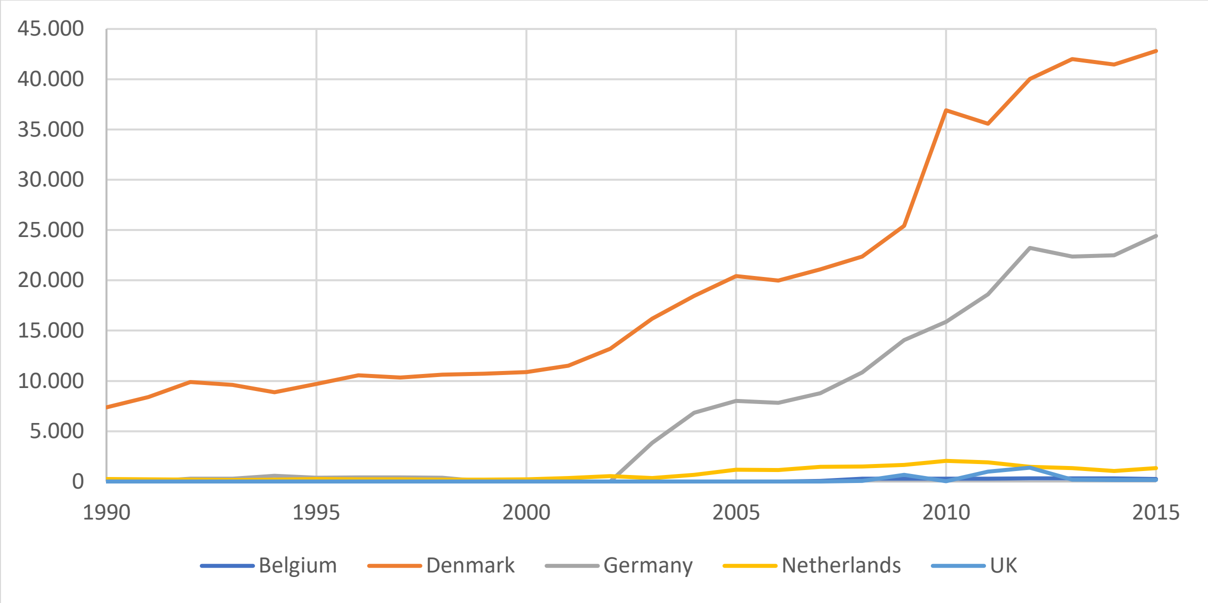


Figure 6 - Total gross derived heat production from solid biofuels [10]

Derived heat is centrally produced heat for commercially purposes, in dedicated heat plants or CHP, sold via heating networks. Figure 6 shows the total gross derived heat production from solid biofuels in NW-EU and Figure 7 shows the share of solid biofuels in overall total gross derived heat production. Denmark stand clearly out as leader in this field. This is due to the large-scale deployment of CHP. Germany also shows growth since the early 2000's, reaching a 8,4% share of solid biofuels in total gross derived heat.

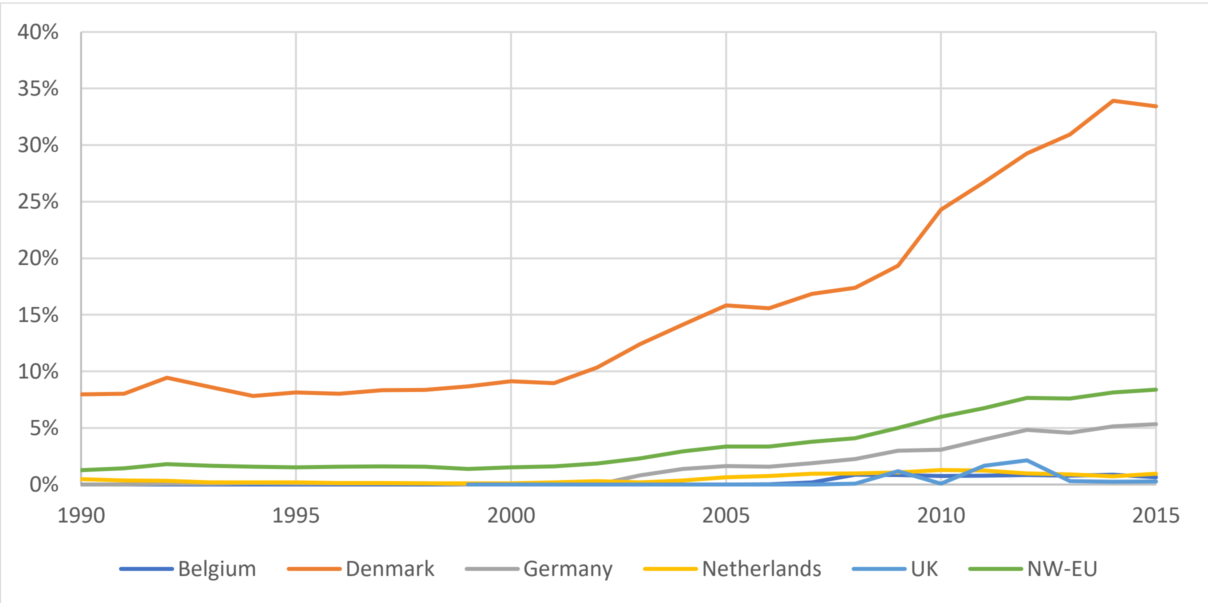
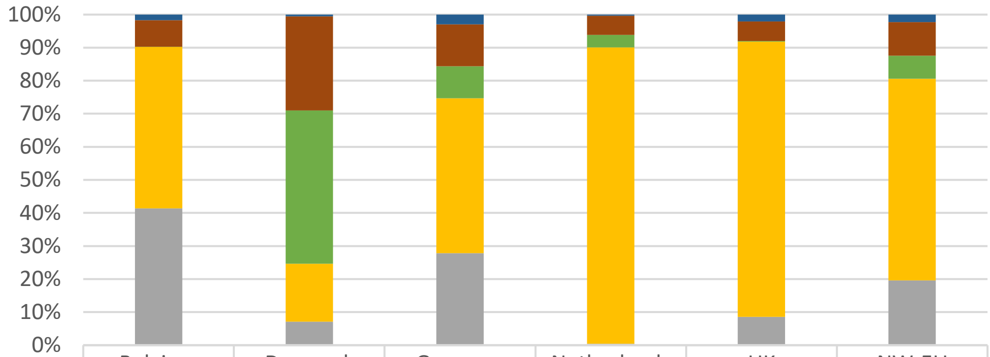


Figure 7 –Share of solid biofuels in total gross derived heat [10]

2.6.3 Small scale heat demand

The main usage of small scale heat is for heating rooms and water in the residential and services sector and heating of facilities, and heat used in production processes in the industrial sector.

There are large differences within NW-EU countries on fuel sources used for meeting heating demand per sector. In Table 2 total final energy consumption by fuel for heating usage per sector per country for the residential sector is shown.



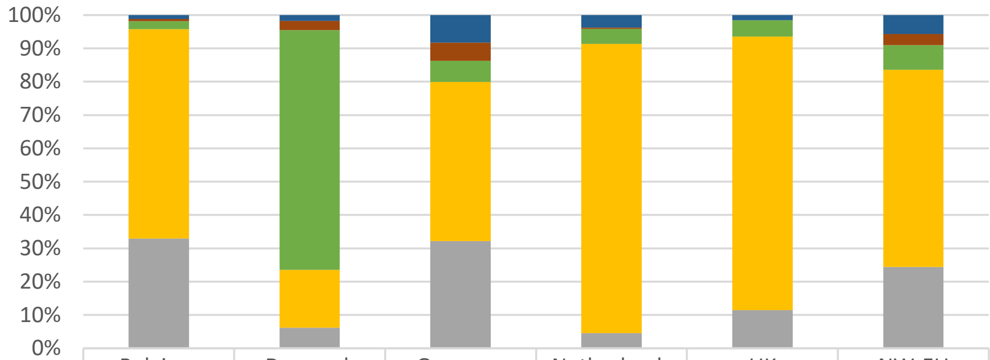
	Belgium	Denmark	Germany	Netherlands	UK	NW-EU
Other	4.670	758	52.633	1.200	23.968	83.229
Solid biofuels	21.750	40.228	222.600	18.368	67.039	369.985
Derived heat	71	65.698	170.404	12.078	2.174	250.425
Gas	133.419	24.776	826.426	285.287	947.430	2.217.338
Petroleum products	112.911	10.024	490.779	1.552	97.397	712.663

Table 2 - 2015 NW-EU Residential Heat usage [9]

Residential heat demand build up is not uniform in NW-EU, it can be roughly divided up in three ways; in both The United Kingdom and The Netherlands, the vast majority of houses is connected to the natural gas grid and the residential heat demand is therefore mainly covered by natural gas (respectively, 83% and 90%). In The Netherlands the remaining 10% of heat demand is covered by derived heat (4%) (heating networks) and renewable heat, 6% (of which 94% is from solid biomass) and in the United Kingdom the remaining 17% is divided between renewable heat, 6% (of which 99,6% is from solid biomass) and off-grid heating solutions such as heating oil (9%) and coal and peat (briquettes) (2%).

Germany and Belgium are defined by a large share of non-natural gas grid connected homes, consequently only roughly halve the total residential heat demand in these two countries is covered by natural gas (47% in Germany and 49% in Belgium). In Germany, another 10% of residential heat demand is covered by derived heat (heating networks) and 14% by renewable heat (of which 89% is from solid biomass) while the remainder of demand is covered by off-grid heating solutions; heating oil (28%) and coal and peat (briquettes) (1%). In Belgium heating networks play no role in covering heating demand, while 8% is covered by renewable heat (of which 95% is from solid biomass) while the remainder of demand is covered by off-grid heating solutions; namely heating oil (41%) and anthracite (1%).

Denmark is a case on its own. It has focused strongly on renewable heat and heating networks to cover (residential) heating demand. Derived heat (heating networks) covers the largest share of residential heating demand, with 46%, followed by 28% renewable heat (of which 98% is from solid biomass). The remainder is covered by natural gas (18%) and heating oil (7%) as off-grid heating solutions.



	Belgium	Denmark	Germany	Netherlands	UK	NW-EU
Other	1.311	745	75.012	5.460	5.237	87.765
Solid biofuels	715	1.152	50.066	592	0	52.525
Derived heat	2.774	30.485	57.865	6.570	16.994	114.688
Gas	70.649	7.342	436.954	126.426	282.373	923.744
Petroleum products	37.046	2.628	294.046	6.620	39.538	379.878

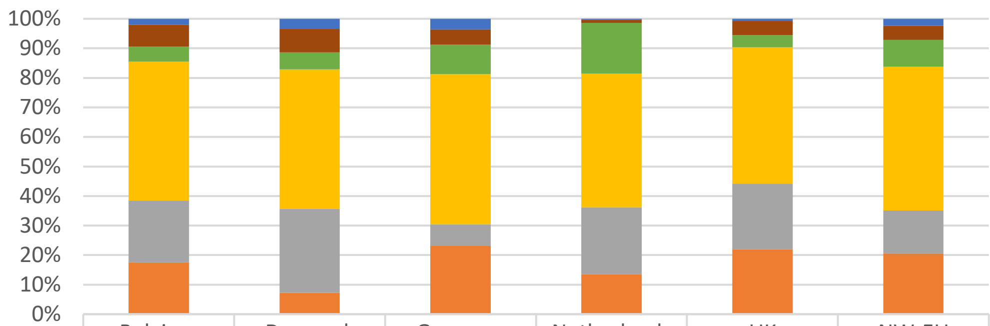
Table 3 - 2015 NW-EU services sector heat usage [8]

Within the sector services the same trends are visible as in the residential sector as shown in Table 3. The fuel use for heat in The Netherlands and the UK is again dominated by natural gas, complemented with derived heat and in the case of The United Kingdom, heating oil. Renewable heat plays only a marginal role in both countries.

Belgium (63%) and Germany (48%) both cover roughly halve of their 2015 services heat demand with natural gas. In both countries heating oil covers roughly a third of total demand, namely 33% for Belgium and 32% for Germany. Renewable heat plays only a marginal role in Belgium, with 2,5% while it covers 13% in Germany, 5%-point of which is from solid biofuels, the remainder from biogas.

As in the residential sector Denmark's services sector heat demand is dominated (72%) by derived heat (mainly heating networks). This is supplemented with natural gas (17%), heating oil (6%) and renewable heat (4%, of 67% is from solid biomass).

For the industrial heat usage, there are also differences between the NW-EU countries, as can be seen in Table 4. However, these differences are harder to interpret. They are probably mostly correlated to the differences in the 'industry-mix' per country, for example the large share of solid fuels in Germany is due to the coal use of their steel industry [8].



	Belgium	Denmark	Germany	Netherlands	UK	NW-EU
Other	7.367	2.028	62.228	1.382	5.008	78.013
Solid biofuels	26.672	4.553	90.388	5.384	33.806	160.803
Derived heat	18.402	3.356	173.430	80.923	29.074	305.185
Gas	169.882	27.477	886.028	214.814	324.437	1.622.638
Petroleum products	75.576	16.511	127.765	107.424	155.429	482.705
Solid fuels	63.376	4.193	402.493	64.062	154.849	688.973

Table 4 - 2015 NW-EU industrial sector heat usage [8]

As can be seen in Table 5 solid biofuels consumption for heat production takes mainly place in the traditional wood processing industries; namely, wood and wood products (60 PJ, 85% of the total heat demand of this industry), the paper, pulp and print industry (34 PJ) and the non-specified industry (45 PJ). These subsectors use wood(products) as an production material (e.g. for paper, furniture etc.) and use their waste as fuel for room heating and/or to drive industrial processes. The solid biomass use of these industries is not primarily an energy demand as more an efficient means of waste usage.

Solid biofuels (excluding charcoal)	Belgium		Denmark		Germany		Netherlands		United Kingdom		NW-EU	
Chemical and Petrochemical	60	0%	0	0%	1.409	0%	0	0%	0	0%	1.469	0%
Construction	0	0%	0	0%	0	-	112	1%	0	0%	112	0%
Food and Tobacco	2.365	6%	1	0%	1.637	1%	0	0%	0	0%	4.003	1%
Iron and Steel	0	0%	1	0%	63	0%	0	0%	0	0%	64	0%
Machinery	40	1%	698	17%	2.144	2%	0	0%	0	0%	2.882	2%
Mining and Quarrying	0	0%	1.205	42%	809	9%	0	0%	0	-	2.014	12%
Non-Ferrous Metals	0	0%	0	-	0	0%	0	0%	0	0%	0	0%
Non-Metallic Minerals	4.947	10%	71	0%	5.787	3%	0	0%	0	0%	10.805	3%
Non-specified (Industry)	915	6%	473	31%	5.415	11%	4.317	39%	33.806	16%	44.926	16%
Paper, Pulp and Print	11.425	55%	117	6%	22.533	14%	0	0%	0	0%	34.075	15%
Textile and Leather	0	0%	8	3%	96	1%	0	0%	0	0%	104	0%
Transport Equipment	0	0%	43	12%	225	0%	0	0%	0	0%	268	0%
Wood and Wood Products	6.920	86%	1.936	87%	50.270	85%	955	67%	0	-	60.081	85%
Total industrial heat usage - solid biofuels	26.672	7,4%	4.553	7,8%	90.388	5,2%	5.384	1,1%	33.806	5,1%	160.803	4,9%

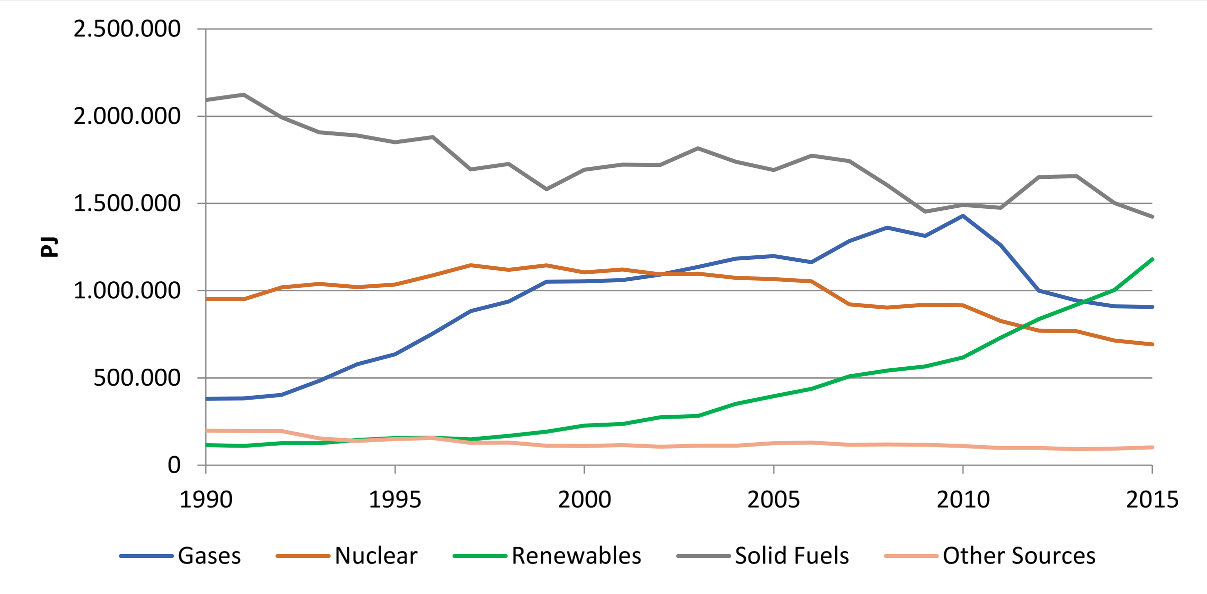
Table 5 – 2015 share of solid biofuels in final energy consumption per NW-EU country industry sector [8]

Belgium and Denmark are relatively the largest users of solid biofuels for industrial heat, with 7,8% and 7,4% respectively. In Belgium, this is mainly due to the wood and wood products industry and the paper, pulp and print industry. In Denmark, this is largely due to the wood and wood products industry and the mining and quarrying industry. In Germany and the United Kingdom, solid biofuels provide roughly 5% of the industrial heat demand. In Germany, this can again be mainly contributed to the wood and wood products industry and the paper, pulp and print industry. For the United Kingdom, solid biofuels are only used in the non-specified Industry. In The Netherlands, solid biofuels contribute only 1,1% of the industrial heat demand, and solid biofuels are only used in the non-specified Industry.

2.7 Main uncertainties in biomass demand

2.7.1 Centralized power

The main uncertainties are competing (renewable) energy options. Figure 8 shows, that while renewables as a whole show rapid growth, already wind and solar PV are growing much faster than solid biofuels, indicating more favorable investment conditions for these two options.



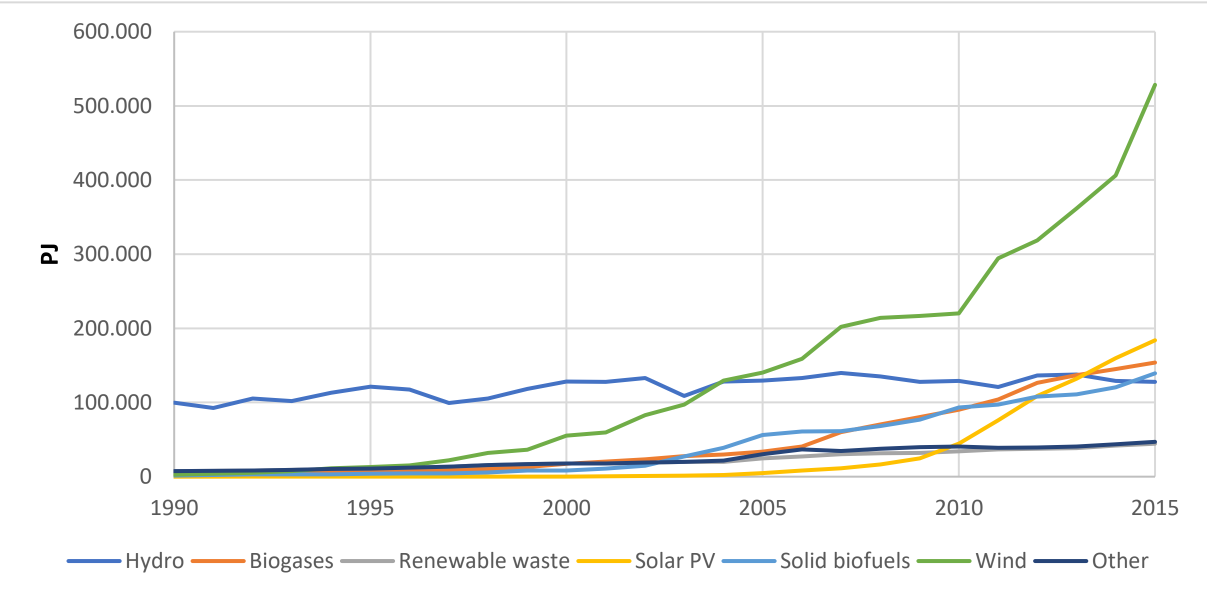


Figure 8 – NW-EU gross electricity generation (upper graph) and NW-EU gross green electricity generation (lower graph) [9].

Also, the level of governmental support for large scale (co)firing of biomass is a main uncertainty, mainly in Belgium, The Netherlands and the UK. The public discussion of whether large scale (co)firing of (imported overseas) biomass is a valid renewable option, since there are still concerns on the sustainable forestry needed for solid biomass to be $C0_2$-neutral. This may lead to lower of pulled governmental support. This has already happened in Belgium with the discontinuation of two advanced plans for biomass firing powerplants. In The Netherlands, there is talk of closing down one or more coal fired power plants, in order to meet CO_2 emission targets, which are currently scheduled for cofiring. Finally, since biomass has to compete with fossil fuels, price competitiveness with mainly coal is a source of uncertainty since this is influenced by a lot of difficult to predict factors such as for example CO_2-prices, coal prices, freight tariffs, biomass feedstock prices etc.

2.7.2 Small scale heat

As with centralized power production the main uncertainty is the rise of alternative heating options, such as heat pumps and geothermal heat. Figure 9 for example, shows the rapid growth of installed heat pumps. Although heating pumps still only occupy a very small share of this market, the rapid yearly growth, 16% annually for NW-EU between 2004 and 2015 [29] showcases that heating pumps are a attractive investment option. Households and businesses in non-grid connected regions have now other heating options as the traditional biofuel based stoves and boilers.

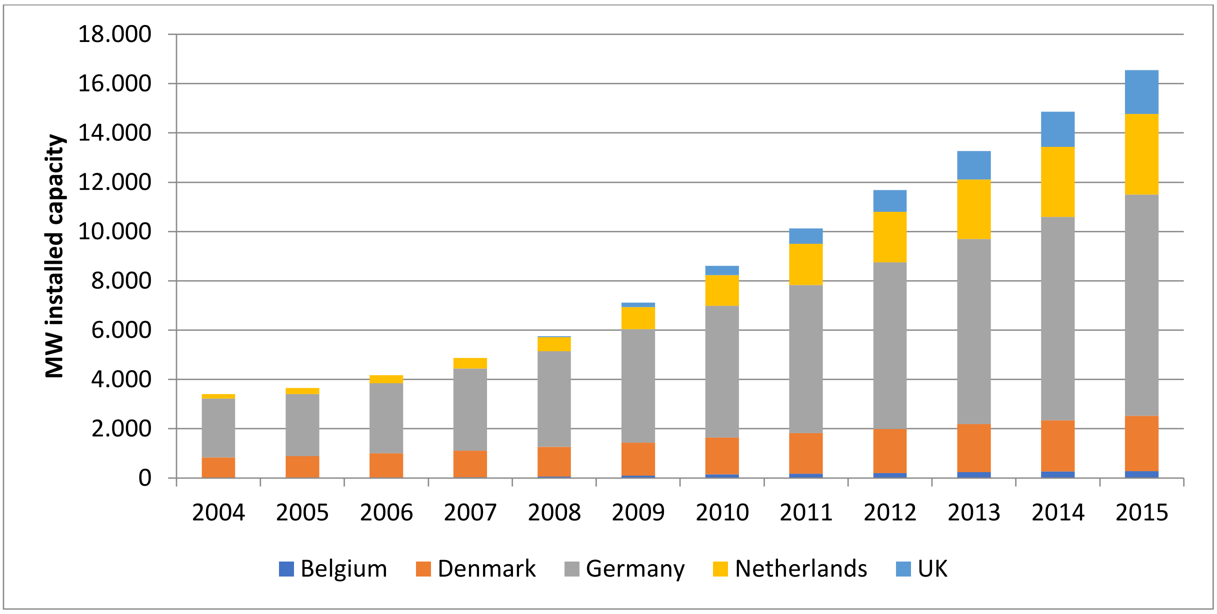


Figure 9 – Total capacity of installed heat pumps in NW-EU [29]

2.8.3 Biorefining

Biorefining has the highest uncertainties of the three distinguished solid biomass demand markets. Firstly, the technology behind solid biomass biorefining has not crystallized yet and will not for at least a few years [30]. At the same time, other technologies are in development to reduce the dependency of the (petro)chemical industry on fossil fuels. Examples are using CO_2, H_2 or recycled plastics as alternative feedstocks or using electricity instead of fossil fuels to drive industrial processes. Secondly, the market for transport fuels is shrinking. In the PoR Wuppertal study [31], depending on the chosen scenario, PoR pipeline market shrinks from 38,1 Mt/year to 25,2 - 33,4 Mt/y. This is mainly due to a lowering demand due to the electrification of road transport and increasing fuel efficiency. Moreover, in their winter package, the EU has proposed to reduce the share of renewable transport fuels, further diminishing the demand. Finally, it is still unclear whether the most ideal location for a biorefinery is near the feedstock (and thus outside NW-EU) or near the customers.

3 Theoretical Framework

3.1 Factors influencing biomass demand:

Based on the data collected so far, the following factors influencing biomass demand for the different demand sectors are recognized or deduced:

1. The price competitiveness of solid biomass versus fossil fuels and/or alternative renewable sources. This is determined by the following factors:
    - Biomass prices, which are in turn affected by:
        - Solid biomass production costs (feedstock costs, processing costs)
        - Logistical costs of solid biomass (shipping, loading etc.)
        - Available solid biomass (fuel) subsidies
    - Fossil fuel prices
    - CO_2-costs (ETS and country specific additional carbon taxes)
    - Cost of competing renewable electricity (such as wind, solar, hydro)
    - Cost of competing heating (equipment) options. (heating oil, heat pumps)
        - Available solid biomass (equipment) subsidies
    - Costs of other options of fossil fuel replacement in the refining sector (e.g. CO_2, or plastics recycling)
2. The total final energy demand, which is in turn affected by:
    - Number of households; more households equals a higher total heating demand, which is affected by:
        - Population growth
        - Average number of inhabitants per household
    - Energy savings; higher annual energy savings lead to lower heating/energy demand (e.g. better isolation, more efficient heating equipment)
    - Economic growth; higher economic growth leads to higher heating demand in the services and/or industrial sectors in comparison to lower economic growth.
3. (Supra)Governmental support for solid biomass
    - Number of subsidized solid biomass (co)firing power plants. When support for biomass (co)firing is low due to for example public discussion of sustainability, no new grants for biomass (co)fired power plants are given nor old ones extended.
    - Level of (supra)governmental support for biorefining (e.g. subsidies for feedstocks or investments, fines for using fossil feedstocks (carbon-tax) and/or obligations)

3.2 Scenarios

By varying the three main factors of uncertainty, identified in paragraph 3.1 influencing the demand for solid biomass in NW-EU till 2030, the following scenarios are proposed:

Factors \ Scenarios	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
Price competitiveness solid biomass	-	↑	↑	↓
Total final energy demand	-	-	↑	↓
Governmental support solid biomass	-	-	↑	↓

Table 6 – an visual representation of how varying the three identified uncertainty factors lead to the four different scenarios

In Scenario 1 - Business as usual (BAU), all three factors are kept constant, i.e. all these factors will follow current forecasts. This way a reference scenario is made, to which the other three scenarios can be compared.

In Scenario 2 - Cheap biomass, only the price competitiveness of solid biomass is positively influenced. This way a scenario can be made exploring solely the effects of improved solid biomass business case(s), such as biorefining, (co)firing and biomass heating.

In Scenario 3 - High, all three factors are set to positive. This way a scenario can be made exploring the maximum size biomass demand could become. Again, an improved price competitiveness of solid biomass leads to more positive solid biomass business cases, while a higher total final energy demand provides a bigger market for solid biomass to play a role in, while improved (supra)governmental support will take away non-financial barriers and/or create additional biomass markets or expand existing ones.

In Scenario 4 - Low, all three factors are set to negative. This is an inversion of the previous scenario, exploring the lowest size biomass demand could become. Not only will the reduced price competitiveness of solid biomass lead to less positive solid biomass business cases, a lower total final energy demand shrinks the markets in which solid biomass can play a role, while deteriorated (supra)governmental support will raise additional non-financial barriers and/or shrink existing markets.

In paragraph 3.4 the parameters which will be used to differentiate the four scenarios from each other will be described, while in paragraph 4.1 the methods to obtain the numerical values of those parameters will be described, and finally, in the paragraph 5.2.1 the numerical values for these parameters will be given.

3.3 Scenario descriptions

3.3.1 Scenario 1 – Business as Usual

The business as usual scenario assumes that current climate policies and support schemes will be executed but no new policies or support schemes will be introduced. Prices for fossil fuels, biomass and CO_2 will follow current trends.

Centralized Users

Participating power plants (co)firing biomass in this scenario are the currently operating plants and power plants which are already approved for subsidy. (Co)Firing biomass for electricity and/or heat is profitable till these subsidies stop. In this scenario, no new subsidy schemes will be introduced, when current subsidy periods run out, (between 2025 and 2027) biomass (co)firing becomes non-profitable and thus stops.

Commercial, industrial and residential heat (small scale heat)

For small scale heat programs like the Dutch SDE+, German EEG and UK's RHI will promote the use of solid biomass. In this scenario, this will mainly target the replacement of off-grid heating equipment using heating oil or solid fuels like coal or peat briquettes by pellet stoves or other solid biomass heating equipment. Furthermore, a growth of solid biomass use in derived heat and co-generation units is expected.

Biorefining

In this scenario, there will be no biorefining of solid biofuels in NW-EU in the period till 2030. Without a cost incentive from high(er) fossil fuels or CO_2 prices, the benefit of cheap solid biomass or some sort of policy incentive (subsidies, fines and/or obligations) producers of refinery products will not switch to another feedstock such as solid biofuels.

3.3.2 Scenario 2 – Cheap Biomass

In this scenario, biomass becomes relatively cheaper than fossil fuels and other renewables. This can either be because fossil fuels and/or CO_2 become more expensive, because biomass becomes cheaper or a combination of these two reasons.

Centralized Users

Since producing electricity and/or heat from solid-biomass sources becomes (relatively) cheaper, this will be favored as opposed to other renewables, since this means less subsidy per MW_e and/or MW_{heath} produced from solid biomass (co)firing is needed, and therefor makes biomass (co)firing more competitive with alternative renewable sources when applying for subsidy schemes. A bigger part of the existing subsidy schemes will thus be granted to solid biomass, and more solid biomass (Co)fired power plants will come online. As in scenarios 1, (co)firing biomass for electricity and/or heat is however only profitable while subsidized. In this scenario no new subsidy schemes will be introduced, when current subsidy periods run out, (between 2025 and 2027) biomass (co)firing becomes non-profitable and will thus stop.

Commercial, industrial and residential heat (small scale heat)

For small scale heat (relative) cheap solid biomass means that when new households or new businesses in the services or industrial sector have to choose heating equipment or when existing household or businesses have to choose replacements for existing heating equipment they are more likely to choose solid biomass options (such as bio boilers, pellet stoves) over alternatives such as heating oil or heat pumps. As in the BAU scenario this affects only the off-grid regions (regions without a natural gas grid or heating network), when a grid is available household and businesses will still favor that over off-grid solutions. In the industrial sector cogeneration units could switch from gas or heating oil fired to biomass fired.

Biorefining

Although even in this scenario, biomass prices are not low enough to let biorefining take off and there is thus no financial incentive for biorefining solid biofuels. Although there is also no additional large scale governmental support for biorefining, the lower biomass price leads to project which can be supported by for example governmental R&D programs. This leads to one or more demo projects started up to demonstrate the technologies involved at a pre-industrial scale, evaluate the techno-economic performance of different value chains for scaling-up towards commercial plants, and demonstrate opportunities for commercial scale follow-up.

3.3.3 Scenario 3 – High

A scenario designed to explore the highest contribution of solid biofuels. Governments are pushing for higher shares of renewables and therefore policies are in place lowering biomass prices in comparison to fossil fuel prices either though subsidizing biomass use and/or penalizing fossil fuels usage though setting high(er) CO_2 prices or fossil fuel taxes. At the same time in this scenario the demand market for heat is increased by defining this scenario with higher economic growth and a larger number of households while at the same time reducing energy savings.

This scenario is comparable with scenario 2 with the following addendums:

Centralized Users

In this scenario governments are pushing for a higher share of renewables. For centralized heat, power plants no longer stop (co)firing after their original subsidy schemes run out. When the costs for (co)firing are by then not competitive with fossil fuels, due to the higher CO_2 tax on fossil fuels, solid biomass (co)firing is subsidized again.

Commercial, industrial and residential heat (small scale heat)

The small scale heat market grows since in this scenario both economic growth is higher than is the reference scenario, leading to an increased heat demand from both the services and industrial sector, and in the residential sector the number of household is greater than in scenario 1 and 2, further increasing heat demand. At the same time, this economic growth leads to higher salaries, which lead to larger homes with more appliance, which lead to lower energy savings compared to scenario 1 and 2, even further increasing heat demand.

Biorefining

To meet the 2015 Paris accords demands, governments seek carbon free or low-carbon alternatives for maritime and aviation fuels and chemical industry feedstocks. Replacing fossil carbon with bio carbon is one of the only alternatives, and policy is made to stimulate the biorefining sector. Thus, with both relatively cheap biomass and governmental support for biorefining this leads to an accelerated take off of biorefining.

3.3.4 Scenario 4 – Low

A reversion of the previous scenario, set to explore the lowest contribution of solid biofuels. In this scenario biomass becomes (relatively) more expensive compared to fossil fuels and other renewables. This can either be because fossil fuel and/or other renewables become cheaper, because biomass becomes more expensive or a combination of these two reasons.

Centralized Users

Since producing electricity and/or heat from solid-biomass sources becomes relatively more expensive, fossil fuels or other renewables are favored. Already subsidized plants will continue (co)firing, but due to the higher cost of biomass, (co)firing is at a disadvantage to other renewable energy sources. This means that no additional plants will be opened and that when already granted subsidy schemes run out, these plants become non-profitable and will close.

Commercial, industrial and residential heat (small scale heat)

For small scale heat a reversed effect from the previous scenario will also take place with heating equipment moving away from biomass based to alternatives like natural gas, or when there is no access to the gas grid, alternatives like geothermal or solar heat, heat pumps or heating oil. Moreover, energy savings are high and household and economic growth low, leading to fewer, but more energy efficient households and businesses, lowering overall total heating demand.

Biorefining

High biomass prices are also a reason to postpone biorefining (demo) plants until biomass and fossil fuel prices come closer together, making the investments more feasible. In this scenario, at least till 2030, no biorefineries will be opened in NW-EU.

3.4 Scenario parameters

The following scenario parameters are needed to variate the three factors identified in paragraph 3.2 (Table 6) which were used to model the four different scenarios.

3.4.1 Price competitiveness solid biofuels

For this study, it is too complex to determine price elasticity for solid biomass prices. In other words, within the timeframe of this study it is impossible to calculate by how much an (relative) increase or decrease of solid biomass prices in comparison to its competitors (other renewables and fossil fuels) would influence total solid biomass demand. Chosen is to work with proxies; price competitiveness is either the same as now (scenario 1 - BAU), positively influenced (scenario 2 – cheap biomass and 3 - High) which would lead to higher solid biomass demand, or negatively influence (scenario 4 - Low) which would lead to lower solid biomass demand.

3.4.2 Total final energy demand

Total final energy demand will be influenced by three parameters.

The first parameter needed is the energy savings rate, since this influences the total final energy demand. Higher energy savings rates lead to lower energy demand.

The second parameter needed is economic growth. Economic growth lead to more economic activates using more energy but also to higher salaries leading to bigger homes with more appliances, needing more energy.

The third parameter needed is the total number of households. Both population growth and dwindling household sizes will lead to more households and thus higher energy use.

3.4.3 Supportive policy for solid biomass use:

This is more or less a binary option, namely the level of governmental support for solid biomass use. This can be as usual, actively promoting the use of solid biomass or actively opposing the use for solid biomass. For example, when support for biomass (co)firing is low due to for example public discussion of sustainability, no new grants for biomass (co)fired power plants are given or old ones extended. Another example is the level of (supra)governmental support for biorefining (e.g. the availability of subsidies for feedstock, R&D projects or investments in equipment or installations, fines for using fossil feedstocks (carbon-tax) and/or obligations)

3.4.4 Small scale residential and services heat – moving to biomass fueled heating equipment

The first parameter needed is the share of new buildings which has biomass heating equipment installed.

The second parameter needed is the replacing rate of old heating equipment, since this defines how fast the stock of old (non-biomass based) heating equipment can be replaced with new and possible biomass based heating equipment.

Finally, the third parameter needed is the share of biomass heating equipment installed in non-grid connected buildings when old heating equipment is replaced.

All these three parameters are influenced by the proxies identified in paragraph 3.4.1 and 3.4.3

4 Methodology

4.1 Calculations methods

4.1.1 Large scale users

Future biomass demand from large scale users is calculated with a binary method. Power plants are either on or off based on the input parameters of each scenario.

Using literature research currently operating and planned solid biofuel (co)firing are identified.

In scenario 1 and 4 only current and currently approved power plants are on, whereas in scenario 2 and 3 also currently planned power plant will come online in the future. In scenario 1, 2 and 4 power plants will stop (co)firing biomass when their subsidy scheme stops, whereas in scenario 3, both the currently operating and currently approved power plants plus the currently planned power plants will all (co)fire biomass till at least 2030.

4.1.2 Residential, service sector and industrial Heat

Solid biofuel use in the residential and services sector is calculated using the following calculations methods:

Firstly, since heat demand in closely related to the weather, the historic data sequences on which the future heating demand is based for both the residential and services sector have been first corrected for yearly heating degree-days (HDD). For industrial heat demand, the majority of heat demand is for industrial processes instead of room heating and is thus less linked to the weather, therefor the data sequences for industrial heat demand will not be corrected for HDD. The historic data sequences are obtained from the eurostat database. [9]

Heating degree-days statistics were obtained from Eurostat for all five NW-EU countries for the period 1990-2015. [32], [33] Yearly correction factors were then calculated by dividing the yearly HDD by the average HDD for the period 1990-2015.

Finally, HDD-corrected data sequences were calculated for all the indicators by dividing the yearly value for an indicator by that year's HDD correction factor.

Future heat demand for the residential and services sectors was calculated based on the following assumptions, and will make use of the parameters proposed in paragraph 3.4, while in the paragraph 5.2.1 the numerical values for these parameters are given.

- Households and businesses become more energy efficient every year, thus lowering the heat demand per household/business.
- The number of households and businesses changes every year based on respectively population growth combined with average household size and economic growth.

- The type of heating equipment of new households and businesses is bases on scenario parameters.
- Every 15 years heating equipment has to be replaced. A share of off-grid households/businesses (not connected to the natural gas grid or a heating network) using solid fuels or petroleum product will move to modern heating options such as heating pumps of pellet stoves.

The calculations are done as follow:

The total solid biofuels use (in TJ) is calculated by multiplying the total number of households using solid biofuels by the average heat demand (in TJ) per household.

*1 - Total Solid Biofuels Use, (year x) = Total Number of Biofuel Household, (year x) * Average Heat Demand, (year x)*

The average heat demand (in TJ) per household is calculated by applying yearly energy savings according to the parameters of the different scenarios. A linear function is chosen based on a review of historic trends.

*2 - Average Heat Demand, (year x) = Average Heat Demand, 2015 - (year x - 2015) * Energy Saving Parameter*

The average heat demand (in TJ) per household in 2015 is calculated by dividing the total residential heat demand in 2015 by the number of households in 2015.

3 - Average Heat Demand, 2015, = Total Residential Heat Demand, 2015 / Number of Households, 2015

The total number of households using solid biofuels is calculated by adding the total number of new solid biofuels equipment using houses and the total number of houses which have replaced old heating equipment with solid biofuels equipment to the number of solid biofuels equipment using houses in 2015.

4 - Total Number of Biofuel Households, (year x) = Total Number of Biofuel Households, 2015 + Number of New Biofuel Households, (year 2015 till year x) + number of Households renovated to Biofuels, (year 2015 till year x).

The number of new biofuel households is calculated by subtracting the number of households in 2015 from the total number of households (which is a scenario input) and multiplying that number with the share of new households with biomass equipment parameter. (a scenario input)

*5 - Total Number New Biofuel Household, (year 2015 till x) = (Total number of Households, (year x) - Total number of Households,2015) * Share of new households with biomass equipment parameter*

The number of households which renovate their heating equipment to biofuels is calculated based on the total number of household in 2015 using solid or petroleum fuels based heating equipment and multiplying that with the yearly replacement parameter, a scenario input. A linear function is chosen

*6 – Total number of Household renovated to Biofuels, (2015 till year x) = (year x – 2015) * yearly replacement parameter * (number of solid fuels households, 2015 + number of petroleum products using households, 2015)*

Heat use - Industry

Calculation for future biomass demand for industrial heating are made using trendlines.

As before for residential and commercial heat, historic heat demand was first corrected for HDD-days. Next, using MS Excel scatter plots were drawn in which trend lines were added. Values from the start of the sequences were omitted till the highest value for R^2 was found, however the minimum amount of values used for a trend line was always at least 10 values, thus at least the sequence 2006-2015. In Figure 10 an example of such a trendline and consequent forecast till 2030 are shown for the total final 2015 NW-EU total industrial heat consumption and the solid biofuels part thereof.

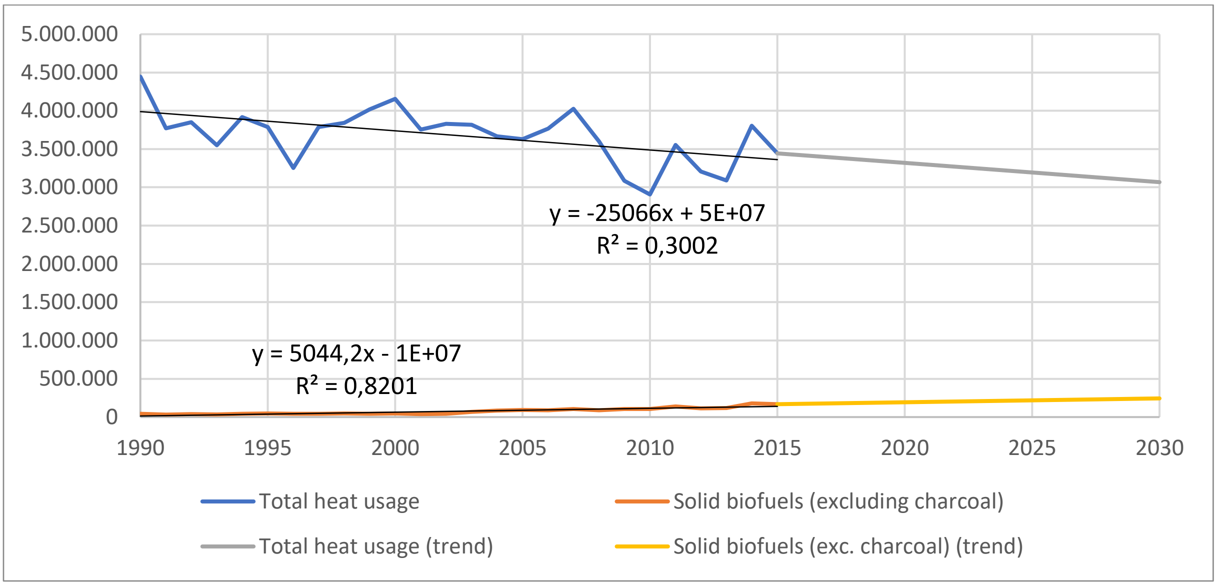


Figure 10 - example of trend analysis for industrial sector

4.1.3 Biorefining

As with future biomass demand from large scale users, biomass demand from biorefining is calculated with a binary method. Biorefineries are either on or off based on the parameters of each scenario. Biorefineries are modeled after the Bioforever plans which aims to build a biorefinery in NW-EU in the period 2022-2015 of 1 Mt biomass input a year, which can be upgraded to 3,0 Mt/y. [30] In both scenario 1 and 4 there will be no biorefining using solid biofuels before 2030. In both scenario 2 and 3, a small demoplant will be operational in 2025. In scenario 2 this plant will be upgraded to a large demoplant before 2030, whereas in scenario 3 this plant will be converted into a full biorefinery before 2030 (based on the Wuppertal study for PoR, in which in one of the proposed scenarios a 7,0 Mt/y FT-refinery will be build [31]). Table 7 shows for NW-EU for each of the four scenarios the solid biofuels demand for biorefining.

Year	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
2020	0t	0t	0t	0t
2025	0t	1.000.000t	1.000.000t	0t
2030	0t	2.500.000t	7.000.000t	0t

Table 7 - Solid biofuels demand for biorefining per scenario

4.2 Building scenario parameters for small scale residential and services heat demand

Parameters	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
Energy Savings	BE - 1,9%/year DK - 1,2%/year DE - 1,4%/year NL - 1,9%/year UK - 2,1%/year	BE - 1,9%/year DK - 1,2%/year DE - 1,4%/year NL - 1,9%/year UK - 2,1%/year	BE - 3,5%/year DK - 1,8%/year DE - 2,4%/year NL - 2,5%/year UK - 2,8%/year	BE - 0,6%/year DK - 0,7%/year DE - 0,6%/year NL - 1,5%/year UK - 1,1%/year
Economic growth	BE - 2,20%/year DK - 1,87%/year DE - 0,99%/year NL - 2,51%/year UK - 2,72%/year	BE - 2,20%/year DK - 1,87%/year DE - 0,99%/year NL - 2,51%/year UK - 2,72%/year	BE - 1,99%/year DK - 1,67%/year DE - 0,95%/year NL - 2,14%/year UK - 2,52%/year	BE - 2,28%/year DK - 2,06%/year DE - 1,04%/year NL - 2,99%/year UK - 2,92%/year
Number of households (millions) total NW-EU	2010 - 82,6 2020 - 84,8 2030 - 87,1	2010 - 82,6 2020 - 84,8 2030 - 87,1	2010 - 82,6 2020 - 85,3 2030 - 87,9	2010 - 82,6 2020 - 84,0 2030 - 86,3
Share of new buildings with biomass heating equipement	25%	37,5%	37,5%	12,5%
Replacing rate of heating equipement	every 15 years	every 15 years	every 15 years	every 15 years
Share of biomass heating equipement when replaced	50%	75%	75%	25%

Energy savings

Unfortunately, no studies could be found providing energy saving forecasts till 2030 for all the NW-European countries in this study. The parameters for energy savings are therefore based on data from the Odysee project which has a database containing overall energy efficiency gains for the period 2000-2015 for EU countries. [36]

For the BAU scenario the average efficiency gains for the period 2000-2015 have been taken for each county. For scenario 3 – high, which has been defined as having a lower energy saving rate, three-year average efficiency gains were taken for the entire 2000-2015 period, so as to smooth out incidental high or low efficiency gain peaks. The lowest three-year average efficiency gains value was viewed as the slowest rate in which the country can become more energy efficient and this value was taken as the parameters for this scenario. For scenario 4 – Low, which has been defined as having a highest energy saving rate, this process was repeated, but instead was focused on finding the highest value, which was then set as this scenarios parameter.

Economic growth

The parameter for economic growth is based on the 2017 OECD long-term GDP forecasts. [37] Forecast for the gross domestic product (GDP) of all the NW-European countries for the period 2015 – 2030 are given in this database and were used to calculate the yearly economic growth parameters.

For the BAU scenario the average yearly GDP growth for the period 2000-2015 has been taken for each county. For scenario 3 – high, which has been defined as having a higher economic growth rate, three-year average economic growth rates were taken for the entire 2000-2015 period, so as to smooth out incidental high or low economic growth peaks. The highest three-year average economic growth value was viewed as the highest rate at which the country economy can grow and this value was taken as the parameters for this scenario. For scenario 4 – Low, which has been defined as having a lower economic growth rate, this process was repeated, but instead was focused on finding the lowest value, which was then set as the scenarios parameter.

Number of households

The total number of households is taken from the EU, PRIMES reference scenario 2016. [38] These values were taken as the BAU parameters. Values for lower and higher total household growth rates, were again constructed. This was done by respectively lowering and heightening the BAU household growth rate by 25%.

Share of new buildings with biomass heating equipment

Unfortunately, almost no information on forecasts of shares of newly build houses using biomass heating equipment could be found. The only value that could be found was that of the current (2015) installation shares in Germany, this data is available at the German statistical Bureau. [39]

This value may be land-specific, i.e. (partly) influenced by country specific factors which are not or very differently present in the other NW-EU countries, such as share of rural households or popularity of biomass heating equipment. However, in the end there was no better data to base this parameter on.

The values for lower and higher installation shares, were constructed by respectively lowering and heightening the BAU installation shares by 50%. This high percentage was chosen since the uncertainty of the share of newly build buildings with biomass heating equipment is very high so a large bandwidth has the be built in these scenarios to capture all this uncertainty.

Replacement rate of heating equipment

The rate in which heating oil based heating equipment is replaced is assumed to be every 15 years for all the scenarios.

Share of biomass heating equipment when replaced

The share of biomass heating equipment which will be installed when current solid-fuel or heating oil based heating equipment is replaced, is again based on the current 2015 new installation shares in Germany, this data is taken from the German statistical Bureau. [39]

Again, the values for lower and higher installation shares, were constructed by respectively lowering and heightening the BAU installation shares by 50% in order to capture the large uncertainty of this parameter.

4.3 Logistics

Since only the import of extra-EU solid biofuels will affect Port of Rotterdam logistics, the results from the demand scenarios developed in this study must be translated into extra-EU imports. In the original capacity study this was done by coupling solid biofuels demand and supply regions using a transport model, while optimizing the entire model for lowest costs. This way, biomass import flows could be determined. This study however, only contains demand scenarios. To be able to translate the solid biomass demand resulting from the scenarios for each demand sector assumption were made, whether or not that specific solid biofuel demand would be imported from oversea locations or not.

Since presently the vast majority of solid biomass demand for the centralized use for heat, steam and electricity is imported from extra-EU sources, it this study it is assumed that will still be the case in the future, for the same reasons as now, namely that the extra-EU feedstocks needed are cheaper and/or from higher quality and/or better available year round, when imported from extra-EU sources.

For biorefining it is also assumed that the entire demand will be imported from extra-EU sources, since the probable feedstocks needed (wood pellets, woodchips or pyrolysis oil) are cheaper and/or from higher quality and/or better available year round, when imported from extra-EU sources.

The vast majority of biomass demand for decentralized use for residential, commercial and industrial heat is presently supplied by domestic of intra-EU sources and this will likely not change in the future, since domestic and intra-EU supply will continue to grow [12]. However, when this demand grows so fast that it surpluses domestic and/or intra-EU supply, extra-EU imports are needed. Literature study was needed for estimations for domestic supply.

The research questions how solid biomass imports can affect logistics in de port of Rotterdam was answered using expert interviews. Therefore, experts on PoR solid biomass imports and logistics, namely stevedores, traders and energy companies were interviewed. They were asked for their professional opinion on how solid biomass imports could develop in the future, which demand sectors and which type of solid biomass feedstock could play a role in the future, and, if applicable, their solid biomass logistics investments strategies. Furthermore, they were asked whether PoR can handle possible larger biomass trade flows and if there is potential for cost reduction in logistical processes ranging from modification of the equipment in import terminals up to the construction of new, dedicated facilities (biomass terminals, handling and storage facilities). The (preliminary results of) expected future extra-EU solid biofuel imports via Rotterdam were taken as an input in the interviews.

5 Results

5.1 Centralized demand

Argus Biomass Markets regularly publishes lists of both currently operational and proposed biomass power plants [34], [35]. Data from these lists was combined with publications of governmental bodies such as RVO and DECC and with publications from power companies themselves. This resulted in the following findings:

5.1.1 Belgium

Country / Power plant	Capacity	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
Belgium					
Les Awirs	80 MW	7,0 PJ/y till 2020	7,0 PJ/y till 2020	7,0 PJ/y	7,0 PJ/y till 2020
Rodenhuizen	180 MW	14,1 PJ/y till 2021	14,1 PJ/y till 2021	14,1 PJ/y	14,1 PJ/y till 2021
Walloon Plant	200 MW		12,7 PJ/y from 2021	12,7 PJ/y from 2021	

Table 8 – Belgian power plants using biomass

Currently there are two power plants firing wood pellets in Belgium; Les Awirs and Rodenhuizen. Les Awirs uses 400 kt/y and has a subsidy scheme till 2020 and Rodenhuizen uses 800 kt/y and has a subsidy scheme till 2021. For scenario 3 – high biomass both these power plants will be kept online till 2030.

The minister for Energy in Wallonia wants a new biomass power plant in Wallonia and wants to write out an tender for this. In both scenario 2 – cheap biomass and scenario 3 – high this additional 200 MW plant will come online in Wallonia in 2021, which will use approximately 720 kt wood pellets a year.

5.1.2 Denmark

Country / Power plant	Capacity	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
Denmark					
Amager CHP unit 1	300 MW	5,3 PJ/y	5,3 PJ/y	5,3 PJ/y	5,3 PJ/y
Amager AMV4	500MW	16,8 PJ/y from Q2'2019	16,8 PJ/y from Q2'2019	16,8 PJ/y from Q2'2019	16,8 PJ/y from Q2'2019
Avedore (Unit 1 & 2)	585 MW	21,1 PJ/y	21,1 PJ/y	21,1 PJ/y	21,1 PJ/y
Verdo Randers CHP	52 MW	2,8 PJ/y	2,8 PJ/y	2,8 PJ/y	2,8 PJ/y
Herning	88 MW	5,4 PJ/y	5,4 PJ/y	5,4 PJ/y	5,4 PJ/y
Skaerbaek (Unit 3)	392 MW	6,3 PJ/y	6,3 PJ/y	6,3 PJ/y	6,3 PJ/y
Studstrup (Unit 3)	350 MW	10,6 PJ/y from 2016	10,6 PJ/y from 2016	10,6 PJ/y from 2016	10,6 PJ/y from 2016
Helsingor	63 MW	1,8 PJ/y from Q4'18	1,8 PJ/y from Q4'18	1,8 PJ/y from Q4'18	1,8 PJ/y from Q4'18

Table 9 – Danish power plants using biomass

In Denmark there are currently five power plants firing wood pellets and/or wood chips. The Amager power plant uses 300 kt/y wood pellets. The Avadore power plant uses 1,2 Mt/y wood pellets, Verdo Randers powerplant can use more than one fuel source and uses 145 kt wood chips and 45 kt wood pellets a year. The Herning power plant is also a multifuel power plant, using 300 kt wood chips and 70 kt wood pellets a year. Finally, the Studstrup power plant uses 600 kt wood pellets a year.

Furthermore, an additional three powerplants will start firing wood pellets and/or wood chips in the near future. The new Amager AMV4 power plant will come online in October 2019 and will use 1,2 Mt wood chips a year. Unit 3 of the Skaerbaek power plant will finish retrofitting in the last quarter of 2017 and will use 450 kt wood chips a year. Finally, in the winter of 2018-2019, Helsingor power plant will become operational and will use 130 kt wood chips a year.

Since all these power plants are given subsidies for their entire economical life. This value is not further specified by the Danish government thus for this study this has been set at 20 years. (IRENA, 2012) All the Danish biomass powered power plants will thus fire biomass till at least 2030 and since no new biomass fired power plant projects are known at the moment, all four scenarios have the same deployment of biomass for large scale power and heat.

5.1.3 The Netherlands

Country / Power plant	Capacity	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
The Netherlands					
Amercentrale	80% of 645 MW	28,7 PJ/y 2018-2026	28,7 PJ/y 2018-2026	28,7 PJ/y from 2018	28,7 PJ/y 2018-2026
ENGIE	10% of 724 MW	4,0 PJ/y 2018-2026	4,0 PJ/y 2018-2026	4,0 PJ/y from 2018	4,0 PJ/y 2018-2026
Uniper	15% of 1.070 MW	9,2 PJ/y 2018-2026	9,2 PJ/y 2018-2026	9,2 PJ/y from 2018	9,2 PJ/y 2018-2026
Eemshaven	15% of 1.550 MW	14,1 PJ/y 2018-2026	14,1 PJ/y 2018-2026	14,1 PJ/y from 2018-2026	14,1 PJ/y 2018-2026

Table 10 – Dutch power plants using biomass

Under the 2016 SDE+, four power plant have been granted subsidies for co-firing biomass. The Amercentrale will be the first to become (partly) operational in 2017, the other three will follow in 2018. All these power plants will use imported wood pellets. The Amercentrale will eventually use 1,63 Mt/y, ENGIE 230 kt/y, Uniper 520 kt/y and Eemshaven 800 kt/y. Subsidies have been granted for eight years, and all these power plants will therefor seize to co-fire wood pellets in 2016 with the exception for scenario 3 – High in which the power plant will continue to co-fire wood pellets till at least 2030. Due to the 25 PJ cap on biomass power, which is already reached with these four power plants, no additional subsidy will be granted and therefore no new biomass power plants will come online in the Netherlands.

5.1.4 United Kingdom

Country / Power plant	Capacity	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
United Kingdom					
Drax 1+2+3	1.935 MW	121,4 PJ/y till 2027	121,4 PJ/y till 2027	121,4 PJ/y	121,4 PJ/y till 2027
Drax 4	635 MW		40,5 PJ/y from 2020	40,5 PJ/y from 2020	
Lynemouth	320 MW	26,4 PJ/y 2018-2027	26,4 PJ/y 2018-2027	26,4 PJ/y from 2018	26,4 PJ/y 2018-2027
Teesside	299 MW	21,1 PJ/y from 2018	21,1 PJ/y from 2018	21,1 PJ/y from 2018	21,1 PJ/y from 2018
Penhros	299 MW		17,6 PJ/y from 2020	17,6 PJ/y from 2020	
Port Talbot	350 MW		31,7 PJ/y from 2020	31,7 PJ/y from 2020	
Uskmouth	363 MW		26,4 PJ/y from 2020	26,4 PJ/y from 2020	

Table 11 – British power plants using biomass

In the United Kingdom there is currently only one biomass fired power plant; Drax Power. Three of the six units of this plant have been converted to run on wood pellets an it uses 6,9 Mt imported wood pellets a year. Drax Power has a subsidy grant till 2027.

Furthermore, two more plant are in development in will start to fire biomass in the near future. The 320 MW Lynemouth powerplant will come online in 2017 and will use 1,5 Mt wood pellets a year. Lynemouth has a subsidy grant till 2027. The 299 MW Teesside CHP plant will come online in 2018, and will use 1,2 Mt wood pellets a year. The subsidy grant is for 15 years and this power plant will thus fire biomass till 2033.

In scenario 2 – cheap biomass and scenario 3 – high, an additional four biomass power plants plans will be further developed and come online in 2020. This are the conversion of a fourth Drax unit, and proposals for new biomass power plants in Penhros, Port Talbot and Iskmouth. All these new powerplants will use wood pellets; respectively 2,3 Mt/y, 1,0 Mt/y, 1,8 Mt/y and 1,5 Mt/y.

5.1.5 Total Northwest European solid biomass use for large scale power

In Figure 11 the total yearly biomass use per country is plotted. It clearly shows that scenario 2 – Cheap and scenario 3 – High have the highest total use of biomass for centralized power, since in these two scenarios additional power plant will come online in both Belgium and the United Kingdom. In scenarios 1, 2 and 4 total biomass use will decline in the period 2020 – 2027 since most power plants lose their subsidy grants in this period.

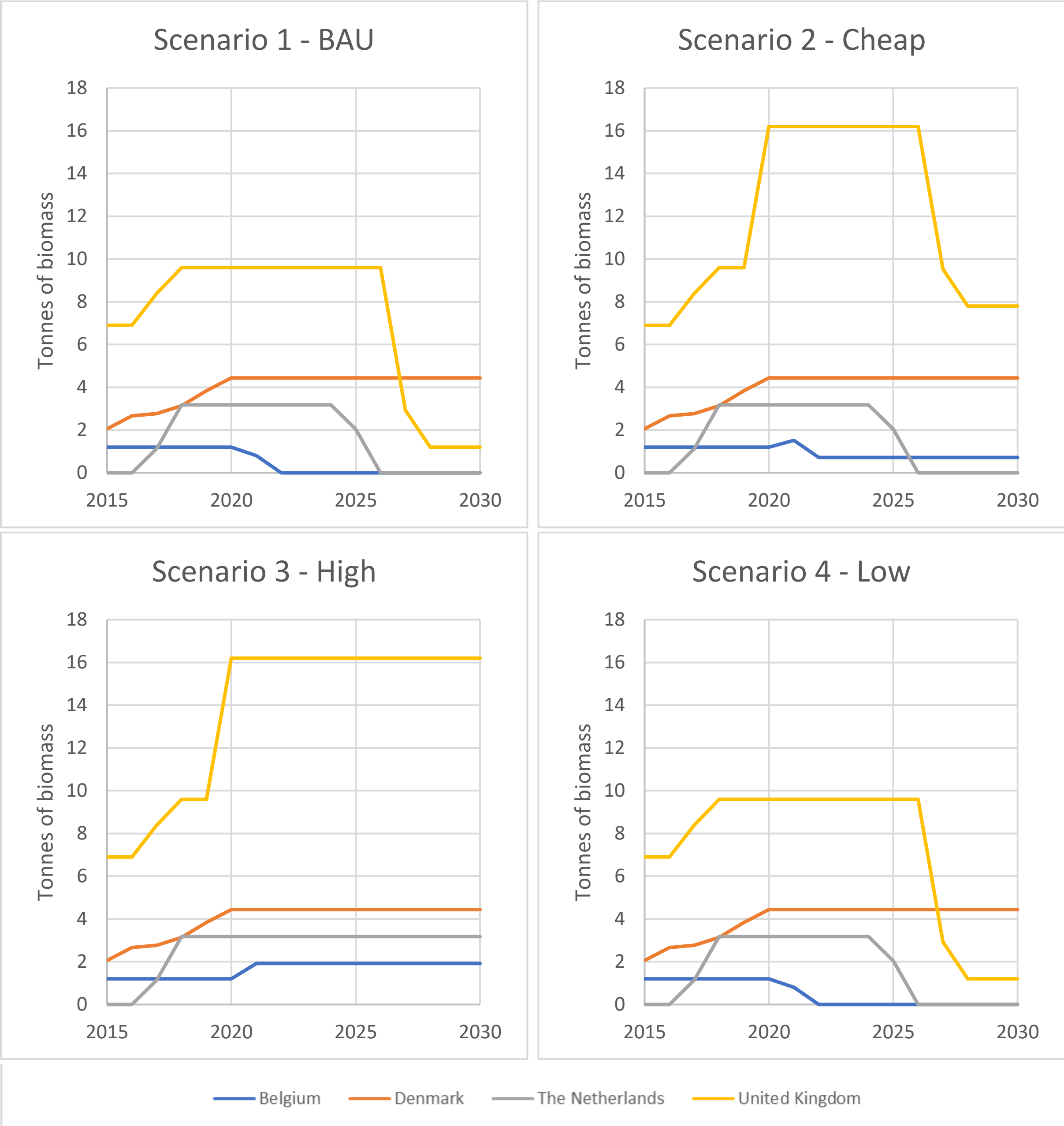


Figure 11 - Total Northwest European solid biomass use for large scale power

Scenario	2015	2020	2025	2030	2030 vs 2015	vs BAU
Scenario 1 - BAU	10,2	18,4	16,1	5,6	-44,5%	
Scenario 2 - Cheap	10,2	25,0	23,4	13,0	+27,6%	+130%
Scenario 3 - High	10,2	25,0	25,7	25,7	+153,3%	+356%
Scenario 4 - Low	10,2	18,4	16,1	5,6	-44,5%	0%

Table 12 - Total Northwest European solid biomass use in tonnes for large scale power

5.2 Small scale heat

5.2.1 Belgium

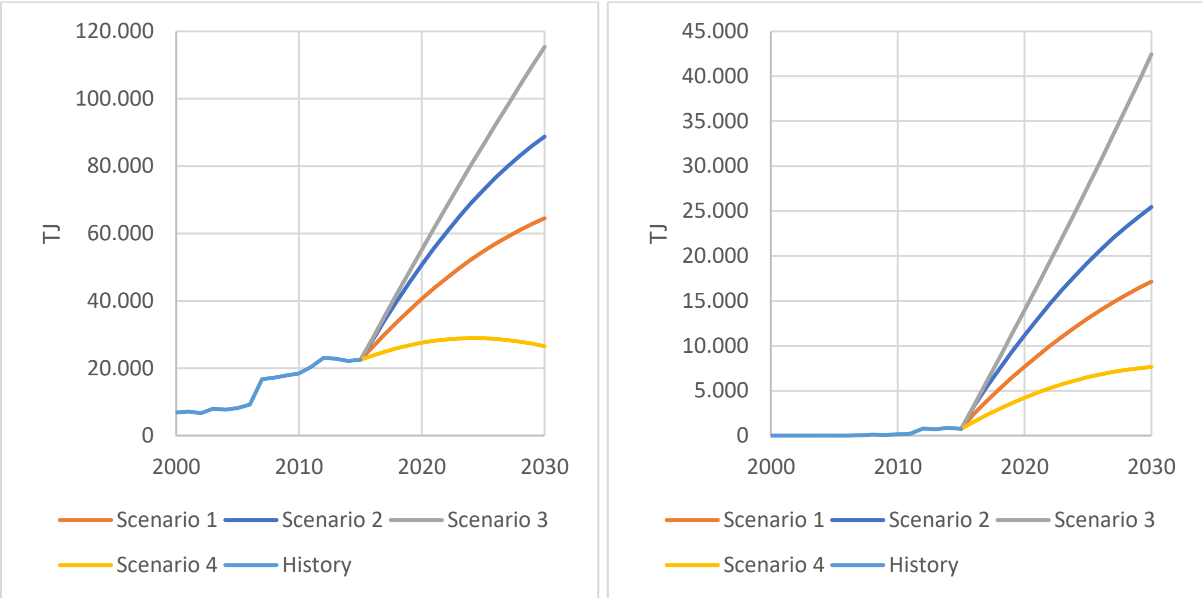


Figure 12 - Belgium, residential sector (left) and services sector (right) solid biofuel use

As can be seen in Table 2 and Table 3, in Belgium there is still a large share of households and businisses using petroleum products for heating. Therefore, significant growth of biomass use for small scale heating is possible in allmost all the scenarios for residential heating when these fuels are replaced by solid biofuels. Only for scenario 4 – Low, the smaller shift to biomass heating equipement combined with the higher energy saving rate results in a relative constant value. The large growth of solid biofuel use in the services sector can be explained by the fact that currently the sercives sector has a very large share (34%) of petroleum product use for heat, while the share of solid biofuels is virtualy non-existend.

5.2.2 Denmark

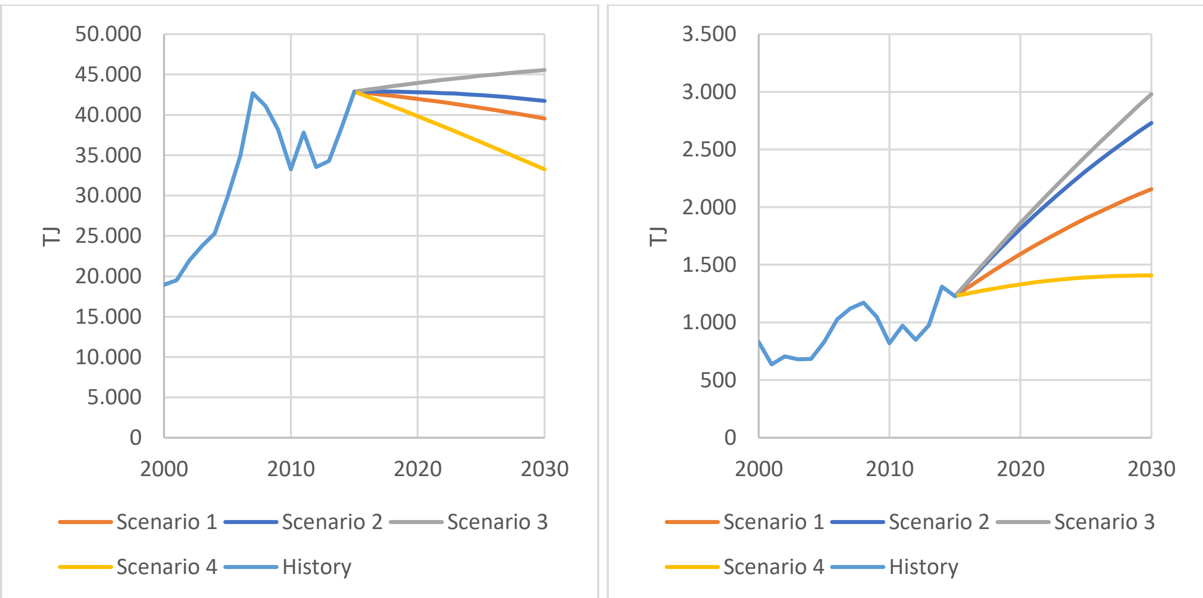


Figure 13 - Denmark, residential sector (left) and services sector (right) solid biofuel use

As could be seen in Table 2, in Denmark there is only a very small share of households using petroleum products for heating. Therefore, only very small growth of residential biomass heating is possible, in most scenarios this growth caused by the increased number of households using solid biofuels based heating equipement is even cancelled out or reversed by the energy savings rate which makes these household on average more energy efficient.

For services heat demand, the use of petroleum product is currently also very small, but there still is growth in all scenarios, although the total numbers are very small. (in 2030 between 3,6% and 6,3% of total service heat demand, up from 2,7% in 2015)

5.2.3 Germany

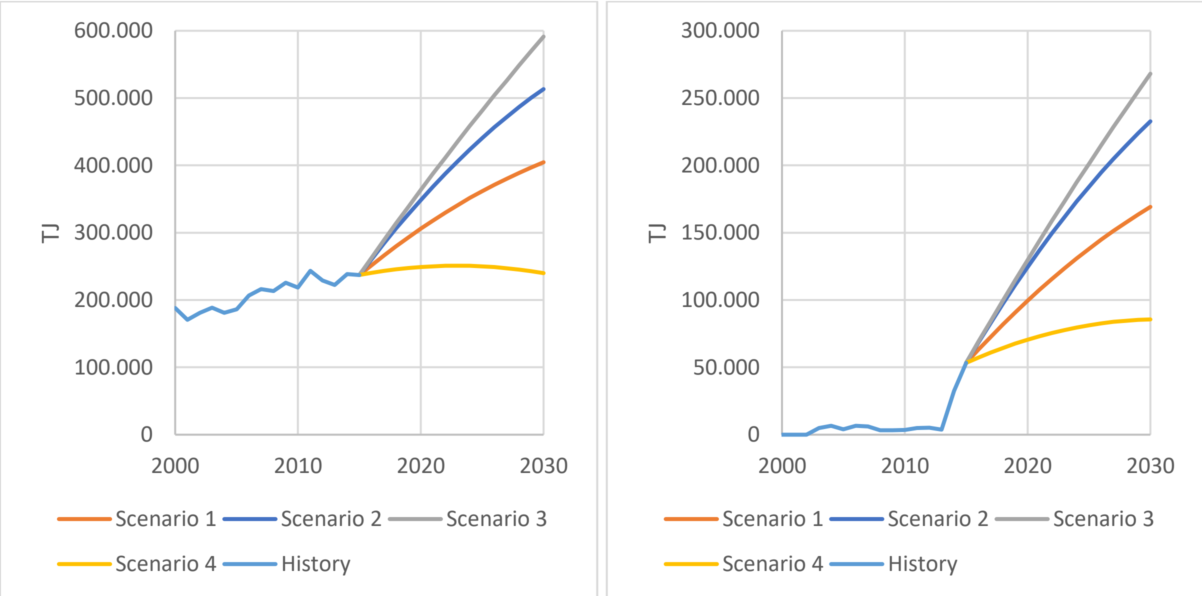


Figure 14 - Germany, residential sector (left) and services sector (right) solid biofuel use

As could be seen in Table 2 and Table 3, in Germany there is still a large share of households and businesses using petroleum products for heating. Therefore, significant growth of biomass heating is possible in all the scenarios as can be seen in Figure 14. As is the case in Belgium and Denmark for scenario 4 – Low, the smaller shift to biomass heating equipement combined with the higher energy saving rate results in a relative constant value.

5.2.4 The Netherlands

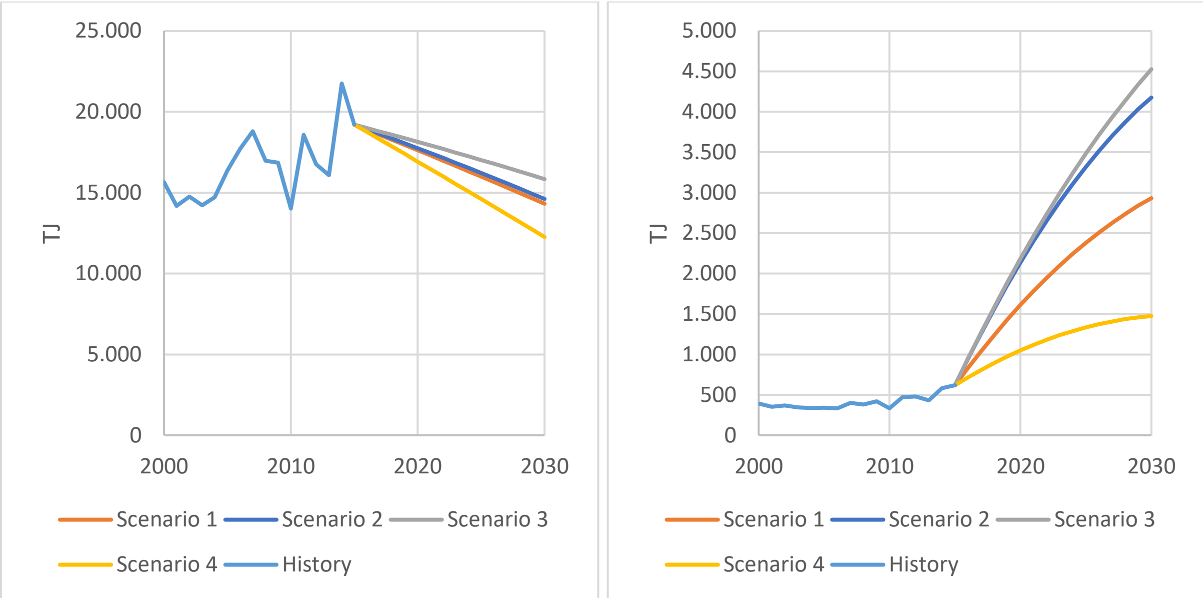


Figure 15 – The Netherlands, residential sector (left) and services sector (right) solid biofuel use

In the Netherlands the situation is the same as for Denmark, only a very small share of households are currently using petroleum products for heating. Therefore, only very small growth of residential biomass heating systems is possible, and in all the scenarios this growth is cancelled and even reversed by the annual energy savings rate.

Since also for services heat demand, the use of petroleum product is currently very small, only a small number of solid biofuel heating systems in installed. However, there is growth in all scenarios, although the total numbers are very small. (in 2030 between 1,2% and 3,2% of total service heat demand is provided by solid biofuels, which is up from 0,4% in 2015)

5.2.5 United Kingdom

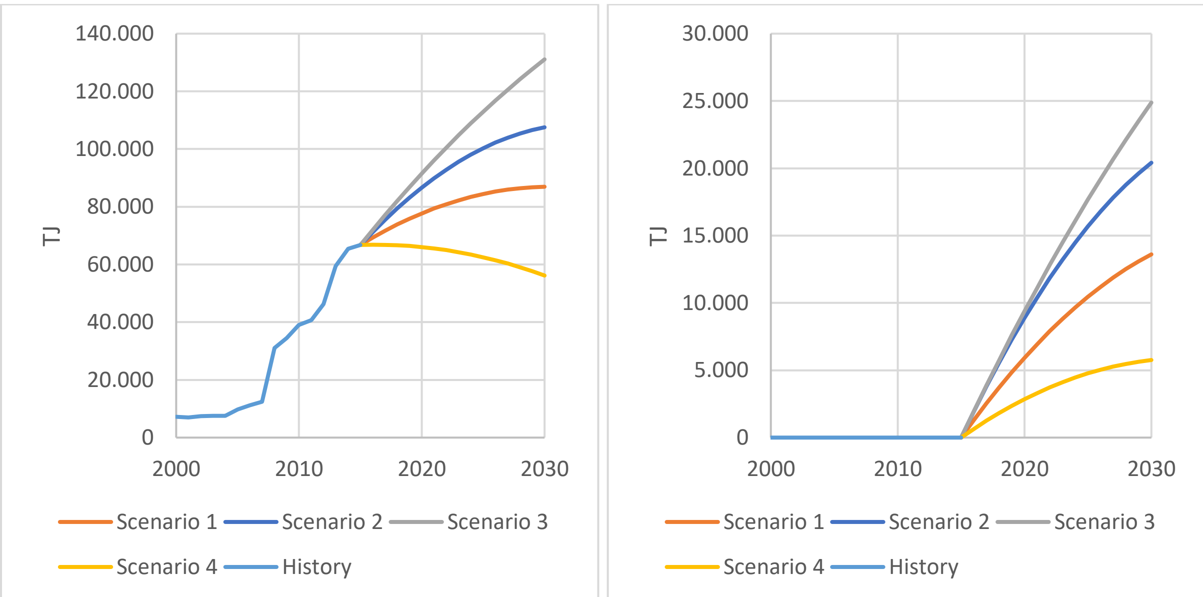


Figure 16 – United Kingdom, residential sector (left) and services sector (right) solid biofuel use

As can be seen in Table 2, in the United Kingdom households are still using a large volume of petroleum products for heating. Therfore, significant growth of biomass heating is possible in all the scenarios as can be seen in the graph above. As in the other NW-EU countries, in scenario 4 – Low, the growth in solid biofuel heating systems is relative slow due to the smaller share of new and replaced biomass heating options combined with the larger energy saving rate in this scenario. This even cancelles out the growth in systems resulting in a lower residential demand of solid biomass for this scenario

For the services heat demand, the use of petroleum product is currently very small. But since there is currenlty no use of biomass heating there is growth in all scenarios, although the total numbers are relatively small. (in 2030 between 2,3% and 7,4% of total service heat demand is covered using biomass, up from 0,0% in 2015)

5.2.6 Total Nordwest European services and residential biomass heat demand

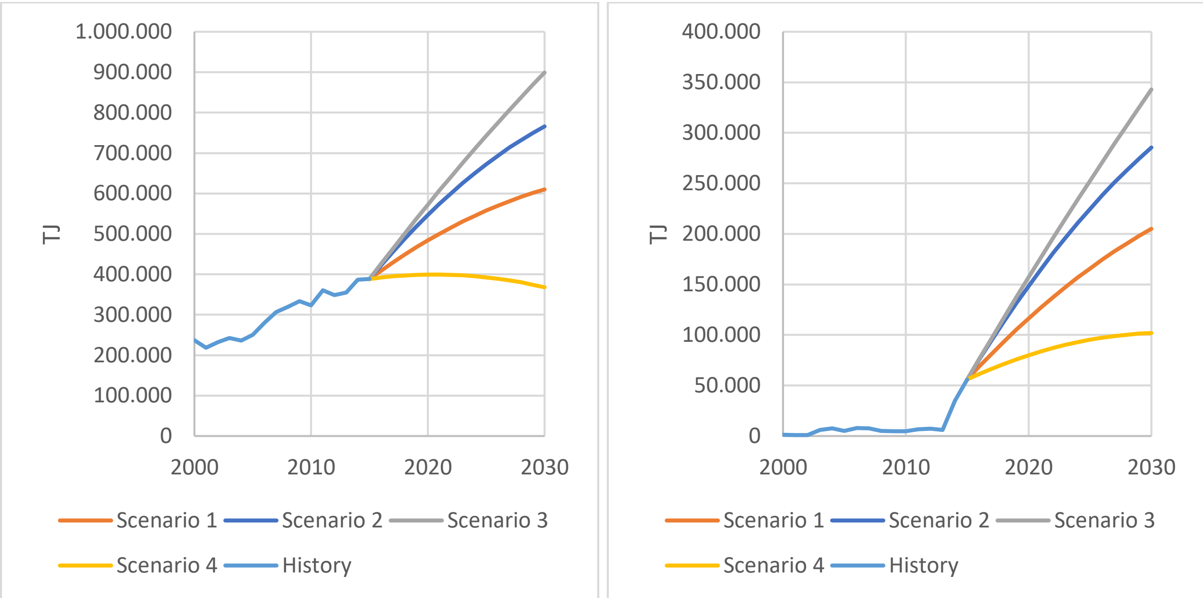


Figure 17 – NW-EU, residential sector (left) and services sector (right) solid biofuel use

Residential	2015	2020	2025	2030	2030 vs 2015	vs BAU
1 - BAU	389	484	558	610	+57,0%	
2 - Cheap	389	546	672	766	+97,1%	+26%
3 - High	389	572	743	899	+131,4%	+47%
4 - Low	389	399	393	368	-5,3%	-40%

Table 13 - NW-EU final solid biofuel use in the residential sector for the four scenarios for 2015 – 2030 in PJ

In scenario 1 – BAU final solid biofuels use in the NW-EU residential sector grows from 389 PJ in 2015 to 610 PJ in 2030, a growth of +57,0%. In both scenario 2 - Cheap and scenario 3 -High final solid biofuels use (more than) doubles from 2015 till 2030. In comparison to these three scenarios scenario 4 – Low stays relatively constant from 2015 till 2030, and even has a lower solid biofuel demand in 2030 compared to 2015 (-5,3%)

Scenario	2015	2020	2025	2030	2030 vs 2015	vs BAU
1 - BAU	56	116	166	205	+266,5%	
2 - Cheap	56	148	225	286	+410,2%	+39%
3 - High	56	157	253	343	+512,9%	+67%
4 - Low	56	80	95	102	+82,1%	-50%

Table 14 - NW-EU final solid biofuels use in the services sector for the four scenarios for 2015 – 2030 in PJ.

In scenario 1 – BAU final solid biofuels use in the NW-EU services sector grows from 56 PJ in 2015 to 205 PJ in 2030, almost quadrupling. In both scenario 2 - Cheap and scenario 3 -High final solid biofuels grows even faster, respectively five- and sixfold from 2015 till 2030. In comparison to these three scenarios scenario 4 – Low only shows a (relatively) small growth of +82% from 2015 till 2030.

5.2.7 Industrial heat demand

Figure 18 and Table 15 shows the results from the scenarios for the industrial solid biomass use in the period 2015 – 2030 in NW-EU. Individual country results can be found in Annex D. A trendline was made for the period 1999 till 2015. This was the trendline with the highest fit of R^2 = 0,9325 while still the remaining 17 data points still constitute a long enough period to make a reliable trend. Moreover from 1990 till approximately 2000 final industrial solid biofuels remains largely the same, only showing a growing trend from the year 2000.

Figure 18 - NW-EU final industrial solid biofuels use for the four scenarios for 2015 – 2030, in TJ.

Scenario	2015	2020	2025	2030	2030 vs 2015	vs BAU
1 - BAU	161	198	235	273	+69,7%	
2 - Cheap	161	211	261	310	+92,8%	+14%
3 - High	161	217	273	329	+104,5%	+21%
4 - Low	161	179	198	217	+34,8%	-21%

Table 15 - NW-EU final industrial solid biofuels use for the four scenarios for 2015 – 2030, in PJ.

In scenario 1 – BAU final industrial solid biofuels use in the NW-EU grows from 161 PJ in 2015 to 273 PJ in 2030, almost 70% growth. In both scenario 2 - Cheap and scenario 3 - High final solid biofuels grows even faster, roughly doubling from 2015 till 2030. In comparison to these three scenarios scenario 4 – Low only shows a small growth of +35% from 2015 till 2030.

5.2.8 Total small scale heat demand

Figure 19 shows the total final solid biofuels demand for the 4 scenarios for the period 2015 – 2030 for NW-EU.

Figure 19 – Total NW-EU solid biofuel demand for small scale heat, 2015-2030 for the 4 scenarios (in TJ)

Scenario	2015	2020	2025	2030	2030 vs 2015	vs BAU
Scenario 1 - BAU	605	798	959	1.088	+79,7%	
Scenario 2 - Cheap	605	900	1.140	1.325	+118,9%	+22%
Scenario 3 - High	605	946	1.268	1.571	+159,5%	+44%
Scenario 4 - Low	605	659	686	687	+13,4%	-37%

Table 16 – Total final solid biofuels use for NW-EU small scale heat demand, 2015-2030 for the 4 scenarios (in PJ)

From Figure 19 and Table 16 it becomes clear that residential heating maintains to be the largest demand sector and in most scenarios (1, 2 and 3) services heat demand grows faster then industrial heat demand. In scenario 4 – Low, residential solid biofuel heat demand even diminished from 2015 till 2030. Since the solid biofuel demand for services and industrial heat grows slightly in the same period, overall it leads to a very small growth of only 13% from 2015 till 2030.

In the BAU scenarios small scale heat solid biofuel demand grows for al subsectors and results in an almost doubled solid biofuel demand (+80%) from 2015 till 2030.

Scenario 2 – Cheap biomass and scenario 3 – High also see growth for all the different subsectors leading to a doubling (respectively +120% and +160%) from 2015 till 2030.

When the small scale heat demand for solid biofuels is showed in wood pellet equivalents (wp-eq.), it shows a grow from 2015 till 2030 ranging from +4,6 Mt (scenario 4 - Low) till +54,9 Mt (scenario 3 – High).

Scenario	2015	2020	2025	2030
Scenario 1 - BAU	34,4	45,4	54,5	61,8
Scenario 2 - Cheap	34,4	51,1	64,8	75,3
Scenario 3 - High	34,4	53,8	72,1	89,3
Scenario 4 - Low	34,4	37,4	39,0	39,0

Table 17 – Total final solid biofuels use for NW-EU small scale heat demand, 2015-2030 for the 4 scenarios (in wood pellet eq.)

5.3 Biorefining

As explained in the methodology this is a binary scenario. Only in scenario 2 and 3 conditions are right for biorefining. In scenario 2 the Bioforever biorefinery is build, while in scenario 3 the Wuppertal scenario with a 7 Mt/y FT-refinery is followed.

Year	Scenario 1 BAU	Scenario 2 Cheap biomass	Scenario 3 High	Scenario 4 Low
2020	0t	0t	0t	0t
2025	0t	1.000.000t	1.000.000t	0t
2030	0t	2.500.000t	7.000.000t	0t

5.4 Total solid biomass demand

Figure 20 and Table 18 show the total NW-EU final solid biomass demand in Mt wood pellet equivalent. Small scale heat plays the most important role in all these scenarios. However, where all the demand for centralized use and biorefining is and will be imported from oversea locations, the 2015 small scale heat demand was supplied almost entirely from domestic sources. While it has the potential to be supplied from oversea sources, this will likely still not be the case in the future. Dafnomilis et al. [12] calculated the total NW-EU domestic biomass sources at 93 – 107 Mt in 2020 and 82 – 119 Mt in 2030. This is ample to cover the 2020 and 2030 small scale heat demand for all four scenarios.

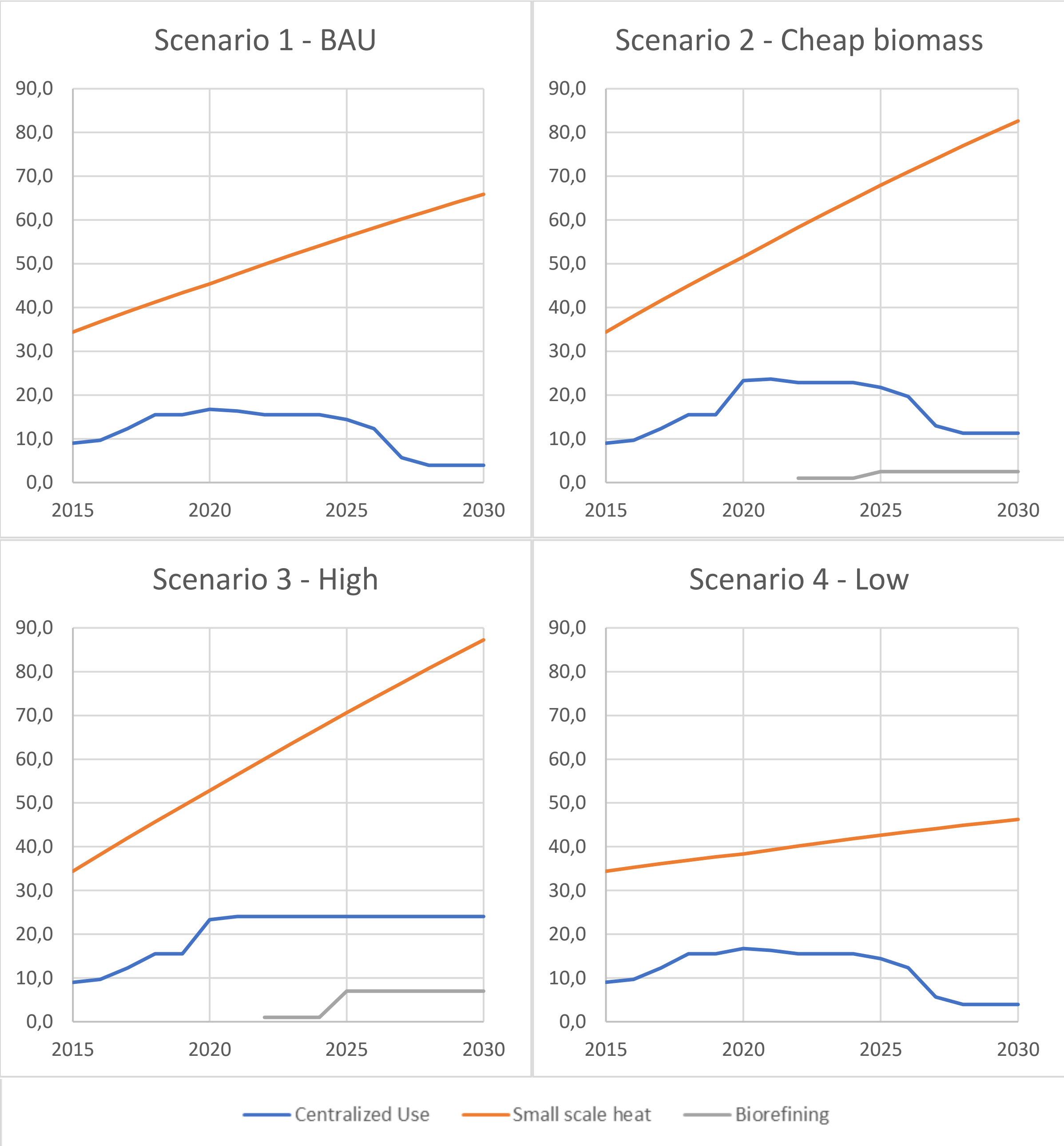


Figure 20 – Total NW-EU final solid biofuels demand for the four scenarios in wood pellet(-eq.)

Scenario	2015	2020	2025	2030	2030 vs 2015	vs BAU
Scenario 1 - BAU	43,4	62,2	70,6	69,8	+60,9%	
Scenario 2 - Cheap biomass	43,4	74,9	92,1	96,4	+122,1%	+38%
Scenario 3 - High	43,4	76,1	101,7	118,3	+172,6%	+69%
Scenario 4 - Low	43,4	55,1	57,0	50,2	+15,6%	-28%

Table 18 – Total NW-EU final solid biofuels demand for the four scenarios in wood pellet(-eq.)

5.5 Logistics

Data was collected using interviews with stevedores, [40], [41], [42], power companies [43] and employees of PoR. [44] Via these interviews expert were asked for their professional opinion on how solid biomass imports could develop in the future, which demand sectors and which type of solid biomass feedstock could play a role in the future, and, if applicable, their solid biomass logistics investments strategies. Furthermore, they were asked whether PoR can handle possible larger biomass trade flows and if there is potential for cost reduction in logistical processes ranging from modification of the equipment in import terminals up to the construction of new, dedicated facilities (biomass terminals, handling and storage facilities). This resulted in the following overall picture for how PoR logistics could develop in the future.

5.5.1 Ideal situation

First off, the most ideal situation for the development of solid biomass logistics was determined to see how solid biomass logistics would ideally develop. This development occurs when the three demand markets (centralized use, small scale heat and biorefining) would succeed and partly overlap each other in time, and all use the same type of fuel, namely wood pellets. That way, logistics would be developed for subsidized large scale biomass trade flows for (co)firing power plants, which could drive logistic costs down due to scale- and learning effects and investments in optimized equipment. The use of larger transport ships would mean lower transport cost, when shipping extra-EU solid biomass, and these would then be transshipped via Rotterdam to other NW-EU power plants. This would lead to the creation of a centralized NW-EU storage of wood pellets from where customers would buy their solid biomass instead of direct from extra-EU supplier would open up the extra-EU wood pellet supply for small scale users. This, would make oversea solid biomass (more) cost-competitive with domestic biomass or alternative small scale heating fuels (such as heating oil). Moreover, a centralized NW-EU storage could be supplied by larger ships than individual clients, further driving down extra-EU solid biomass prices. This would further increase oversea solid biomass trade flows, which could further develop logistics. Finally, when the technology is ready, around 2020-2025 biorefining can profit from the now present solid biomass logistics and (partly) take over the share of the imports from the power plants, whose grants will end in the same time period. These biorefineries can then supply these power plants with (cheap) lignin so they can still produce green electricity and the biorefineries have a customer for part of their production.

5.5.2 Current situation and imports for centralized use

Unfortunately, this is not the present situation for PoR. Currently, there are three power companies importing or starting to import solid biomass for cofiring through the PoR. RWE, Uniper and ENGIE will import a combined 2,4 Mt a year for their Amer 9 (1,63 Mt/y), MPP3 (520 kt) and ENGIE Centrale Rotterdam (230 kt/y). As is currently the case with all NW-EU solid biomass (co)firing power plants all three of them have set up their own logistics. This means that the largest share of their solid biomass supply is fixed in long-term contracts with solid biomass suppliers. Moreover, since storage of solid biomass is expensive, power plants want to keep their solid biomass reserves as low as possible. This leads to just-on-time deliveries, stored in barges, which, although more expensive on a daily basis than fixed storage, can be discontinued when emptied. Both these developments lead to a small to non-existent spot market, so centralized storage of wood-pellets cannot take off. Without such a centralized storage or hub (new) biomass powered power plants in other NW-EU countries will continue (to set up) their own, direct logistics, since only the benefits of large scale central storage; such a larger, cheaper ships and specialized equipment, would offset the cost of longer trade routes and additional transshipping.

5.6.3 Small scale heat demand

As became clear in paragraph 5.5, the growth of NW-EU small scale heat demand for solid biomass in the period 2015 – 2030 would most likely be met by domestic or intra-EU sources. Only when extra-EU solid biomass becomes cheaper or as cheap as domestic or intra-EU solid biomass there is potential for extra-EU solid biomass imports. Again, some sort of centralized storage would be needed to trade the large volumes brought in by bulk vessels (depending on vessel type between 15.000t (Handy size) to 80.000t (Panamax)) to clients such a small(er) businesses and households who require tonnes instead of kilotons of solid biomass a year.

Forsaking the centralized storage, another option is that extra-EU wood pellets will be imported prepackaged in small bags (typically 10-20kg each) in 20' or 40' containers. This would however mean, that there would be little overlap with existing wood pellet logistics

5.5.4 Effect of biorefineries

If a biorefinery would be located in the PoR this would mean an additional solid biomass trade flow of 1,0 – 7,0 Mt/year, just in the period the PoR biomass powered power plants would most likely lose their grants. However, such a biorefinery would most probably use another form of biomass, most likely wood chips since these are cheaper per GJ than wood pellets, but pyrolysis oil is also an option, meaning that there would be little overlap with existing wood pellet logistics. If biorefineries would be located outside PoR, in for example Antwerpen, the lack of a centralized biomass storage in PoR would mean that the chances of (part of) the import trade flow would be via Rotterdam would be very small since direct logistics would then most probably be cheaper.

5.5.5 Logistic investments

Currently the Rotterdam stevedores only have business cases for investments in logistics for the period of the subsidies grant of the Dutch power companies, since there is almost no overseas import of solid biofuels for small scale heat nor do they expect it in the near future. Moreover, biorefineries are still years away and even then still uncertain. The relatively short period of only eight years of guaranteed extra-EU solid biomass imports makes large or risky investment impossible. If investments occurs, they are therefore often in multiple-purpose equipment, so logistics are not as cheap as they could be.

5.5.6 Logistic conclusion

None of the stevedores interviewed for this study expects significant solid biomass trade flows via Rotterdam, except for the import of solid biofuels for the PoR power plants. Nor, they do expect that Rotterdam will be used for transshipping extra-EU solid biomass to other NW-EU countries, now or in the near future. None of them will therefor invest in solid biomass logistics unless they have a customer for solid biomass logistics with a viable business case. None of them expect that the Port of Rotterdam could be a biohub in the near future, since there is simply not enough NW-EU demand for solid-biomass imports to make clustering (part of) them to a single harbor such a viable project.

6 Discussion

6.1 Completeness of solid biomass demand sectors

In this study three demand sectors were taken into account; centralized demand, small scale heat and biorefining. Overall, these three sectors cover the largest part of the entire solid biomass demand (as can be seen in Table 1) and are the only three sectors which have the potential to import extra-EU solid biomass. However, adding the agricultural-, forestry- and decentralized power sector would have given an even completer picture of total solid biomass demand. Moreover, these sectors compete with the small scale heat sector for domestic and intra-EU solid biomass supply and this could lead to higher extra-EU imports when domestic and intra-EU supply is not large enough to supply all of these sectors.

6.2 Factors influencing solid biomass demand

In this study, several factors influencing solid biomass demand were identified and grouped into three categories; solid biomass price competitiveness, total final energy demand and governmental solid biomass support. Parameters were created which could be varied between scenarios in order to capture these uncertainties in ranges. Not for all the parameters suitable values could be found in literature. For example the upper and lower ranges of both economic growth and energy saving had to be constructed from the BAU values, inviting uncertainty. However, the largest uncertainty lies with the parameters used to calculate residential and services heat demand. A method was chosen to replace current petroleum based heat demand over time by solid biofuel bases heat demand. The parameters needed to calculate the shift over time from petroleum to biofuels were based on a German value for newly build household. Since no better data was available, this data was not only used for calculating the share of petroleum based heating system replaced by biofuel based heating systems when a heating system needs replacing but was also used for the other NW-EU countries. It is very plausible that not only for the replacement market, but also for each of the other NW-EU markets other barriers (financial, technical, customer preferential) play a role, making these parameters value highly uncertain. A further study into these barriers could reduce the uncertainty now inherent in these parameters.

6.3 Factors influencing solid biomass demand not taken into account

6.3.1 Centralized use

Firing solid biofuels in large scale power plants for power and/or heat has two important advantages over wind (and solar) power, the renewable technology solid biofuels has to compete with. First off, unlike wind (and solar) solid biofuels is not an intermittent energy source. This could mean that when countries would endeavor for a high share off green electricity using wind and solar, and the electricity storage problem has not been solved yet, biomass fired power plants instead of coal or gas-fired power plants could be used in periods with no or little wind and/or sun, and thus even in these periods be able to produce green electricity. Currently, biomass fired power plants are not used for this purpose, be could be in the future when (intragovernmental) national renewable electricity shares or national CO_2 emission levels are set to higher levels.

Secondly, when combined with carbon capture technology, solid biofuels could be a net negative CO_2 emitting energy source. The captured CO_2 could be stored underground or even be used as a feedstock for the chemical industry or glasshouse horticulture. Although there are currently no active CO_2 capture project in NW-EU, when countries are struggling to meet CO_2 emission norms, solid biomass (co-)firing combined with carbon capture technology could be pursued.

More country specific, in The Netherlands, there is an ongoing public debate to close all remaining coal fired power plants, in order to meet CO_2 emission norms. This would mean an end to co-firing solid biomass. Alternatively, the remaining four coal power plants might be adapted to 80% solid biomass or even 100% conversion to solid biomass. It remains to be seen what the new Dutch government will decide after the formation. Since the four co-firing power plants are still new, closing them will be expensive, moreover, without the 25 PJ renewable energy contribution of solid biomass co-firing, meeting the 2020 RED objectives will be very hard for the Netherland which already struggle to meet those objectives.

6.3.2 small scale heat demand

For residential and services small heat demand, only the replacement of fossil fuel based off-grid heating solutions, such as heating oil or solids (like anthracite) are taken into account. However, both residential and services heating play an important role in CO_2 emissions and in time even natural gas based heating solutions will have to be replaced with renewable options. This is even more relevant in The Netherlands since domestic natural gas production will be scaled back. Although the largest part of the residential and services CO_2 emissions reductions will come from energy savings, through improved isolation and heat pumps combined with solar panels, as in currently the case is large scale housing renovations in The Nehterlands (Nul-op-de-Meter projects) solid biofuel are also likely to play an role in this, predominantly through small scale heating networks.

For industrial heat demand there are currently few renewable options that can produce high temperature heat, therefor, solid biomass will likely remain the main source of renewable industrial heat, and since this is presently in all countries is still at a small share, there is still much room for growth.

6.3. Results

6.3.1 Comparing result with other studies

In the 2013 capacity study, in 2020 between 544 and 706 PJ renewable heat will be generated from solid biomass in NW-EU and between 155 and 272 PJ solid biofuels will be used for renewable electricity, for a combined total use of between 699 and 978 PJ. In 2030 these numbers are between 734 and 1.337 PJ for renewable heat and between 165 and 362 PJ for renewable electricity, making a combined total use of between 899 and 1.699 PJ. The 2017 study done by Dafnomilis et al. which provides an up-to-date view of bioenergy supply, demand and trade in NW-EU till 2030 projects an NW-EU bioenergy demand of between 1.212

and 1.348 PJ for electricity and heat in 2020 and between 1.068 and 1.717 PJ in 2030. This study projects a total 2020 solid biofuel demand of between 983 and 1.387 PJ in 2020 and between 786 and 2.147 PJ in 2030. This means that both the result from scenario 1 – BAU and scenario 2 – Cheap biomass fall neatly within the boundaries of the results from the Dafnomilis et al. study. As expected since they were designed to be extreme scenarios, scenario 3 – High projects (much) higher solid demand in 2030 (at 2.147 PJ) while scenario 4 – Low, project (much) lower solid biomass demand both in 2020 (at 983 PJ) and 2030 (at 786 PJ).

From this can be concluded that the parameters used to create both scenario 1 – BAU and scenario 2 – Cheap biomass are well choses to represent current latest insights in future NW-EU solid biomass demands. While the differences with the 2013 capacity study can be largly explained by the inclusion of extra demand sectors (biorefining and services and industrial heat demand) in this study.

6.3.2 Completeness of results

For centralized demand, the four scenarios combined with the completeness of current and possible future power plants (co)firing solid biomass give a very good overview of the total range between which solid biomass demand for large scale power plants could lie.

The future solid biofuel demand for biorefining on the other hand is still very much unclear. There is still not enough data available to accurately model future demand since this technology is still in its infancy and the first solid biofuel based biorefineries are not expected before 2025. At this point in time, not much can be done to reduce this uncertainty.

6.4 Extra-EU solid biomass imports

The main aim of this study was to calculate future NW-EU solid biomass demand and to gain more insight in how this extra demand can influence port logistics. Since port logistics are only influenced by oversea import stream assumptions were made as to the source of solid biomass supply. Both centralized demand and biorefining were assumed to be imported from oversea locations, while for small scale heat, domestic and/or intra-EU solid biomass supply was assumed to be preferred. Given the time constraints, this was the best possible option. This section of the study could however be much improved by an additional biomass supply study and consequently coupling the biomass supply and demand regions via a transport model. This way biomass transport flows could be calculated much more precise, and even more insight in factors influencing biomass transport flows could be gained.

7 Conclusion

In this chapter the research question, stated in the introduction will be answered.

How will the demand for solid lignocellulosic biomass in the Port of Rotterdam hinterland develop till 2030, what are the main sources of uncertainty influencing this and how can this effect port logistics?

To answer this question several sub-questions have to be answered first:

1. How can the demand for solid lignocellulosic biomass in the Port of Rotterdam hinterland develop till 2030?

2. How can solid lignocellulosic biomass import flows affect port logistics?

How can the demand for solid lignocellulosic biomass in the Port of Rotterdam hinterland develop till 2030?

In this study three demand sectors were identified, namely centralized demand, small scale heat and biorefining;

Only when biomass becomes more cost competitive in comparison to other renewables and fossil fuels and/or has more governmental support, there is still growth possible in this demand sector in the form of additional power plants, and even then these are only foreseen in Belgium and the United Kingdom. The power plants in the direct hinterland of Rotterdam, the ENGIE and Uniper Maasvlakte power plants will cease to co-fire biomass in 2025, with the exception off scenario 3 – High in which they will co-fire till at least 2030.

There is also still very little known of how biorefining will develop in the future. Only in two of the four scenarios some wood pellet or wood chip imports (1 Mt/y in 2025 and 2,5 – 7,0 Mt/y in 2030) is foreseen in the near future.

Small scale heat however shows growth for all the four scenarios, ranging from +13% till +160% growth from 2015 till 2030. This results in an additional NW-EU need of 82 – 966 PJ of solid biomass in 2030 in comparison to 2015, the equivalent of 4,6 – 54,9 Mt wood pellets.

How can solid lignocellulosic biomass import flows affect port logistics?

The imports for centralized demand are to small and to fragmented to really affect PoR port logistics. No additional import for centralized use in expected since there is no more growth capacity for the Maasvlakte Power Plants, and the limited growth scenarios show for other NW-EU power plants is expected to be processed locally, as is also currently the case.

Even if biorefining would reach the high end (7,0 Mt/y in 2030) of the scenario predictions, this would not significantly affect PoR port logistics, since this is still a small import flow and stevadors such as EBS and EMO could easily accommodate such import flows.

The additional NW-EU small scale heat demand of 82 – 966 PJ of solid biomass in 2030 in comparison to 2015 is the equivalent of 4,6 – 54,9 Mt wood pellet equivalents, the higher end of these numbers could affect port logistics, but according to expert opinions, much of this additional demand will be filled using domestic or intra-EU sources which will further develop along with demand.

Moreover, most of these import flows take place in other time periods. Solid biomass demand for the Maasvlakte power plants will most likely stop in 2026 when subsidy grants run out, while biorefining is not expected to take off before 2025.

Finally, the specific form of solid biomass these three different demand markets would need, probably is not the same. For power plants and small scale heat the preferred form of solid biomass is wood pellets, while biorefining most likely prefers wood chips. These two kinds of biomass (partly) require their own logistics, fragmenting logistics. Furthermore, the wood pellets for small scale heat could be imported via small bags in shipping containers, while the wood pellets for centralized demand are shipped in bulk, which would again fragment logistics.

Based on these observations, is it probably best when investment decisions have to be made, to invest in flexible logistical solutions which can easily switch from one form of biomass to another or even from biomass to entire other products. This way operational time of logistics could stay optimized, even when the type of biomass imported changes, or when import flows diminishes.

8 References

1. UN (United Nations). 1992. United Nations Framework Convention on Climate Change. FCCC/INFORMAL/84 GE.05-62220 (E) 200705. Bonn: UN.
2. European Parliament and the Council of the European Union. Directive 2009/28/EC of the European Parliament and of the Council – on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/ 30/EC. Brussels, Belgium: European Commission; 2009. 62 p."
3. European Parliament and the Council of the European Union. DIRECTIVE (EU) 2015/1513 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources
4. European Commission, COM/2014/015 Final, a Policy Framework for Climate and Energy in the Period from 2020 to 2030 (2014), pp. 1–18
5. Scarlat, N., Dallemand, J. -., & Banja, M. (2013). Possible impact of 2020 bioenergy targets on european union land use. A scenario-based assessment from national renewable energy action plans proposals. Renewable and Sustainable Energy Reviews, 18, 595-606
6. Stralen, van JNP, Uslu A, Dalla Longa F, Panoutsou C. The role of biomass in heat, electricity, and transport markets in the EU27 under different scenarios. Biofuel Bioprod Biorefining 2013;7(2):147–63.
7. Scarlat, N., Dallemand, J. -., & Banja, M. (2013). Possible impact of 2020 bioenergy targets on european union land use. A scenario-based assessment from national renewable energy action plans proposals. Renewable and Sustainable Energy Reviews, 18, 595-606
8. Eurostat, 2017, Complete energy balances - annual data (nrg_110a)
9. Eurostat, 2017, Supply, transformation and consumption of electricity - annual data (nrg_105a)
10. Eurostat, 2017, Supply, transformation and consumption of heat - annual data (nrg_106a)
11. Eurostat, 2017, Supply, transformation and consumption of renewable energies - annual data (nrg_107a)
12. Ioannis Dafnomilis, Ric Hoefnagels, Yudistira W Pratama, Dingena L Schott, Gabriel Lodewijks, Martin Junginger, 2016, Review of solid and liquid biofuel demand and supply for Northwest Europe towards 2030 – a comparison of national and regional projections
13. Eurostat, 2017, EU trade since 1988 by CN8 [DS-016890]
14. Duscha V, Ragwitz M, Breitschopf B et al. (2014) Employment and growth effects of sustainable energies in the European Union - FINAL REPORT. Karlsruhe, 181 pp.
15. Universiteit Utrecht; Ric Hoefnagels, Martin Junginger, André Faaij, 2012, Capacity Study for Solid Biomass Facilities, Part I - Scenarios for supply and demand of solid biomass for electricty and heat in North West Europa
16. Universiteit Utrecht; Ric Hoefnagels, Martin Junginger, André Faaij, 2013, Capacity Study for Solid Biomass Facilities, Part II - A tool to assess scenarios of global supply, demand and trade ol solid biomass for notrhwest Europa
17. Department for Business, Energy & Industrial Stratagy, 2016, BEIS 2016 Fossil fuel price assumptions
18. RVO, 2017, retrieved from: https://www.rvo.nl/subsidies-regelingen/sde/windenergie-op-zee/windgebied-hollandse-kust-i-en-ii
19. Statistisches Bundesamt (Destatis), 2017, Building permits for new buildings: Germany, years, type of building, energy use, type of energy (31111-0008)
20. Port of Rotterdam, fact & figures, energy port, 2016
21. Ministerie van Economische Zaken, 2015. Biomassa 2030 - Strategische visie voor de inzet van biomassa op weg naar 2030
22. Bio based Industries Consortium, 2013, Strategic Innovation and Research Agenda (SIRA) Bio-based and Renewable Industries for Development and Growth in Europe

23. Ric Hoefnagels, Martin Junginger, Gustav Resch, DiaCore - Coordination of biomass resource availability import strategies and demand, 2015
24. EU (European Union), 2008, REGULATION (EC) No 1099/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
25. Gerssen-Gondelach, S. J.; Saygin, D.; Wicke, B.; Patel, M. K.; Faaij, A. P. C. ,2014, Competing uses of biomass: Assessment and comparison of the performance of bio-based heat, power, fuels and materials, Renewable and Sustainable Energy Reviews, volume 40, pp. 964 - 998
26. IEA Clean Coal Centre, Dr. Colin Henderson, 2015, Cofiring of biomass in coal-fired power plants - European experience, Presentation at FCO/IEA CCC workshop
27. IEA Bioenergy Task 42 Biorefinery, de Jong E; Langeveld H; and van Ree R; Available from: http://www.iea-bioenergy.task42-biorefineries.com/publications/brochures/
28. Laser M; Larson E; Dale B; Wang M; Greene N; Lynd L.R; 2009, Comparative analysis of efficiency, environmental impact, and process economics for mature biomass refining scenarios. Biofuels, Bioprod Biorefining 2009;3(2):247–70.
29. Eurostat, 2017, SHARES 2015 detailed results, available from http://ec.europa.eu/eurostat/documents/38154/4956088/SHARES-2015-detailed-results.zip/d38ec7e6-b112-497e-bf6a-269c40b44325
30. Robek, A; Bio Refinery Development BV, personal communication
31. Wuppertal Institut, 2016, Decarbonization Pathways for the industrial Cluster of the Port of Rotterdam, available from: https://www.portofrotterdam.com/nl/file/18544/download?token=4Ri58reM
32. Eurostat, 2017, Heating degree-days by NUTS 2 regions - annual data [nrg_esdgr_a]
33. Eurostat, 2017, Heating Degree Days - Monthly, available from http://ec.europa.eu/eurostat/web/energy/data
34. Argus Media, 2017, European operational biomass power plants >20MW, released on 10-01-2017
35. Argus Media, 2017, European biomass plant projects, released on 05-01-2017
36. ODYSSEE-MURE, 2017, available from http://www.indicators.odyssee-mure.eu/energy-indicators/energy-efficiency-global-gains.html
37. OECD, Organisation for Economic Co-operation and Development, 2017, GDP long-term forecast, available from https://data.oecd.org/gdp/gdp-long-term-forecast.htm
38. EC (European Commission), 2016, EU Reference Scenario 2016, Energy, transport and GHG emissions, Trends to 2050
39. Dico Regoord, Sales Manager ZHD, personal communication
40. Leo Lokker, Commercial & Business Development Manager, EMO BV, personal communication
41. Frank van der Stoep, Sales Manager, European Bulk Services (EBS)
42. Mark Bouwmeester, Project Development Manager RWE, personal communication
43. Hugo du Mez, Advisor Business Intelligence - Dry Bulk at Port of Rotterdam, personal communication
44. Bob Flach, Sabine Lieberz, Marcela Rondon, Barry Williams, Carrie Teiken, Biofuels annual-UE28 2015, USDA Foreign agricultural service GAIN Report Number NL5028

Annex A – Definitions

Since data series from Eurostat are used not only to analyses historic and current final energy consumption, but also to model expected future demand, for this study the definitions of Eurostat for a following variables are adopted;

Solid biofuels: Covers organic, non-fossil material of biological origin which may be used as fuel for heat production or electricity generation. It comprises of purpose-grown energy crops (poplar, willow etc.), a multitude of woody materials generated by an industrial process (wood/paper industry in particular) or provided directly by forestry and agriculture (firewood, wood chips, wood pellets, bark, sawdust, shavings, chips, black liquor etc.) as well as wastes such as straw, rice husks, nut shells, poultry litter, crushed grape dregs etc. Combustion is the preferred technology for these solid wastes. The quantity of fuel used should be reported on a net calorific value basis.

Derived heat: Covers the total heat production in heating plants and in combined heat and power plants. It includes the heat used by the auxiliaries of the installation which use hot fluid (space heating, liquid fuel heating, etc.) and losses in the installation/network heat exchanges. For autoproducing entities (= entities generating electricity and/or heat wholly or partially for their own use as an activity which supports their primary activity) the heat used by the undertaking for its own processes is not included.

Renewable energies: Covers hydro power, wind energy, solar energy, tide, wave and ocean, biomass and renewable wastes and geothermal energy. Renewable energies (Code 5500) are the sum of hydro power (Code 5510), wind energy (Code 5520), solar energy (Code 5530), tide, wave and ocean (Code 5535), biomass & renewable wastes (Code 5540) and geothermal energy (Code 5550).

The industry sector: covers the consumption in all industrial sectors with the exception of the "Energy sector". This refers to fuel quantities consumed by the industrial undertaking in support of its primary activities. For heat only or CHP plants, only quantities of fuels consumed for the production of heat by autoproducers are applicable. Quantities of fuels consumed for the production of heat that is sold, for the production of electricity, and the quantities of coke transformed into blastfurnace gas should be reported under the appropriate Transformation sector. It consists of the following subsectors:

- B_101805 Iron and Steel
- B_101815 Chemical and Petrochemical
- B_101810 Non-Ferrous Metals
- B_101820 Non-Metallic Minerals
- B_101846 Transport Equipment
- B_101847 Machinery
- B_101825 Mining and Quarrying
- B_101830 Food and Tobacco
- B_101840 Paper, Pulp and Print

- B_101851 Wood and Wood Products
- B_101852 Construction
- B_101835 Textile and Leather
- B_101853 Non-specified (Industry)

Transport sector: covers the energy used in all transport activities irrespective of the economic sector in which the activity occurs, i.e., rail, road, aviation and domestic navigation; NACE Divisions 49, 50 and 51. It consists of the following subsectors:

- B_101910 Rail
- B_101920 Road
- B_101931 International aviation
- B_101932 Domestic aviation
- B_101940 Domestic Navigation
- B_101945 Pipeline transport
- B_101950 Non-specified (Transport)

Residential sector: Covers quantities consumed by all households including "households with employed persons" (NACE Divisions 97 and 98). Household means a person living alone or a group of people who live together in the same private dwelling and sharing expenditures including the joint provision of the essentials of living. The household sector, also known as the residential (or domestic) sector is therefore, a collective pool of all households in a country. Collective residences which can be permanent (e.g. prisons) or temporary (e.g. hospitals) are excluded as these are covered in consumption in the service sector. Energy used in all transport activities are reported in the transport sector and not in the household sector. Energy consumption associated with significant economic activities of households are also excluded from the total household energy consumption. These activities include agricultural economic activities on small farms and other economic activities carried out in a household's residence and are found in the corresponding sector.

Fishing sector: consists of quantities consumed for inland, coastal and deep-sea fishing as specified in NACE Division 03. Fishing should cover energy consumption in ships of all flags that have refueled in the country (include international fishing)

Agriculture/Forestry sector: consists of quantities consumed by users classified as agriculture (including engines used for agricultural transportation), hunting and forestry; NACE Divisions 01 and 02.

Services sector: consists of fuels consumed by business and offices in the public and private sectors.

NACE Divisions 33, 36, 37, 38, 39, 45, 46, 47, 52, 53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 84, 85, 86, 87, 88, 90, 91, 92, 93, 94, 95, 96 and 99.

Non-specified (Other) sector: consists of final energy consumption not classified under any other code. These are activities not included elsewhere. This category includes military fuel use for all mobile and stationary consumption (e.g. ships, aircraft, road and energy used in living quarters), regardless of whether the fuel delivered is for the military of that country or for the military of another country. If used, what is included under this heading should be explained in the report.