BalticBiomass4Value

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Report on Market Outlook and Future Viability of Different Bioenergy Products and Value Chains in the Baltic Sea Region Energy System

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Preface

This report is an output of the implementation of the Group of Activities 2.1 "Analysis of Market Outlook and Future Viability of Different Bioenergy Products and Value Chains in the Baltic Sea Region Energy System" as specified in the latest approved version of the BalticBiomass4Value project application.

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I. Introduction to the BalticBiomass4Value project

The BalticBiomass4Value project brought an opportunity to build the transnational partnership representing eight countries of the Baltic Sea Region (BSR) to support the replacement of fossil fuels with renewable biomass based energy sources and to promote innovative circular bioeconomy production approaches.

The project aims to enhance the capacity of public and private actors within the BSR to produce sustainable bioenergy by utilizing new biomass sources (chiefly, biological waste) for energy production, as well as to use possibilities to utilise bioenergy side streams for higher value bio-based products. Biomass from different sources (agriculture, food and feed industry, forestry, wood industry, municipal waste and sewage sludge, fishery, algae), its logistics, various biomass conversion technologies and value chains will be mapped to identify best practices of bioenergy generation and the potential of more efficient and sustainable deployment of biomass in the BSR.

Seventeen partners from Lithuania, Latvia, Estonia, Germany, Poland, Sweden, Norway and the Russian Federation will bring together the producers of biomass and bio-based products, as well as relevant public authorities and policy stakeholders to stimulate green growth.

Project coordinator:

- Vytautas Magnus University (Lithuania)

Project partners:

- Ministry of Energy of the Republic of Lithuania (Lithuania)
- Forest and Land Owners Association of Lithuania (Lithuania)
- Lithuanian Biotechnology Association (Lithuania)
- Vidzeme Planning Region (Latvia)
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- Municipal enterprise of the city of Pskov "Gorvodokanal" (Russian Federation)

For more information please visit the project website: www.balticbiomass4value.eu

II. List of concepts and abbreviations

Baltic region	Nine countries around the Baltic Sea covered in this report, i.e. Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and Norway
Baltic Sea Region (BSR)	Area of the Interreg Baltic Sea Region Programme, which includes eight EU Member States (i.e. Denmark, Estonia, Finland, Germany (the States (Länder) of Berlin, Brandenburg, Bremen, Hamburg, Mecklenburg-Vorpommern, Schleswig-Holstein and Niedersachsen (only NUTS II area Lüneburg region)), Latvia, Lithuania, Poland, Sweden) and two partner countries (i.e. Norway, Russia (St. Petersburg, Arkhangelsk Oblast, Vologda Oblast, Kaliningrad Oblast, Republic of Karelia, Komi Republic, Leningrad Oblast, Murmansk Oblast, Nenetsky Autonomous Okrug, Novgorod Oblast and Pskov Oblast))
CDD	Cooling Degree Days
CHP	Combined Heat and Power
DH	District Heating
EU	European Commission
GDP	Gross Domestic Product
GHG	Greenhouse gas
GJ	Gigajoule
HDD	Heating Degree Days
MWh	Megawatt-hour
TJ	Terajoule
TWh	Terawatt-hour

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1. Historic developments in energy consumption, prices and fuels

The total energy use in the Baltic region, i.e. Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and Norway, is reduced by 2.2% over the last 10 years. The energy use in the transport sector has increased by 10% in this period, whereas the energy consumption in households and the industrial sector has declined somewhat (Eurostat, 2019a).

The share of renewables in the gross final energy consumption has increased steadily in the Baltic region over the last decade (Figure 1).

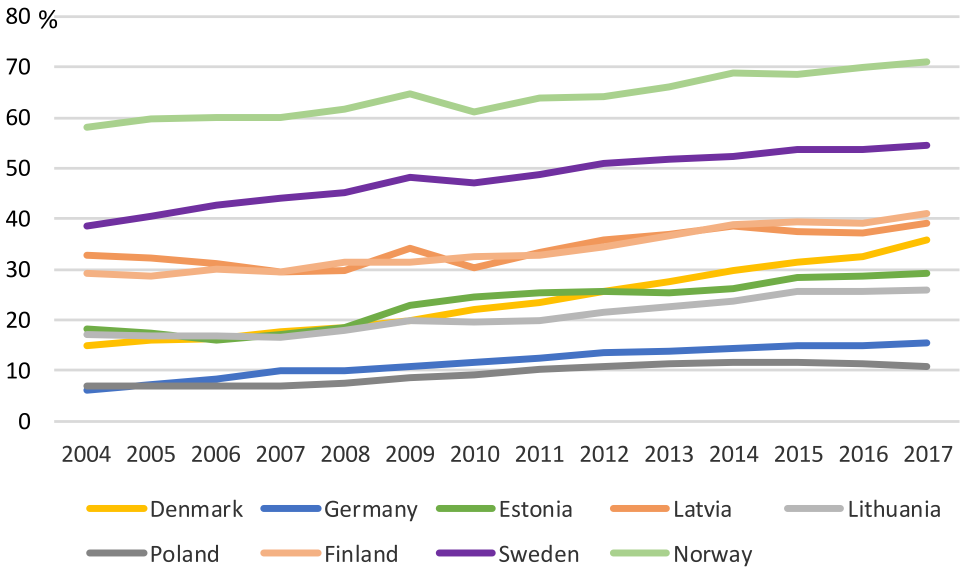

Figure 1. Share of renewable energy in gross final energy consumption in the Baltic region countries, 2004-2017. Source: Eurostat [sdg_07_40].

Use of biomass in the Baltic region has also increased significantly in the period 2007-2016 (Figure 2).

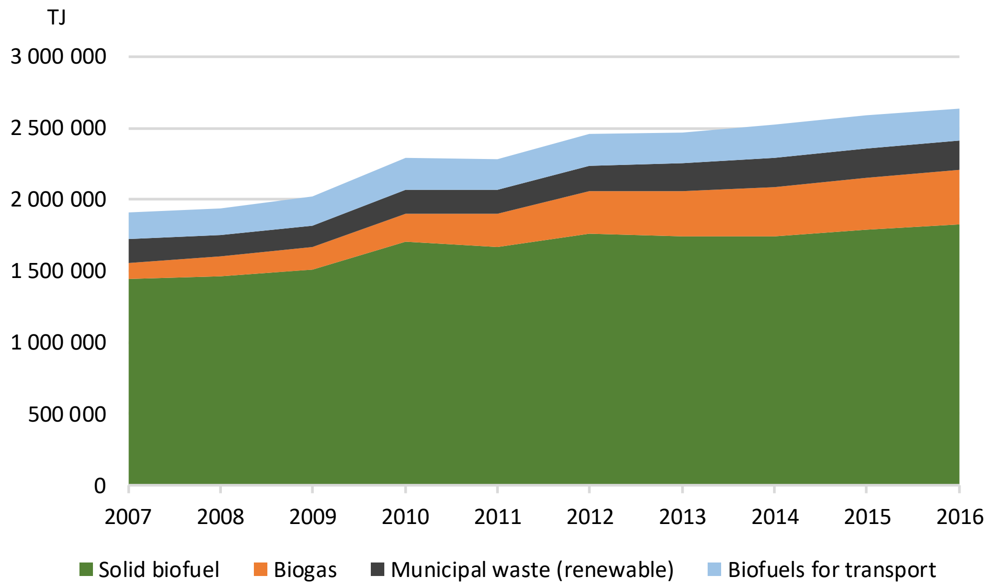

Figure 2. Use of biomass for energy in the Baltic region (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and Norway), 2007-2016. Source: Eurostat [nrg_110a].

Figure 3 shows the use of biomass as shares of gross inland energy consumption in the Baltic region countries in 2016.

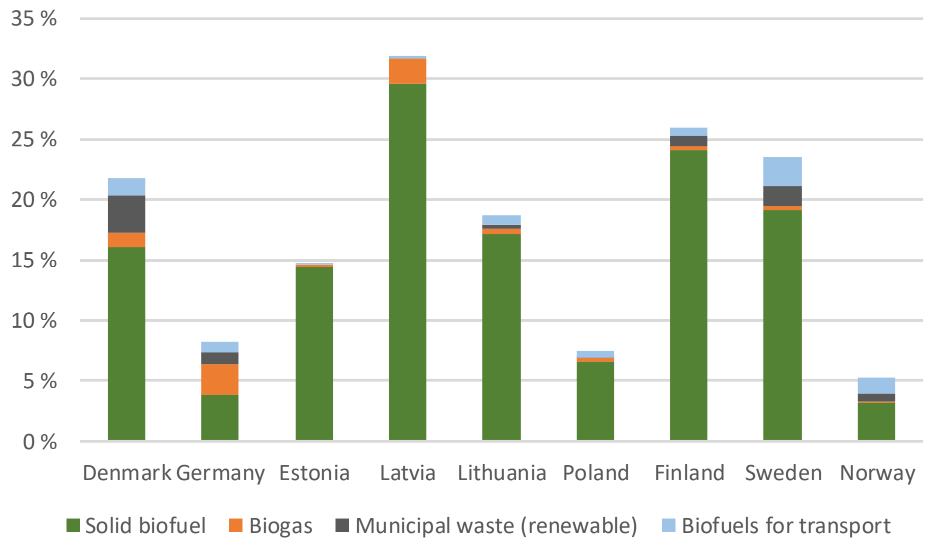

Figure 3. Use of biomass as shares of gross inland energy consumption in the Baltic region countries, 2016. Source: Eurostat [nrg_110a].

Solid biofuels (except charcoal and waste) constituted 6.4% of the total gross electricity production in the Baltic region in 2016. Solid biofuel is most important in Finland (15.4% of the electricity production) and Denmark (11.4%), as well as in Estonia, Latvia, Lithuania and Sweden (in all about 6%). Biogas is most important in Latvia (6.2% of the electricity production) and Germany (5.2%). The electricity production based on solid biofuels increased from 31 to 43 TWh from 2007 to 2016, whereas the production based on biogas increased from 11 to 36 TWh over the same period.

1.1. Heat and power consumption

Heating and cooling account for more than a half of the energy consumption in most Baltic region countries. In EU households, space and hot water heating account for 79% of the total final energy use, whereas 71% of the industrial energy use is for thermal purposes (European Commission, 2019a). As energy use by purpose or service has to be estimated, historical development of thermal energy use is not possible to obtain.

Derived heat covers the heat production in heating plants and in combined heat and power plants, and is also called District Heating (DH). The gross heat production from DH in the EU-28 has declined somewhat from 2008 to 2017, but it increased somewhat in the Baltic region due to growth in Sweden, Latvia and Norway. The heat from DH available for the final consumption in the Baltic region was 336 TWh in 2016, corresponding to about 1/4 of the total electricity consumption (Eurostat, 2019b). 54% of the derived heat was consumed in the residential sector, 25% in the industrial sector, and 22% in other sectors (Figure 4). 84% of heating and cooling is still generated from fossil fuels, while only 16% is generated from renewable energy sources (data on households in Figure 5). In order to fulfil the EU's climate and energy goals, the heating and cooling sector must sharply reduce its energy consumption and use of fossil fuels. More data on the use of biomass for heat is available in statistical report of the Bioenergy Europe (2019).

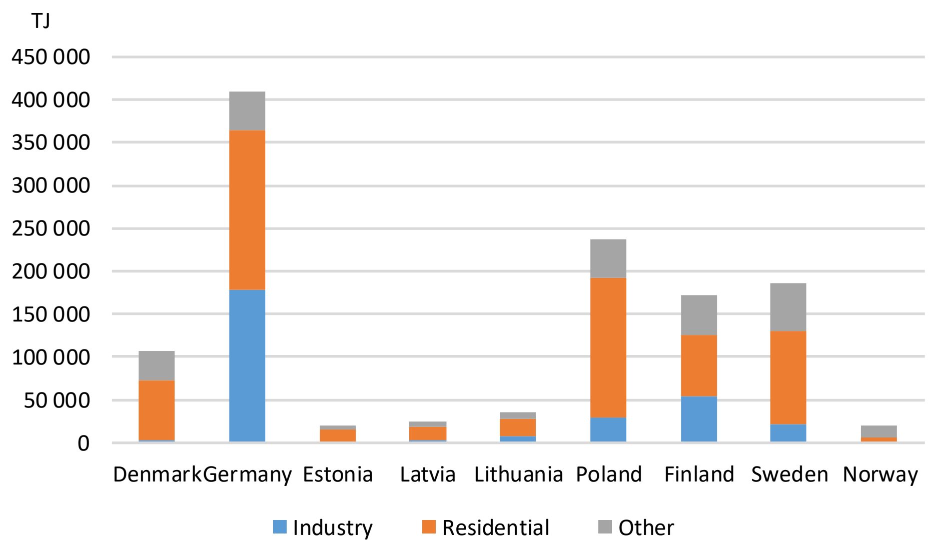

Figure 4. Consumption of derived heat (e.g. district heating) by sector and country in the Baltic region, 2016. Source: Eurostat [nrg_110a].

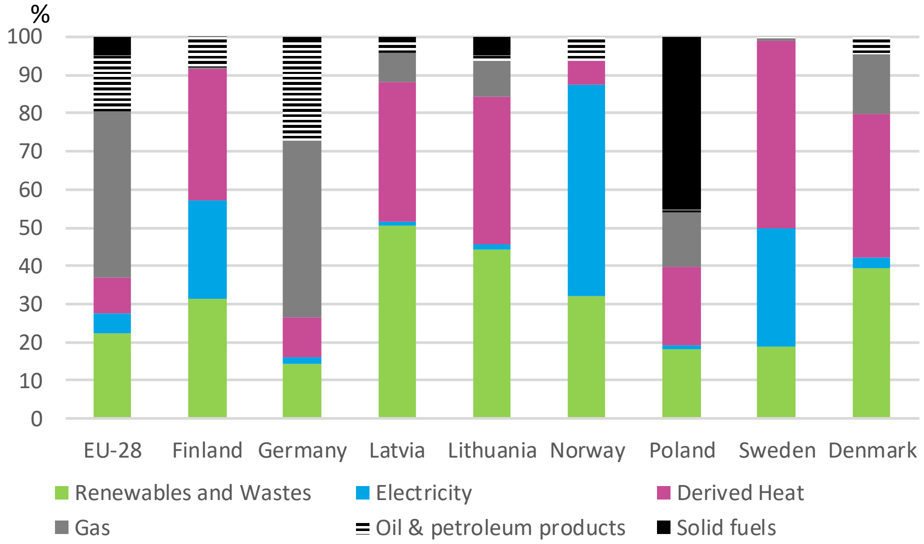

Figure 5. Fuels for space heating in households across the Baltic region countries, 2016. Data for Estonia is not available, but figures from 2017 indicate that close to 50% of space heating in households is provided by renewables and waste (mainly wood based biomass) and about 35% from derived heat. Source: Eurostat [nrg_106a].

The power generation in the Baltic region has been stable over the last decade with only a 0.5% increase in total gross electricity production from 1,238 TWh in 2007 to 1,244 TWh in 2016. As in the EU, there is a reduction in the use of fossil fuels for power generation and an increase in the use of renewables (Figure 6).

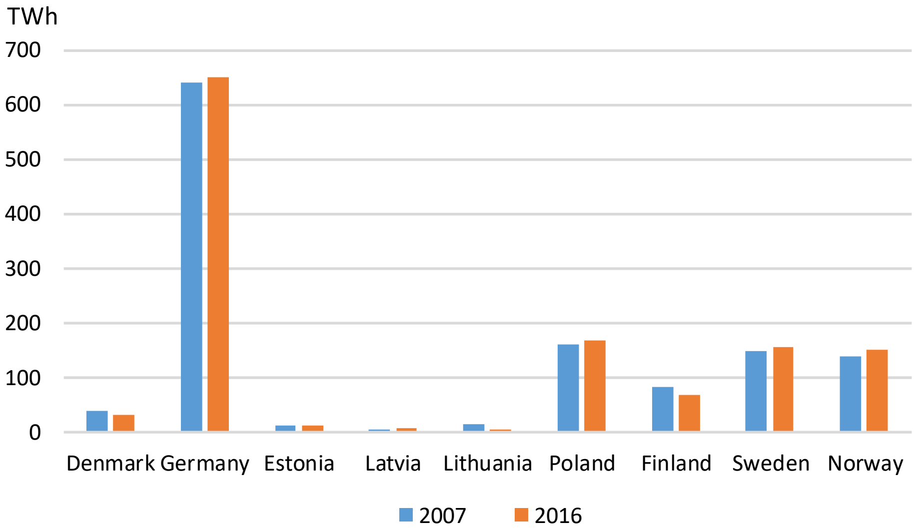

Figure 6. Gross electricity production, 2007 and 2016. Source: Eurostat [nrg_105a].

The use of biofuels in the Baltic region is steadily increasing (Figure 7). In 2017, Sweden and Norway had the highest blending shares among the Baltic region countries (Figure 8).

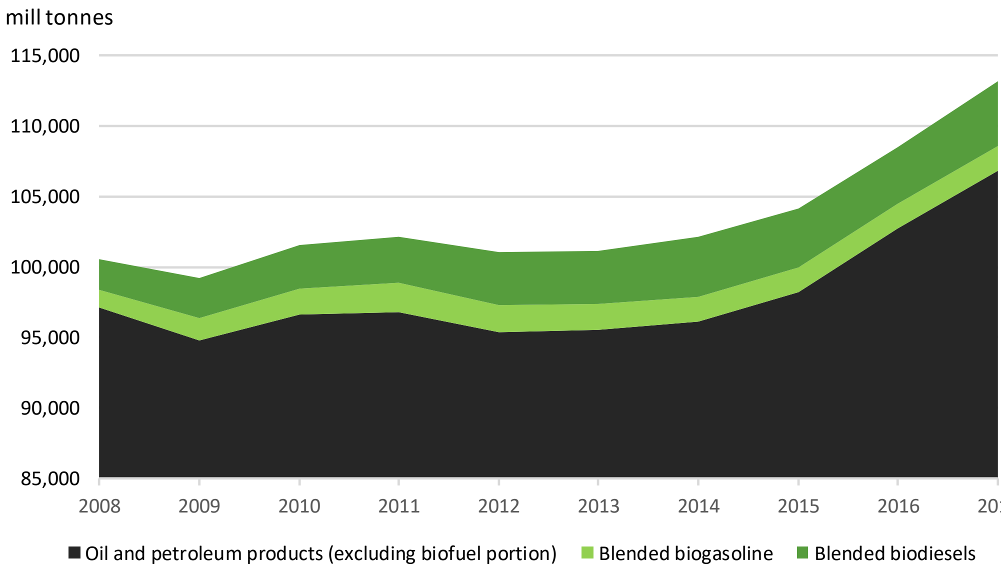

Figure 7. Use of blended biogasoline and blended biodiesel compared to oil and petroleum products for transport. Source: Eurostat [nrg_cb_oil].

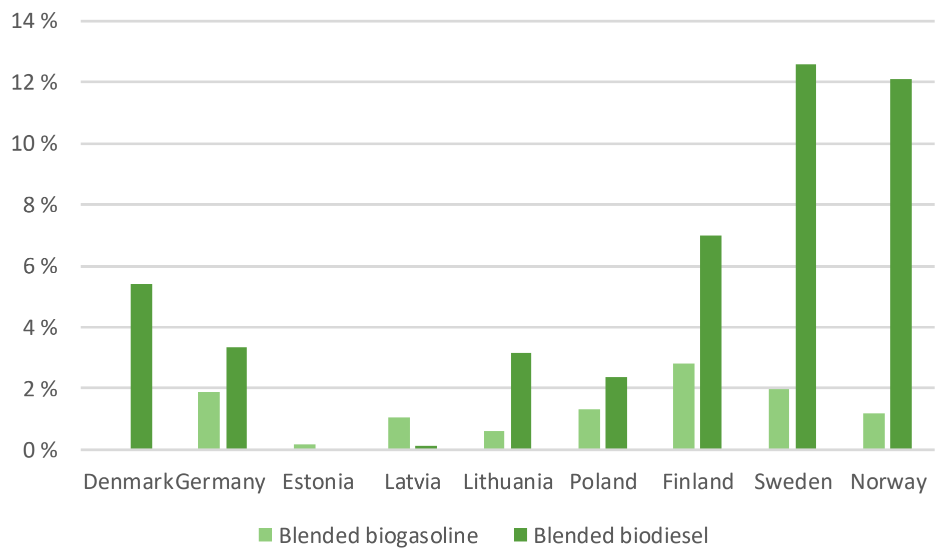

Figure 8. Share of blended biogasoline and blended biodiesel compared to oil and petroleum products for transport per country, 2017. Source: Eurostat [nrg_cb_oil].

1.2. Heat prices

Heat is a heterogeneous product due to different heating technologies, such as direct space heating, water born heating, heat pumps, and wood stoves. Heat prices (or heat costs) are thus in practice alternative costs for different technologies and energy carriers. The average natural gas price in the EU-28, including taxes and levies, is about 50% higher for households than for non-households. Electricity costs constitute of the power price, grid tariffs, taxes and levies. Electricity taxes and thus total electricity costs vary significantly between countries as can be seen in *Figure 9* (European Commission, 2019b). Electricity costs vary more among households than for non-household consumers, whereas gas prices show less variation overall.

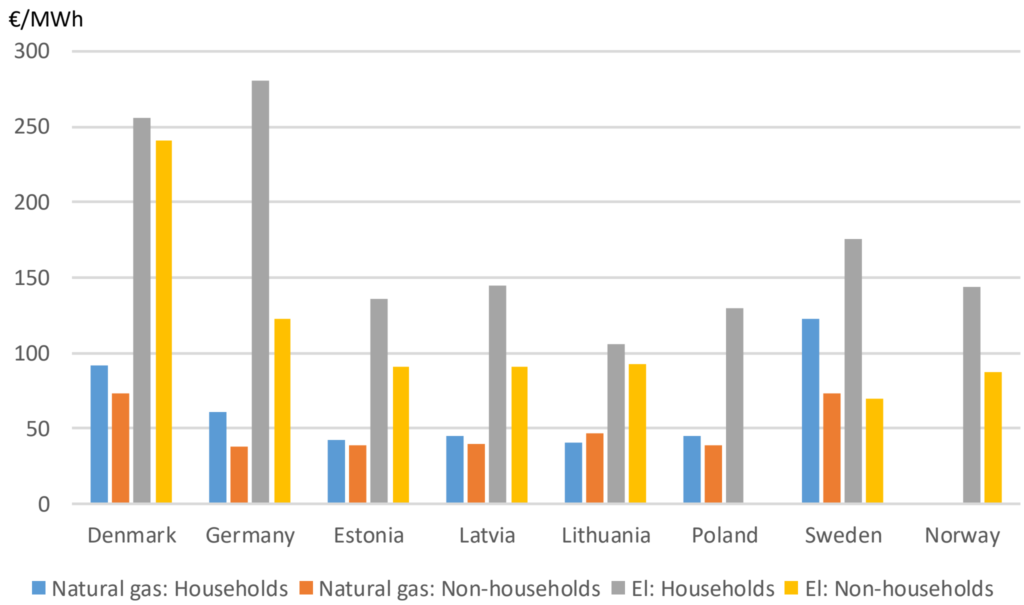

Figure 9. Natural gas and electricity prices, including taxes and levies, for households and non-household consumers in the Baltic region countries in the second half of 2018. Households with gas consumption between 20 and 200 GJ and with electricity consumption between 5 and 15 MWh, while non-household consumers with gas consumption between 1,000 and 10,000 GJ and with electricity consumption between 20,000 and 70,000 MWh. Source: Eurostat [nrg_pc_202], [nrg_pc_203], [nrg_pc_204], [nrg_pc_205].

2. Outlooks for biomass in heat, power and transport

2.1. Drivers in heat demand and biomass for heating

The energy use for heating and cooling is driven by the following main direct drivers:

- Building numbers and size (the amount of commercial floor space and the numbers and size of houses)
- Service demands and preferences (activities, indoor temperatures, heating requirements)
- Building standards
- Outdoor temperatures
- Heating and cooling systems

Indirect drivers that influence the direct drivers are:

- Population, which drives the number of homes, schools and other community buildings
- Economic (real GDP) growth, which is a major driver of new floor space in offices and retail buildings, as well as industrial activities
- Technological developments
- Real energy prices
- Policies and regulations

Better insulation, more efficient equipment and higher outdoor temperatures have reduced the energy shares used for heating and cooling in the last decades. However, total home energy consumption tends to rise, owing in large to a substantial increase in the demand from appliances, electronics and lighting, as well as due to an increase in the average to-be-heated volume of single-family homes.

The residential sector is the most susceptible to temperature fluctuations as space heating, water heating and cooling account for 60-70% of the final energy consumption. Short-term changes in consumption have generally shown the effects of mean inter-annual air temperature fluctuations. The number of Heating Degree Days (HDD) has shown a significant negative trend in Europe since 1980, whereas the number of Cooling Degree Days (CDD) is increasing[1].

For hourly variation, time of use and calendric information are also important for estimates of heat demand. Outdoor temperature, dwelling type, floor space and number of residents are the most important variables for modelling energy consumption in dwellings. In the service sector, the type of building/activity is also important.

Year of construction is often used as a proxy for energy standard, since building codes have become gradually stricter over the last decades. However, since renovation and rehabilitation of a building may take place several times during its lifetime – often improving its energy standard – the year of construction alone does not necessarily reflect the current energy standard.

The development of the above-specified drivers decides future heat demand. Major uncertainties in estimates of future heat demand are: a) the level and location of population growth and the influences

[1] Data provided by the European Environment Agency: https://www.eea.europa.eu/data-and-maps/daviz/trend-in-heating-and-cooling-1#tab-dashboard-01.

on the number of buildings of different categories; b) the dwelling renewal rate; c) the efficiency of buildings and the activity in heat consuming industries. Technological developments and policy decisions on international and national levels will influence these factors.

2.1.1. Drivers for biomass demand in the heat sector

Within the expected or estimated heat demand, the technology and energy carrier to be used might change. Due to a low renewable energy share in heating and district heating, increased use of renewables, including biomass and electricity from renewable energy sources, can be expected. The technology mix in the future heat supply often depends on policy driven technological developments. Policies, which support specific technologies, not only make the given technology more profitable and more used in the short run, but the increased use also enhances technological learning and further reduces costs. Overall greenhouse gas (GHG) targets and specific targets for GHG reductions within the heat sector, the development of biomass heat technologies, as well as the costs of other renewable technologies and relative prices will define the demand for biomass in the heat sector. Electricity prices and the cost of heat pump technologies are likely to be especially important for the future use of biomass in the Nordic countries. Replacement of fossil fuels with biomass is the main potential for increased use of biomass in the Baltic region. In Sweden and Norway, with already high renewable energy shares, increased biomass use for heating is to a large extent dependent on the expansion of district heating.

2.2. Drivers in power demand

Energy intensity in households has started to decline and is expected to continue to do so until 2040 due to new building standards. The expected growth in population in the Baltic region contributes, however, to the opposite direction. Also, with relatively low power prices in the coming 10 years and a positive export surplus, more electricity will likely be used in the heating sector – especially in district heating in Sweden, Finland and Denmark. An increasing number of electric vehicles will also contribute to an increase in consumption, especially in the latter half of the forecasting horizon. With the exception of Denmark, the Nordic countries have a large power intensive industry sector. The power intensive industries experience strong competition from producers in countries with lower cost levels. The pulp and paper industry is currently consuming significant power volumes (40 TWh annually in the Nordic countries). We expect a major transition of the forest industry from paper production to bio-refineries producing biofuels and having excess energy (in the form of power and/or heat), contributing to the reduction in industrial consumption. On the other hand, a revitalization of the power intensive industries is also possible.

Investments in data centres are one example of possible "new demand" with a large potential, and we assume increasing demand from data centres in the Baltic region. Overall, the industry sector consumption represents the largest uncertainty in future demand.

Wind and solar power generation capacities are growing fast in Europe. The learning effect of this increase in capacity contributes to lower costs of renewable power. Combined with ambitious targets for further emission reductions, the wind and solar photovoltaic capacities will likely continue to grow in the coming decades. Increased use of biomass for power is possible due to the increased need for stable and foreseeable power supply that will be needed so as to supplement the variable supply from wind and solar, combined with a reduced power supply from fossil energy resources.

2.3. Drivers in the demand for biofuel for transport

Biofuels for transport have increased significantly in the Baltic region as shown in Figure 7. Political decisions regarding blending requirements will greatly affect the future biofuel volumes. Technological developments and incentives for use of advanced biofuels based on ligno-cellulotic feedstock will determine how the demand for biofuels will influence the markets for different biomass types.

3. Modelling of future biomass use in large scale heat and power plants

3.1. Balmorel model

Balmorel is a partial equilibrium model for the North European power and heat market (Ravnn et al., 2001). Balmorel has been continuously developed from the first version in 2001. See Wiese et al. (2018) for a description of the current model. The model itself, along with data, can be found on the Balmorel community at the Github Repository (2019)[2]. Further we describe the most important parts of the model.

The version of Balmorel used in this study optimizes the production of heat and power, and transmission of electricity to fulfil the assumed exogenously specified demand for heat and electricity, assuming perfectly competitive market. Different primary energy sources are converted into heat and electricity. Both renewable fuel and fossil fuel may be used. The most important energy sources are wind, solar, water (both storages and run of river), coal, oil shale, natural gas, nuclear fuel, chips, other bioenergy, and different grades of waste. The primary energy has exogenously given prices equal for all regions: *constant market prices* for nuclear fuel at 0.76 €/GJ, for chips at 7 €/GJ, and for waste at 0.10 €/GJ; *increasing prices* for natural gas from 5.64 €/GJ in 2020 to 9.29 €/GJ in 2040, for oil shale from 1.70 €/GJ in 2020 to 2.02 €/GJ in 2040, and for coal from 2.31 €/GJ in 2020 to 2.74 €/GJ in 2040; while wind, solar and water do have no direct fuel prices. These prices are based on the IEA (2016). The constant chips prices are a rough assumption, since chips tend to have regional price differences, and the chips prices here are chosen from a forest sector model (Jåstad, Bolkesjø, Trømborg, & Rørstad, 2019).

The production capacity is included in Balmorel both exogenously and endogenously. Planned capacity increases, both commission and decommission are included in the model exogenously, while the model chooses future investment endogenously. The capacities reduce for all fuels except for hydropower. Decommission of installed capacities follows phase-out strategies and is expected to remain through techno-economical lifetime. Capital cost for exogenously defined capacities are not included.

Due to the decommission of existing plants, Balmorel needs to invest in new production units to fulfil the consumption shown in Table 1. All technologies included in the model are represented with efficiency, operation and management costs, investment costs, technical lifetime, year of possible investment, and fraction of heat and power produced in CHP plants. Variable renewable energy technologies have exogenously given inflow profiles for every time step and region. The optimization model will calculate investments according to the techno-economical most profitable technology that is available in order to fulfil the demand. The final consumption of heat and electricity shown in Table 1 is equal for all scenarios.

[2] The model used in this study is from branch F4R_Final_Model_002 downloaded on 21.06.2019 (c19cb83b6b4da49951affb8f9f601bea3ccad206), and data is from branch F4R_Final_002 downloaded on 21.06.2019 (4a0c3434d7c72ca8306c5998fac07a44dbd1e9f4).

Table 1. Assumed consumption of heat and electricity (TWh/year). The consumption is assumed constant for all scenarios, except for increased use of electricity in transport (the IEA (2016) and own assumptions). Figures for electricity consumption in Lithuania is based on electricity generation in 2016 (NORDPOOL, 2019).

	Heat demand			Electricity demand		
	2020	**2030**	**2040**	**2020**	**2030**	**2040**
Germany	116	116	116	530	530	530
Denmark	33.2	33.4	32.2	32.0	32.0	32.0
Estonia	5.0	5.0	4.9	7.7	7.7	7.7
Finland	79.2	76.8	76.2	82.0	82.0	82.0
Lithuania	7.7	7.1	6.0	6.5	6.5	6.5
Latvia	6.0	5.9	5.9	10.6	10.6	10.6
Poland	66.4	76.9	87.5	144	144	144
Sweden	89.7	85.8	84.8	131	131	131
Norway	12.7	15.0	15.4	121	121	121
Total	416	422	429	1065	1065	1065

The model version used in this study covers the heat and power supply and demand in the Baltic region, where each country consists of one or multiple regions. In this model version we account for 24 regions, with the same borders as the NordPool regions (NordPool, 2018). Inside each region is the electricity consumed and exchanged with neighbouring regions (Balmorel is assuming infinite transmission capacity within a region). Similar as the countries consist of regions, regions also consist of one or multiple areas. Heat and electricity production and heat demand take place inside an area. Heat produced within an area is assumed to be consumed within the same area.

Balmorel has a flexible time resolution, which lets the user decide between 1 and 8,736 (hourly resolution) time steps each year. The time resolution has three levels, a year that consists of 52 seasons, and a season consisting of 168 hours. In this study, we simulate three years: 2020, 2030 and 2040, 6 seasons that are evenly distributed across each year and 72 time steps evenly distributed across each season. We further assume perfect foresight within the current year, but no knowledge about the next year.

The study employs a cost-minimizing version of Balmorel where the lowest costs are obtained for fulfilling the energy demand. The objective function includes cost components as fuel costs, operation and maintenance costs, cost related to hydro storage, transmission costs, annuity of investment costs of increasing the production, transmission, storages capacities, and taxes and levies. The most important constraint in Balmorel is an energy balance constrain, which ensures that the sum of energy consumption, production, transmission, losses and storages of energy is equal to zero for every time step and region.

3.1.1. Carbon and biomass price scenarios

In this analysis, we run three different carbon price scenarios shown in Table 2 The carbon price scenarios are based on a literature study covering 22 different energy studies and reports (Chen, Hexeberg, Rosendahl, Bolkesjø, 2019). Base scenario uses the average carbon price, while Low and High represent one standard deviation lower or higher, respectively, than the mean.

Table 2. Carbon prices (€/ton) used in the scenarios for 2020-2040.

	2020	2030	2040
Low	23	14	32
Base (medium)	23	37	63
High	23	59	94

3.2. Modelling results

3.2.1. Production of district heat in the Baltic region

The modelled production of district heat from waste and biomass is 168 TWh in 2020 (Figure 10). Of the modelled countries, Sweden (68 TWh) and Finland (42 TWh) produce most district heat from biomass, while the Baltic countries (Estonia, Latvia, Lithuania) produce 11 TWh from waste and biomass (Figure 10). The most used grade of biomass in the modelled countries is wood chips, which account for 51% (85 TWh) of the total utilization of biomass and waste. More than 30% of the total district heat is produced from wood chips in Estonia (37%), Finland (32%), Latvia (44%), Lithuania (39%), Sweden (51%). Germany, Norway and Poland, according to the modelling results, will not use biomass for heat production in 2020. Germany produces around 18 TWh heat from waste and Norway produces 5 TWh from waste, while Poland produces heat almost solely from lignite and coal.

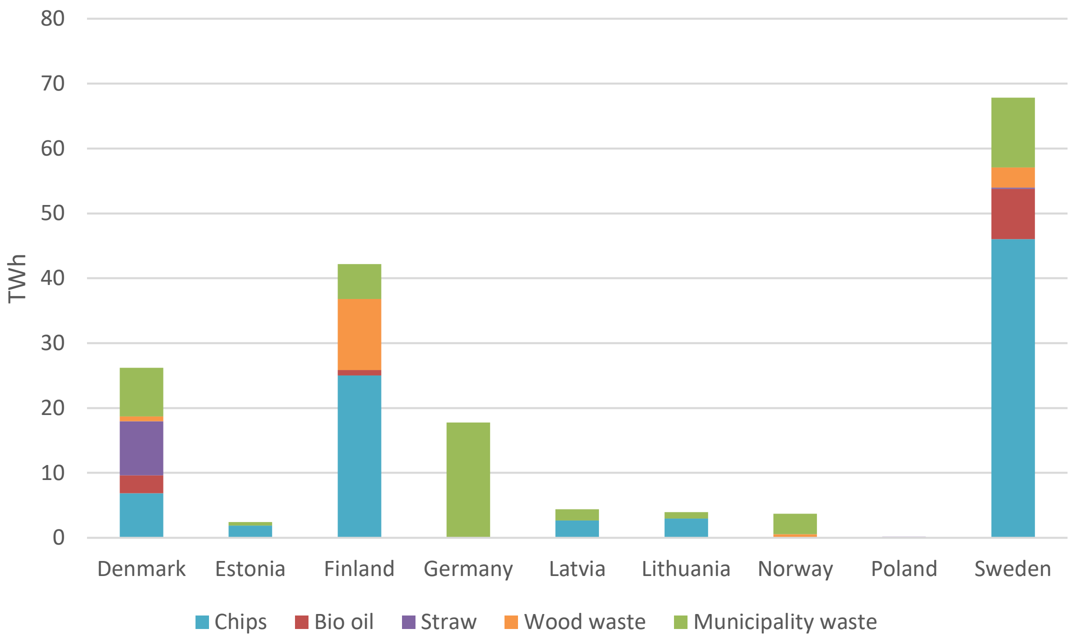

Figure 10. Modelled production of district heat from different grade of bioenergy for the base scenario in 2020 (biogas is not included).

The total production of district heat increases from 416 TWh in 2020 to 432 TWh in 2030, and then to 447 TWh in 2040 for the Baltic region based on the carbon price scenarios (Figure 11). The total produced district heat is slightly higher than the consumption shown in Table 1. This comes from losses in heat storages, mainly in pits. The utilization of biomass and wood chips would increase if the carbon prices rise, because in the lowest carbon price 2040 scenario, the amount of biomass reduces.

In the 2030 scenario, coal and lignite will be less used because of the increased carbon price, while for the 2040 scenario the biomass and natural gas will be substitute. In the 2040 scenario, almost all of the different production units that use coal and oil shale in the Baltic region become out-dated and close even if the carbon price is high. Besides that, with high carbon prices all the coal power and heat plants are phased-out. The district heat production from coal would be mainly produced in Germany and Poland in 2030, while in 2040 coal would be only used for district heat production in Poland. Germany would increase the wood chips use for district heat production in 2030 if the carbon price is high, while in 2040 it would increase the production of heat from wood chips from 5 TWh due to a low carbon price, to 41 TWh when the carbon price is high.

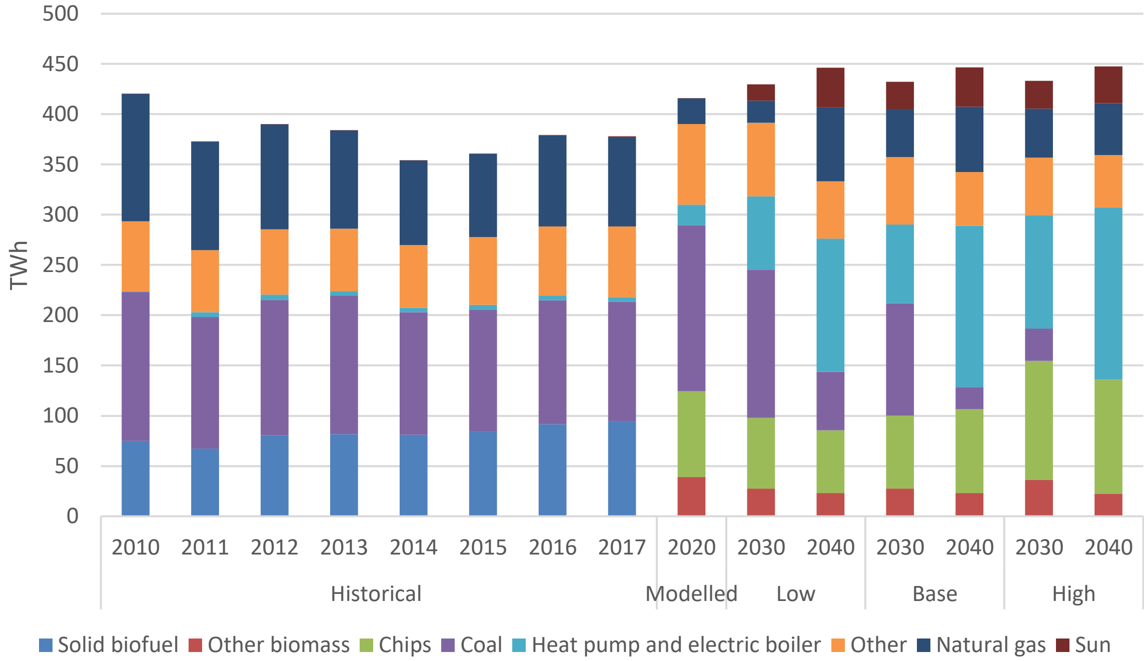

Figure 11. Modelled district heat production from different raw materials for different carbon price scenarios in the Baltic region for 2020-2040, and historical production of heat in 2010-2017 from Eurostat (2019c). Solid biofuel for the historical data includes both chips and other biomass, while all types of waste is included as other.

The amount of district heat produced from biomass is increasing with increasing carbon prices in Denmark, Estonia, Finland, Germany, Latvia, Norway and Poland, while the use of biomass for heat production remains stable at 15% in Lithuania and 41% in Sweden (Figure 12) (Lithuania and Sweden almost do not utilize any fossil fuel for heat production). The most significant biomass shares in 2030 are found in Denmark (67%) and Finland (55%) in the high carbon price scenario, and are caused by a high utilization of straw in Denmark and chips in Finland. In Germany, the utilization of coal is most profitable for low and moderate carbon prices, while chips are covering 29% of the district heat production in the high carbon price scenario.

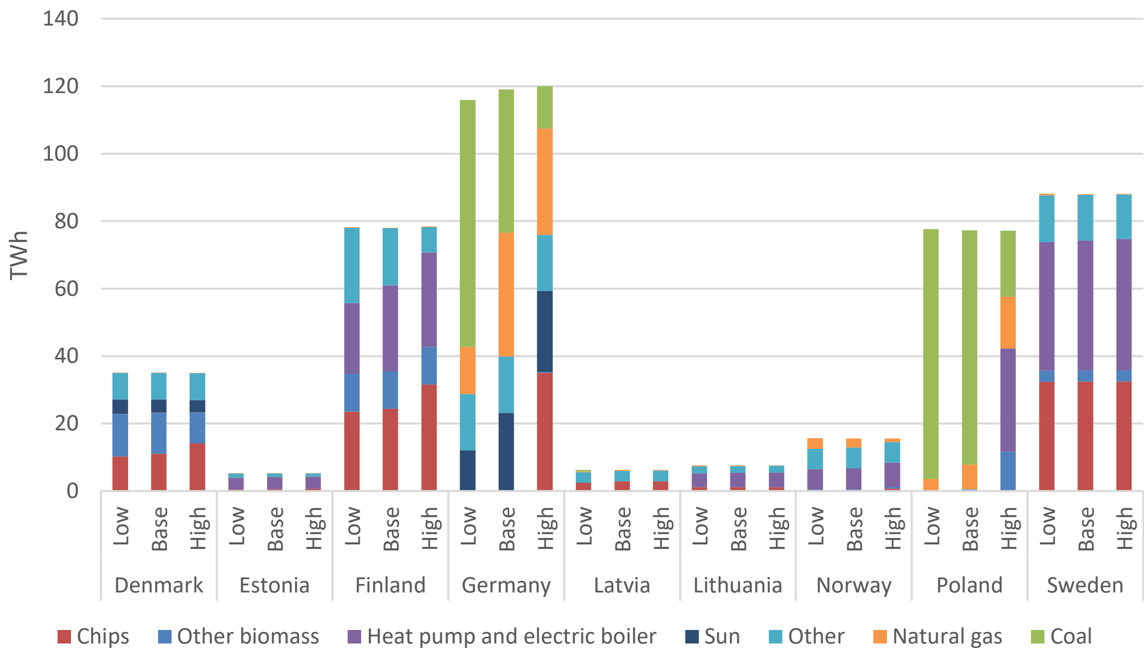

Figure 12. Modelled district heat production in selected countries for different carbon price scenarios in 2030.

3.2.2. Production of electricity in the Baltic region

The amount of electricity produced from biomass at CHP plants is between 2.3% in the low carbon price scenario and up to 3.9% in the high carbon price scenario (Figure 13). This shows that the biomass is not an important raw material for electricity production in the Baltic region, while it is important for heat production, since around 33% of the produced district heat comes from biomass (Figure 13). The biomass in the heating sector competes partly with use of electrical boilers and heat pumps that have electricity as feedstock.

In 2030, the produced electricity from natural gas increases with increasing carbon price. The reason for this is that natural gas used for balancing increased shares of variable renewable power supply is increasing. The model includes pumped hydro and the model may invest in batteries and heat storages. In 2040, if the carbon price is high enough, wind and solar power is able to compete with both natural gas and coal power. The amount of natural gas is decreasing with increasing carbon prices in 2040, but the produced electricity from natural gas is still higher in 2040 than in 2030.

Wind and solar power has an increasing role in electricity production. Its share is increasing from 25% in 2020 to 56% in the high carbon price scenario in 2040. By 2030, wind and solar power constitutes more than a half of the total electricity production in Denmark, Estonia, Poland and Germany when the carbon price is high (Figure 14). Hydropower produces up to 90% of the electricity in Norway and 63% in Latvia, while the share of hydropower in Latvia reduces from 63% for a low carbon price to 58% for a high carbon price due to increased investments in wind power.

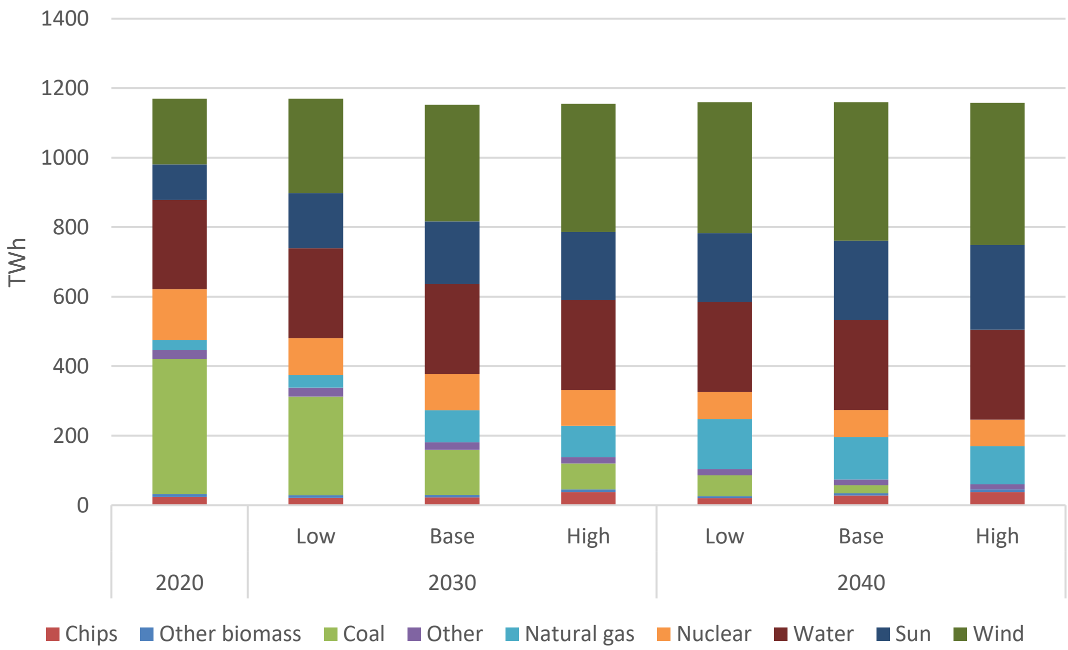

Figure 13. Modelled power production from different raw materials for different carbon price scenarios in the Baltic region for 2020-2040.

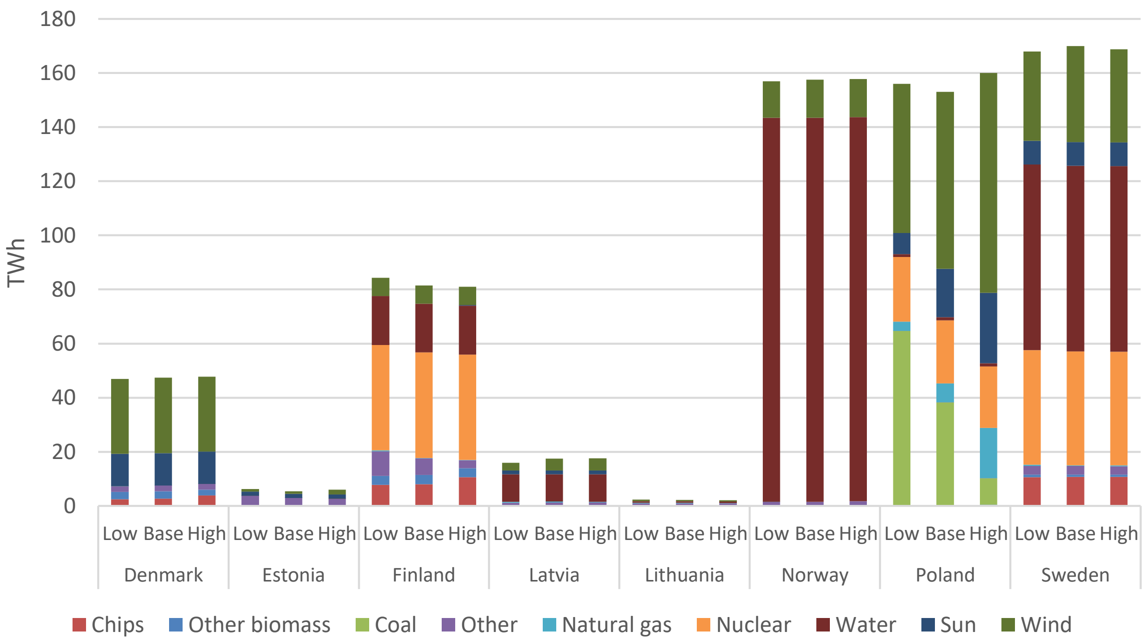

Figure 14. Modelled power production in selected countries for different carbon prices scenarios in 2030[3].

[3] It is assumed that a total nuclear capacity of 2.8 GW will be open in Poland in 2030. This may be a bit too fast, but was the construction year when the initial data was collected.

3.2.3. Heat and electricity prices

The price of delivering district heat is increasing from 2020 to 2040 in all countries, except Estonia (Figure 15). The reason for this is that as the fossil fuel is nearly phased-out, more expensive technologies are introduced in order to fulfil the demand. For example, the heat storages facilities in the Baltic region would increase from 0.5 TWh in 2020 to more than 4 TWh in 2040. The highest increase happens in countries that today are heavily dependent on fossil fuel, such as Germany and Poland. The reason for the slight decrease in heat prices in Estonia is that this country does only use some gases, oil shale and biomass for district heat production in 2020, thus will not invest in expensive new equipment. Moreover, Estonia also switches from a heating system based on mainly biomass and fossil fuel to mainly electricity, when the old biomass equipment reaches its technical lifetime.

The carbon price only affects the heat prices marginally (Figure 15), except in the case of Poland. The reason for this is that Poland is producing up to 74 TWh heat from coal in the low carbon price scenario, while the coal power production is only 20 TWh in the high carbon price; the difference is mainly that the coal heat plants are closed. This mean that for a low carbon price, Poland has only small investments in new production units (in total 27 GW), while for a high carbon price the investment is as high as 60 GW, and this results in a doubling in heat prices from the low to high carbon price scenario in 2030. For 2040, the high carbon price scenario will imply phase-out of old power plants in Poland.

Countries with high utilization of biomass in the heating sector, such as Denmark, Finland, Latvia and Sweden have relatively small changes in heat costs when the carbon price increases, except Denmark, which utilizes some coal in the base year. There are greater changes between years, especially in Latvia, where there are increasing heating prices from 21 €/MWh in 2030 to 32 €/MWh in 2040 due to the introduction of heat pumps. The modelled power prices are shown in Figure 16.

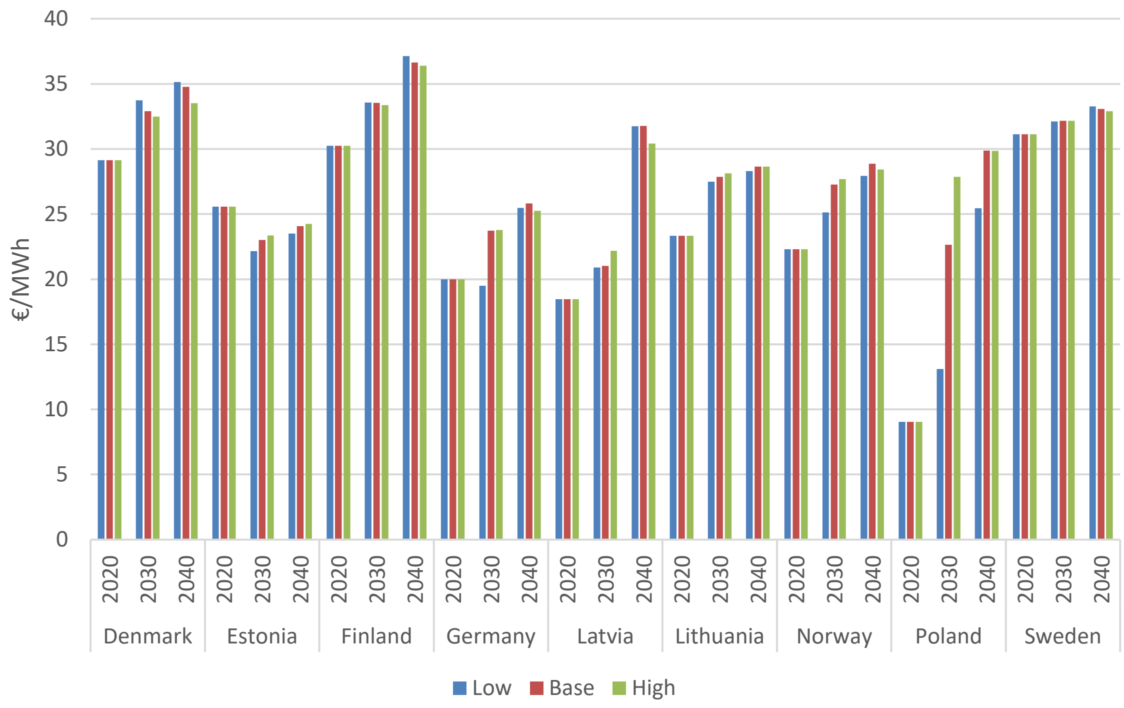

Figure 15. Modelled district heat prices by country for different carbon price scenarios and year.

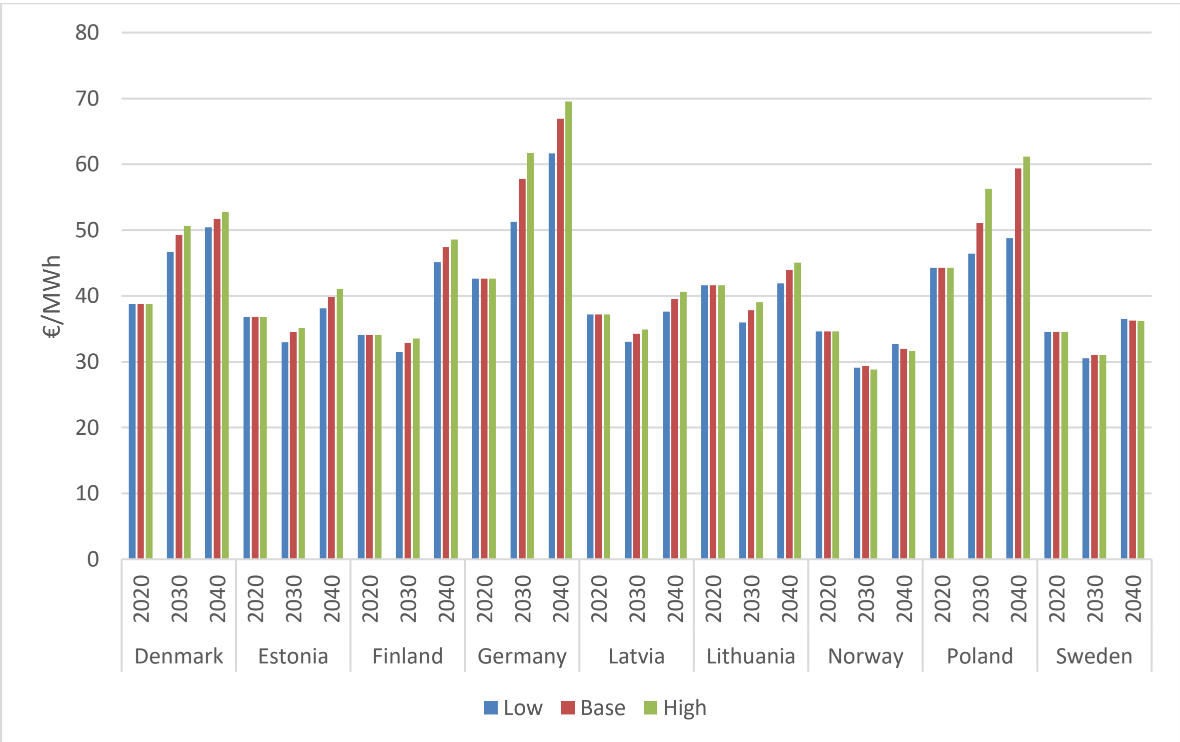

Figure 16. Modelled power prices by country for different carbon price scenarios and year.

3.2.4. Different biomass types grades

The most dominant type of biomass used for production of heat and electricity in the Baltic region are wood chips (Figure 17). The level of consumed wood chips is heavily dependent on the carbon price. If the carbon price increases from medium to high in 2030, the consumption of chips increases by 62% (mainly at CHP plants in Germany, where wood chips technologies replace coal). The usage of biogas increases both with year and carbon price. In 2030, 76-85% of the produced energy that come from biogas is power, while in 2040, only 25-42% of the produced energy from biogas is used for electricity production and the rest is used in district heating plants. The reason for this is that the model estimates an increased investment in heat only boilers in 2040 compared with 2030. This follows that heat only boilers has higher effectivity than CHP plants. Bio oil is only used as a peak load for heat production in 2020 (Figure 18). The use of bio oil is reduced, because of the higher cost of using bio oil than the cost of using electricity and chips for heating. Biogas is increasingly used when the carbon price increases. It should be stressed that the model does not upgrade biogas to natural gas quality, which means that the model has to invest in production units that solely use biogas, something that may underestimate the importance of biogas in the energy system.

The utilization of biomass is highest when the consumption of heat is highest, i.e. in the winter times. Biogas and bio oil are solely used as peak loads in the winter weeks. The fraction of heat production covered by biomasses varies between 11-28% in the summer weeks and between 18-24% in the winter weeks (Figure 18). The reason for this is that the need for base load heating is higher in the winter weeks than in the summer weeks, where also the use of solar collectors increases the need for technologies that have possibilities to ramp the production up and down during a day.

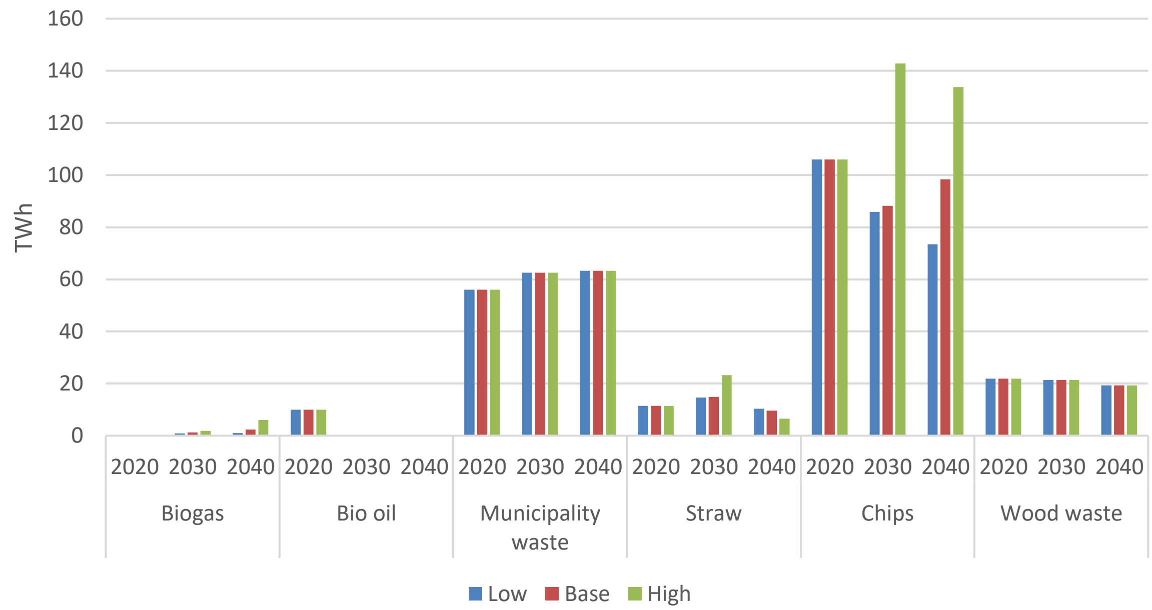

Figure 17. Modelled fuel consumption distributed on different biomass grades for different carbon price scenarios and all countries in the Baltic region.

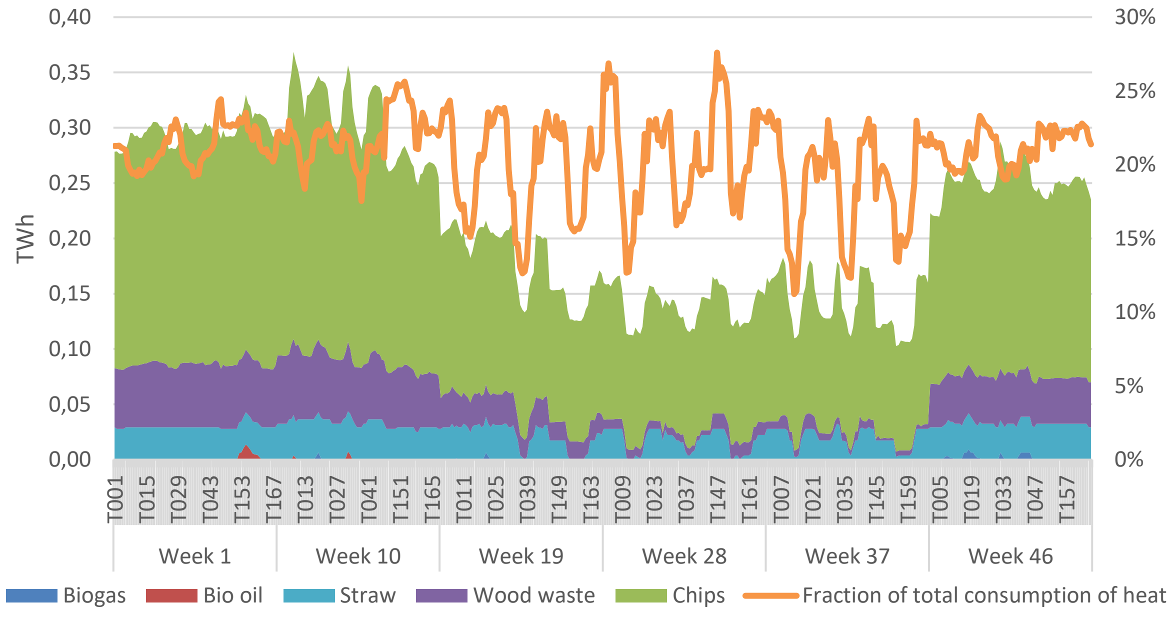

Figure 18. Hourly production of heat by burning biomass and the fraction of total hourly consumption of heat covered by biomass (right axis) for the Baltic region in 2030 with base as the carbon price scenario.

3.2.5. Special case – the Baltic countries

Producing district heat in the Baltic countries (Estonia, Latvia, Lithuania) comes from various sources, and varies among the countries and years (Figure 11). For example, the model results show that in Estonia more than 68% of the delivered heat will be produced by electrical boilers or heat pumps (assumed the coefficient of performance (COP) value of 3.6-3.8), while in Lithuania around 6% of the produced heat is produced from electricity in 2020, but increases to approximate half in 2030, before the electricity share is reduced to 6% in 2040. In Latvia, only up to 12% of the produced district heat is likely to be produced by electrical boilers or heat pumps. The reason for this is that Latvia is utilizing more municipality waste and wood chips than Estonia and Lithuania.

In all three Baltic countries, the electricity prices decrease from 2020 to 2030 and increase from 2030 to 2040 (Figure 19). The reason for this is the increased import from Finland and reduced import from Poland between 2020 and 2030 due to increased investment in transmission lines between the Baltic countries, which further allows increased transmission between Estonia and Lithuania.

Coal is almost phased-out in the Baltic countries in 2020 (Figure 20), with less than 0.5 TWh of coal still in use in Latvia due to its low price. The renewable shares increase from 54% in 2020 to 75% in 2040 for a high carbon price. For comparison, the renewables share in the Baltic countries was 44-68% in 2017 within the district heating sector, while the renewables share for electricity generation was 14-79% (Eurostat, 2019c), lowest being in Estonia. This shows that the trend of increasing renewables share will likely continue in the Baltic countries for all carbon price scenarios. The highest increase happens in Estonia, where the base scenario increases the renewable share from today's level of 32% to 68% in 2040. The lowest increase occurs in Lithuania, where the renewable share increases from 32% that is today to 39% in 2040.

In 2040, wind power may be one of the most important energy sources in the Baltic countries (Figure 20), with around 30% of the primary energy consumed. Wind power is followed by hydropower as the second most important energy source, with around 26% of the primary energy consumed, while fossil fuel accounts only for 7-15% of the used primary energy in 2040. This follows an increased use of variable energy sources in the Baltic countries, which makes it necessary to use some natural gas in order to balance the grid.

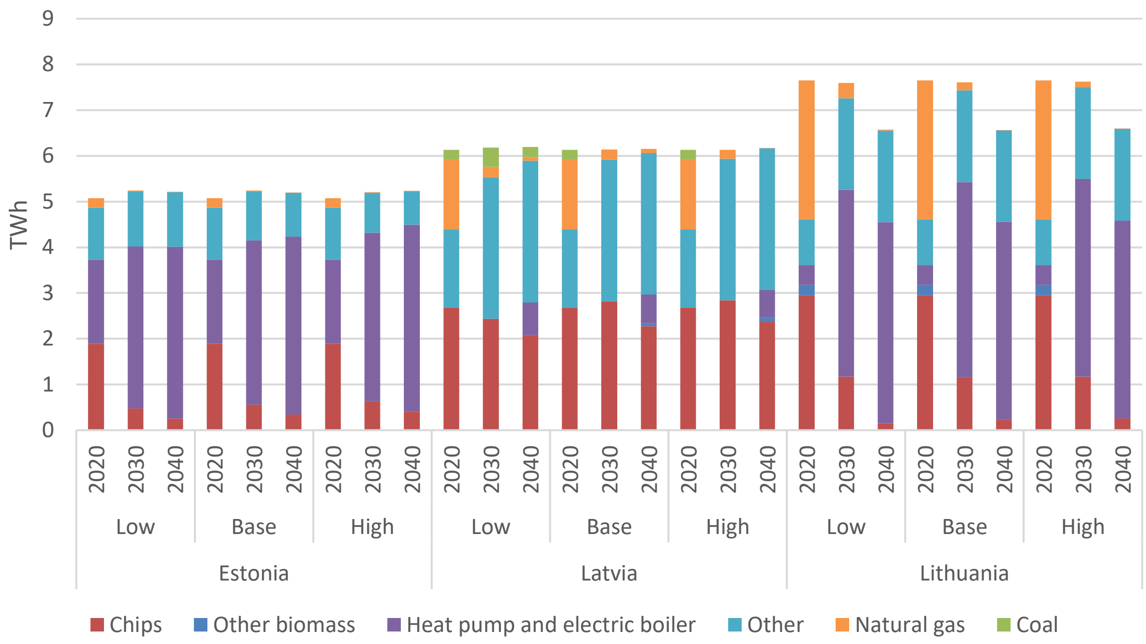

Figure 19. District heating production by fuel in the Baltic countries for different year and for different carbon price scenarios.

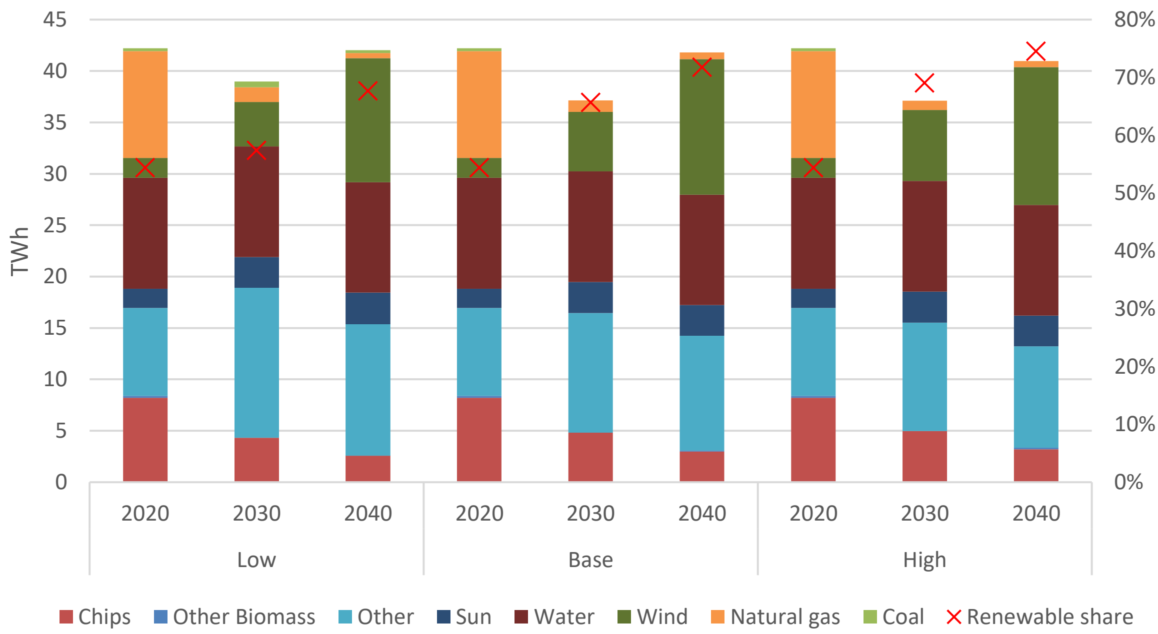

Figure 20. Total fuel use in Estonia, Latvia and Lithuania for different carbon price scenarios and year (crosses show the renewable share in the Baltic countries).

4. Prospects for individual heating

Figure 5 above shows the fuel use in space heating in households and the Bioenergy Europe (2019) data shows biomass use by sector for the EU Member States. Data on specific applied technologies for individual heating is, however, hard to obtain. To assess the use of biomass in heating and the main opportunities to increase the use of biomass for heating in the Baltic region, a survey among the BalticBiomass4Value project partners was carried out. The main opportunities and actions needed are specified in Table 3

Table 3. Main opportunities and needed actions for more use of biomass for heating in the Baltic region.

Country	Main opportunities	Needed actions
Germany	More bioenergy use in rural areas without DH or gas grid. New law to household, agriculture and forestry residual materials use is introduced (in Germany, household residues cannot be mixed with agriculture and forestry residuals).	Information and engagement of stakeholders in the Energiewende, the planned transition to a low carbon, environmentally sound, reliable and affordable energy supply.
Estonia	Stable prices and access of wood fuel, efficient distributed systems compared to old inefficient district heating solutions.	Reduction of local air pollution. Regulations and establishment of local energy cooperatives. Improved efficiency in district heating.
Finland	National policies and strategies, forest resources and agricultural residues. Replacement of fossil fuels in district heating.	Investment subsidies and tax benefits. Information and promotion for consumers and potential producers.
Lithuania	National Renewable Energy Sources targets.	Promotion of biomass from forestry and agriculture, use of biogas opportunities, improvement of boilers.
Latvia	Increase the energy efficiency in heating in order to increase the biomass share. More use of wood chips based on low value species. Increased use of biogas.	-
Poland	Replacement of boilers for hard coal with pellet boilers both on an individual scale and in small heating plants. The development of biogas plants and the use of electric energy and heat.	Clear legal regulations and the country's policy towards Renewable Energy Sources.

Sweden	Forest resources.	Use of excess heat from other bioenergy productions.
Norway	Replacement of oil burners.	Increased electricity costs.

5. Prospects for biofuels for transport

The current shares of biofuels in road transport in the Baltic region countries and their initiatives for production of advanced (second generation/ligno cellulotic) biofuels are shown in Table 4. Below provided initiatives are identified by the BalticBiomass4Value project national teams.

Table 4. Current (2017) shares of biofuels for transport and initiatives for production of advanced biofuels. Statistical data source: Eurostat (2019d).

Country	Current share of biofuels in domestic transport	Initiatives for production of advanced biofuels	Sources
Germany	4.6%	Clariant (formerly Süd-Chemie) sunliquid® demonstration plant of cellulosic ethanol from agricultural residues. bioliq® pilot plant at Karlsruhe Institute of Technology (KIT), which combines flash pyrolysis, high-pressure entrained flow gasification, hot gas cleaning, and synthesis. Concord Blue Energy planned facility at Herten, using a thermolysis process based on heat transfer to covert waste feedstocks to syngas.	ETIP Bioenergy: http://www.etipbioenergy.eu/images/EBTP_Factsheet_Germany.pdf [23.09.2019].
Denmark	5.2%	-	-
Estonia	0.1%	None.	-
Finland	9.5%	Several planned projects with total wood use of about 5 million m³, but uncertain realization. Green Fuel Nordic starts in 2020.	Green Fuel Nordic: http://www.greenfuelnordic.fi/bio-oil.
Lithuania	3.4%	Ambitions of 6 Mtne by 2030 are given (to be specified).	Integrated National Action Plan on Energy and Climate of the Republic of Lithuania (project).
Latvia	0.9%	None.	National statistics: http://data1.csb.gov.lv/pxweb/en/vide/vide__energetika__ikgad/ENG051.px/table/tableViewLayout1/.
Poland	3.2%	Research projects only.	-

Sweden	19.9%	Setra and Preem from 2021 – pyrolysis of forests feedstock. Sødra 2020 – bioethanol from forest feedstock.	Swedish Forest Industries: https://www.skogsindustrierna.se/skogsindustrin/produkter/produktion-av-fossilfria-biodrivmedel/. Mönsterås kommun: https://www.monsteras.se/Nyheter/Soedra-investerar-100-miljoner-i-biobraenslefabrik-i-Moensteraas.
Norway	12.2%	Borregaard – 20 million litres bioethanol from forest feedstock in production. Biozin (Bergene Holm in collaboration with Preem AB) 120 million litres bio oil from forest feedstock from 2023. Silva Green Fuel (Statkraft and Södra) – 25 million litres bio oil from forest feedstock at Tofte from 2020.	Borregaard: https://www.borregaard.com. Biozin Holding AS: http://biozin.no.

6. Conclusions

The share of renewables in the gross final energy consumption has increased steadily in the Baltic region over the last decade. The use of biomass has increased by close to 40%. Solid biofuels constitute 2/3 of the biomass use, but the production of biogas has increased more than 200% and is currently about 15% of the bioenergy consumption in the Baltic region.

Heating and cooling account for more than a half of the energy consumption in most countries. In EU households, space and hot water heating accounts for 79% of the total final energy use, whereas 71% of the industrial energy use is for thermal purposes. 84% of heating and cooling is still generated from fossil fuels, while only 16% is generated from renewable energy sources. The production of biogas has increased significantly in the Baltic region in the last decade and is very important for reduction of GHG emissions from waste and agricultural residues[4].

The use of biomass in the energy sector is expected to increase due to the reduced use of fossil fuels. Increased use of biomass in district heating and biofuels for transport represent important opportunities for increased use of bioenergy in the Baltic region.

The utilization of biomass and chips is increasing with increasing carbon prices. Most of the biomass is used if the carbon price is high in 2030, while the lowest amount of biomass is used if the carbon price is low in 2040.

The biomass is not an important raw material for electricity production in the Baltic region, but indirectly the use of biomass is important to the electricity production, since around 33% of the produced district heat comes from biomass. The biomass in the heating sector competes partly with use of electrical boilers and heat pumps, which use electricity as a feedstock.

The most dominant grade of biomass used for production of heat and electricity in the Baltic region is wood chips. The level of consumed chips is heavily dependent on the carbon price. The usage of biogas increases both with year and carbon price. Bio oil is only used as a peak load for heat production in 2020. The use of bio oil is reduced with year, because of the higher cost of using bio oil than the cost of using electricity and chips for heating. Biogas is increasingly used when the carbon price increases. Initiatives to produce second generation biofuels for transport from lingo-cellulotic feedstock is likely to increase the use of biomass in the transport sector.

Consumption of biomass in the industry sector consumption represents the largest uncertainty in future biomass demand. Replacement of fossil coal and coke in the metallurgical industry carbon represents important opportunities for increased biomass use.

[4] Biodegradable waste forms landfill gas, half of it methane, which is one of the worst greenhouse gases. The EU Landfill Directive (Directive 1999/31/EC) expired on 16 July 2009, meaning that henceforth all European landfill sites were to meet harmonized requirements or to be shut down. Source: https://www.umweltbundesamt.de/en/topics/waste-resources/waste-disposal/landfill [17.10.2019].

Targeted incentives are required to ensure economic sustainability for increased use of biomass in the energy sector in the Baltic region. Increased costs for emission of carbon from fossil fuels will imply an increased use of biomass in the Baltic region, especially in district heating, which represents a low hanging fruit for reduced GHG emissions in many countries. Carbon costs, regulations, incentives and knowledge are needed for this change. Biofuels for transport will continue to be based on agricultural products in the next decade, but establishment of second generation biofuel plants is likely to gradually influence the biofuel market.

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Appendix

In this appendix, we provide data illustrated in the figures of this study. For all tables below, empty space means that the product is not producing the scenario, while a zero means that the product produces less than one unit.

A.1. Data shown in Figure 10

Table 5. Data shown in Figure 10: Modelled production of district heat from different grade of bioenergy for the base scenario for 2020 (biogas is not included). Unit: TWh.

	Biogas	Bio oil	Municipality waste	Straw	Chips	Wood waste
Denmark		2.78	7.50	8.34	6.87	0.69
Estonia		0.53		1.89		
Finland	0.87	5.39		25.00	10.92	10.92
Germany			17.76		B	
Latvia		1.71		2.68		
Lithuania			1.00		2.96	
Norway	0.00	3.17		0.03	0.53	0.53
Poland			0.18			
Sweden	7.75	10.78	0.20	46.02	3.10	3.10

A.2. Data shown in Figure 11

Table 6. Data shown in Figure 11: Modelled district heat production from different raw materials for different carbon price scenarios in the Baltic region for 2020-2040, and historical production of heat in 2010-2017 from Eurostat (2019a). Solid biofuel for the historical data includes both chips and other biomass, while all types of waste is included as other. Unit: TWh.

		Solid biofuel	Other biomass	Chips	Coal	Heat pump and electric boiler	Other	Natural gas	Sun
Historical	2010	75			148	1	70	127	0
	2011	67			131	5	62	108	0
	2012	81			134	5	65	104	0
	2013	82			138	4	62	98	0
	2014	81			122	5	62	84	0
	2015	84			122	5	67	83	0
	2016	92			123	5	69	91	0
	2017	95			119	4	71	89	0
Modelled	2020		39	85	165	20	80	25	0
Low	2030		28	70	148	73	73	22	16
	2040		23	62	58	133	57	74	39
Base	2030		28	72	112	78	67	48	27
	2040		23	83	22	160	53	65	39
High	2030		36	119	32	113	57	49	28
	2040		22	113	0	171	52	52	37

A.3. Data shown in Figure 12

Table 7. Data shown in Figure 12: Modelled district heat production in selected countries for different carbon price scenarios in 2030. Unit: TWh.

		Other biomass	Chips	Coal	Heat pump and electric boiler	Other	Natural gas	Sun
Denmark	Low	12.54	10.23		0.10	7.91	0.05	4.25
	Base	12.10	11.07		0.09	7.91	0.05	3.86
	High	9.16	14.10		0.08	7.90	0.03	3.65
Estonia	Low		0.48		3.54	1.21	0.02	
	Base		0.56		3.59	1.07	0.02	
	High		0.63		3.69	0.88	0.01	
Finland	Low	11.11	23.59		21.03	22.26	0.26	
	Base	11.13	24.35		25.49	16.93	0.16	
	High	11.12	31.62		28.00	7.49	0.14	
Germany	Low	0.06		73.16		16.72	14.04	11.95
	Base	0.15		42.49	0.04	16.69	36.75	22.94
	High	0.23	35.05	12.54	0.00	16.58	31.54	24.03
Latvia	Low		2.43	0.42		3.10	0.23	0.06
	Base		2.82			3.10	0.22	0.10
	High		2.84			3.10	0.20	0.11
Lithuania	Low		1.17		4.09	2.01	0.33	
	Base		1.16		4.27	2.01	0.18	
	High		1.17		4.33	2.01	0.12	
Norway	Low	0.49	0.01		6.00	6.07	3.07	
	Base	0.49	0.01		6.28	6.09	2.71	
	High	0.49	0.72		7.21	6.09	1.07	
Poland	Low	0.01		74.11		0.01	3.55	
	Base	0.51		69.36		0.02	7.35	
	High	11.72		19.55	30.50	0.01	15.39	
Sweden	Low	3.33	32.36		38.09	13.89	0.40	
	Base	3.34	32.45		38.48	13.52	0.24	
	High	3.33	32.44		38.95	13.19	0.21	

A.4. Data shown in *Figure 13*

Table 8. Data shown in Figure 13*: Modelled power production from different raw materials for different carbon price scenarios in the Baltic region for 2020-2040. Unit: TWh.*

		Other biomass	**Chips**	**Coal**	**Other**	**Natural gas**	**Nuclear**	**Sun**	**Water**	**Wind**
2020		9	24	389	26	29	146	102	257	189
2030	Low	7	21	284	26	36	105	159	259	272
	Base	8	22	130	22	92	104	180	259	335
	High	8	38	74	18	91	104	196	259	369
2040	Low	6	21	59	19	144	78	198	259	377
	Base	7	28	23	17	123	77	229	259	398
	High	7	38		15	109	77	243	259	410

A.5. Data shown in Figure 14

Table 9. Data shown in Figure 14: Modelled power production in selected countries for different carbon prices scenarios in 2030. Unit: TWh.

		Other biomass	Chips	Coal	Other	Natural gas	Nuclear	Sun	Water	Wind
Denmark	Low	3	2		2	0		12	0	28
	Base	3	3		2	0		12	0	28
	High	2	4		2	0		12	0	28
Estonia	Low		0		4	0		2	0	1
	Base		0		3	0		2	0	1
	High		0		2	0		2	0	2
Finland	Low	3	8		9	0	39		18	7
	Base	3	8		6	0	39		18	7
	High	3	11		3	0	39	0	18	7
Latvia	Low		0		1	0		1	10	3
	Base		0		1	0		1	10	4
	High		0		1	0		1	10	5
Lithuania	Low		0		1	0			1	0
	Base		0		1	0			1	0
	High		0		1	0			1	0
Norway	Low				1	0			142	13
	Base				1				142	14
	High		0		2				142	14
Poland	Low	0		65	0	3	24	8	1	55
	Base	0		38	0	7	23	18	1	65
	High	0		10	0	19	23	26	1	81
Sweden	Low	1	11		3	0	42	9	69	33
	Base	1	11		3	0	42	9	69	35
	High	1	11		3	0	42	9	69	34
Germany	Low	0		219	5	31		128	18	131
	Base	0		91	5	84		139	18	180
	High	1	12	65	4	71		146	18	198

A.6. Data shown in Figure 15

Table 10. Data shown in Figure 15: Modelled district heat prices by country for different carbon price scenarios and year. Unit: €/MWh.

		Low	Base	High
Denmark	2020	29.1	29.1	29.1
	2030	33.7	32.9	32.5
	2040	35.1	34.8	33.5
Estonia	2020	25.6	25.6	25.6
	2030	22.2	23.0	23.4
	2040	23.5	24.1	24.2
Finland	2020	30.2	30.2	30.2
	2030	33.6	33.5	33.4
	2040	37.1	36.6	36.4
Germany	2020	20.0	20.0	20.0
	2030	19.5	23.7	23.8
	2040	25.5	25.8	25.2
Latvia	2020	18.5	18.5	18.5
	2030	20.9	21.0	22.2
	2040	31.7	31.8	30.4
Lithuania	2020	23.3	23.3	23.3
	2030	27.5	27.9	28.1
	2040	28.3	28.6	28.7
Norway	2020	22.3	22.3	22.3
	2030	25.1	27.3	27.7
	2040	27.9	28.9	28.4
Poland	2020	9.1	9.1	9.1
	2030	13.1	22.6	27.9
	2040	25.5	29.9	29.9
Sweden	2020	31.1	31.1	31.1
	2030	32.1	32.2	32.2
	2040	33.3	33.1	32.9

A.7. Data shown in Figure 16

Table 11. Data shown in Figure 16: Modelled power prices by country for different carbon price scenarios and year. Unit: €/MWh.

		Low	Base	High
Denmark	2020	38.8	38.8	38.8
	2030	46.7	49.3	50.6
	2040	50.4	51.7	52.7
Estonia	2020	36.8	36.8	36.8
	2030	33.0	34.5	35.1
	2040	38.1	39.8	41.1
Finland	2020	34.1	34.1	34.1
	2030	31.5	32.9	33.5
	2040	45.1	47.4	48.6
Germany	2020	42.6	42.6	42.6
	2030	51.2	57.8	61.7
	2040	61.7	66.9	69.5
Latvia	2020	37.2	37.2	37.2
	2030	33.1	34.3	34.9
	2040	37.6	39.5	40.6
Lithuania	2020	41.6	41.6	41.6
	2030	36.0	37.8	39.0
	2040	41.9	44.0	45.1
Norway	2020	34.6	34.6	34.6
	2030	29.1	29.4	28.8
	2040	32.7	32.0	31.7
Poland	2020	44.3	44.3	44.3
	2030	46.4	51.0	56.3
	2040	48.8	59.4	61.2
Sweden	2020	34.6	34.6	34.6
	2030	30.5	31.0	31.0
	2040	36.5	36.3	36.2

A.8. Data shown in Figure 17

Table 12. Data shown in Figure 17: Modelled fuel consumption distributed on different biomass grades for different carbon price scenarios and all countries in the Baltic regions. Unit: TWh.

		Low	Base	High
Biogas	2020			
	2030	0.88	1.27	1.92
	2040	1.05	2.37	5.99
Bio oil	2020	10.03	10.03	10.03
	2030	0.05	0.09	0.07
	2040	0.08	0.06	0.05
Municipality waste	2020	56.03	56.03	56.03
	2030	62.50	62.50	62.50
	2040	63.29	63.29	63.29
Straw	2020	11.42	11.42	11.42
	2030	14.60	14.94	23.27
	2040	10.28	9.56	6.54
Chips	2020	106.05	106.05	106.05
	2030	85.80	88.16	142.83
	2040	73.47	98.41	133.72
Wood waste	2020	21.84	21.84	21.84
	2030	21.44	21.44	21.44
	2040	19.26	19.26	19.26

A.9. Data shown in Figure 19

Table 13. Data shown in Figure 19: District heating production by fuel in the Baltic countries for different year and for different carbon price scenarios. Unit: TWh.

			Other biomass	Chips	Coal	Heat pump and electric boiler	Other	Natural gas
Estonia	**Low**	2020		1.89		1.83	1.15	0.21
		2030		0.48		3.54	1.21	0.02
		2040		0.25		3.76	1.19	0.00
	Base	2020		1.89		1.83	1.15	0.21
		2030		0.56		3.59	1.07	0.02
		2040		0.34		3.89	0.96	0.00
	High	2020		1.89		1.83	1.15	0.21
		2030		0.63		3.69	0.88	0.01
		2040		0.41		4.08	0.74	0.00
Latvia	**Low**	2020		2.68	0.21		1.71	1.54
		2030		2.43	0.42		3.10	0.23
		2040	0.00	2.08	0.22	0.71	3.10	0.08
	Base	2020		2.68	0.21		1.71	1.54
		2030		2.82			3.10	0.22
		2040	0.06	2.28		0.63	3.10	0.09
	High	2020		2.68	0.21		1.71	1.54
		2030		2.84			3.10	0.20
		2040	0.09	2.37		0.61	3.10	0.01
Lithuania	**Low**	2020	0.22	2.96		0.44	1.00	3.04
		2030		1.17		4.09	2.01	0.33
		2040	0.00	0.15		4.40	2.01	0.01
	Base	2020	0.22	2.96		0.44	1.00	3.04
		2030		1.16		4.27	2.01	0.18
		2040	0.00	0.23		4.32	2.01	0.01
	High	2020	0.22	2.96		0.44	1.00	3.04
		2030		1.17		4.33	2.01	0.12
		2040	0.00	0.26		4.33	2.01	0.01

A.10. Data shown in Figure 20

Table 14. Data shown in Figure 20: Total fuel use in Estonia, Latvia and Lithuania for different carbon price scenarios and year (crosses show the renewable share in the Baltic countries). Unit: TWh, while for the renewable share – %.

		Other Biomass	Chips	Coal	Other	Natural gas	Sun	Water	Wind	Renewable share
Low	2020	0	8	0	9	10	2	11	2	54%
	2030		4	1	15	1	3	11	4	57%
	2040	0	3	0	13	1	3	11	12	68%
Base	2020	0	8	0	9	10	2	11	2	54%
	2030		5		12	1	3	11	6	66%
	2040	0	3		11	1	3	11	13	72%
High	2020	0	8	0	9	10	2	11	2	54%
	2030		5		11	1	3	11	7	69%
	2040	0	3		10	1	3	11	13	75%