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TOPWASTE Background Energy Scenarios - Draft version

2035 and 2050

Raffaele Salvucci & Marie Münster

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Report
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By
Raffaele Salvucci & Marie Münster

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Preface

This report is a data documentation report for the TOPWASTE research project financed by the Danish Innovation Foundation (formerly the Strategic Research Council).

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Lyngby, October 2015

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Summary

The surrounding (background) energy system determines the electricity and heat prices which waste-to-energy plants may see in the future. Furthermore, the background energy system is often determining for the environmental impact of waste treatment solutions producing or saving energy. In order to take into account possible developments of the surrounding (background) energy system it is necessary to model scenarios for the possible future development of the Nordic electricity market, of which Denmark forms part. This paper describes the assumptions used regarding the future energy systems in Denmark, Sweden, Norway, Finland and Germany, which are included in the modelling of the future Nordic electricity market. The main assumptions are on: electricity and DH demands, data on conversion technologies, RE resource potentials and energy prices. The future scenarios are illustrated in *Table 1*.

Table 1 - Future Scenarios

	Base (2012)	**DK Wind (2035)**	**DK Wind (2050)**	**DK Bio+ (2035)**	**DK Bio+ (2050)**
SE, NO, FI, DE Base	2012Base				
SE, NO, FI, (CNBS), DE (*Ref*)				2035Bio	2050Bio
SE, NO, FI, (CNES), DE (*Ref*)		2035Wind	2050Wind		

The scenarios for Denmark relate to scenarios from the Danish Energy Agency and the scenarios for the remaining countries relate to the "Carbon Neutral high Bioenergy Scenario" (CNBS) and the "Carbon Neutral high Electricity Scenario" (CNES) from the Nordic Energy Technology Perspectives (ETP).

Furthermore, for the aim of this study, the identification of a global electricity marginal is needed to quantify environmental impacts due to energy consumption, which takes place out of the defined modelled geographical scope. In order to obtain such evaluation, results from the IEA ETP 2012 are used as inputs.

1. Future Nordic energy system scenarios

The background energy scenarios have great influence on the feasibility of waste management solutions, particularly in a country such as Denmark, where incineration of MSW constitutes up to 20% of the district heating and 4% of the electricity demand.

When identifying the affected energy production (sometimes referred to as marginal energy production) it is necessary to identify it on the relevant markets. In the TOPWASTE project, the district heating marginals are identified as part of the optimisation in the OptiWaste tool by modelling the production and consumption in the main DH areas and aggregating the remaining, depending on their geographical placement in relation to municipalities.

As the electricity production is part of a Nordic and German market, the affected electricity production will be identified on this market, by use of the Balmorel tool.

This paper describes the assumptions used regarding the future energy system in Denmark, Sweden, Norway, Finland and Germany. The main assumptions entered into the models are: electricity and DH demands, data on conversion technologies, RE resource potentials and energy prices.

The waste management scenarios will furthermore depend on the biomass consumption at a global scale, which can be illustrated as a scenario with high biomass consumption: the "Carbon Neutral high Bioenergy Scenario" (CNBS), or with a low biomass consumption in the rest of the world "Carbon Neutral high Electricity Scenario" (CNES). The scenarios are related to the Nordic Energy Technology Parespectives 2013 project. The future scenarios analysed are illustrated in *Table 1*.

Table 2 - Future Scenarios

	Base (2012)	**DK Wind (2035)**	**DK Wind (2050)**	**DK Bio+ (2035)**	**DK Bio+ (2050)**
SE, NO, FI, DE Base	2012Base				
SE, NO, FI, (CNBS), DE (*Ref*)				2035Bio	2050Bio
SE, NO, FI, (CNES), DE (*Ref*)		2035Wind	2050Wind		

In the following part, a description of the future energy systems is presented for the following countries: Denmark, Norway, Sweden, Finland and Germany.

1.1 Denmark

Future energy scenarios for Denmark rely on specific scenarios made by the Danish Energy Agency (DEA) in "Energiscenarier frem mod 2020, 2035 og 2050". This vision includes four main scenarios for Denmark's future energy supply in the period up to 2050. The basic framework used to provide such analyses includes an overview of the different interactions between the energy sector and the other economic activities of the society as transport and industry. In this way the resulting vision is consistent and complete in terms of overall resource and energy use ((Danish Energy Agency 2014a), pp. 5).

The resulting scenarios comply with the fossil-free vision in 2050 and the government's target toward a green electricity and heat sector in 2035. Denmark's long-term goal includes several milestones: 50% of electricity supply from wind power in 2020; phasing out coal consumption at power plants by 2030; phasing out oil burners by 2030; and covering all electricity and heat supply with renewables by 2035. Denmark's 2050 target is to have the entire energy supply covered by renewable energy. Calculations from the Danish Commission on Climate Change Policy show that when domestic energy and transport systems no longer use fossil fuels, GHG emissions will be reduced by approximately 85% in comparison with 1990 level. This is in line with the EU target ((Norden & International Energy Agency 2013), pp. 36).

The focus of this study is restricted to two DEA scenarios: the Wind scenario and the so-called Bio+ scenario. The Wind scenario is based on Denmark's bio energy independency vision, which envisages a bio energy consumption limited by what the country itself can provide (around 230 PJ). Biofuels are expected to be largely produced in Denmark, with the construction of biofuel factories integrated into electricity and heat supply. In order to fulfil this vision a massive electrification of transport, industry and district heating is considered necessary in parallel with a powerful offshore wind farm development. Moreover, hydrogen is produced and used as fuel supplement for upgrading biomass, in order to keep bioenergy use at a moderate level ((Danish Energy Agency 2014a), pp. 9). Concerning the transportation sector, a large number of private cars, railways and busses are assumed to be electrified; while the remaining part is fuelled with biofuels and synthetic natural gas based on biogas upgrading.

The Bio+ scenario involves a fuel-based system, similar to what we have today, with the difference that coal, oil and natural gas are replaced with bioenergy, whose consumption is expected to be around 700 PJ while no hydrogen use is included. This indirectly involves a large import of biomass. The electricity grid in the Bio+ scenario is assumed to be similar to what we have today ((Danish Energy Agency 2014a), pp. 9), while the transport sector is mainly based on biofuels and modestly on electricity.

1.1.1 Renewable Energy Potential

In *Table 2* and *3,* data concerning renewable energy (RE) sources utilization in Denmark today and estimated future potentials are presented.

Table 2 - Local and imported biomass resources available for electricity and district heating sector in Denmark. (PJ), ((Energy Analyses 2014), pp. 27).

Category	**Consumption in 2013**	**2035**	**2050**
Straw	*21*	*21*	*7,6*
Woodchips	*41*	*41*	*0*
Pellets	*124*	*83*	*0*
Wood Waste	*0*	*0*	*0*
Biogas	*5*	*24*	*24*

Table 3 - RE Potential in Denmark (PJ), ((Danish Energy Agency 2014a), pp. 15 - 16).

Category	Total Generation in 2011	Potential
Wind Onshore	*35*	*33*
Wind Offshore "Coastal"		*150*
Wind Offshore (North Sea)		*1040*
Solar PV Cells	-	*104*

Wave power is not taken into account in the available renewable technology future fleet in any of the selected scenarios due to its uncertain development ((Danish Energy Agency 2014a), pp. 16).

The numbers cited in *Table 2* were used as base for renewable potential, then such values were adjusted in the model in order to represent the different assumptions on which the DEA scenarios are built, mainly involving the transport sector. Additional information can be found in section: "Modelling the Scenarios in Balmorel".

1.1.2 Electricity

The general guidelines on which the DEA scenarios are built, aim to cover the peak electricity demand with a combined action of CHP and condensing capacities, together with a great exploitation of the interconnections with Norway and Sweden. Moreover, a certain amount of gas turbine capacity is always included in all the scenarios as power reserve.

The main technologies included by DEA within its future power sector perspective are: offshore and onshore wind power, solar PV, central biomass CHP plants, which is the unique example of central plant, fuel cells and gas turbines. In addition, use of CCS is not allowed in fossil fuels plants and nuclear power is excluded from the available energy technologies ((Danish Energy Agency 2014a), Ch. 10).

In *Table 4* , different types of electricity consumption, as well as generation which is not mainly driven by the electricity market are shown as electrical installed capacities ((Danish Energy Agency 2014a), pp. 56 - 59). Some of these actors belong to the industrial sector (such as e.g. “Biomass CHP Industry”), to the transportation sector (such as the electrical vehicles), and to the individual heating and bio-refinery sectors. Moreover, the category “Classic Consumption” refers to the yearly net electricity peak demand excluding the above contributions. The breakdown of these categories is provided with the purpose to identify different demand types that typically follow other hourly profiles than the classic one. A portion of this demand is assumed interruptible, such as electric boilers, heat pumps and hydrogen plants (see *Table 4* under Flexibility). On the other hand, classical electricity consumption and fuel factories, except for the hydrogen case, is considered non-interruptible ((Danish Energy Agency 2014a), pp. 56).

Table 4 – Electricity Demand Breakdown & Extra Electricity Production Capacities in 2035 and 2050 (MW el installed), ((Danish Energy Agency 2014a), pp. 57 - 59).

Scenario	**Wind 2035**	**Wind 2050**	**Bio+ 2035**	**Bio+ 2050**	**Flexibility (+/-)**
Electric Cars	*-211*	*-846*	*-9*	*-36*	+
Electric Vans	*-82*	*-328*	*0*	*0*	+
Electric Buses	*-11*	*-44*	*0*	*0*	+
Electric MC	*-3*	*-12*	*0*	*0*	+
Electric Trains	*-73*	*-106*	*-73*	*-106*	-
Biomass CHP Industry	*76*	*305*	*107*	*427*	-
Gas CHP Industry	*334*	*0*	*445*	*89*	-
Electric Boilers	*-328*	*-1313*	*0*	*0*	+
Heat Pumps Process	*-42*	*-167*	*-8*	*-33*	-
Air Heat Pumps Individual	*-125*	*-250*	*0*	*0*	+
Ground Heat Pumps Individual	*-278*	*-556*	*-111*	*-222*	+
Biodiesel 2G Straw	*0*	*0*	*12*	*49*	-
Biodiesel 2G Wood	*0*	*0*	*6*	*24*	-
Biodiesel 2G Hydrogenation	*12*	*50*	*0*	*0*	-
Bio kerosene 2G	*0*	*0*	*23*	*92*	-
Bio kerosene 2G Hydrogenation	*18*	*73*	*0*	*0*	-
Hydrogen Factory	*-1034*	*-4138*	*0*	*0*	+
Biogas Prod.	*-12*	*-19*	*-12*	*-19*	-
Biogas Upgrade	*-24*	*-1226*	*-39*	*0*	-
Biogas Upgrade Hydrogenation	*-306*	*0*	*0*	*-60*	-
Classic Consumption	*-5217*	*-4968*	*-5217*	*-4968*	-

As it can be noticed from *Table 4*, classic consumption has the same value in both scenarios, while the other contributions participate to a different degree to the whole frame. As a result, the overall electricity demand, including flexible and not flexible contributions, is quite different in the two scenarios in terms of magnitude and composition. In Figure 1, the net classic electricity demand (identical for the Wind and Bio+ scenario), is compared to the two different demands resulting from flexible consumptions (electric vehicles, individual heating and hydrogen generation). A linear trend is assumed between data available for selected years.

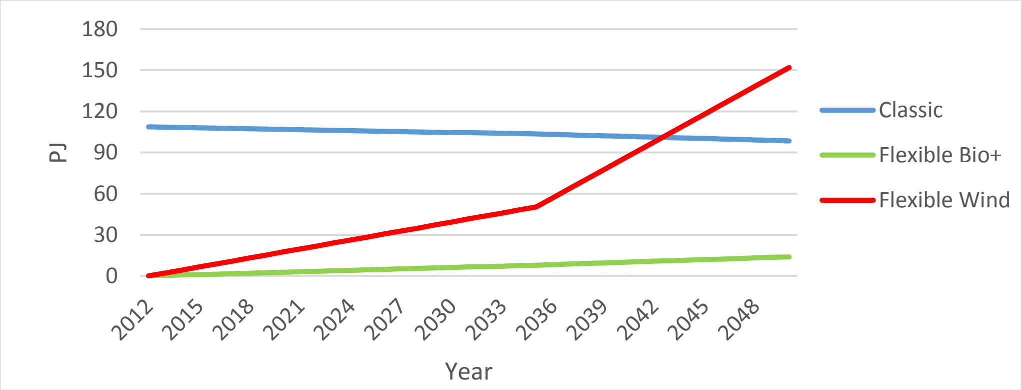

Figure 1 - Net Electricity Demand in Denmark, (Danish Energy Agency 2014a).

1.1.3 Transport

All the scenarios are based on a few common assumptions. The first priority in terms of fuel supply is given to air transport that is expected to consume only bio kerosene in 2050, while ships fuel demand is assumed to be covered by biodiesel and synthetic natural gas.

In the wind scenario, most of the passenger cars are assumed to be electric, while in the Bio+ scenario there is almost no electric vehicles and all the transport sector rely on biofuels, most of it imported ((Danish Energy Agency 2014a), pp. 42).

The reader should note that it is assumed that after 2030 electric vehicles (EVs) can fulfil roughly the same driving needs as conventional vehicle with respect to range, etc. This is a key precondition for the Wind scenario but not for the Bio+ scenario, where EVs are almost omitted from the transport fleet ((Danish Energy Agency 2014a), pp. 9).

Furthermore, in order to achieve the intended target of a fossil free transport sector in 2050 it is assumed that in 2035 the transformation is 25% on the way. This means that if in 2050 it is assumed 23.2 PJ mechanical output from electric cars, then the relative value for 2035 is 5.8 PJ. This assumption is driven by the fact that such revolution brings a radical change in different infrastructures that requires a long period to be implemented.

Another important key point is the refining sector that will provide the domestic biofuels production. An analysis of such infrastructure is important, not only to understand how the national biomass potential will be managed among the different fuel productions to cover the transportation and energy demand, but it is also relevant considering that excess heat produced by such processes could theoretically cover a high share of the national heating demand.

The projected refinery capacities in 2035 and 2050 are shown in *Table 5*. Hydrogen factories are included in the same table even though hydrogen is mainly used for biomass upgrading and only to a lower level for transport. The reason of doing that is because they are also a source of surplus heat.

Table 5 - Refining Sector Capacities in 2035 and 2050 (PJ, except for hydrogen expressed in MW), ((Danish Energy Agency 2014a), Ch. 10).

Scenario	**Wind 2035**	**Wind 2050**	**Bio+ 2035**	**Bio+ 2050**
Hydrogen Factory	*600.0*	*2400.0*	*0.0*	*0.0*
Biodiesel 2G Straw	*0.0*	*0.0*	*5.0*	*20.0*
Biodiesel 2G Wood	*0.0*	*0.0*	*2.5*	*10.0*
Biodiesel 2G hydrogenating	*6.4*	*25.5*	*0.0*	*0.0*
Bio kerosene 2G	*0.0*	*0.0*	*9.4*	*37.6*
Bio kerosene 2G hydrogenating	*9.4*	*37.6*	*0.0*	*0.0*
Biogas Plant	*27.0*	*42.0*	*27.0*	*42.0*
Biogas Upgrading Plant (hydrogen)	*16.2*	*64.7*	*0.0*	*0.0*
Biogas Upgrading Plant	*16.5*	*0.0*	*27.0*	*42.0*

Considering the focus of this study, the future refinery sector is modelled as a source of continuous heat production, which is exploited in the central district heating areas, as in the DEA scenarios. A further expansion of this sector in the model will possibly carried out in future works because of its interesting interconnection with the remaining energy sector.

1.1.4 Heat

Considering future scenarios for the heat sector, a crucial point in the assumptions, is related to future efficiency development. Improvements in energy savings are assumed at the same extent in both scenarios: Wind and Bio+; resulting in a decreasing heating demand from 2035 to 2050.

In *Table 6* the key figures related to the individual heating sector are expressed in terms of future installed capacities. Please note that the heat consumption in *Tables 6, 7* and *8* is expressed as net peak demand.

Table 6 - Individual Heating Installed Capacities (MW, except for solar thermal expressed in PJ), ((Danish Energy Agency 2014a), pp. 51).

Scenario	**Wind 2035**	**Wind 2050**	**Bio+ 2035**	**Bio+ 2050**
Solar Thermal	*2.5*	*5*	*2.5*	*5*
Air Heat Pumps	*500*	*1000*	*0*	*0*
Ground Source Heat Pumps	*1250*	*2500*	*500*	*1000*
Biomass Boilers	*4300*	*3500*	*5600*	*5000*
Heat Consumption	*-6162*	*-5016*	*-6162*	*-5016*

Considering the district heating (DH) sector, the demand evolution for the selected period is shown in *Figure 2*, where the net heat demand for DH is presented. Please note that the projection includes both the centralized and the decentralized contributions and it is identical for the Wind and the Bio+ scenarios.

As it can be noted, the heat demand decreases through the years even though it is estimated that the number of heating consumers increases. This is due to an assumption on substantial energy savings ((Danish Energy Agency 2014a), pp. 89).

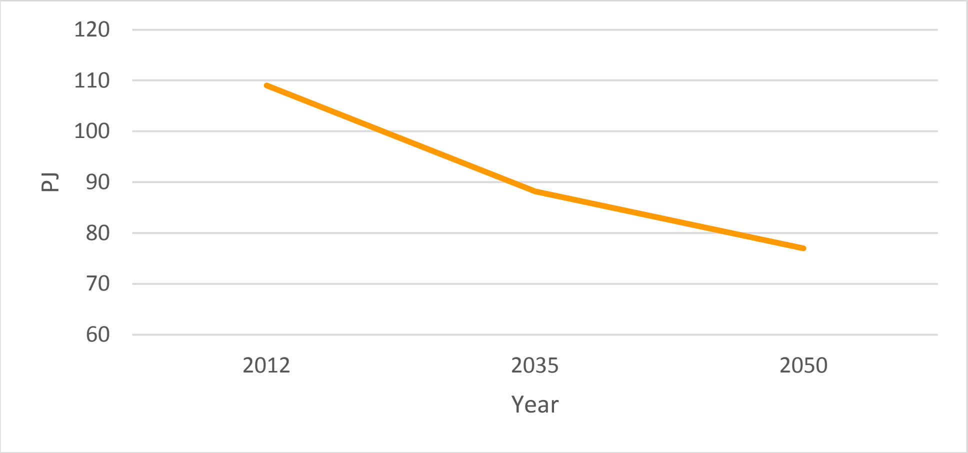

Figure 2 - Net District Heating Demand in Denmark, *(Danish Energy Agency 2014a)*.

The district heating sector can be divided in two main areas: centralized and decentralized. The main assumption made by DEA concerning all the scenarios in the centralized DH is that 3.2 PJ of heat is provided by industries as industrial waste heat, which is valid for both 2035 and 2050. Moreover, a large amount is provided by refineries. These data are summarized in *Table 7* together with the expected heat demand for years 2035 and 2050.

Table 7 - Central DH Extra Heat Capacities and Heat Demands in 2035 and 2050 (MW, except for industrial heat expressed in PJ), ((Danish Energy Agency 2014a), pp. 53 - 55).

Scenario	**Wind 2035**	**Wind 2050**	**Bio+ 2035**	**Bio+ 2050**
Industrial Waste Heat	*3.2*	*3.2*	*3.2*	*3.2*
Biodiesel Straw	*0*	*0*	*87*	*347*
Biodiesel Wood	*0*	*0*	*43*	*173*
Biodiesel Hydrogenation	*91*	*364*	*0*	*0*
Bio kerosene	*0*	*0*	*163*	*653*
Bio kerosene Hydrogenation	*135*	*538*	*0*	*0*
Heating Consumption	*-4161*	*-3631*	*-4161*	*-3631*

The main assumption valid for all the selected scenarios concerning the decentralized DH is the exploitation of 1.5 PJ of industrial waste heat, in both years 2035 and 2050 ((Danish Energy Agency 2014a) pp. 53 - 55). Moreover, some biofuels facilities - mainly involved in biogas upgrading and hydrogenation - are responsible for consumption or production of excess heat. In *Table 8*, data related to the decentralized DH sector and its future heat demand are shown again for years 2035 and 2050.

Table 8 - Decentralized DH Extra Heat Capacities and Heat Demands Breakdown in 2035 and 2050 (MW, except for industrial heat expressed in PJ), ((Danish Energy Agency 2014a), pp 53 - 55).

Scenario	**Wind 2035**	**Wind 2050**	**Bio+ 2035**	**Bio+ 2050**
Industrial Waste Heat	*1.5*	*1.5*	*1.5*	*1.5*
Biogas Facilities	-	*-162.0*	-	*-162.0*
Biogas Upgrading	*0*	-	*0*	-
Biogas Hydrogenation	*77.0*	*308.0*	*0*	*0*
Heating Consumption	*-2774.0*	*-2421.0*	*-2774.0*	*-2421.0*

Lastly, the main technologies included in the future fleet in the district heating sectors by DEA are: waste CHP, central biomass plants, heat pumps, geothermal, solar thermal, wood and straw boilers, chips CHP, gas or synthetic natural gas CHP and biogas CHP.

1.2 Norway, Sweden & Finland

In this project, future energy scenarios for Norway, Sweden and Finland rely on a recent study made by the International Energy Agency (IEA) in collaboration with Nordic research institutions, and the Nordic Council of Ministers through its energy research funding institution, Nordic Energy Research (Norden & International Energy Agency 2013), the main document followed is the "Nordic Energy Technology Perspectives".

One of the main assumptions adopted in constructing future energy scenarios for these countries is to rely on the challenging goals that the Nordic states have announced in terms of energy system emissions reduction towards 2050. Three new different scenarios are presented in the "Nordic Energy Technology Perspectives" (NETP) besides the 2°C Scenario (2DS) outlined in the "Energy Technology Perspectives 2012" (ETP 2012), which represents the IEA strategy to contain the future global average temperature increase within 2°C.

The new, and even more ambitious, future energy scenarios for the Nordic countries, the "Carbon Neutral Scenarios" (CNS) reflect the leading role of Nordic countries in the reduction of fossil fuels within the energy sectors; rich in renewable energy resources, they are in a promising position to make the transition from fossil fuels to low- or zero-carbon energy sources. Moreover, they are pioneers in innovative policy actions towards long-term energy targets, including the establishment of grid interconnections and a common liberalised power market ((Norden & International Energy Agency 2013), pp. 8).

The CNS target is to reduce energy-related carbon dioxide emissions in the Nordic region by 85% by 2050 compared to 1990, including international carbon credits to offset the remaining 15%. The scenarios are complying with the EU Energy Roadmap 2050 not only in the long-term perspective but also in the intermediate targets as: 25 % reduction of total domestic GHG emissions by 2020 and 40 % by 2030 respect to 1990 ((Norden & International Energy Agency 2013), pp. 36).

Sweden's long-term vision is to release no net GHG emissions into the atmosphere. The Swedish government has set an ambitious plan, which includes reaching independency from fossil fuels for all vehicles by 2030, and achieves 49 % of renewable energy shares of total energy use by 2020.

Presently, Norway's target is to be carbon neutral in 2050, on the other hand the Norwegian government will aim to achieve carbon neutrality by 2030 if strong commitment by other countries will be showed; the actual 2020 goal for Norway is, however, to have a renewable energy share of 67.5 %, the highest among the Nordic countries.

Finland's goal consists of supplying the road transport sector with 20 % renewable energies by 2020; moreover, through the “CleanTech programme”, the Finnish government aims to decrease the use of oil, coal and natural gas by 2025 (e.g. phasing out condensing coal-fired power plants), resulting in a share of 38 % renewable energy related to total energy use by 2020 ((Norden & International Energy Agency 2013), pp. 36). For Sweden and Finland these strategies incorporate the 2020 targets of the National Renewable Energy Action Plans (NREAP) for renewable electricity generation ((Norden & International Energy Agency 2013), pp. 60).

Beside the CNS scenario, two other variants are provided for reducing CO_2 emissions: the "Carbon Neutral high Bioenergy Scenario" (CNBS) and the "Carbon Neutral high Electricity Scenario" (CNES). In the CNBS lower import prices for biofuels (bio-ethanol, biodiesel) are assumed in comparison to the other variants. Considering that in CNS the Nordic domestic biomass potential (1600 PJ) by 2050 is already fully utilised, cheaper biofuels imports gives the option to free up some of the domestic biomass use for other purposes (e.g. electricity, heat generation). In the CNES, no constraints have been imposed on additional investment in transmission lines within the Nordic region, whereas the interconnections with the rest of the European countries has been limited approximately to 17 GW ((Norden & International Energy Agency 2013), pp. 165).

Moreover, within the selected scenarios, the Nordic region is considered a net importer of bioenergy, importing 13% of its supply in the CNS scenarios. The high biomass consumption is consistent with the analysis of global availability of biomass for energy purposes conducted in "Energy Technology Perspectives" (ETP) 2012, which underlines that by 2050 bioenergy is the world’s largest energy carrier, accounting for some 30% of the total global supply ((Norden & International Energy Agency 2013), pp. 153).

Assumptions made on future biomass potential and transmission lines investments within this project are discussed further in this document.

1.2.1 Renewable Energy Potential

Following the "Fjernvarmeanalyse - bilagsrapport" report by EA, the total available local bioenergy resources in the Nordic region for electricity and district heating generation is assumed to be 412 PJ; in Table 9 a breakdown of such potential in its different parts is presented for each country.

Table 9 - Available local bioenergy resources in the Nordic countries and Germany for electricity and district heating generation (PJ), ((Energy Analyses 2014), pp. 70).

	Wood & Wood Pellets	**Biogas**	**Straw**	**Wood Waste**	**Total**
Finland	*40*	*8*	*13*	*120*	*181*
Norway	*30*	*-*	*6*	*-*	*36*
Sweden	*75*	*13*	*17*	*90*	*195*

A discussion related to wind power and hydro power potential is postponed to section: "Modelling the Scenarios in Balmorel".

1.2.2 Electricity

Currently, the Nordic electricity sector is characterised by relatively low CO_2 emissions per kilowatt hour compared to the global and European average, which can be even four times higher depending by the seasonal fluctuations. Following the NETP framework, an almost fossil free Nordic power and district heating sector could be achieved by 2040 ((Norden & International Energy Agency 2013), Ch. 3).

The final electricity demand in the CNS scenarios is characterised by different counteracting trends: a more efficient use of electricity in the industry and residential sectors, the electrification in the transport sector and, to a lesser extent, also an increased electricity use for Carbon Capture Storage (CCS) in some industries ((Norden & International Energy Agency 2013), pp. 60). The result is an increase in electricity demand, which can be particularly seen in Sweden. In *Figure 3*, the net classic electricity demand is shown for the whole considered period (blue lines); this type of electricity demand constitutes an equivalent base for all the scenarios, while some differences can be found in the transport sector, where a different use of electric and hydrogen vehicles characterize the scenarios with a different flexible electricity demand (red and green lines).

It is worth to note that a significant contribution to the electricity consumption is predicted to come from the heat sector, where heat pumps and electric boilers play a significant role in the NETP scenarios. Despite this, since the share of these technologies is a target question for this study as well as an optimization target of the software used, the electricity demand due to changes in the heat sector structure are not included in the classic profile (shown in *Figure 3),* but, on the contrary, it is endogenously estimated within the simulations.

As already stated above, an extra contribution to the overall electricity demand, which is not included in the classic profile, is the hydrogen production, mainly adopted in the CNES scenario as wind power fluctuations buffer. In this case, the electricity demand is implemented in the software as a flexible consumption separated by the classic profile, which by definition is inflexible. Further information about such contribution can be found in the transport section (*Figure 5*).

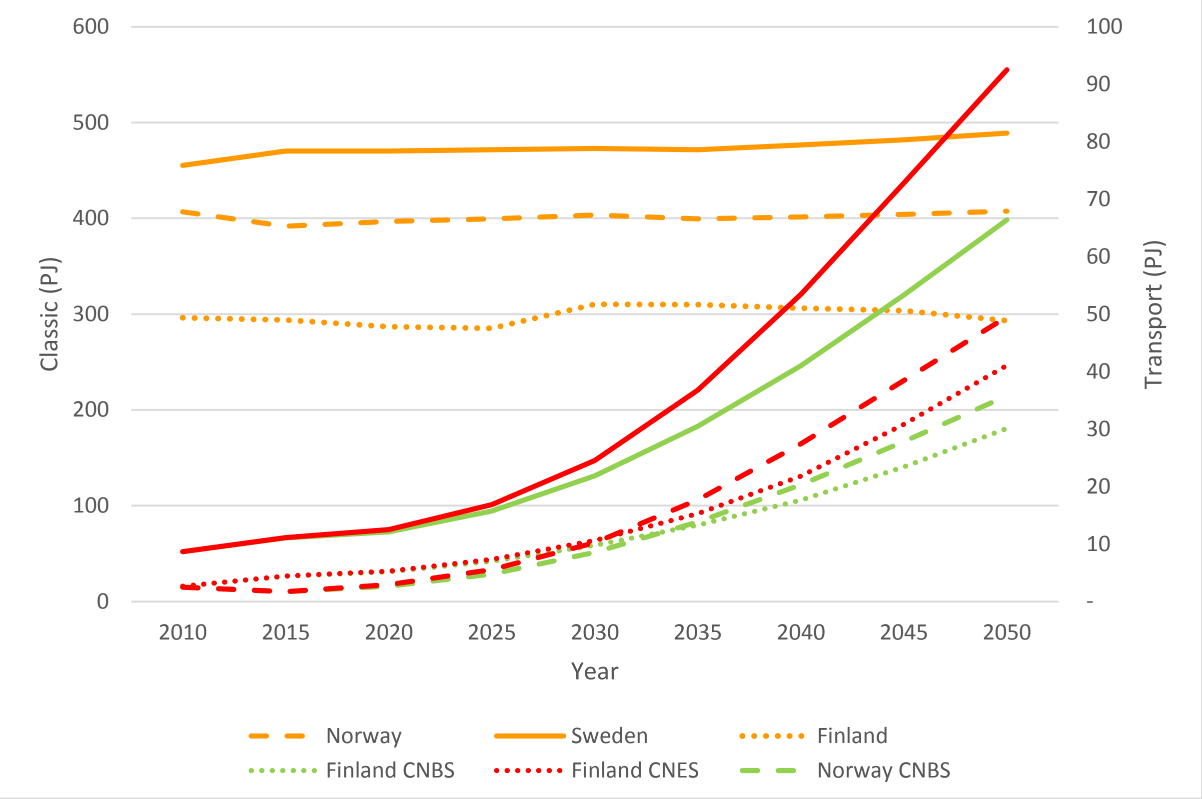

Figure 3 - Net Electricity Demand. Classic demand shown in orange and transport demand in red and green (Norden & International Energy Agency 2013).

Considering the results from the NETP project, in the CNBS and CNES scenarios, classic electricity demands are slightly different due to different assumptions on the building sector (higher/lower penetration of heat pumps for the individual heating) ((Norden & International Energy Agency 2013), pp. 60); in this study such differences were considered negligible and a common profile was assumed for the classic electricity demand.

As already stated above, the electricity and fuel future demands are directly interconnected to the industrial, residential and transport sector activities. Assumptions regarding these sectors explain how the CNS scenarios are built to underline the specific interconnections among the different society aspects in the future projections.

An important assumption is that the industrial sector in the Nordic region will remain relatively steady in comparison with today. Thanks to the industrial maturity of the Nordic region, only a small general increase in material production volumes is expected despite a combined effect of population growth and GDP development (which are assumed the main key drivers for industrial production). This could be achieved with a higher share of recycled materials, improving energy efficiency and using best available technologies (BAT) including a massive use of CCS in several industrial sectors as e.g. iron, steel, pulp and paper. This requires a considerable effort in increasing industrial research investments ((Norden & International Energy Agency 2013), Ch. 4).

In *Figure 4* the assumed values for population and GDP growth through the years are presented for Sweden, Norway and Finland.

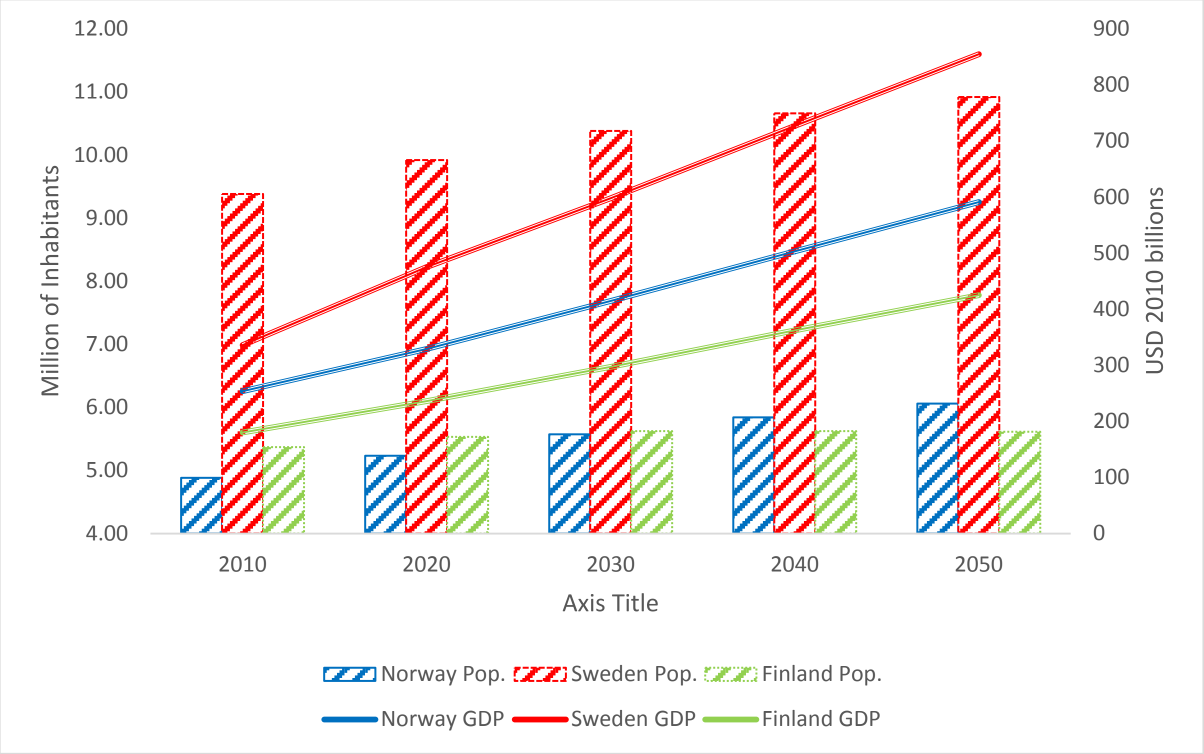

Figure 4, Population and GDP Growth, ((Norden & International Energy Agency 2013), Annex B)

The main factors that are assumed to influence building energy demand include population, income growth, number of people per household, appliances, efficiency of building structures (roofs, walls, windows) and climate. A complex interaction exists among energy, material, economic, climate and demographic factors that has an impact on the heating and cooling load, the number and types of appliances owned, and their patterns of use. Those key parameters are included in all the selected scenarios analyses. The CNS variants include different assumptions for technology penetration, fuel shares, adoption of BATs and implementation of energy efficiency measures. Despite this, there is no large difference in terms of energy use shares between the two variants ((Norden & International Energy Agency 2013), Ch. 6).

Briefly, a general decrease in energy demand in the building sector is assumed to take place in 2050 referring to 2010, however space and water heating continues to be the heaviest contributors to this demand ((Norden & International Energy Agency 2013), Ch. 6). The CNS scenario includes phasing out of all fossil-fuel-fired heating equipment with more biomass, district heating and heat pumps. CNBS differs from CNS in terms of a stronger increase in local biomass boilers use while CNES favours an higher penetration of heat pumps ((Norden & International Energy Agency 2013), Annex C).

1.2.3 Transport

The basic forces that drive the transport demand (including international transportation) are assumed again to be population and gross domestic product (GDP) trends ((Norden & International Energy Agency 2013), pp. 106). Besides building up a transportation energy demand based on such projections, other assumptions were introduced within the CNS scenarios in order to adjust it in accordance with specific measures to increase efficiency and reduction in CO_2 emissions.

The CNS, CNES and CNBS scenarios include the same strategies to achieve modal shifts and to limit growth in demand for transport. In all the selected scenarios around 4 % of transport is avoided by 2050 in comparison with a business as usual behaviour, while 20 % of passenger transport shifts from individual to bus and trains. Over the same period, 50 % of freight transport shifts from road to railway, and an overall efficiency improvement is expected.

Moreover, two important challenges introduced are the switch in fuels in parallel with a switch/improve in technologies. In all carbon neutral scenarios, conventional Internal Combustion Engines vehicles (ICE) are for the greatest part phased out by 2050. While, the difference between the CNS scenarios variants consists only in the exploration of different technology pathways. The CNBS is more optimistic concerning the potential for biofuels to replace totally gasoline and diesel by 2050, whereas the CNS and CNES have a maximum blending of biofuels in gasoline and diesel set at 75 %.

The technology switch towards electrical vehicles (EVs) is very pronounced in the CNS and CNES as already shown in *Figure 3*. Anyhow, electricity covers almost one quarter of the transportation energy demand in both the CNBS and the CNES scenarios considering the whole Nordic region. EVs and biofuels are assumed the main contributors in the reduction of fossil fuels consumption within this sector. However, other technologies such as hydrogen fuel cell vehicles are also included as future solutions. In the CNS and CNES, hydrogen accounts for 6.5 % of the energy used for transport in 2050. In CNBS, hydrogen fuel cell vehicles are not included at all because of a higher availability of cheaper solutions (biofuels) ((Norden & International Energy Agency 2013), Ch. 5).

In this study, electricity demand for hydrogen production is assumed to be flexible in order to represent a situation where electrolysers are used when surplus of wind power is available, a vision that is also embodied by the NETP scenarios. For this reason such demand is modelled separately from the classic one. Projections for the whole period are shown in *Figure 5*.

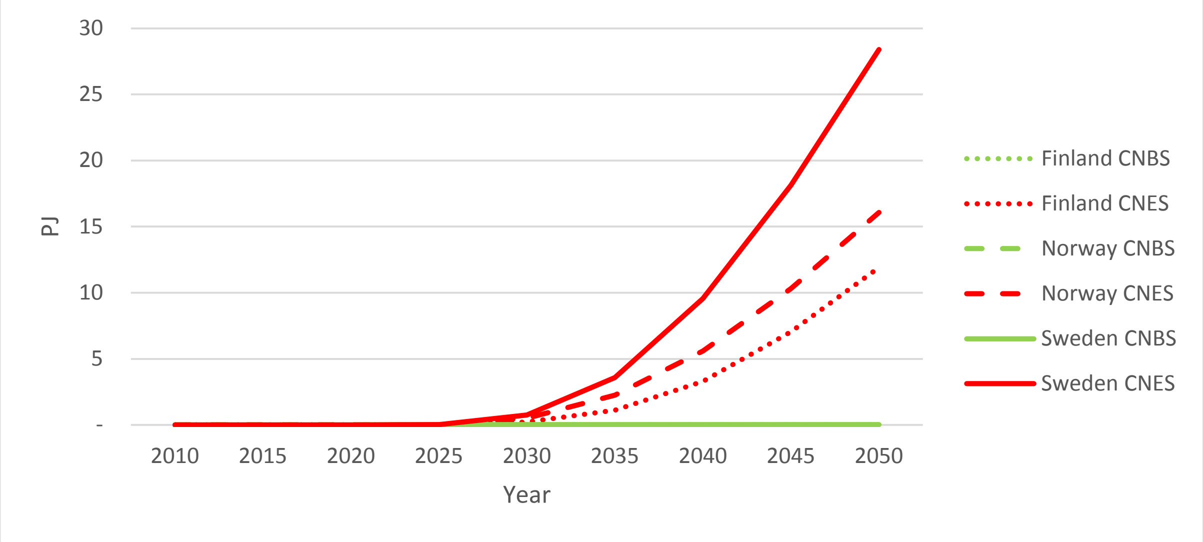

Figure 5, Net Electricity Demand for Electrolysis (Norden & International Energy Agency 2013).

1.2.4 Heat

District heating has been increasing steadily in all Nordic countries for decades and has reached reasonable maturity in all countries except Norway. In 2009, district heating share in heat demand was approximately 50 % in Finland and Sweden, while 6 % in Norway. The growth potential in district heating is, therefore, considered limited in Sweden and Finland while growth opportunities still exist in Norway ((Norden & International Energy Agency 2013), Ch. 3).

In *Figure 6* the net heat demand in the DH sector is shown for Sweden and Finland for each of the CNS variants. Data for Norway is omitted from the figure because it is out of scale (only 19 PJ in 2010); however contrary to the general trend, district heating demand faces a slight increase in Norway within all the CNS scenarios.

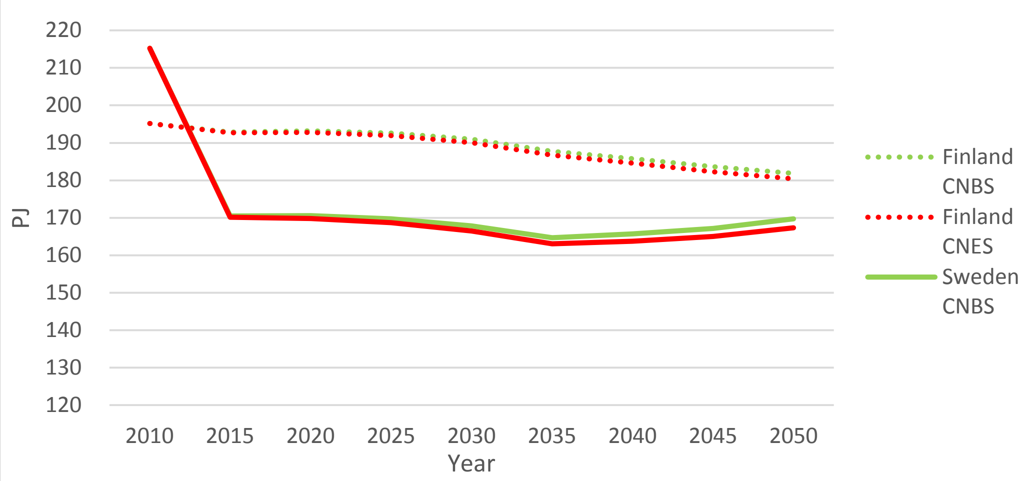

Figure 6 - Net District Heating Demand in Finland and Sweden, (NETP).

1.3 Germany

For Germany, less detailed data on future scenarios has been available, and hence the basic assumptions for a future scenario describing the German energy system are mainly extracted from the report: "Fjernvarmeanalyse - bilagsrapport" report by Energy Analyses (EA). A less detailed description for Germany than for the Nordic region is provided in this study in terms of future possible pathways to reach a sustainable energy system.

In September 2010, the so-called "Energy Concept" was launched in Germany with the aim to provide a road map toward a green energy system. The federal government strategy behind this environmental programme includes several key goals as e.g. to achieve a 40 % reduction in GHGs emissions by 2020, 55 % by 2030, 70 % by 2040 and between 80 % and 95 % by 2050, compared to 1990 level (International Energy Agency 2013). Important policy actions, as the expansion of the renewable energy fleet, an increase in the overall energy efficiency, and the development of the electricity transmission network, are included in the Energy Concept.

In June 2011, after the Fukushima Daiichi nuclear accident in Japan, the Energy Concept plan was revised to boost the phase-out of German nuclear reactors without modifying the environmental targets mentioned above. The government decided that all German nuclear plants will be phased out by the end of 2022 at the very latest. Already in 2011 8.4 GW of nuclear power were shut down and additionally 12 GW will be decommissioned by 2022 ((International Energy Agency 2013), pp. 30). Considering this planned reduction in the German power fleet, several large coal-fired power plants are currently under construction, despite the Energy Concept targets. Such plants will have a technical lifetime at least until 2050 and are likely to remain important parts of Germany’s electricity production. If Germany has to fulfil its emissions reduction targets, then a cleaner alternative to coal use needs to be found. Considering this perspective, it is worth to say that the Energy Concept supports the testing and, where appropriate, the use of CCS technology. A regulatory framework for CCS has been established despite the fact that progress to date has been slow and some planned projects cancelled; "More efforts are needed to encourage CCS demonstration and testing in new coal-fired power plants and to explore and test CCS storage options, especially in the North and Baltic Seas, together with neighbouring countries." ((International Energy Agency 2013), pp. 11) For these reasons the future of this technology is still uncertain even if it may have a central role in the future German energy system.

Besides the reduction in GHGs emissions, several additional goals have been set up by the German government, as a decrease in primary energy consumption of 20 % by 2020 and 50 % by 2050; particularly electricity consumption must fall by 10 % by 2020 and by 25 % by 2050, compared to 2008; in parallel, the heat demand in buildings has to be reduced by 20 % by 2020. Moreover, renewable energies should cover 18 % of gross final energy consumption by 2020, 20 % by 2030, 45 % by 2040 and 60 % by 2050. Lastly, renewable energies should have a share of at least 35 % in gross electricity consumption by 2020, 50 % by 2030, 65 % by 2040 and 80 % by 2050 ((International Energy Agency 2013), pp. 64).

Last but not least, the second National Energy Efficiency Action Plan (NEEAP) published by the German government in 2011 includes a target on improving energy efficiency by 9 % between 2007 and 2016, resulting in an energy saving goal of 748 PJ by 2016, most of the energy savings will be achieved in the residential sector ((International Energy Agency 2013), pp. 40).

1.3.1 Electricity & Heat

As already stated, a huge effort is going on in Germany to phase out nuclear power within 2022. In *Table 10* a breakdown scheme showing the scheduled phasing out of the different reactors is shown.

Table 10 - Present & Future Status of German Nuclear Power Plants, ((International Energy Agency 2013), pp. 172).

Nuclear Power Plant	Construction Year	Max. Output Capacity (MW)	Shut-off date
Biblis A	*1975*	*1167*	*2011*
Neckarwestheim 1	*1976*	*785*	*2011*
Biblis B	*1977*	*1240*	*2011*
Brunsbüttel	*1977*	*771*	*2011*
Isar 1	*1979*	*878*	*2011*
Unterweser	*1979*	*1345*	*2011*
Philippsburg 1	*1980*	*890*	*2011*
Krümmel	*1984*	*1346*	*2011*
Grafenrheinfeld	*1982*	*1275*	*2015*
Gundremmingen B	*1984*	*1284*	*2017*
Philippsburg 2	*1985*	*1402*	*2019*
Gundremmingen C	*1985*	*1288*	*2021*
Grohnde	*1985*	*1360*	*2021*
Brokdorf	*1986*	*1410*	*2021*
Isar 2	*1988*	*1410*	*2022*
Emsland	*1988*	*1329*	*2022*
Neckarwestheim 2	*1989*	*1310*	*2022*

The role of renewable energies in the future German energy system will be central, providing 58 % of the total electricity in 2030, where 30.6 % from wind power. There is a big expectation in renewable energies exploitation: wind power is expected to triple over the next 19 years, while electricity generation from solar is expected to double. In addition, following the IEA review, electricity production from hydropower will grow by 35.8 % accounting for 5.2 % of total generation. The same it can be stated for the use of biofuels, growing by 39.1 % to reach 13.3 % of the total ((International Energy Agency 2013), pp. 135). Moreover, the federal government has established a target to increase the share of CHP to 25 % by 2020 respect to the present situation (16 %) ((International Energy Agency 2013), pp. 157).

Following the "Fjernvarmeanalyse - bilagsrapport" report by EA, the total available local bioenergy resources in Germany for electricity and district heating generation is assumed to be 512 PJ; in *Table 11* a breakdown of this source in its different parts is presented.

Table 11 - Available Local Bioenergy Resources in Germany for Electricity and District Heating Generation, ((Energy Analyses 2014), pp. 70).

PJ	Wood & Wood Pellets	Biogas	Straw	Wood Waste	Total
Germany	236	134	142	-	512

The net electricity demand forecasted by EA is shown in *Figure 7* for the analysed period.

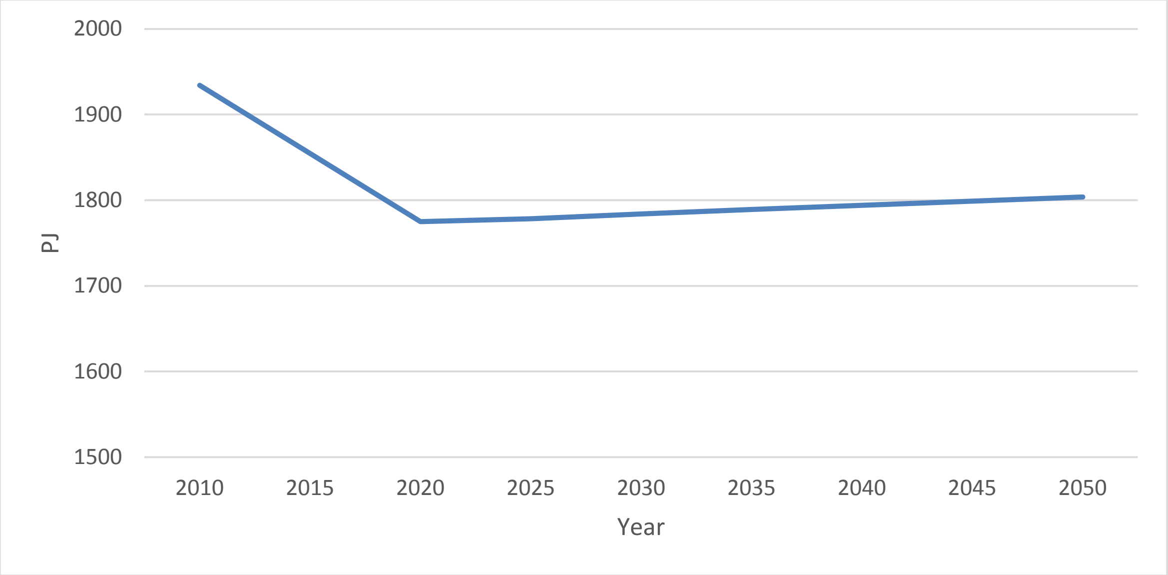

Figure 7 - Net Electricity Demand, ((Energy Analyses 2014), pp. 17).

Lastly, *Figure 8* shows the net heat demand in the German DH sector and its projection through the analysed period. Again, a decreasing trend is shown; in light of what has been assumed for the other countries, this tendency can be traced back to assumptions related to strong energy savings improvements in the residential sector as it is supported by the Energy Concept.

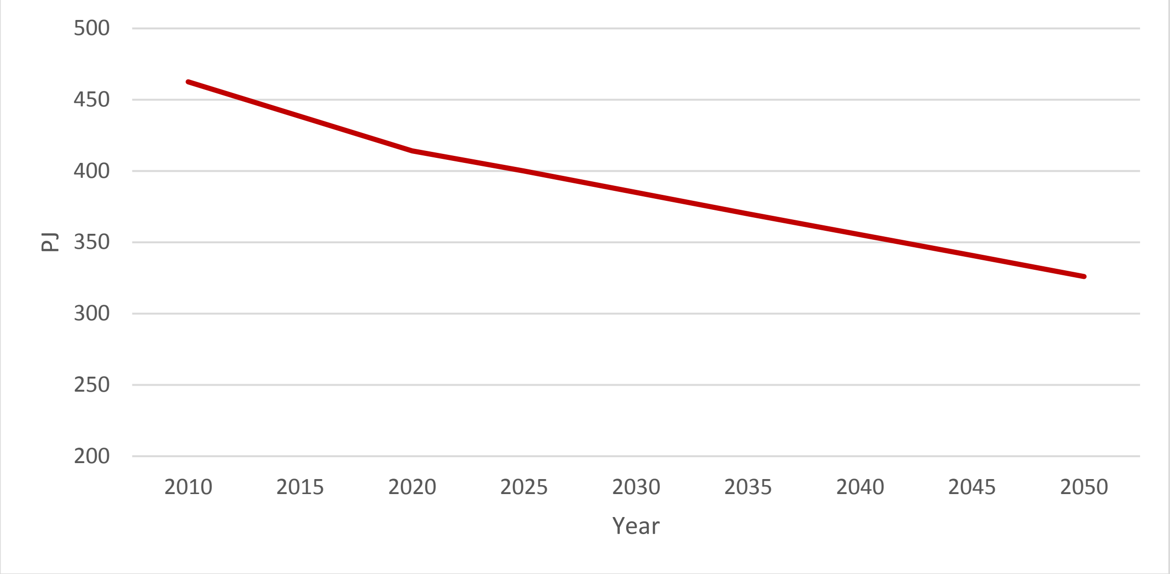

Figure 8 - Net District Heating Demand, (Energy Analyses 2014), pp. 18).

2. Fuel Prices

In this section, the fuel prices used for the project are presented.

2.1 Fossil Fuel Prices

Fossil fuel price projections, particularly for hard coal, crude oil and natural gas, are taken from the "Nordic Energy Technology Perspectives" report ((Norden & International Energy Agency 2013), Annex B, pp 161). The fuel prices used are referring to the CNS scenarios, which in turn refer to the 2DS scenario by the IEA ((International Energy Agency 2012), Annex A, pp. 639). A basic assumption on the price projections is that in the 2DS scenario there is a low demand for fossil fuels due to strict policies to reduce CO_2 emissions. As a result, the oil price for instance is kept below 100 United States Dollars (USD) per barrel throughout the whole considered period, showing even a drop in price during the last decades before 2050 ((Norden & International Energy Agency 2013), Annex B, pp. 161). In *Figure 9*, prices for fossil fuels are presented for the whole period analysed.

It is worth to state that prices for light oil and fuel oil were projected assuming the same future trend as for crude oil. It was assumed that the difference in prices between these petroleum products and their primary source would be the same through the years; data related to present light and fuel oil prices (2015) were obtained from the "Forudsætninger for Samfundsøkonomiske Analyser på Energiområdet" report ((Danish Energy Agency 2014b), pp. 11).

Considering other minor fuels as lignite, peat and orimulsion, price projections were obtained assuming the same future trend of hard coal but with different magnitude in terms of prices; precisely, lignite was assumed to have 50% of hard coal price, while peat and Orimulsion 92%.

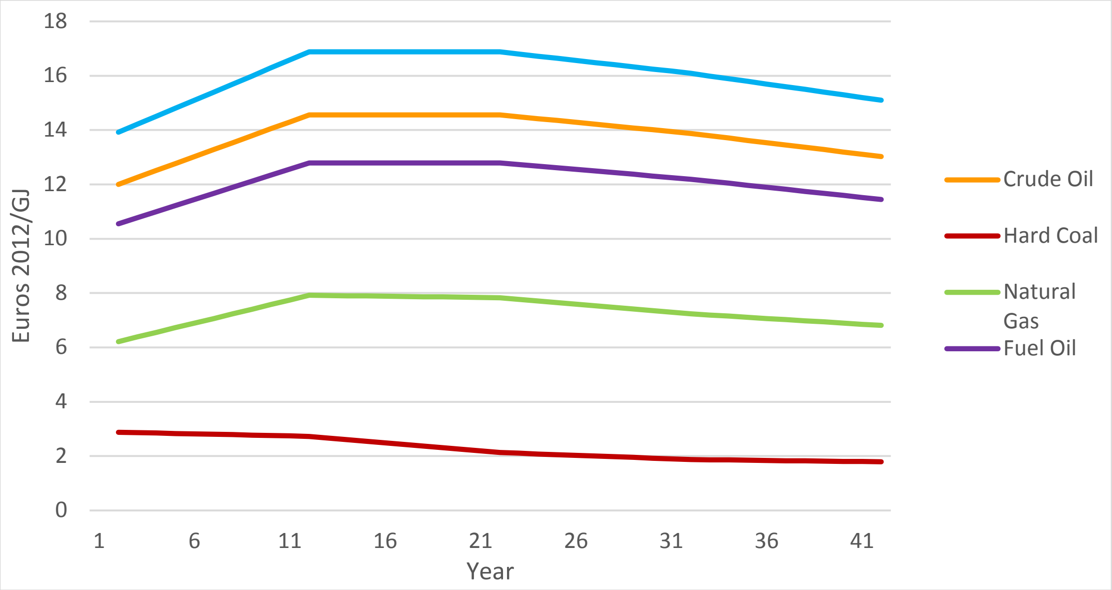

Figure 9 - Fossil Fuels Prices Projections, ((Norden & International Energy Agency 2013), Annex B),((Danish Energy Agency 2014b), pp. 11).

2.2 Biomass Prices

The main source used for biomass price projections is the report “Analysis of Biomass Prices” by Ea. This study provides a deep analysis of price projections for solid biomass fuels, focussing on the period from 2012 to 2050. A basic assumption on which the analysis is built is to follow regional and global demand for biomass described in the New Policy scenario in the IEA publication World Energy Outlook 2012. Moreover, it is assumed that the global trade of biomass fuels will intensify in the future ((Energy Analyses 2013), pp. 12). The mentioned study focuses on providing Cost, Insurance and Freight (CIF) prices for Denmark for straw, wood chips and wood pellets. With respect to this, it was assumed, within the present project, that these prices were also representative for the other countries studied: Finland, Norway, Sweden and Germany. This is a strong simplification, since, e.g., transportation costs are related to the importing country. Moreover, CIF prices are theoretically not representative of local resources, for example local straw in Denmark ((Energy Analyses 2013), pp.16), in this project, for simplicity reasons it is assumed that they are.

In the first part of the analysis carried out by Ea, an eight-scenario study was carried out to deepen how different factors can interact and affect biomass prices. Different assumptions involving future climate policy, diet trend and crop yield were analysed, finding that they represent the predominant factors on future price for biomass ((Energy Analyses 2013), pp. 79). Afterward, in order to get CIF prices for Denmark, processing and transport costs were added. In *Figure 10* CIF prices for solid biomass fuels are presented. The base price trend best embraces, through its assumptions, the New Policies Scenario in the IEA’s World Energy Outlook (WEO) ((Energy Analyses 2013), pp. 80), while the high and low profiles are obtained following different assumptions on future climate policy, diet trend, crop yield, transport costs whose results most differ from the base one.

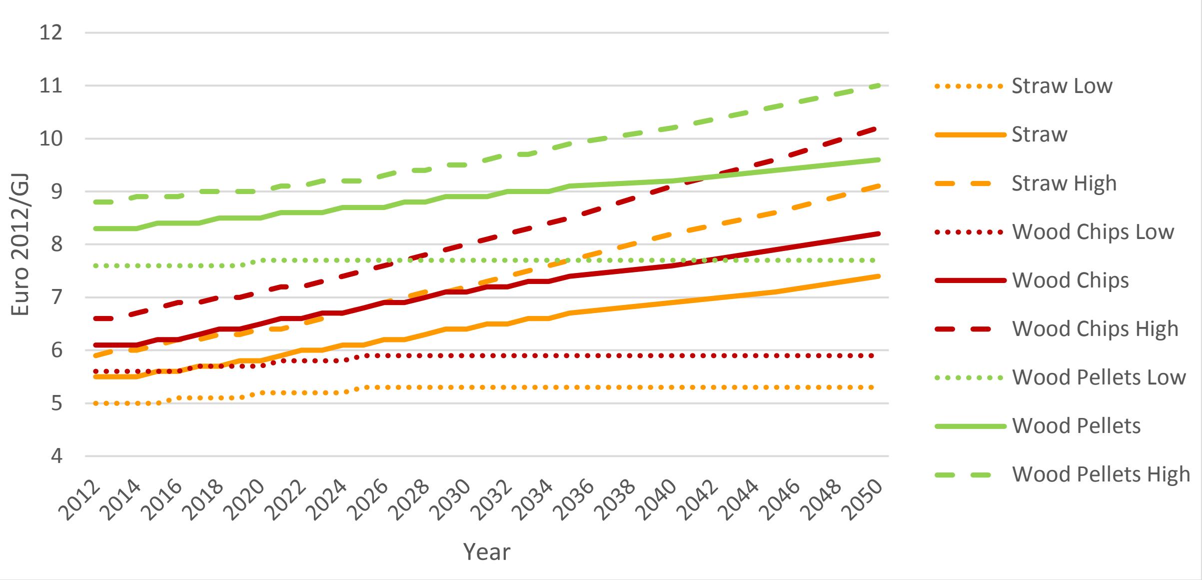

Figure 10 - Solid Biomass Fuel Prices, ((Energy Analyses 2013), pp. 96).

As far as regarding future prices for biodiesel and biogas, the main reference used is the report “Technology Data for Advanced Bioenergy Fuels” by DEA. In the case of biodiesel, it was assumed that the main technology involved in the production will be a second generation Biomass to Liquid (BTL) technology using straw as raw material. Today price is assumed equivalent to the marginal cost at the bio refinery gate, while future projections were obtained applying the same trend of straw taken from ((Energy Analyses 2013), pp. 96).

In the case of biogas, the production technology is assumed anaerobic digestion of 95 % manure and 5 % straw. Again, the marginal production cost is assumed equal as today price, while projections were obtained assuming the same trend of straw. Lastly, fuel cost of upgraded biogas were simply obtained adding the upgrading cost to the biogas price, the process involved is a water scrubbing process whose economic features are taken from ((Energinet & Danish Energy Agency 2014), pp. 206).

Fuel prices for fluid biomass fuels (liquid and gaseous) are shown in *Figure 11.*

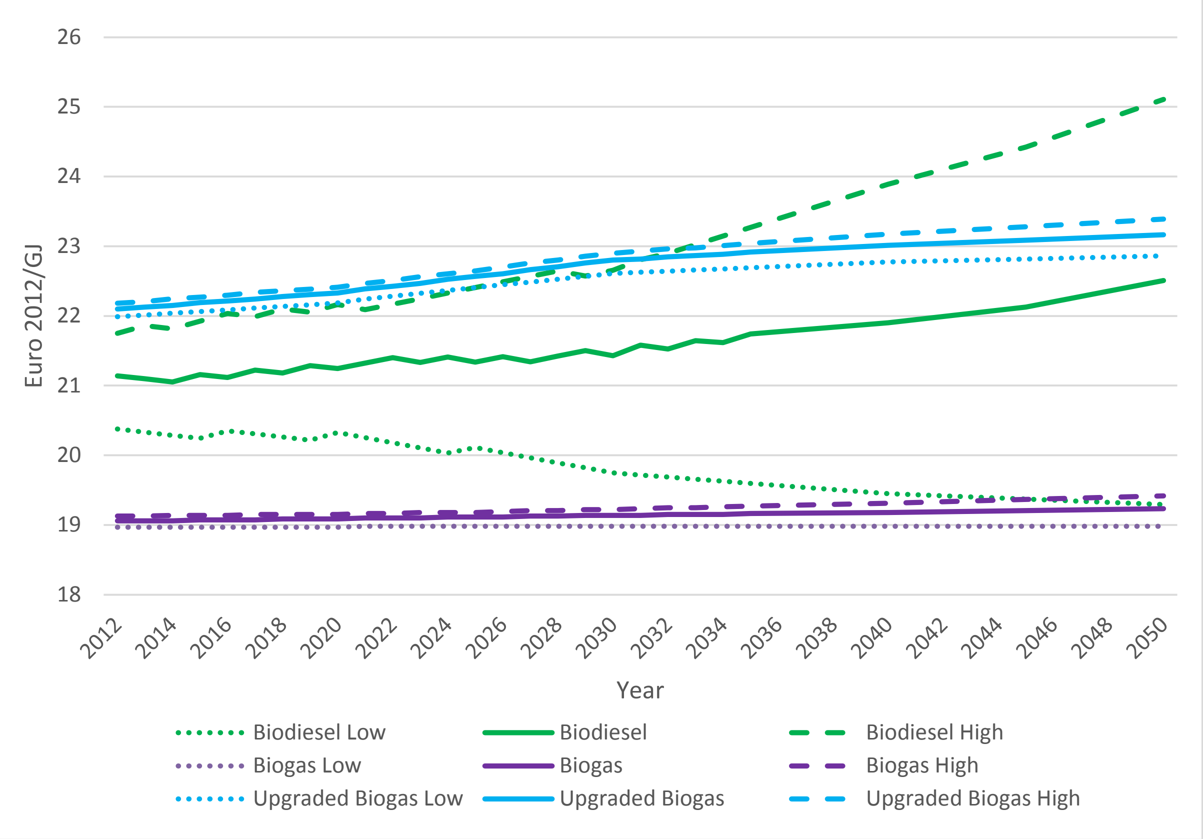

Figure 11 - Fluid Biomass Fuel Prices.

In this project, only the low price trend is implemented in the model, while the others are included as a base on which to build future sensitivity analysis on fuels prices.

3. Technology Data and Transmission Capacity

In this section the technology data and transmission capacities used for the analyses are described.

3.1 Technology Data

The main source used as reference for future technological data such as efficiency and costs, is the "Fjernvarmeanalyse - bilagsrapport" report by Ea, which in turn refers to the "Technology Data for Energy Plants" report by DEA and Energinet. Moreover, when new data were available in the updated version of (Energinet & Danish Energy Agency 2012) published in January 2014 (Energinet & Danish Energy Agency 2014) they were implemented in the model.

Technological and economic data related to power plants used in the model can be found in *Table A1* in the appendix.

3.2 Transmission Capacity

A crucial point in modelling future energy scenarios is the transmission system. Power interconnections are especially relevant when analysing future power systems rich in renewable energies that could potentially introduce a large extent of variability in energy generation as in the case of wind power. An appropriate transmission system can smoothen fluctuations in balancing the electricity demand thereby avoiding inefficiency in the dispatch as for example wind curtailment.

Capacity of the transmissions lines is exogeneously modelled, considering the current existing and planned capacity until 2025 (Energinet 2013) (Energy Analyses 2014). No further investments in expanding the transmissions lines is assumed.

4. Modelling the Scenarios in Balmorel

In order to model future energy scenarios in an optimization software as Balmorel[1], it is necessary to embrace the same assumptions on which the selected foresights are based such as, for example, future projections of fuel prices or expansion of the transmission lines. This sometimes is not enough to get the same future vision of the original scenarios, because of many reasons such as, for example, the utilization of a different software which emphasizes different features in the power system, or the choice of different boundary conditions imposed by the research question that is embodied by the study which usually is different than the original one.

Therefore, the user can implement different constraints in the software in order to best represent the scenarios that he wants to replicate. These constraints can be of diverse nature, e.g., a forced use of a specific fuel whose consumption would not be achieved otherwise, or a maximum cap on the installed capacity allowed for a specific technology particularly favourable. It is worth to say that, the use of constraints in an optimization model represents a double edged sword, meaning that a closer vision to the original scenarios can be gotten through the use of such measures at the expense of the quality of the optimal solution that could be obtained through the application of only the base assumptions. In other words, the more constraints the software has forced to respect, the less freedom it has choosing the optimal result, resulting in a sub-optimal solution compared to a situation where all the variables involved were free.

Moreover, within a perspective such as the one of this study, where the identification of marginal energy technologies is crucial due to the nature of the research question, the use of constraints should be kept even more limited as the constraints determine which marginals may be achieved. Details related to the implementation of constraints into the Balmorel tool are presented in the following paragraph in relation to the time scope analysed: 2035 and 2050.

4.1 Constraints

The fuels and the technologies modelled inside this project have already been presented in the previous sections. Some of them were limited or constrained in terms of installed capacity or fuel use. The implementation of such constraints differs depending by the country and the scenario analysed. The few assumptions valid for all the countries and all the scenarios are that the consumption of peat, lignite and shale is forbidden. Moreover, concerning combustible waste, no liberalization of the market was assumed, and hence the model was forced to incinerate the full amount within the original country. Available waste from incineration in Denmark is estimated according to the prognosis made with the econometric tool FRIDA (Andersen & Larsen 2012), while in the case of the other countries projections were taken from (Energy Analyses 2014).

Capacities of nuclear and hydropower plants are exogeneously fixed in the model, according to current and planned installed capacities. No further investments in these technologies is considered.

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[1] For a full documentation of the Balmorel model please refer to the homepage: www.balmorel.com

It is important to note that individual heating was not modelled for any countries, the only characteristic taken into account from this sector, was the electricity consumption due to heat pumps in the case of Denmark, whose consumption was added to the overall electricity demand.

4.1.1 Denmark

Considering the Danish case the main constraint involving both the scenarios: Wind and Bio + is the total exclusion of fossil fuels for heat and electricity generation. Fuel oil, light oil, coal and natural gas technologies are excluded from the available fleet, with or without carbon capture storage.

As already stated in the previous sections, the available amount of biomass for the electricity and the heat sector in the future were taken from (Energy Analyses 2014) and used as maximum consumption bounds in Balmorel for not traded fuels as wood chips, wood pellets and straw. Moreover, such bounds were adjusted in order to better represent the DEA scenarios analysed. Particularly, the amount of available straw were reduced in order to emulate DEA assumptions related to the production of liquid bio fuels, since a portion of the local straw is used to produce bio-diesel. The same was carried out for biogas, whose potential was adjusted in order to be coherent with assumptions in the transport sector where a certain portion of it is used to supply the energy transport demand. Lastly, the final available amount of biogas calculated was forced to be used in Balmorel since it is considered a waste and manure treatment option. Furthermore, no constraints were put on traded biomass fuels such as wood pellets.

Concerning photovoltaic and solar thermal technologies, Balmorel was forced to install a certain amount of capacity each year depending on the scenarios. These data were directly obtained from (Danish Energy Agency 2014a). For the wind power case, a cap was put on the maximum electricity produced yearly by this technology. These bounds equal the total electricity produced from wind power in each of the scenario from DEA.

Lastly, as already stated in the previous section, surplus heat produced by bio-refineries, hydrogen factories and so on was taken into account when supplying the heat to balance the heat demand in the district heating. These data were also taken from (Danish Energy Agency 2014a).

Geographical scope in Denmark

Denmark is administratively divided into 98 municipalities and has 460 district heating networks (Fjernvarmens Informationsfond, 2011). Due to the large number of district heating networks in the country, for this study they are aggregated into two categories, urban and rural, hereinafter called Areas, which supply to densely populated areas in urban communities and to smaller district heating networks in rural locations. In order to take into account the different size of urban district heating networks, this category is further divided into four, depending on the total district heating demand: large, medium-large, medium-small and small urban Areas.

Denmark is also divided into two Regions, as there are two separated electricity transmission systems (connected through the Great Belt with limited transmission capacity) of which the eastern one is synchronous with Nordic power grid (in this study Norway, Sweden and Finland are included) and the western one with the grid of continental Europe (Germany included). As the electricity and heat markets are related, this division is maintained in the study.

The different Areas might integrate several existing district heating grids. Each municipality might have some rural and urban district heating networks. The urban district heating network will be allocated to an urban Area large, medium-large, medium-small and small, depending on its size within a Region. All the district heating Areas, which fall under the same category in a Region are aggregated together, and they will have the possibility to invest in similar plants.

Therefore, the existing 460 district heating networks are in the Balmorel model used here aggregated into ten Areas: large, medium-large, medium-small and small urban and rural in East and West Denmark (Regions). This division is used, e.g. to limit the investment in large plants to large district heating urban Areas, to assume that biogas can only be used in rural areas, etc.

4.1.2 Norway, Sweden and Finland

Considering the fossil fuels (fuel oil, light oil, coal and natural gas), a maximum cap was put on their consumptions based on the values extracted from the CNES and CNBS scenarios from (Norden & International Energy Agency 2013), the same was done for the carbon capture storage technologies using the same fuel.

As already stated, the available amount of biomass for the electricity and the heat sector in the future were taken from (Energy Analyses 2014) and used as maximum consumption bounds in Balmorel for not traded fuels such as wood chips, wood pellets and straw, while no constraints were put on traded biomass fuels such as wood pellets.

Concerning photovoltaic technologies, Balmorel was forced to install a certain amount of capacity each year depending by the scenarios. These data were directly obtained from (Norden & International Energy Agency 2013), while solar thermal technologies were not constrained because of a lack in the available data. Moreover, wind power was not constrained for Norway, Sweden and Finland.

4.1.3 Germany

Concerning fossil fuels, a maximum cap on the allowed fuel use was implemented in Balmorel. These values were obtained through a proportion between the final fuel consumption taken from ((European Commission 2013), pp. 110 - 111) and the relative electricity demand assumed in the same scenario, with the electricity demand assumed in this project. The same was carried out for carbon capture storage fossil fuels technologies.

As already stated, the available amount of biomass for the electricity and the heat sector in the future were taken from (Energy Analyses 2014) and used as maximum consumption bounds in Balmorel for not traded fuels as wood chips, wood pellets and straw, while no constraints were put on traded biomass fuels as wood pellets.

Concerning photovoltaic technologies, Balmorel was forced to install a certain amount of capacity depending by the year, data were calculated as in the fossil fuels case from (European Commission 2013), while solar thermal technologies were not constrained because of a lack in the available data. In the case of wind power, a cap was put on the maximum allowed electricity produced yearly by this technology. This bound was obtained in the same way of the fossil fuels constraints. Lastly, the nuclear power fleet decommissioning was implemented following data presented in *Table 10.*

5. Global Long-Term Electricity Marginal

For the aim of this study, the identification of a global electricity marginal is needed to quantify environmental impacts due to energy consumption, which takes place out of the defined modelled geographical scope for example in recycling or virgin production plants whose geographical position is unknown. In order to obtain such evaluation, results from the ETP 2012 are used as inputs for a calculation method briefly described hereafter.

Considering a time frame which elapses from now to a certain moment in the future, and considering a "small" change in electricity demand what kind of consequences does it produce in the long term on the energy system structure? In order to address such question without the help of optimization software, some considerations can be carried out to estimate potential energy technologies that may be identified as marginal.

5.1 Methodology

In this section, a calculation example is provided with the aim to exemplify the methodology assumed within this project concerning the identification of global long-term marginal technologies.

Considering a "small" change in the electricity demand due to a certain decision defined within a consequential LCA perspective, the consequences of such a change affect the so-called marginal technologies. The main assumption adopted is that the change in electricity demand is small in comparison with the production in the society; the change is analysed in isolation under a ceteris paribus condition ((Weidema, Frees, & Nielsen, 1999), pp. 48). Moreover, the focus is on the long-term, which is defined as a period long enough that change in demand affects replacement of capital investment.

Moreover, the analysed process, which involves an electricity consumption, has no time preference, in the meaning that such consumption does not differ between peak and off-peak hours demand. This allows us to say that there are no sub-markets particularly involved, which can make the purchase of electricity from a specific energy source preferable.

The methodology followed here is the one developed by Jannick H Schmidt et al. in "Inventory of Country Specific Electricity in LCA". As it is described in ((Schmidt, Merciai, Thrane, & Dalgaard, 2011), pp. 16-17): "…the long-term marginal electricity suppliers in a country are defined as the national mix of planned/predicted new installation during a specified period of time.". Those technologies that face a decrease trend in the future are considered to be phased out or to be uncompetitive in the future market. Moreover, some of the selected technologies can be excluded from the marginal because they may be affected by some constraints.

This approach is also in line with Weidema et al., who argues that assuming that the global production volume of electricity is expected to increase in the future ((International Energy Agency, 2012), pp. 384), the marginal technology should be identified among the most preferred technology, which are represented by unconstrained technology with the lowest, long-term production costs ((Weidema et al., 1999), pp. 52).

In other words, the main idea is to analyse the global electricity production by energy source projected by IEA, looking for those technologies that will increase their share in the electricity market because of the expected increase in the electricity demand and the expected phasing out of specific fuels. The constraints that can limit the potential of a specific technology to compete in the future electricity market can be of various nature: natural constraints as for example the future availability of primary sources, as in the case of some renewables like hydro power, that can limit capacity expansion to be stacked to the actual level. Moreover, political constraints can influence the development of a specific energy source, as in the case of nuclear power. Some countries, e.g. Germany, plans a reduction in nuclear capacity within the next decade (International Energy Agency, 2013). Considering this perspective it can be stated that even if an increase in the global nuclear power production is predicted to happen this can be assumed to be mainly driven by political decisions rather than small changes in the market volume ((Weidema et al., 1999), pp. 53). Lastly, fossil fuels technologies are not generally considered constrained, but may be constrained in some areas by emissions quotas or carbon taxes.

In light of this, marginal technologies can be identified comparing the present electricity fuel share with the future one. In this example, the period chosen is between 2009 and 2050, while the future scenario selected is the 2 degree scenario (2DS) by IEA.

In *Table 13,* the global electricity production by energy source is shown for the two time extremes. Moreover, the variation in electricity production for each source which takes place within the analysed temporal frame is presented. A negative value represents a reduction in fuel share and vice versa.

It is assumed here that the resulted changes in fuel share are obtained through economic considerations, which includes future environmental policies, which can have a direct effect on the competitiveness of the analysed technologies. In light of this, a small change in electricity demand will affect only those technologies that increase their fuel share in the future, which are assumed to be the most preferred ones since their expected increase is the outcome of techno-economic analysis complemented with constraint considerations (ETP 2012).

Considering an increase in demand, this will cause an increase of electricity production of such technologies. The logic is equivalent in the opposite case from a higher electricity demand to a lower electricity demand, the affected technologies are the same but their capacities are affected in the opposite way ((Weidema et al., 1999), pp. 49).

Those technologies that face a reduction in fuel share as coal, natural gas and oil, cannot be considered marginal. In the case of nuclear power, as already stated, even if an increase in electricity production is expected in the future, some countries as Germany are planning to phase out all their reactors because of the continuous decrease in the security confidence of such technology even more pronounced after the events of Fukushima in 2011. This is a clear evidence that, even if an increase in nuclear power is expected in the future (see *Table 13*), it will not be driven by small changes in demand, but mainly by political decisions resulting in a planned increase. This is the reason why such technology is excluded from the mix.

Table 13 - Gross Electricity Generation ((International Energy Agency, 2012), pp. 384).

Gross Electricity Generation (TWh) - Global Case			
Fuel	**2009**	**2DS, 2050**	**Change**
Coal	*8118*	*629*	*-7489*
Coal CCS	-	*4303*	*4303*
Nat. Gas	*4299*	*3190*	*-1109*
Nat. Gas CCS	-	*1588*	*1588*
Oil	*1027*	*120*	*-907*
Biomass & Waste	*288*	*2750*	*2462*
Biomass CCS	-	*338*	*338*
Nuclear	*2697*	*7918*	*5221*
Hydro	*3252*	*7094*	*3842*
PV	*20*	*2655*	*2635*
CSP	*1*	*3333*	*3332*
Wind, onshore	*270*	*4197*	*3927*
Wind, offshore	*3*	*1948*	*1945*
Geothermal	*67*	*981*	*914*
Ocean	*1*	*521*	*520*
Total	*20043*	*41565*	*21522*

In order to quantify the weight that each technology has on the final marginal composition, its contribution can be obtained by comparing the specific increase in production with the total increase attributable to marginal technologies. In *Figure 12,* the electricity marginal composition is shown as percentages. A unitary change in electricity demand will boost or hamper the identified technology capacities to a certain extent determined by the ratios expressed in *Table 14*. A higher percentage in the composition of the marginal share represents a higher degree of competitiveness in the market due to lower future production costs since constrained technologies are excluded at the beginning.

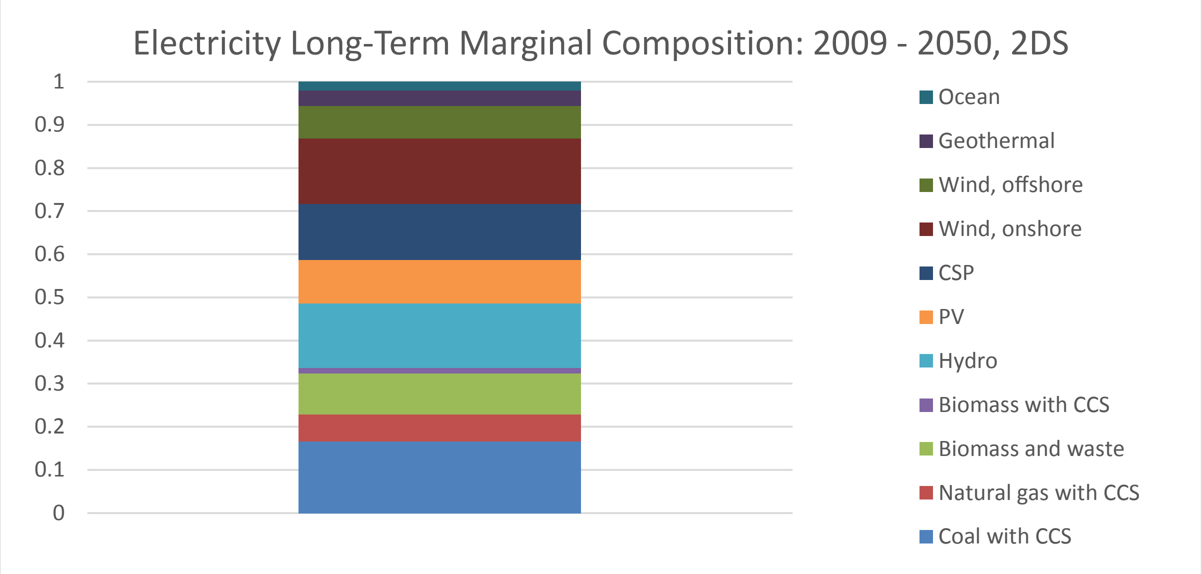

Figure 12 Long term marginal electricity composition 2009-2050, 2DS

Table 14 Long term marginal electricity composition 2009-2050, 2DS

Electricity Marginal Composition: 2009 - 2050, 2DS	
Fuel	**%**
Coal with CCS	*16.7*
Natural Gas with CCS	*6.2*
Biomass & Waste	*9.5*
Biomass with CCS	*1.3*
Hydro	*14.9*
PV	*10.2*
CSP	*12.9*
Wind, onshore	*15.2*
Wind, offshore	*7.5*
Geothermal	*3.5*
Ocean	*2*

In order to calculate the relative emissions due to such marginal composition, it is important to point out that different fuels correspond to different technologies, which in turn have different efficiencies. Therefore, the calculation of the produced/avoided emissions should take this issue into account.

5.2 Results

In this section global electricity marginal are presented for the case study. The data provided should be interpreted as conclusive, with the aim to be used within this project. Three different periods are included: 2009[2] - 2025, 2025 - 2035 and 2035 - 2050, resulting in three different marginal identifications. Moreover, such calculations are carried out for three different scenarios. The 2DS is assumed the base one on from which the official marginal compositions are calculated, while the 4DS and the 6DS are included to provide two other cases on which to base sensitivity analyses. In other words, the 2DS scenario is representative of a global effort targeting a more ambitious environmental goal than the other two scenarios; while the 4DS and the 6DS embody a less optimistic future vision in terms of global warming.

The calculation framework used is the same presented in the previous section, with the only exception that all the technologies identified as marginal are included in the final composition. In other words, no technology was assumed to be constrained. This choice is driven by the will to let the user decide which assumption to adopt in order to exclude a specific technology from the mix. Obviously, such decision leads to a recalculation of the final marginal composition balance.

In order to make the user capable of modifying the final marginal composition, the original data used in the identification are also presented (*Table 16*). The global electricity marginal compositions are shown in *Table 15*.

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[2] Data for 2009 are assumed to be representative for the year 2012, which constitutes the present situation in this project.

Table 15 Global electricity marginal composition

Electricity Marginal Composition Share - Global Case									
Fuel	**6 Degree Scenario**			**4 Degree Scenario**			**2 Degree Scenario**		
	2025	**2035**	**2050**	**2025**	**2035**	**2050**	**2025**	**2035**	**2050**
Coal	*0.445*	*0.449*	*0.554*	*0.224*	*0.051*	*0.050*	-	-	-
Coal CCS	*0.001*	*0.002*	*0.003*	*0.003*	*0.067*	*0.109*	0.051	*0.209*	*0.136*
Natural gas	*0.178*	*0.245*	*0.212*	*0.271*	*0.229*	*0.156*	0.201	-	-
Natural gas CCS	-	-	-	-	*0.002*	*0.007*	0.015	*0.049*	*0.075*
Oil	-	-	-	-	-	-	-	-	-
Biomass and waste	*0.048*	*0.068*	*0.044*	*0.054*	*0.127*	*0.103*	0.080	*0.081*	*0.064*
Biomass CCS	-	-	-	-	*0.003*	*0.012*	0.002	*0.012*	*0.016*
Nuclear	*0.083*	*0.030*	*0.027*	*0.114*	*0.108*	*0.097*	0.177	*0.144*	*0.150*
Hydro	*0.110*	*0.085*	*0.046*	*0.144*	*0.117*	*0.075*	0.183	*0.098*	*0.072*
Solar PV	*0.025*	*0.017*	*0.009*	*0.036*	*0.063*	*0.049*	0.049	*0.093*	*0.095*
Solar CSP	*0.005*	*0.015*	*0.028*	*0.010*	*0.035*	*0.124*	0.021	*0.066*	*0.194*
Wind onshore	*0.085*	*0.057*	*0.040*	*0.121*	*0.136*	*0.129*	0.170	*0.126*	*0.068*
Wind offshore	*0.012*	*0.016*	*0.013*	*0.013*	*0.034*	*0.037*	0.033	*0.090*	*0.056*
Geothermal	*0.007*	*0.011*	*0.016*	*0.010*	*0.020*	*0.036*	0.016	*0.023*	*0.041*
Ocean	-	*0.005*	*0.008*	*0.001*	*0.010*	*0.016*	0.001	*0.008*	*0.034*

Table 16 - Gross Electricity generation ((International Energy Agency, 2012), Scenario Summary)

Gross Electricity Generation (TWh) - Global Case										
Fuel	**2009**	**6 Degree Scenario**			**4 Degree Scenario**			**2 Degree Scenario**		
		2025	**2035**	**2050**	**2025**	**2035**	**2050**	**2025**	**2035**	**2050**
Coal	*8118*	*13787*	*17160*	*22419*	*10637*	*10926*	*11308*	*6868*	*1966*	*629*
Coal CCS	*0*	*14*	*26*	*52*	*30*	*411*	*1245*	*557*	*2570*	*4303*
Natural gas	*4299*	*6567*	*8408*	*10418*	*7346*	*8653*	*9851*	*6483*	*5896*	*3190*
Natural gas CCS	*0*	*0*	*0*	*0*	*3*	*17*	*70*	*166*	*636*	*1588*
Oil	*1027*	*698*	*607*	*528*	*613*	*525*	*453*	*490*	*349*	*120*
Biomass and waste	*288*	*904*	*1416*	*1833*	*894*	*1616*	*2407*	*1155*	*1940*	*2750*
Biomass CCS	*0*	*0*	*0*	*0*	*0*	*15*	*107*	*23*	*136*	*338*
Nuclear	*2697*	*3757*	*3982*	*4236*	*3981*	*4595*	*5337*	*4623*	*6012*	*7918*
Hydro	*3252*	*4659*	*5298*	*5738*	*4877*	*5547*	*6121*	*5236*	*6183*	*7094*
Solar PV	*20*	*338*	*468*	*556*	*421*	*780*	*1153*	*552*	*1451*	*2655*
Solar CSP	*1*	*59*	*174*	*439*	*115*	*312*	*1264*	*229*	*867*	*3333*
Wind onshore	*270*	*1357*	*1785*	*2163*	*1629*	*2407*	*3398*	*2117*	*3335*	*4197*
Wind offshore	*3*	*152*	*268*	*395*	*151*	*343*	*625*	*363*	*1232*	*1948*
Geothermal	*67*	*159*	*242*	*390*	*180*	*292*	*567*	*237*	*461*	*981*
Ocean	*1*	*4*	*39*	*117*	*9*	*63*	*182*	*11*	*88*	*521*

It is worth to say that the identification of marginal technologies has been carried out for the different years calculating differences in the electricity generation mix between the extremes of the analysed period. In other words, the marginal technologies for 2050 are obtained assuming as a starting point the electricity technology share of 2035. This has been pointed out here, because in the methodology section the explanatory calculation for 2050 are based on the electricity technology shares of the years 2009 and 2050, while for the aim of this study intermediate steps are needed in order to be coherent within the overall approach.

Although the marginal affected technologies will in real life become a mixture of technologies, for some life cycle assessments, an approach is used where one single marginal is applied. In *Table 17,* a single marginal is identified for each of the selected period. This identification is obtained selecting the technology that faces the higher increase in gross electricity generation in the selected period. In other words, the identified marginal is, neither more nor less, the heavier contribution in the marginal composition of *Table 15* for the selected period*.*

Table 17 Global single electricity marginal identification

Electricity Marginal Identification (Single) - Global Case			
	6 Degree Scenario	**4 Degree Scenario**	**2 Degree Scenario**
2009 - 2025	*Coal*	*Natural Gas*	*Natural Gas*
2025 - 2035	*Coal*	*Natural Gas*	*Coal w CCS*
2035 - 2050	*Coal*	*Natural Gas*	*Solar CSP*

Since the calculations carried out so far cannot be accurate, for the nature of the addressed problem, the identification of the specific technologies affected is problematic. However, referring to ((International Energy Agency, 2012), Ch. 11), a continuous deployment of ultra-supercritical and supercritical plants in coal-based generation and natural gas combined-cycle plants will take place in the future scenarios. Co-generation plants capacity is supposed to increase in all the future scenarios but to a different extent.

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Appendix B Technology Database

In *Table A1* data related to power plants implemented in this study are shown. The main reference used is (Energy Analyses 2014), which in turn refers to (Energinet & Danish Energy Agency 2012). Moreover, for few technologies other data were assumed based on (Norden & International Energy Agency 2013) and the updated version of "Technology Data for Energy Plants" (Energinet & Danish Energy Agency 2014), where this was the case * or ** were added in the comments column. For wind power, data are taken from (Energy Analyses 2014), a cross check was carried out comparing them with the range provided by the NETP database, this resulted in a satisfactory match. Costs are expressed in Euros 1990. The Cb coefficient (back-pressure coefficient) is defined as the maximum power generating capacity in back-pressure mode divided by the maximum heat capacity. The Cv-value for an extraction steam turbine is defined as the loss of electricity production, when the heat production is increased one unit at constant fuel input.

Table A1 - Technology Database

Technology	Generation Type	Fuel Type	Period	Cv-Value	Cb-Value	Fuel Eff.	Invest. Cost	Var. O&M	Annual O&M	Life Time	Size of Unit Type	Comments
							Mil. € /MW	*€ /MWh*	*1000 € /MW*	*Years*	*MW*	
Steam Turbine	Condensing	Coal	2010-2019	-	-	0.46	1.2458	1.2294	34.9248	40	550	
			2020-2029	-	-	0.485	1.2392	1.3113	37.6114	40		
			2030-2049	-	-	0.52	1.2154	1.3113	37.6114	40		
			2050	-	-	0.535	1.1540	1.3113	37.6114	40		
		Coal CCS	2030-2050	-	-	0.43	1.5266	10.0243	39.6911	40	620	**
		Natural	2010-	-	-	0.465	0.8548	0.4917	23.2018	30	400	

		Gas	2019									
			2020-2050	-	-	0.465	0.7934	0.4917	23.2018	30		
		Wood	2010-2019	-	-	0.448	1.3007	2.0489	14.7881	30	55	
			2019-2029	-	-	0.465	1.2581	2.0489	14.7881	30		
			2030	-	-	0.485	1.2089	2.0489	14.7881	30		
		Wood Pellets	2010-2019	-	-	0.46	1.2458	1.2294	34.9248	40	325	
			2020-2029	-	-	0.485	1.2392	1.3113	37.6114	40		
			2030-2049	-	-	0.52	1.2154	1.3113	37.6114	40		
			2050	-	-	0.535	1.1540	1.3113	37.6114	40		
		Wood Pellets CCS	2030-2050	-	-	0.43	1.5266	10.0243	39.6911	40	620	**
Steam Turbine	Extraction	Coal	2010-2019	0.15	0.75	0.46	1.2458	1.2294	34.9248	40	550	
			2020-2029	0.15	0.84	0.485	1.2392	1.3113	37.6114	40		
			2030-2049	0.15	1.01	0.52	1.2154	1.3113	37.6114	40		
			2050	0.15	1.01	0.535	1.1540	1.3113	37.6114	40		
	Extraction	Coal CCS	2030-2050	0.15	1.01	0.43	1.5266	10.0243	39.6911	40	620	**
	Extraction	Natural Gas	2010-2019	0.17	0.7	0.465	0.8548	0.4917	23.2018	30	400	
			2020-	0.17	0.7	0.465	0.7934	0.4917	23.2018	30		

			2050									
	Extraction	Wood	2010-2019	0.15	0.5	0.448	1.3007	2.0489	14.7881	30	55	
			2019-2029	0.15	0.55	0.465	1.2581	2.0489	14.7881	30		
			2030	0.15	0.61	0.485	1.2089	2.0489	14.7881	30		
	Extraction	Wood Pellets	2010-2019	0.15	0.75	0.46	1.2458	1.2294	34.9248	40	325	
			2020-2029	0.15	0.84	0.485	1.2392	1.3113	37.6114	40		
			2030-2049	0.15	1.01	0.52	1.2154	1.3113	37.6114	40		
			2050	0.15	1.01	0.535	1.1540	1.3113	37.6114	40		
	Extraction	Wood Pellets CCS	2030-2050	0.15	1.01	0.43	1.5266	10.0243	39.6911	40	620	**
Steam Turbine	Back Press.	Straw	2010	1	0.403	1.01	2.4423	0.5737	11.7230	25	30	
	Back Press.	Straw	2010-2019	1	0.49	0.9	3.9684	3.4422	62.8892	20	30	
			2020	1	0.49	0.9	3.6635	1.3113	56.1729	20		
	Back Press.	Wood	2010	1	0.377	1.06	2.4423	0.6557	17.7067	30	30	
	Back Press.	Wood	2010-2019	1	0.3	1.03	3.9684	1.8850	45.7931	20	30	
			2020	1	0.3	1.03	3.6635	1.8850	45.7931	20		
	Back Press.	Wood	2010-2019	1	0.5	1.03	1.6121	0.6557	14.7875	30	55	
			2019-2029	1	0.55	1.03	1.5261	0.7376	14.7875	30		
			2030	1	0.61	1.03	1.4351	0.8196	14.7875	30		

	Back Press.	Wood Waste	2010-2019	1	0.3	1.03	3.9684	1.8850	45.7931	20	30	
			2020	1	0.3	1.03	3.6635	1.8850	45.7931	20		
	Back Press.	Wood Waste	2010	1	0.377	1.06	2.4423	0.6557	17.7067	30	30	
Gas Turbine	Condensing	Biogas	2010-2019	-	-	0.395	0.3844	0.8196	4.9823	25	82.5	
			2020	-	-	0.46	0.3295	0.9015	5.2937	25		
	Condensing	Biogas Upgrad.	2010-2019	-	-	0.395	0.3844	0.8196	4.9823	25	82.5	
			2020	-	-	0.46	0.3295	0.9015	5.2937	25		
	Condensing	Natural Gas	2010-2019	-	-	0.395	0.3844	0.8196	4.9823	25	82.5	
			2020	-	-	0.46	0.3295	0.9015	5.2937	25		
Gas Turbine	Extraction	Biogas	2010-2019	-0.01	0.94	0.3911	0.4270	0.9835	5.8615	25	82.5	
			2020	-0.01	1.07	0.4554	0.3664	1.0655	6.2279	25		
	Extraction	Biogas Upgrad.	2010-2019	-0.01	0.94	0.3911	0.4270	0.9835	5.8615	25	82.5	
			2020	-0.01	1.07	0.4554	0.3664	1.0655	6.2279	25		
	Extraction	Natural Gas	2010-2019	-0.01	0.94	0.3911	0.4270	0.9835	5.8615	25	82.5	
			2020	-0.01	1.07	0.4554	0.3664	1.0655	6.2279	25		
Gas Turbine Combined Cycle	Condensing	Biogas	2010-2019	-	-	0.565	0.4778	1.3113	15.5697	25	250	
			2020-2029	-	-	0.6	0.4508	1.3113	15.5697	25		
			2030-2049	-	-	0.615	0.4450	1.3113	15.5697	25		

			2050	-	-	0.615	0.4344	1.3113	15.5697	25		
	Condensing	Biogas Upgrad.	2010-2019	-	-	0.565	0.4778	1.3113	15.5697	25	250	
			2020-2029	-	-	0.6	0.4508	1.3113	15.5697	25		
			2030-2049	-	-	0.615	0.4450	1.3113	15.5697	25		
			2050	-	-	0.615	0.4344	1.3113	15.5697	25		
	Condensing	Natural Gas	2010-2019	-	-	0.56	0.4778	1.3113	15.5697	25	250	
			2020-2029	-	-	0.6	0.4508	1.3113	15.5697	25		
			2030-2049	-	-	0.62	0.4450	1.3113	15.5697	25		
			2050	-	-	0.62	0.4344	1.3113	15.5697	25		
	Condensing	Natural Gas CCS	2030-2050	-	-	0.525	0.7938	4.8306	23.2040	25	620	**
Gas Turbine Combined Cycle	Extraction	Biogas	2010-2019	0.13	1.34	0.565	0.5311	1.5572	18.3172	25	250	
			2020-2029	0.13	1.75	0.6	0.5008	1.5572	18.3172	25		
			2030-2049	0.13	1.75	0.615	0.4942	1.5572	18.3172	25		
			2050	0.13	1.75	0.615	0.4827	1.5572	18.3172	25		
	Extraction	Biogas Upgrad.	2010-2019	0.13	1.34	0.565	0.5311	1.5572	18.3172	25	250	
			2020-2029	0.13	1.75	0.6	0.5008	1.5572	18.3172	25		
			2030-2049	0.13	1.75	0.615	0.4942	1.5572	18.3172	25		

			2050	0.13	1.75	0.615	0.4827	1.5572	18.3172	25		
	Extraction	Natural Gas	2010-2019	0.13	1.34	0.565	0.5311	1.5572	18.3172	25	250	
			2020-2029	0.13	1.75	0.6	0.5008	1.5572	18.3172	25		
			2030-2049	0.13	1.75	0.615	0.4942	1.5572	18.3172	25		
			2050	0.13	1.75	0.615	0.4827	1.5572	18.3172	25		
	Extraction	Natural Gas CCS	2030-2050	0.13	1.75	0.525	0.7938	4.8306	23.2040	25	620	**
Gas Turbine Combined Cycle	Back Pressure	Biogas	2010-2019	1	1.28	0.855	0.8245	0.8196	18.3172	25	55	
			2020	1	1.333	0.91	0.8851	0.9015	18.3172	25		
	Back Pressure	Biogas Upgrad.	2010-2019	1	1.28	0.855	0.8245	0.8196	18.3172	25	55	
			2020	1	1.333	0.91	0.8851	0.9015	18.3172	25		
	Back Pressure	Natural Gas	2010-2019	1	1.28	0.855	0.8245	0.8196	18.3172	25	55	
			2020	1	1.333	0.91	0.8851	0.9015	18.3172	25		
Central-CHP	Extraction	Biogas	2015	-0.01	0.957	0.4455	3.6963	34.3403	16.8518	20	5.5	
	Extraction	Biogas	2010-2019	-0.01	0.833	0.4293	2.2110	10.1979	61.1937	20	5.5	
			2019-2029	-0.01	0.969	0.4596	2.0932	10.1979	61.1937	20		
			2030	-0.01	1.067	0.4798	2.0932	10.1979	61.1937	20		
	Extraction	Biogas Upgrad.	2015	-0.01	0.957	0.4455	1.9670	21.8008	16.8518	20	5.5	
Gas Engine	Extraction	Biogas	2010-2019	-0.01	0.9	0.4356	0.7630	2.7866	16.8518	22.5	5.5	

			2020-2029	-0.01	0.9	0.4604	0.7630	2.7866	16.8518	22.5		
			2030-2049	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
			2050	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
	Extraction	Biogas Upgrad.	2010-2019	-0.01	0.9	0.4356	0.7630	2.7866	16.8518	22.5	5.5	
			2020-2029	-0.01	0.9	0.4604	0.7630	2.7866	16.8518	22.5		
			2030-2049	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
			2050	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
	Extraction	Natural Gas	2010-2019	-0.01	0.9	0.4356	0.7630	2.7866	16.8518	22.5	5.5	
			2020-2029	-0.01	0.9	0.4604	0.7630	2.7866	16.8518	22.5		
			2030-2049	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
			2050	-0.01	0.9	0.4851	0.7630	2.7866	16.8518	22.5		
Geothermal	Condensing	-	2010-2019	-	-	1	3.1087	2.0489	14.4876	40	-	
		-	2020-2029	-	-	1	3.1087	2.0489	14.4876	25		
		-	2030-2050	-	-	1	3.1087	2.0489	14.4876	25		
Nuclear	Condensing	Nuclear	2035	-	-	0.37	1.8995	0.0000	37.9896	50	1000	*
Waste-To-Energy	Back Pressure	Waste	2010-2019	1	0.324	0.98	5.1896	3.7701	246.5562	20	30	
			2020	1	0.366	0.97	5.1896	3.7701	227.5918	20		
Wind	Offshore	-	2010-	-	-	1	2.0278	3.1006	35.3883	20	-	

			2019									
		-	2020-2029	-	-	1	1.5847	2.7604	34.7669	20		
		-	2030-2049	-	-	1	1.5158	2.5903	34.1520	25		
		-	2050	-	-	1	1.3780	2.4072	32.5887	30		
	Far Offshore	-	2020-2029	-	-	1	1.9016	2.7604	34.7669	20	-	
		-	2030-2049	-	-	1	1.8189	2.5903	34.1520	25		
		-	2050	-	-	1	1.6536	2.4072	32.5887	30		
	Near Offshore	-	2020-2029	-	-	1	1.3470	2.7604	34.7669	20	-	
		-	2030-2049	-	-	1	1.2884	2.5903	34.1520	25		
		-	2050	-	-	1	1.1713	2.4072	32.5887	30		
	Onshore	-	2010-2019	-	-	1	0.9158	2.2371	19.1725	20	-	
		-	2020-2029	-	-	1	0.8635	2.0670	19.2510	20		
		-	2030-2049	-	-	1	0.8438	1.9820	19.0417	25		
		-	2050	-	-	1	0.7980	1.8970	18.4988	30		
	Onshore LCI	-	2020-2029	-	-	1	1.0793	2.0670	21.5077	20	-	
		-	2030-2049	-	-	1	1.0548	1.9820	21.2788	25		
		-	2050	-	-	1	0.9975	1.8970	20.6705	30		
Solar	PV	-	2010-2019	-	-	1	1.2212	2.0489	14.9469	30	-	* *Full load*

		-	2020-2029	-	-	1	0.7934	1.6392	11.6497	30		*hours of oper. 816 hrs/y in DK*
		-	2030-2049	-	-	1	0.6712	1.1474	8.3526	30		
		-	2050	-	-	1	0.5491	0.8196	5.6855	30		
Solar	Thermal	-	2010-2019	1	-	1	0.2263	0.3467	0.0000	30	-	** Full load hours of oper. 816 hrs/y in DK*
		-	2020-2029	1	-	1	0.2053	0.3467	0.0000	30		
		-	2030	1	-	1	0.1556	0.3467	0.0000	30		
Hydro	Pumped-Storage	Electr.	Mature Tech.	-	-	0.8	0.0392	0.0001	0.4121	40	-	
		-	Mature Tech.	-	-	-	1.0000	0-9	20.0000	-	-	*No life time is considered-only maintenance*
	Run-of-River	-	Mature Tech.	-	-	-	1.0000	0.0000	20.0000	-	-	
Boiler	Heat-only	Natural Gas	Mature Tech.	1	-	1.01	0.0606	0.4098	1.1295	35	-	
	Heat-only	Straw	Mature Tech.	1	-	1.03	0.4885	1.2294	3.6634	20	-	
	Heat-only	Waste	Mature Tech.	1	-	0.976	0.6901	3.2783	32.3605	20	-	
	Heat-only	Wood	Mature Tech.	1	-	1.08	0.4885	1.6392	4.9457	20	-	
	Heat-only	Wood Pellets	Mature Tech.	1	-	0.95	0.2442	0.8196	2.4728	20	-	
Electric		Electr.		1	-	0.99	0.0459	0.3278	6.7164	20	-	

Boiler												
Heat Pump		Electr.	2010-2019	1	-	2.8	0.4155	0.2459	1.6791	20	-	
			2020-2029	1	-	2.9	0.3844	0.1639	1.1143	20		
			2030-2049	1	-	3	0.3508	0.1639	1.1143	20		
			2050	1	-	3.2	0.3205	0.1639	1.1143	20		
Geothermal Heat Pump			2010-2019	1	-	4.4311	0.9769	1.6392	11.2957	25	-	
			2020	1	-	4.4311	0.9769	1.4752	10.3798	25		
Heat Storage	Seasonal Storage	Heat	2010	-	-	0.95	0.0020	0.0001	0.0000	20	-	
	Long Seasonal Storage	Heat	2010-2029	-	-	0.875	0.0003	0.0001	2.3219	20	-	
	Long Seasonal Storage	Heat	2030-2049	-	-	0.875	0.0003	0.0001	2.2058	20		
	Long Seasonal Storage	Heat	2050	-	-	0.875	0.0003	0.0001	1.9736	20		