NTNU

Assessment of district heating network potential in replacing individual electric heating in residential sector.

MASTER'S THESIS

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Map of Norway

Abstract

In recent years Norway is considered as the “green battery” of the European Energy System due to its large hydro resources. At the end of 2017, over 31 GW was powered by Norway’s internal waters, generating 144 TWh of green power. Already today, Norway accomplishes this role by importing excess electricity from Europe and exporting electricity when Europe lacks it. Electricity is the dominant energy carrier. It accounts for a large proportion of energy use in Norway. There is a large energy-intensive manufacturing sector, and electricity is widely used to heat buildings and water.

The trends in recent years suggest the choice of technologies that are competitive and environmentally friendly, at the same time. The use of electricity in the heating sector may be a provisional option but not a long-term solution. The choice of a district heating system is a permanent solution, especially for cold countries with a considerable wintertime and high difference between indoor and outdoor temperatures. The expansion of the district heating system would reduce the use of electricity to a significant percentage contributing to the Norway’s future energy strategies and its role in Europe. Reducing the amount of electricity used increases Norway's ability to export to European countries. The growth of this export means decreasing carbon footprints in regional terms and an increase in energy security within the country, by diversifying energy sources.

Moreover, the implementation of the 4th generation of district heating in Norway would result a very convenient and efficient technology. This state-of -the-art technology is introduced considering its major constrains. Another challenge was the transition from the current system, whereby individual consume electricity in a new system with a high share of district heating in the heating supply. Physical and legal barriers were mostly identified in the organizational framework and in the current infrastructure for district heating. Some DH were proposed and its impact on the final energy consumption was analyzed. On this basis, the best optimized scenario is introduced.

Sammendrag

I de senere årene har norge blitt sett på som «det grønne batteriet» av det europeiske energi systemet, dette på grunn av de store vann resursene. I slutten av 2017, over 31GW var drevet av Norges store vannresurser. Noe som utgjorde over 144 TWh med fornybar, grønn energi. Norge gjennomfører denne rollen i dag, ved å importere overskytende elektrisitet fra rundt om i europa og ved å eksportere elektrisitet til andre steder når behovet fremtreder. Elektrisitet er den foretrukne måten å transportere energi på i Norge i dag, dette gjenspeiler seg i den store delen av energiforbruken i Norge. Her er en stor og energiomfattende produksjonssektor, hvorpå mye av energien blir brukt på oppvarming av bygninger og vann.

I den senere tid viser det seg at folk gjerne velger alternativ oppvarming, som både er konkuransedyktig, men i tillegg er miljøvennlig. Bruken av elektrisk oppvarming viser seg å være et provisorisk valg, men ikke en langsiktig løsning. Dersom en velger å bruke fjernvarme, så er dette et dette et godt og langsiktig valg. Spesielt for land med lave gjennomsnittstemperaturer, lange vintre og generelt store forskjeller mellom inne- og utetemperaturer. Utbyggingen av fjernvarmeanlegg vil føre til en sterk reduksjon i elektrisitetsforbruk, noe som fører til at Norge kan eksportere mye mer grønn elektrisitet og dermed er en positiv bidragsyter til Norges klimapolitikk. Utbyggingen av denne typen energioverføring, fører til at en vil redusere utslipp både kommunalt og regionalt. En vil også få en større tryggehet med tanke på energisikkerhet, ved å diversifisere bruken av av energi.

Altså ikke ha alle eggene i samme kurv. Ved å implementere bruken at fjerde generasjons fjernvarme i Norge, vil kunne resultere i en effektiv og fremtidsrettet teknologi. Denne toppmoderne teknology blir introdusert, til tross for den begrensningen den står ovenfor. En annen utfordring er overgangen fra det nåværende systemet, hvorpå i et nytt system vil det være sentralt at individuelle aktører deltar i et felles system for fjernvarme. Praktiske og legale barrierer er for det meste definert i det organisatoriske rammeverket og til dels i nåværende infrastruktur som fjernvarme vil inngå i. Noen av typene av fjernvarmeteknologi var foreslått og deres virkning og forbruket til sluttbrukeren analysert. På grunnlag av disse funnene, ble de beste metodene iverksatt.

Preface

This report is the result of a Master Thesis project carried out between February 1st, 2019 and June 3rd ,2019 in the master programme Sustainable Manufacturing at Norwegian University of Science and Technology, Norway.

The supervisor of the project was Alemayehu Gebremedhin, Professor, Department of Manufacturing and Civil Engineering, Faculty of Engineering, Gjøvik.

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List of Abbreviations

CHP	Combined Heat and Power
CCS	Carbon Captured Systems
COP	Coefficient of Performance
DH	District Heating
DC	District Cooling
ENTSO	European Network of Transmission System Operators for Electricity
EU	European Union
EWS	Efficiency World Scenario
FEC	Final Energy Consumption
GHG	Greenhouse Gas
HP	Heat Pump
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LPG	Liquefied petroleum gas
PEC	Primary Energy Consumption
PV	Photovoltaic
OECD	Organization for Economic Cooperation and Development
RES	Renewable Energy Sources
SSB	Statistics Norway (Statistisk Sentralbyra)
STH	Storage thermal
TFC	Total Final Consumption
TPEC	Total Primary Energy Supply
TPES	Total Primary Energy Consumption
MSW	Municipal Solid Waste
NTNU	The Norwegian University of Science and Technology
NECD	National Emission Ceilings Directive
NVE	Norges Vassdrags-og Energidirektorat
NOK	Norwegians Krone
VRE	Variable Renewable Energy

INTRODUCTION

2.1 PERSONAL MOTIVATION

Energy is undoubtedly one of the biggest challenges of this century. The most widespread dilemma is that countries must meet increasing energy demand and must achieve the aim of reducing energy consumption at the same time. In addition, the demand is rising rapidly, in tandem with increasing concerns about global warming and greenhouse gas emissions.

Energy is the most important driver of economic growth and as the world moves towards the future, three indexes of Energy Trilemma should be fulfilled: Security of supply, Affordability and Sustainability (Stephen Church 2017). This provides us with both a challenge and an opportunity to decide the future course of our countries and more importantly the quality of life of citizens of the future. We need to ensure smart sustainable cities for our future generations and sustainable solutions that will work on a large scale. While capacity addition is required to meet the growing energy demand, there will be two sources of energy that will play a key role in the future. The first source is "energy efficiency"[1] in existing infrastructure and the second source is from renewables like solar and wind energy. Globally, many governments and corporates are embracing renewables to reduce their carbon footprint and move towards clean energy sources like wind and solar. Energy efficiency is a great potential source of energy in cities that is largely untapped. It can play a major role in freeing up energy demand from existing buildings/infrastructure and can also ensure the new buildings have minimized energy demand.

In this framework, a strategy needs to be developed not only in the power sector, but also in the *heating sector.* The EU is committed to reducing the GHG emissions to 80-95 (%) below 1990 levels by 2050. So far, electricity sector has been the focus of low carbon policies. This is a start but decarbonization efforts will need to be expanded in other sectors, including heating and cooling sector. This sector is the largest single energy user in Europe (Honore May 2018). District Energy is a proven technology that can help us be more energy efficient. It is surely one of the technologies that will immediately contribute to the growth of energy security and serve as a vital infrastructure for cities, campuses, communities. I strongly believe that this technology will have a contribution to the future of efficiency in the heating sector.

[1] "Energy efficiency has been called a 'hidden fuel', yet it is hiding in plain sight," IEA Executive Director Maria van der However said as she presented the report at the World Energy Congress in Korea. "Indeed, the degree of global investment in energy efficiency and the resulting energy savings are so massive that they beg the following question: Is energy efficiency not just a hidden fuel but rather the world's first fuel?" International Energy Agency

2.2 RESEARCH AIMS AND OBJECTIVES

Checking that energy consumed in the heating sector has a high share on the final energy consumption graph, a new efficient system should be proposed. From this study research, I intend to propose a new way of heating space and water in the residential sector. The proposed new system will be tested to meet the needs for the study area based on the available resources (urban waste, wood waste, other residues).

This system has four positive aspects compared to the current system:

- First, the electricity used for heating will be significantly reduced and Norway can increasingly contribute to the supply of electricity to other European countries which do not meet the European emissions reduction directives due to lack of renewable energy resources. Interconnection lines between Norway and other countries can also be sup-plied in periods of electricity shortages in certain regions.
- Secondly, the district heating system uses and treats waste. This process of treatment turns out to be very efficient while heat energy will be gained from a waste combustion process.
- Third, diversification of energy sources its important according to European directives related to future objectives. According to Norway's energy trilogy index, this component could be improved: Energy Security. The proposal of a district heating system is a step towards increasing energy security.
- Fourthly, a 'perfect' infrastructure for such a system will be associated with secondary benefits such as melting of frozen winter season roads, heating through heat exchangers hot sanitary water in dwellings.

2.2.1 **Aim**

Norwegian heating sector is uncommon in EU because it is mostly based on individual heating. Certainly, in the case of Norway, the use of electricity for heating purposes has the highest advantages compared to the traditional fossil fuel sources used in the heating sector regionally and extensively.
As Europe is moving towards the fulfillment of energy directives and highest acceptance of fluctuating renewable energy sources, the system requires greater flexibility. Norway can contribute to guarantee this flexibility by increasing energy efficiency inland and exporting the excess of electricity to European countries.
Norway should also meet reduction rates of GHG emissions in the forthcoming years. The need to reduce GHG emissions will be accompanied by an inescapable shift in sectors such as transport, offshore oil and gas, from fossil fuels to electricity. This can have the opposite effect and instead increase the national demand for electricity in these sectors within the country. This change will modify this demand and will increase the need for higher energy capacity from renewable sources. Therefore, knowing the extraordinary potential of energy efficiency measures to reduce consumed final energy and the importance of investment in renewables will help keeping the energy balance and avoiding inconvenient possible shifts of the energy system. Consequently, the aim of this master thesis is to estimate how possible interventions in the residential sector.
District heating is in the European energy system often seen to increase reliability and flexibility in the energy system and decreasing GHG-emissions by increasing the total

efficiency of the energy system. However, it is unclear what effects an expansion of the district heating systems will have in a highly electrified Norwegian energy system characterized mainly by controllable dammed hydro facilities and a very low share of district heating systems in the heating sector.

2.2.2 Objectives

The main objective of this study is to set the scene and to provide a framework to study heating sector in Norway. This objective will be achieved considering initially a basic scenario. The base scenario will reflect the current state of the heat sector of the year when the data is available. The analysis of the trend of the past and the future will bring us closer to current results, with a small margin of error. For future trends, the targets and guidelines will normally be considered.

Then, the selection of DH scenarios will bring to the analysis the suggested changes of the system. Seeing at how some key energy indices will change and evaluating their impact implicitly, we will give our ratings and results.

2.3 STRUCTURE OF THE THESIS

This Master Thesis report will have the following structure:

Introduction- Introduction will comprehensively summarize my personal motivation to write about this topic, goals and objectives that are expected to be fulfilled by this study.

Background- This chapter will contain quantitative data related to indicators to be used during analysis and building models in EnergyPlan. Illustrative graphics will be all built in excel, referring to the collected data.

Problem Analyses- This chapter represents an overview of the energy system situation in Norway. It is summarized the reason why Norway should intervene on the heating sector and what are the objectives that in a way obligates that.

Heating Sector in Norway-Heating sector in Norway is highly depended on electricity. In this chapter, the most important heat related indicators are analyzed and based on that scenarios will be proposed.

District Heating Theory- This presents a short overview of the District Heating systems in different countries and worldwide. The most important characteristics about each generation are described. The share of DH and DC is taken into consideration for further analyzes on the coming chapters.

Methodology-Methodology explains what have in common chosen energy model EnergyPlan and our study work. Based on that a list of requirements are analyzed and this software resulted the most relevant one.

Problem Explanation-The problem is detailed and explained in this chapter. Problem is showed argued by results of the reference scenario.

Reference Scenario- This scenario represents the current energy system in Norway. All the data collected are explained in paragraphs from where are taken and assumed.

DH Scenarios-District heating scenarios are the proposed scenarios. These scenarios change from the reference scenario and from each other because they use different ways of potential available sources combination. From DH scenarios the optimal scenario will be chosen. The optimal national energy system will be the one that will reduce electricity demand and increase the use of those production technologies that result on the lowest cost.

Results from DH scenarios- Results for comparison will be shortly showed. Each change on EnergyPlan outputs will be showed on comparative graphs and interpreted.

Constrains- This section will include all the barriers on this master thesis. This barriers affect the quality of the study in cases when there is lack of information. Also, different barriers that affect DH proposed are taken into consideration.

Discussion- This chapter obtains discussions about the things that can be done better on the future work.

Conclusion- Is the finalization of this master thesis. The conclusions from all the analyses and interpretation of information, data and results will be summarized in this last chapter.

BACKGROUND

3.1 OVERVIEW OF THE ENERGY SYSTEM

We will analyze the current and the expected tendencies of energy system at four levels: Global, European, Regional (Nordic countries) and National (Norway).

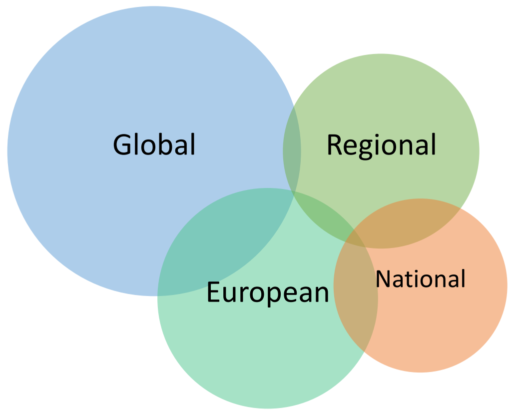

Figure 1: Own figure. Four levels of analyses of the Energy System

Assessing the four levels we can determine what is the role and effect of Norway's energy policies in its energy system compared to the Global, European and Regional progress. Having the general picture will lead us to the effects of switching from electric heating to district heating systems in the residential sector.

3.1.1 Primary Energy Consumption

By 2016, world's total final energy consumption was approximately 160'045 [TWh] (corresponding to 13 761 449 ktoe). This consumption increased by 1.2% compared to a year earlier. The average annual growth in the period 1990-2016 is estimated to be 1.5% per year. According to recent statistics, growth continues to be at a higher percentage in 2017 by 2.2%. This percentage is the highest in recent years since 2013.

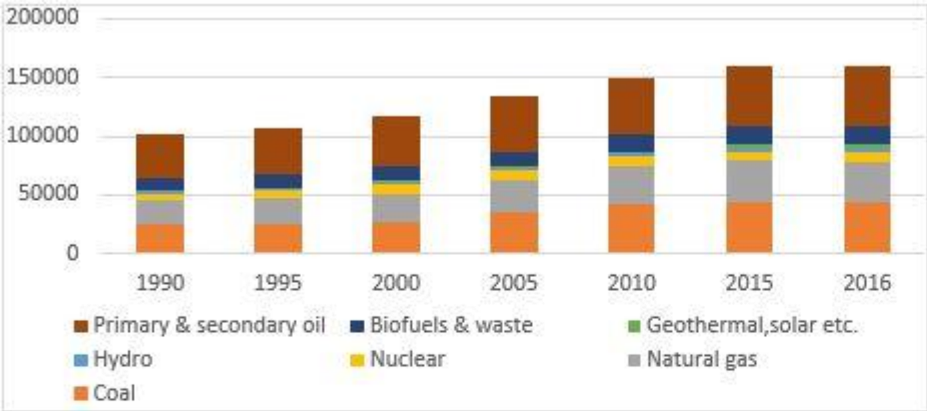

Figure 2: Total Primary Energy Supply (TPES) by source [TWh] (International Energy Agency 2016)

In the total final energy consumption, seen in a global perspective, source with the highest share remains oil products (41%) with an increase of about 26% referring to 2000. While heating occupies only 3% of the TPEC, with a growth of 12 % in the period from 2000-2016. The residential sector accounts for 22% of final energy consumption in 2016. Heat has value 5% in the final energy consumed in the residential sector and it is reduced by 1.1% compared 2000.

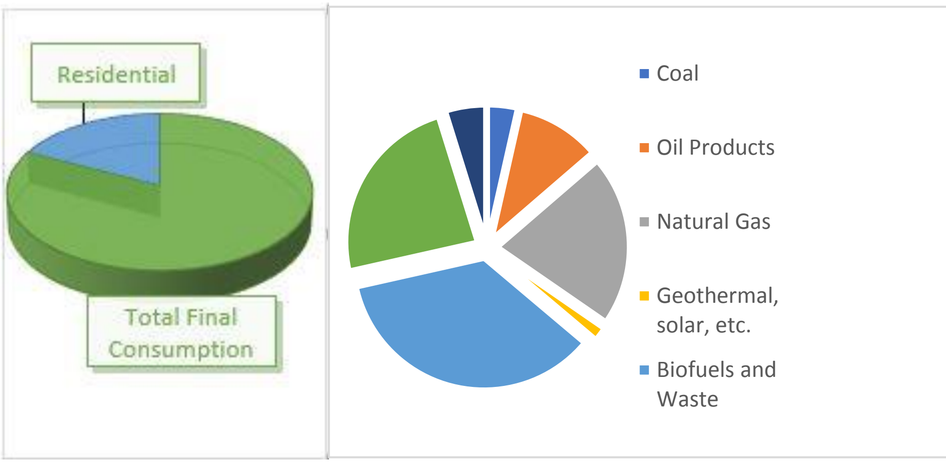

Figure 3: Share of Residential in TFC (%)

In 2016, primary energy consumption in EU was 4,3% above the 2020 energy target with a value of 17945.09 TWh. From 2005 to 2016 this consumption decreased by 10% as a result of the application of energy efficiency measures and continuously introducing to the national energy system high share rates of renewable energy sources (hydro, solar photovoltaic power, wind). Also, economic recession and climate change gave strong alerts that affected final energy consumption. According to the Eurostat last release, in 2017 PEC grew by 1.3% compared to a year ago reaching the value of 18177.69 TWh and increasingly diverting the 2020 target by 5,3%.

The energy system of EU countries is in most parts still dependent on fossil fuels. Fossil fuels continue to dominate the primary consumed energy, but their share has been reduced by 6% from 2005 to 2016. While in 2016 the proportion of fossil fuels is 72%, the share of renewable resources almost doubled during the same period resulting in 14% in 2016. This growth followed an annual average rate of 5.4%.

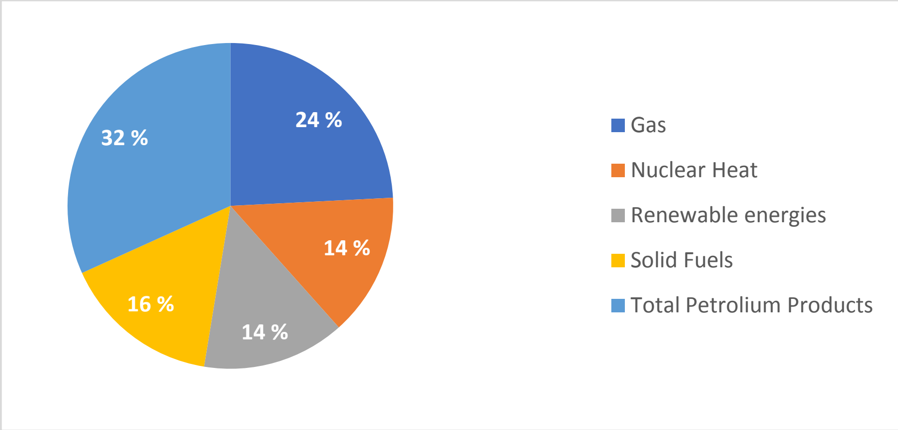

Figure 4: Primary energy consumption, by source(%) (European Energy Agency 2016) (International Energy Agency 2016).

Table 1: Primary Energy Consumption and distance 2020 and 2030 targets EU-28 (Eurostat- Renewable Energy 2017)

Primary Energy Consumption and distance 2020 and 2030 targets EU-28					
Year	2006	2014	2015	2016	2017
Primary Energy Consumtion (Mtoe)	1729,2	1511,1	1537,3	1546,7	1561
Distance to 2020 Target (Mtoe)	246,2	28,1	54,3	63,7	78
Distance to 2020 Target (%)	16,6	1,9	3,7	4,3	5,3
Distance to 2030 Target (Mtoe)	456,2	238,1	264,3	273,7	288
Distance to 2030 Target (%)	35,8	18,7	20,8	21,5	21,6

A technological and economic path to pushing the Nordic region towards a carbon-free energy system exists. This road only needs compromise and cooperation. Nordic countries have the potential to send signals to the global communities to contribute to the fulfillment of the Paris Climate Agreement aims.

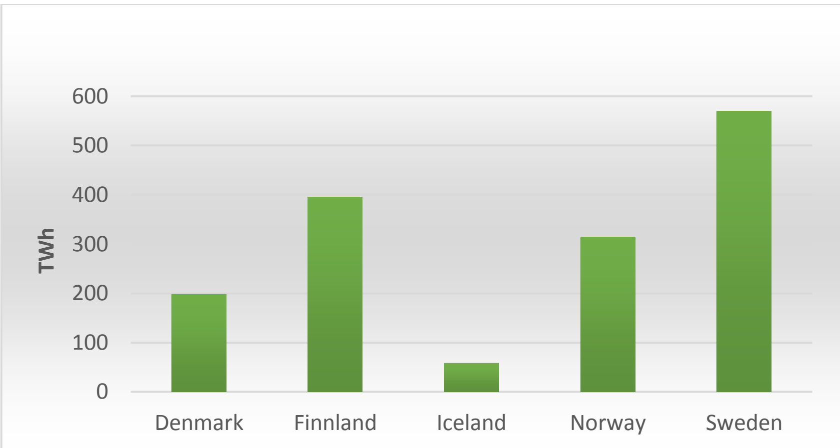

Figure 5: Total Primary Energy Supply in Nordic Region [TWh], 2016 (International Energy Agency 2016)

Access to energy is the most important issue of nowadays wellbeing and development. Making sure that every person in the world can easily use energy is the greatest challenge for the world's development. But we would not need more than a comparative view to understand that it's time to make a big difference to this energy system. The growth of the final energy consumption spans all sectors, and unfortunately the tendencies are on the increase. The following graphs give an overview of changes occurring in the period 1990-2016. Year 2017 was not included in this comparison because of not available data for every country.

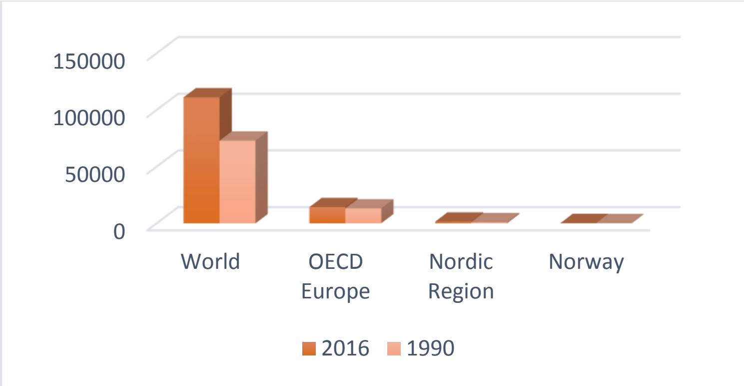

Figure 6: Total Final Energy Consumption comparison between 1990-2016 [TWh].

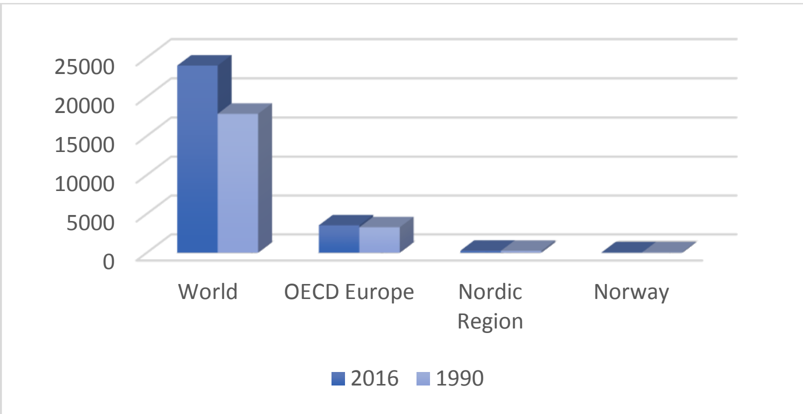

Figure 7: Total final energy consumption in residential sector comparison between 1990 and 2016 [TWh]

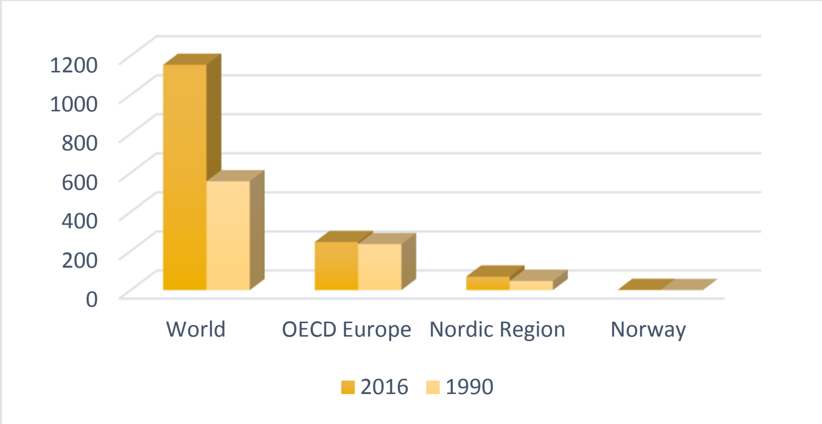

Figure 8: Total final energy consumption in residential sector from heat comparison between 1990 and 2016 [TWh].

Every system is usually very complex. The challenge of reducing energy consumption at a significant value is very difficult to be achieved in global or regional levels. Therefore, interventions and improvements of the energy system should start from countries level. A country cannot improve their entire energy system without going deeper in energy sectors. Further in each sector, systems and equipment should be evaluated. New investments and state of the art technologies would provide the basis for change of levels one by one and fulfillment of future targets. Now that we have taken a general view of Norway compared to the Global, European and Regional (Nordic) energy system we will continue in the next chapters the analysis of the heating systems.

3.1.2 Progress on Energy Efficiency

Globally, energy efficiency increased 13% from 2000 to 2016. In 2016, the world would have been using 12 % more energy if it were not the progress in energy efficiency started since 2000. This is comparable to adding another European Union in the global energy market. In developing countries, energy efficiency has limited the increase in energy use related with economic growth. However, by taking a range of cost-effective energy efficiency opportunities widely available today, energy intensity would improve by around 3% per year, between now and 2040.

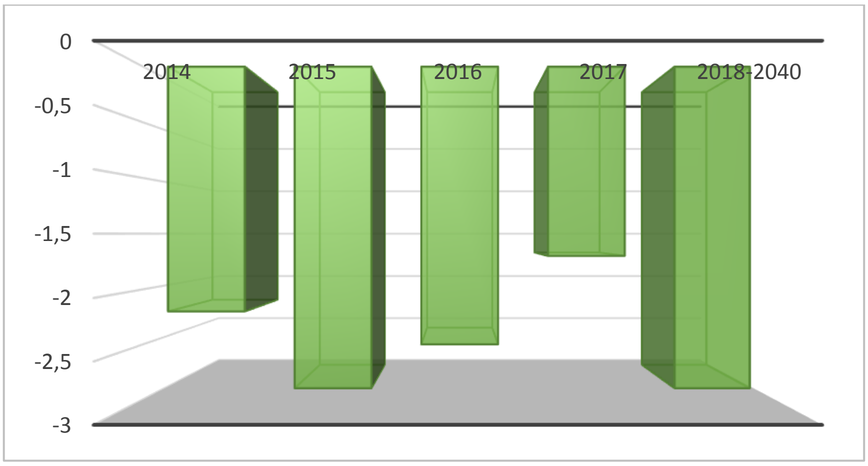

Figure 9: Average annual change in energy intensity (from 2014 and the tendency according EWS) [%].

Energy efficiency of end-use sectors improved by 30% in the EU-28 in the period 1990-2016. The average annual growth rate is 1.4% per year as measured by the ODEX indicator[2]. Almost every sector has contributed to the growth of energy efficiency. However, the sectors with the highest contribution have been the industrial sector by 1.8% per year, and the residential sector by 1.6% per year.

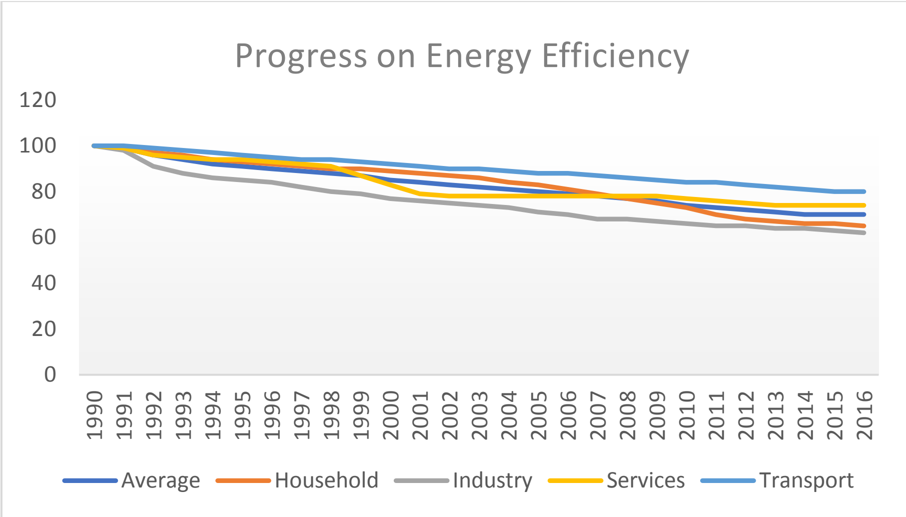

Figure 10: Progress on energy efficiency EU-28 (European Energy Agency 2016) [%].

The growth in energy efficiency in the industrial sector was 38% referring to 1990. Growth rate has been higher in the last 10 years and has gradually fallen by 2016. Efficiency has grown to almost all branches of industry. Growth has been slower in 4 of the highest intensity energy sectors such as chemicals, steel, cement and paper, which account for 55% of industrial energy consumption in 2016.

Efficiency is increased in the residential sector by 35%. A great contribution to this improvement was by interventions in space heating systems. Improving efficiency in new constructions and renewing the existing stock generated considerable energy savings. This is also result of the directives and savings targets set by the EU (Eco-design, the directive of Energy Performance in Buildings, Energy Efficiency Directive) and different nationals initiatives. In the energy sector, energy efficiency was up 20%. The highest level of training was the increase of efficiency in the aviation branch and then the cars. The service sector had a 26% improvement or 1.1% per year between 1990-2016.

3.1.3 Emissions

If we look at a global scale carbon emission[3], we will see that CO2 emissions have increased by 36.5% between 1990 and 2016. The same indicator has followed a positive tendency in OECD Europe countries by being reduced at a value of 30 Mt CO2 during the same period. Unfortunately, in Norway this trend had not the same direction because the amount of CO2 emitted only from fuel combustion has increased since 1990.

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[2] OEXD is the energy efficiency index. It is calculated by sector by weighting the trends of energy consumption or the specific values from their indexes. These measures are observed by sub-sectors or end-use.

[3] *CO2 Emissions from fuel combustion only.*

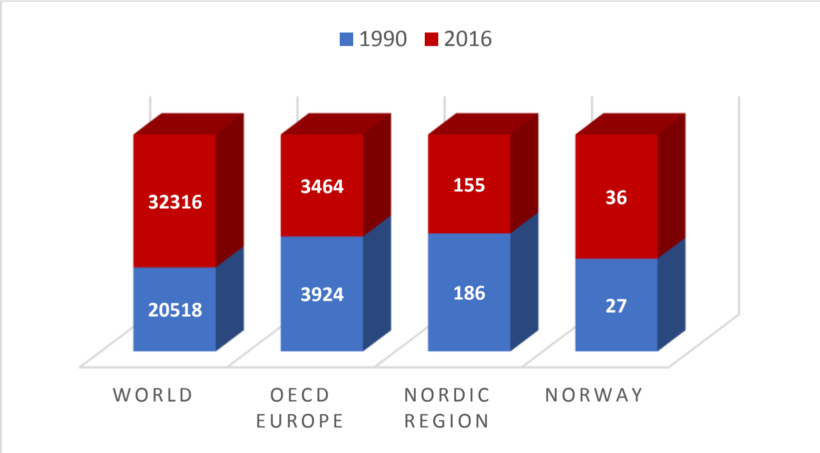


Figure 11: CO2 emissions tendency comparison (European Energy Agency 2016) [Mt CO2].

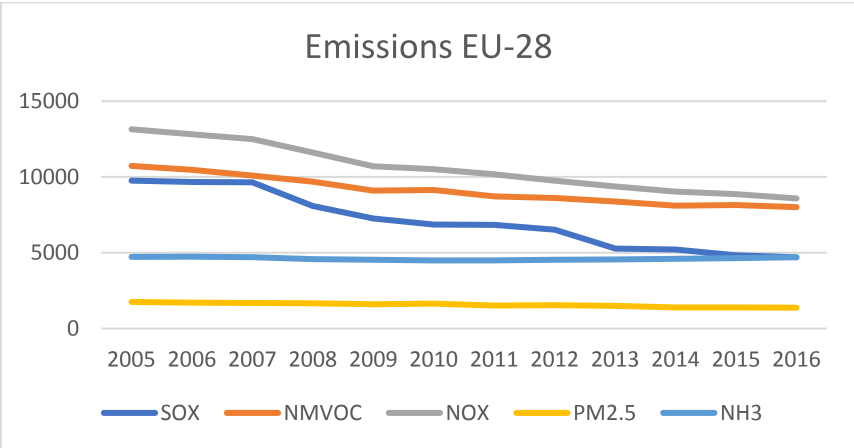


Figure 12: Emissions of the main air pollutants (European Energy Agency 2016) [Mt CO2].

The EU-28 meets its continuing obligation to maintain emissions of NOX, SOX, NH3 and NMVOC below legally binding targets, as specified by the National Emission Ceilings Directive (NECD). Emission reduction commitments for 2020 and 2030 have been set under the NECD, and for 2020 under the revised Gothenburg Protocol. The EU-28 is on track to meet its future reduction commitments.

3.2 Tendency of the European energy system

For some years now, the European energy system is in a transition process. The first outcome of this transition is expected to be the fulfillment, or not, of the 2020 targets. For the pressure to remain, after 2020, the targets of 2030 should be fulfilled and so on. This is a very difficult challenge, if we consider the:

- Transition from fossil fuels to low intensity renewable energy sources;

- Transition from existing infrastructure and traditional power plants (PP) to new technological and costly power plants CHP;

The closest challenge is that of 2020. This energy strategy involves the completion of the three pillars below:

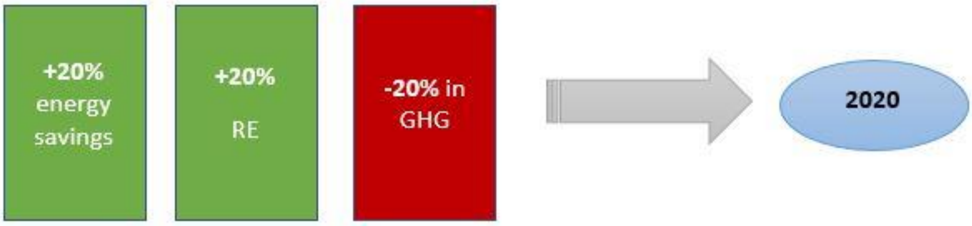


Figure 13: Own figure. EU 2020 targets

In addition to these goals, a 10% share of RES in the transport sector is to be reached by 2020 in all EU countries.

Ambitious policies that were planned to fulfill the 2020 objectives are now giving their prime effects. However, new policies should be introduced to further improve the achievements reached so far. The objectives of 2030, 2040 and 2050 will require stricter behavior and broader acceptance. The European Union must make progress by taking actions now to move to low-carbon society and economy. With a coherent and appropriate policy framework is more possible achieving 2050 goals.

Table 2: Low-Carbon Economy goals in 2030, 2040 and 2050 referring to 1990.

Year	2030	2040	2050	
Emission Reduction	40%	60%	80%	Compared to 1990

All sectors of the economy should be focused as leverage points where improvements and integration of energy policies can be implemented. The interventions should include energy consumer behavior, technologies used, and policies followed. The biggest change is expected to happen in the power sector where decarbonization possibilities are the greatest. This sector will be followed by residential sector with its energy efficiency improvements, insulation, use of low carbon electricity and use of renewable sources to provide heating. Industry can have a significant role in the decarbonization process by implementing CCS and increasing production processes productivity. Transport and agriculture will be part of the future improvements and they will contribute somehow in reaching these targets by 2050.

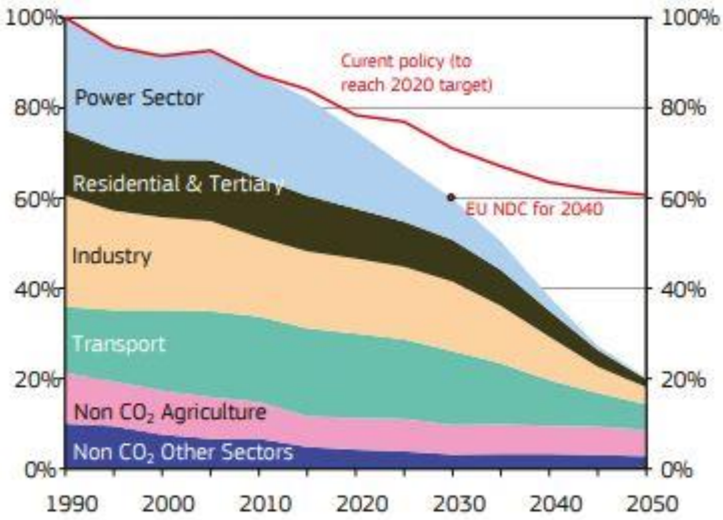


Figure 14: Roadmap 2050 will affect all sectors (Comission 2011) [%].

The transition from a traditional fossil fuel-based system to a system RES-based system will require new balancing options. While the traditional fossil fuel system is easily controllable in most of the cases, based on demand, the new systems are difficult to be controlled. Its control will depend on the technology used. Technologies like PV or wind turbines will produce fluctuating energy which does not always follow the demand for energy. This brings the need for flexible energy consumption through electricity storages, interconnection links between countries, conservation in other forms of energy and integration of different sectors within a country.

The increase of share of district heating systems would contribute to the European energy system to be more flexible. District heating systems can be considered as flexible energy consumption. As a technology that basically reuses energy that is considered lost, it has a high efficiency. As stated by European Commission in 2016, one of the objectives to achieve the "EU Heating and Cooling strategy" is establishing a cooperation between electricity and heating and cooling sector. Furthermore, DH systems are suitable for integrating the electricity that comes from renewable energy sources and heat from solar and geothermal sources. They can use the excess of heat, which is otherwise waste, being a great substituent of fossil fuels in the future. This is the way how district heating system could serve as flexible energy consumption for the EU energy system by storing heat in thermal storages.

Problem Analyses

4.1 White Paper on Norway's energy policy

The Norwegian government introduced the 28th August 2017 in the White Paper on energy policy towards 2030. Energy security is the main theme that requires a solution. As estimated by the Energy Trilogy Index, Norway has a B in 2018 rating for this indicator (Council 2018).

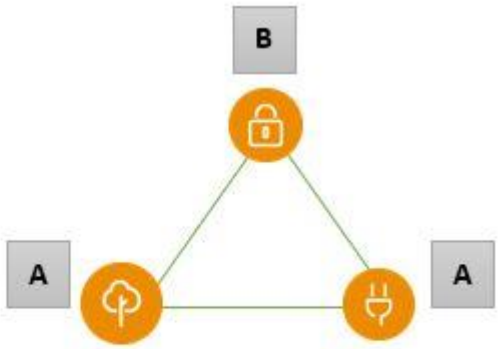


Figure 15: Own figure. Norway's Energy Trilemma Index

The main message is that supply security due to climate change and increased demand for energy is uncertain. Therefore, the energy policies of Norway towards 2030 are oriented to four main areas:

I. Enhanced security of supply

II. Efficient production of renewables

III. More efficient and climate-friendly use of energy

IV. Economic growth and value creation through efficient use of profitable renewable resources.

Nowadays, Norway manages successfully its hydrocarbon resources and contributes to a very significant level to global energy security. At the same time, it is striving towards reaching decarbonization targets in 2050. This is the right strategy to be followed to not confront a future with unsafe reserves of oil ang gas. To avoid this 'bad case' scenario precautionary measures should be taken. Diversification of current energy sources is an added value that increases energy security and reduces system dependence.

4.1.1 Position of Norway towards EU energy strategies

Norway owns almost half of the European power storage capacity. It can increase this capacity without the need of new hydropower installations. Norway can therefore offer largescale, cost-effective, efficient, and emission-free energy. This high capacity can play the role of a giant storage that will compensate the immediate needs of European countries to use carbon-free energies (like wind and solar).

Therefore, Norway can make a difference as the most important provider of balancing power. Large amounts of renewables can be integrated in Europe. That's why a good use of Norway's resources can be a great solution to reduce conventional energy from fossil fuels, within Norway and beyond. This solution can require improvements of the existing infrastructure like: Reinforcement of the power grid inside Norway with transmission cables and built of new interconnection lines between Norway and other countries for the expansion of the area. The use of maximum capacity in the existing hydropower plants, putting all the turbines in operation, is one of the solutions for increasing the storage capacity. Energy efficiency is another option to be suggested. This "hidden fuel" can play a major role to attain in the same time the reduction of 20% of energy and the increase of 20% of energy efficiency. Despite the progress achieved until now, on the efficiency side there is still a huge potential for energy saving. Residential sector represents a great option for this potential in thermal insulation and more efficient heating systems. Extension of the range of other renewable energy sources helps Norway at the same time: diversify its energy sources, so improving its Energy Security Index and saving water in reservoirs, so substitute conventional energy from fossil fuels elsewhere. Progress has been noted with wind energy, however other sources need to be considered (Biomass, Geothermal). To sum up, nearly 100% of the electricity use in the transport and oil sectors is renewable according to statistics. If fossil fuels used by the off-shore industry and transport are considered than there is an issue to intervene and reduce carbon emissions. This to be reached needs a greater capacity of power storage (Junge June 2013).

4.2 Norwegian energy System

Norway is one of the largest energy exporters in the world. As a result, it advances the energy security compared to other consuming countries and at the same time is engaged in sustainable environmental and climate policies. From a brief analyses of Norwegian energy policies, it can be noted that the country continues to manage its energy resources in the most reliable way and remains one of the biggest gas and oil suppliers. Historically, hydro power has been the essential energy source for generation of electricity. Hence, today 98-99% of the overall electricity generated is hydropower based. Norway, in a way, is privileged by its resources and its renewable capacity in comparison to the most European Countries. The Norwegian energy system have various attributes different from most countries giving challenges and opportunities within SMART Grid context:

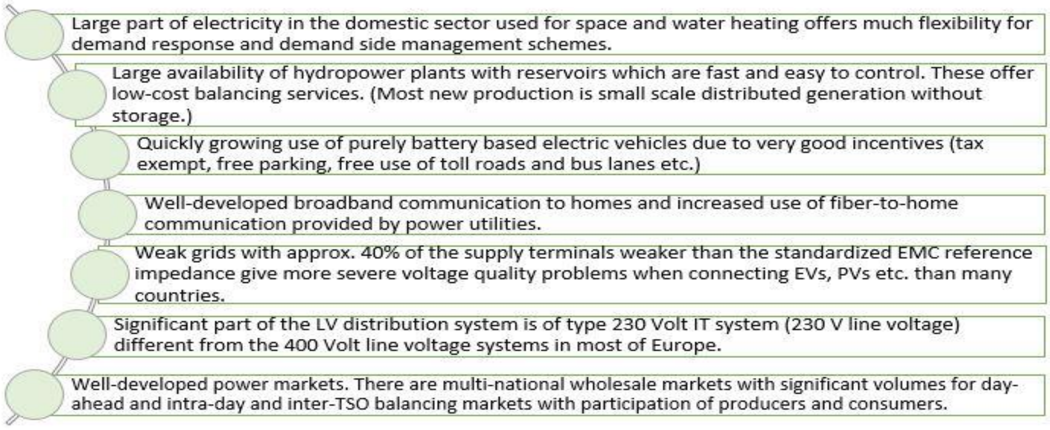


Figure 16: Own figure (Coldeven 2017)

In total, Norway's power system and -markets are well positioned for a future smarter and more renewable power and energy system, but some barriers such as weak grids in parts of the LV system needs to find their cost efficient and smart solutions. Full scale demonstration projects connected to real power systems are necessary to properly develop, test and verify Smart Grids solutions. Immature and high-risk solutions are best studied and tested in laboratories while the more mature cases and cases which include the behavior or human response of customers need to be tested in demonstration projects that are linked to real power systems with real customers.

4.2.1 Electricity Production

The Norwegian energy system is mainly based on electricity. According to International Energy Agency the electricity consumption per capita is high compared to the average. As can be seen from the graph, this value has been changing over years in the range 25,59-23,74 MWh per capita between 1990-2017. The main reason behind this could be that Norway has replaced other sources with electricity to provide space heating, domestic hot water, heating in industries. On the other hand, Norway has the electricity production with a high share of RES compared to the IEA average.

If we analyze values in 2015, the electricity consumption per capita is 23,59 MWh against the average of IEA of 8,72 MWh. While the share of RES in electricity production is 98 % compared to the average of 24% in 2016. Electricity consumption in 2017 is calculated by dividing total net consumption of electricity in 2017 resulting 124.827 [TWh] with the total population number in 2017 of 5 258 000 (Statistics Norway 2017).

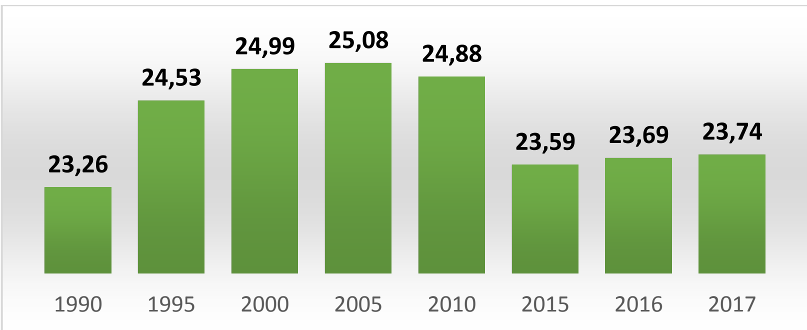


Figure 17: Electricity consumption per capita (IEA 2018) [MWh/capita].

Figure 18: Total electricity production in 2015-2016-2017 (Statistics Norway 2017) [TWh].

Total production of electricity has increased recent years. Electricity is the dominant energy carrier, followed by petroleum products. Electricity dominates energy use in manufacturing, the household sector and service industries, while petroleum products account for a large proportion of energy use in sectors that make heavy use of transport and machinery. District heating and natural gas account for only a small share of energy use, but this has been increasing in recent years. Consumption of district heating has risen, particularly on service industries and households, while there has been an increase in the use of gas in manufacturing industries and the transport sector. These energy carriers have been replacing fuel oil for heating and coal, coke and heavier petroleum products in industrial processes (EnergiFakta Norge 2017).

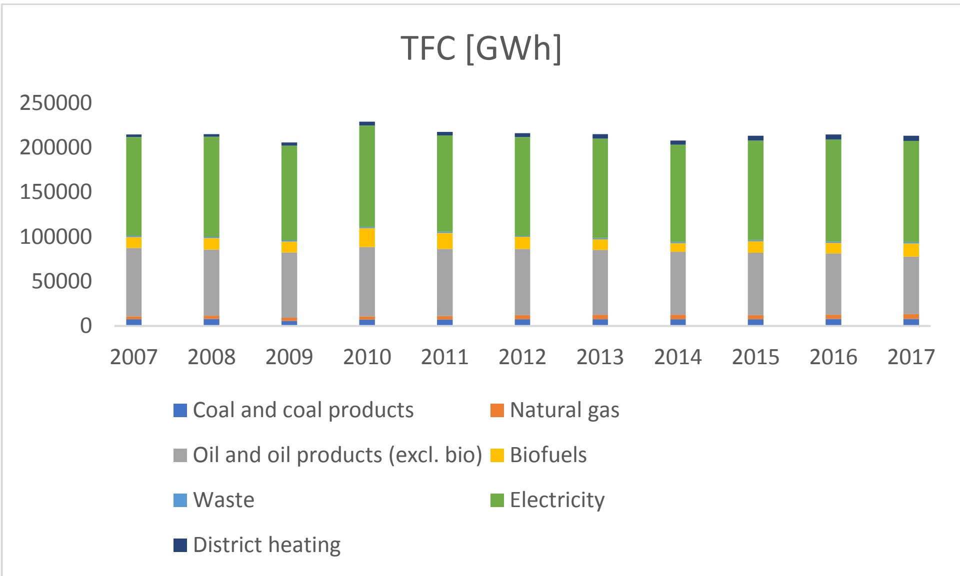


Figure 19: Total Final Consumption (TFC) by source (Statistics Norway 2017) [GWh]

In 2015, the residential and commercial sectors consumed 7.3 [Mtoe] combined, or 36% of the TFC. Energy consumption in the residential sector increased slightly by 0.2% over the past decade, whereas commercial and public services grew by 9% over the same period. However, energy demand varies year-on-year according to heating needs. Electricity accounts for three-quarters of the total energy consumption in the sectors. This is significantly higher than that in any other IEA member country and is largely explained by the widespread use of electric heating. Small volumes of residential and commercial energy demand are supplied by oil, biofuels, and district heating. The government is working on legislation to ban oil (and other fossil fuel) use for space heating from 2020 on. In 2017, final energy consumption in Norway totaled 213 TWh. As the figure below shows, manufacturing and transport were the sectors that used most energy in 2015, followed by services and households. Other sectors such as construction, agriculture and forestry and fisheries accounted for only a small proportion of energy use. This pattern has not changed much since 1990, although total energy use has risen in this period.

4.3 Electricity in different sectors

Electricity is different from other goods in that it cannot easily be stored. There must therefore always be an exact balance between generation and consumption. In the wholesale market, prices are determined for each separate hour of the following 24-hour period, based on bids and offers from many different participants, and given the availability of grid capacity. This short-term market adjustment ensures that the lowest-cost production resources are used first. Electricity prices also provide investment signals because they indicate where there may be a power supply deficit.

In contrast to most other countries in the world the electricity supply system in Norway consists, as mentioned above, almost exclusively of hydro power. The abundant access to watercourses, which have been developed over the years at very low costs compared with thermal power, has furthermore implied that a relatively large share of total energy consumption in Norway is covered by electricity. The supply of cheap electrical energy from hydro power projects was an important factor behind the rapid industrial development in Norway at the beginning of the last century. Foremost in this development was the establishment of electrochemical and electrometallurgical manufacturing plants in remote areas near the source of hydro power. Furthermore, relatively low electricity prices have motivated consumers to use electricity for heating purposes than may be observed in other countries.

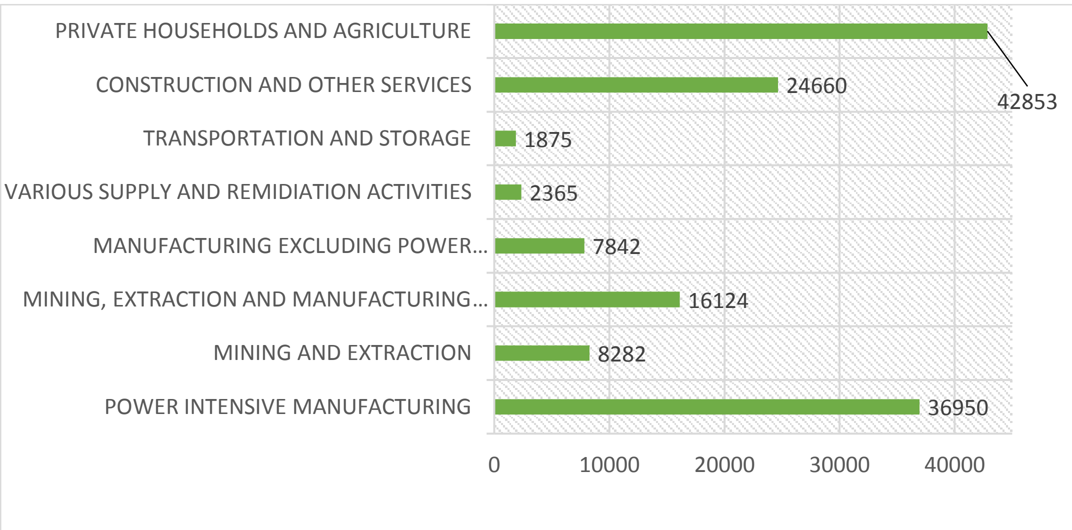


Figure 20: Net consumption of electricity [GWh], by consumer group, contents and year (Statistics Norway 2017)

4.3.1 Electricity in 2030

The trend of using electricity instead of fossil fuels is predicted to continue in the future. Households sector is more and more excluding heating oil and paraffin. Therefore, it will be replaced by heat electricity and other renewable thermal technologies. The same trend is to be followed in transport and industry sector where every day and more electric battery motors are replacing traditional combustion engines that are used in most of cars and other types of vehicles and working machines. These developments with increase the use of electricity but contrarywise they will contribute to lower the final energy consumption and GHG emissions.

The main factor in analyzing energy consumption tendencies is population variation. According to Statistics Norway and Population World meter population in Norway will follow the curve below:

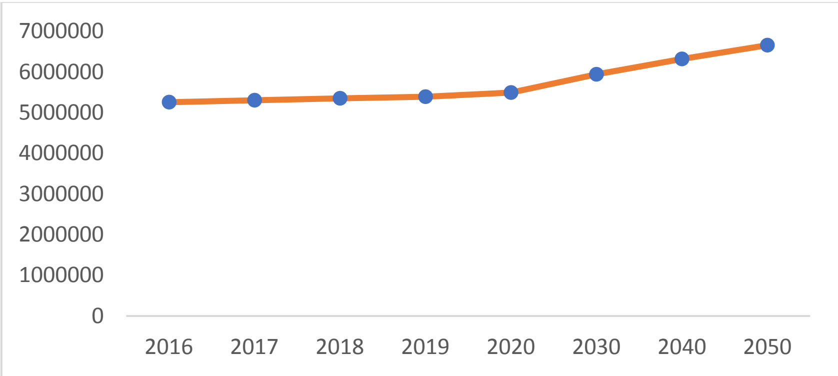


Figure 21: Population trend in Norway ((PopulationPyramid.Net 2016) [People]

Based on population growth prediction is estimated an increase in the use of electricity. It is expected higher electricity consumption in most sectors. In the households sector more residents means more houses that will consume electricity. In industry sector, more inhabitants mean more workers that need more professional buildings. The growth of electricity consumption will however grow slow because of better buildings and efficient appliances and systems.

According to NVE forecast is expected a growth of about 5% compared to 2012 when total gross electricity consumption was 130 TWh. The fastest growth will happen during first ten years and after that stronger policies will play the role of reducing the overall energy consumption. Building and manufacturing processes will be more efficient, heating sector will go towards low carbon heating systems and decarbonization to be fulfilled will affect every subject that uses energy.

A great increase of electricity is expected in the aluminum industry because of Karmøy pilot plan and possibilities for a complete aluminum production plant afterwards. Moreover, production of chemical row materials will play a significant role in electricity demand and in petroleum industry greater land facilities and electrified areas will provide more electricity with a peak of about 10 TWh in 2020s. In addition, growth is expected in the production of chemical raw materials. If the full-scale Karmøy plant is not realized, there may be little growth in the industry's electricity consumption by 2030. In the petroleum industry, extensions of land facilities and electrification of new fields will provide higher electricity consumption. The peak of the petroleum industry's electricity consumption is

expected to be reached in the middle of the 2020s, with an electricity consumption of around 10 TWh.
The transport sector is expected to face the biggest electricity consumption growth in 2030. Currently most of public and private transport vehicles have the highest electricity consumption in Norway and according to NVE prediction the growth will continue, and it will reach an increase of 3 TWh by 2030. This is a positive side of this development because it will reduce fossil fuels and in the same tame this is a good way of storing electricity and helping grid stabilization (Lund 2018). Total final electricity consumption is expected to grow to 130 TWh in 2030 proportional to 10% in the 2012-2030.

The trend of using electricity instead of fossil fuels is predicted to continue in the future. Households sector is more and more excluding heating oil and paraffin. Therefore, it will be replaced by heat electricity and other renewable thermal technologies. The same trend is to be followed in transport and industry sector where every day and more electric battery motors are replacing traditional combustion engines that are used in most of cars and other types of vehicles and working machines. These developments with increase the use of electricity but contrarywise they will contribute to lower the final energy consumption and GHG emissions.

Heating Sector in Norway

5.1 Development of the Heating Sector in Norway

Energy used in residential sector accounted for 22% of final energy consumption in 2016 or 47 TWh of FEC. The model of energy use in residential and service sector is almost the same because in both heating, lighting and electric appliances occupy a large scale of overall energy consumption.

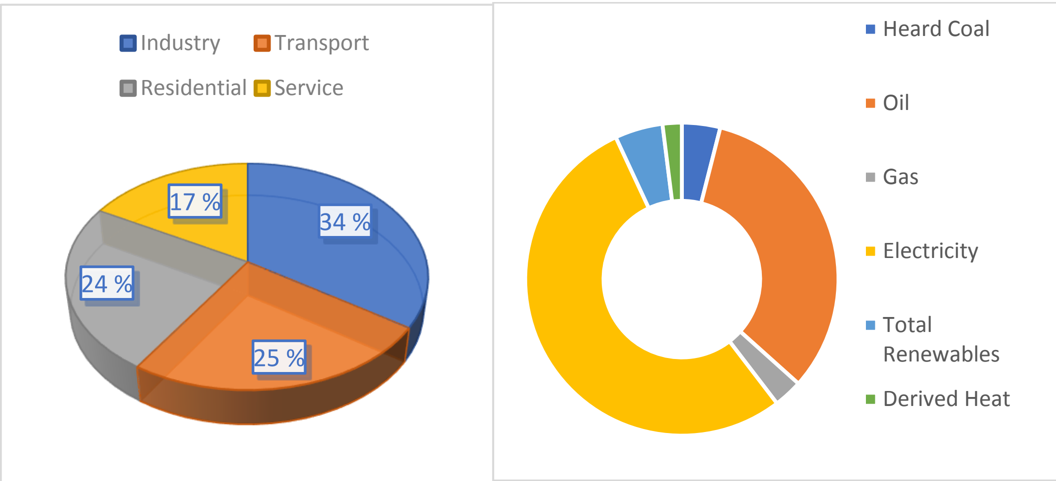


Figure 22: Final energy consumption by sector and fuel in 2017 (EnergiFakta Norge 2017) & (Statistics Norway 2017) [%].

Electricity is the source with the highest distribution in space heating and sanitary water in the residential sector and service sector. According to data collected in 2016, indoor space heating is mainly based on electricity (86%) and almost 90% of houses have access to heating to electric heaters and heating pipes. The share of electricity in household has reached 83% in 2016. The explanation about that high share is the increasing usage of electrical equipment and the aim of banning the use of fossil fuel energy sources in buildings (especially heating purposes). Compared to 1990 fossil fuels share in this sector were much higher than in 2016.

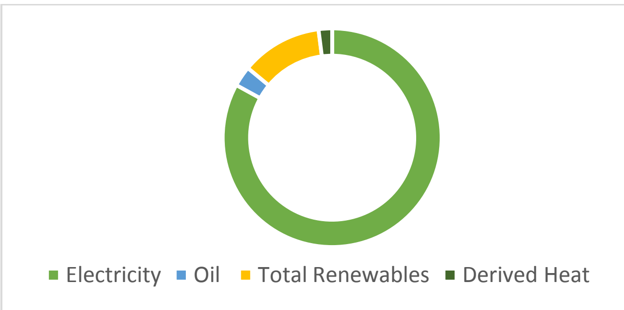


Figure 23: Final Energy Consumption by sector and energy carrier (EnergiFakta Norge 2017) [%].

Total renewables are second largest fuels used in heating in form of biofuels (wood, pellets and bio oils). Biofuels supplied about 5.5 TWh of energy use 12 of residential overall energy consumption. Electricity has been historically been the most used source in heating sector due to its renewable resource and cheap price. While oil, with oil fired heating (residential and commercial buildings) and fuelwood (private homes), and gas have furnished the rest. Recently, there have been a shift from fossil fuel energy sources to electricity, heat pumps and district heating systems. The share of district heating is increased with 85% in 2016 referring to 1990. Whilst, heat produced by heat pumps changed from 0,4 TWH to 15 TWh in 2016.

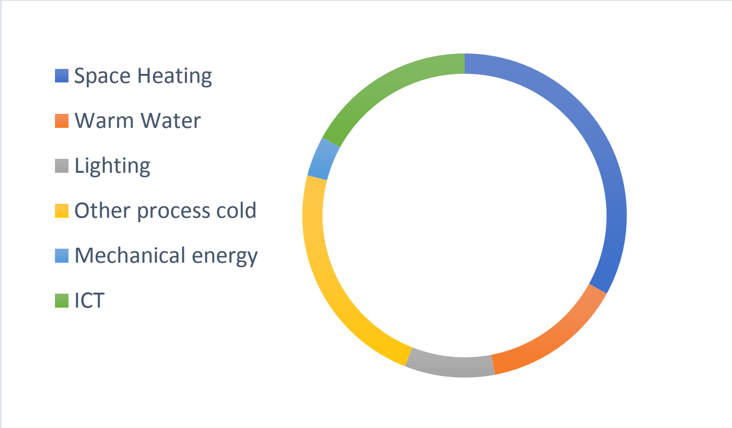


Figure 24: Final energy consumption by application in residential sector (EnergiFakta Norge 2017) [%].

The final demand in the residential sector in 2016 according to the applications was mostly used in space heating at 33%. It is followed by other process cold and by information and communication technologies respectively with 23% and 17%. Other applications when energy is used in the residential sector are warm water, lighting and mechanical energy. Application like warm water and lighting are continuously moving towards renewable and efficient solutions like thermal collectors and more efficient lamps.

5.2 District Heating

Norway has a total installed capacity of district heating 3200 [MW_{th}] and 95% of district heating comes from renewable energy sources. Currently, district heating has a minor part in Norwegian residential sector. It is often used as a back-up system in huge cities. Before, DH systems have been slowly expanded due to warm winters and because electricity excess offers low electricity price. District heating covered around 3% or 5,5 TWh of heat demand in the residential sector in 2016. Electric heating remains still in its dominant position for space heating and hot water. In total, district heating systems provide heat from renewable sources and recycled heat, while fossil fuel is basically used for peak loads. While district heating systems are improving their technology and becoming more efficient with lower temperatures, they expand the range of renewable sources that can be used.

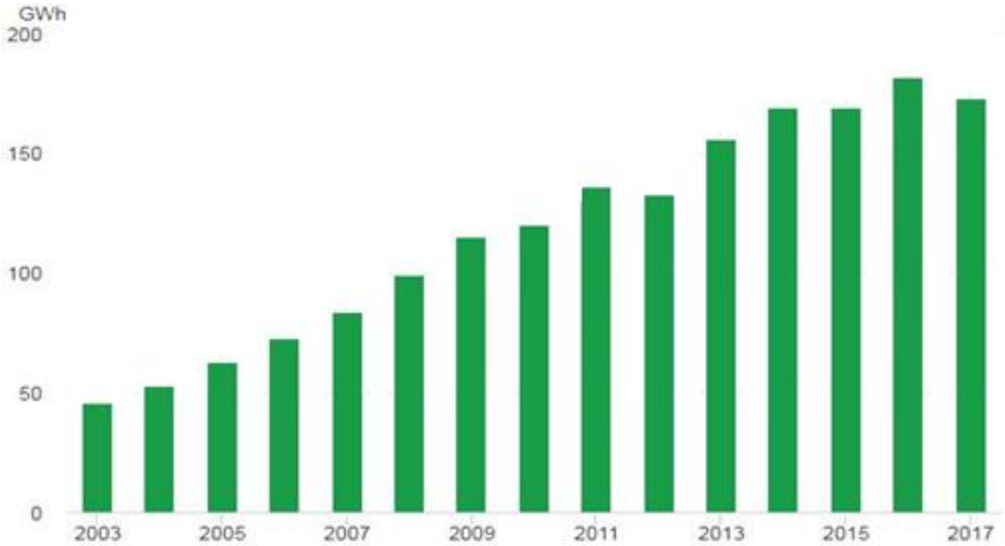


Figure 25: Consumption of District Cooling from 2003 to 2017 (Statistics Norway 2017) [GWh].

District cooling is expanding rapidly, by 17% from 2012 to 2013, and by 8% from 2013 to 2015 (169 GWh). Consumption of district cooling came to 173 GWh in 2017; about 5 per cent lower than the year before. The main driving force behind this expansion is the population growth and urbanization, and there is no regulation leading to higher prices than for district heating and better profitability.

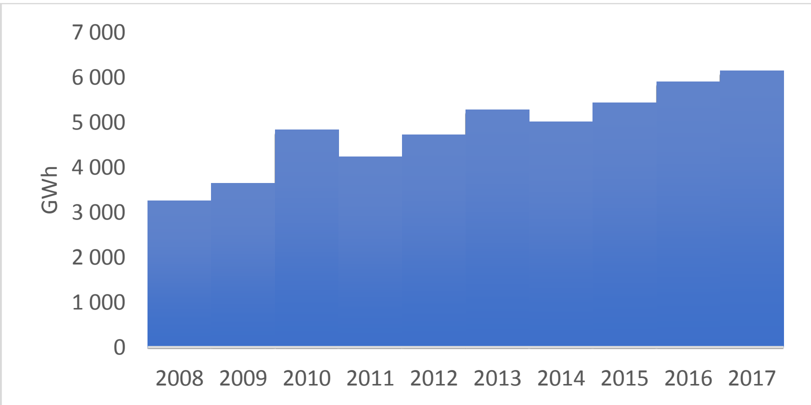


Figure 26: Net production of district heating [GWh].

In 2017, net production output from district heating plants was 6,149 TWh and increased by 3.8% compared to the previous year. In the period from 2008 to 2017, net production of district heating increased with 2,889 TWh or by about 46.9%. As seen from the chart above, the increase in net production by district heating has increased year by year. This increase is explained by the increased capacity of existing plants as well as by the construction of new plants. This growth lean toward energy targets of the future and the role of Norway balance of electricity in Europe. District heating deliveries totaled 5.5 TWh, an increase of 4.4 percent since the record year 2016. This is equivalent to about one tenth of the total need for energy to heat buildings and water in Norway. District heating has a total installed effect of 3 600 MW. District heating is most widely used in Norway's largest towns. In 2017, consumption of district heating in Oslo totaled 1.7 TWh.

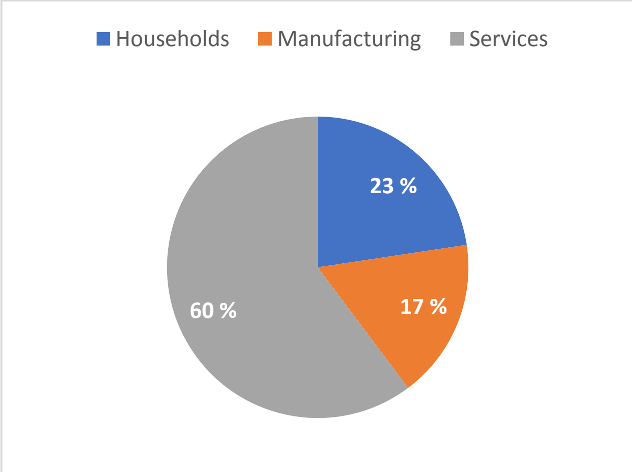


Figure 27: District heating delivered to the consumer [%].

About 60% of district heating production is used in the service sector, such as hospitals, buildings used for cultural and research activities and office buildings. District heating is also used in blocks of flats and in the manufacturing sector respectively 23% and 17%. District heating can be produced using many different types of fuel. In 2017, about 50 % of district heating was produced from waste and about 20 % from bioenergy. The use of bioenergy has increased over the last ten years, while the use of fossil fuels has decreased. Oil and gas accounted for about 5 percent of the production of district heating. District heating is a useful supplement to electricity. District heating can replace electricity consumption for heating purposes in winter and thus limit the need for investment in the power supply system. District heating systems can use electricity as an energy source when prices are low and other energy carriers when electricity prices are high. In Oslo, district heating can meet 25 % of peak energy demand.

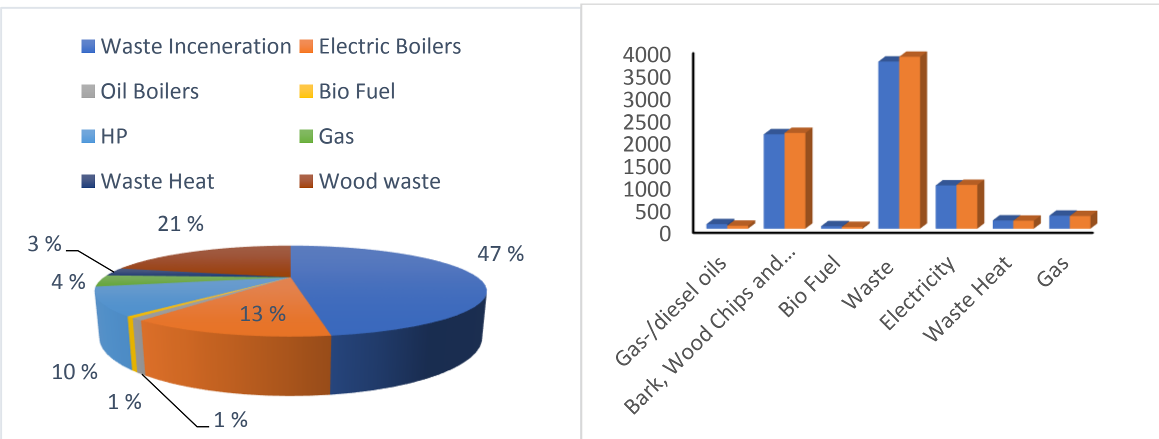


Figure 28: Consumption of fuel used for gross production of district heating [%]&[GWh-2017].

In total, over 90% of district heat came from direct renewable sources and recycled heat. There are several requirements for using renewable and CO_2 neutral resources in the district heating system in Norway. Fossil fuel is used only for the peak load and has decreased every year. District cooling is expanding rapidly, by 17% from 2012 to 2013, and by 8% from 2013 to 2015 (169 TWh). The main driving force behind this expansion is the population growth and urbanization and there is no regulation leading to higher prices than for district heating and better profitability.
The average price for district heating increased from 63.5 øre/kWh in 2016 to 66.7 øre/kWh in 2017. For households and the service sector, the average price was 68.9 and 73.8 øre/kWh respectively, but industry was lower, at 38.7 øre/kWh. The price for cooling amounted to 98.3 øre/kWh in 2017, which is 4 per cent higher than 2016. Increased district heating consumption and higher prices led to higher sales revenues from district heating in 2017. The revenues from district heating increased by about 10 per cent compared to 2016 and amounted to NOK 3.7 billion. The revenue from district cooling was NOK 170 million.

5.3 Transforming Norway's Heating Market

First district heating systems were introduced in U.S and they used steam as a heating carrier. District heating systems are heating and cooling provider to residential/commercial building and different manufacturing processes through hot and cold-water pipes. These type of systems have been improving over years and nowadays a transition towards fourth generation is happening. Technology changes and energy targets come very fast and therefore soon we will be surely talking about the fifth generation.

With its substantial access to low-carbon and very low-priced electricity, Norway started using district energy behindhand and today it is using district heating third generation. It means an integration of a high share of renewable energy sources. District heating usage has been doubled since 2008 with investments that accounted 190 million Dollar in 2015 and district heating covers already 10% of the heat demand in buildings. The main source is waste incineration followed by local resources like seawater, ground heat, residual wood waste and industrial waste.

In the commence of the millennium, Norway went through a sequence of cold and dry winters. Popular attention was on this issue and on the challenge of implementing new renewable thermal technologies. This awareness started from heat pumps and is today converging toward district energy. Renewable Thermal Technologies (RTTs), now growing its values as emission reduction tool represent the solution to achieve 2050 decarbonization. Simultaneously, new policies and regulations have the main role aspiring new technologies, such as:

- Building code banned oil boilers in new buildings and required a certain share of renewable thermal energy, sending strong signals that fuel oil for heating was to be phased out.
- The EU Building Energy Directive requires all buildings that are sold or rented to post an Energy Performance Certificate, allowing customers to compare the energy performance of buildings. Integrated thermal technologies benefited from this.

The new pattern of the sector is primary for leading to build the low carbon buildings of the future and ‘less carbon’ future.

District Heating Theory

6.1 District Heating Concept

District heating concept is mainly based on the idea of 'recycling' the energy that is otherwise lost. It would have gone to waste if district heating systems had not taken this energy into use where it is needed. Evolution of new, efficient heating systems, that use the left-over energy in society, has an enormous importance nowadays when the whole world is suffering increasing energy demand. To better comprehend how DH systems, contribute to energy efficiency it is substantial to first know the correct meaning of the term "primary energy".

Primary energy is the energy available in the environment and directly usable without transformation. Given the energy losses during each stage of transformation, storage and transport, the quantity of primary energy is always higher than the quantity of final energy available (Futura-Sciences 2002). To convert primary energy into a useful energy for the consumers, is often indispensable a transformation process. The most common form of transformed energy used is electricity.

Transformation processes of primary energy to final energy are accompanied with losses that depend on the efficiency of the processing process or the transformation device performance. The following figure shows a clear scheme of the transformation of energy to the final user. The figure below shows how primary energy sources are incorporated into a processing process to give end users energy for light, work, heat and cooling, and how this gives energy loss and emissions along the way. Apart from the loss of energy and emissions of pollutants in nature, the extraction or use of primary energy affects the intervention and damage of natural environments by increasing the anthropogenic impact.

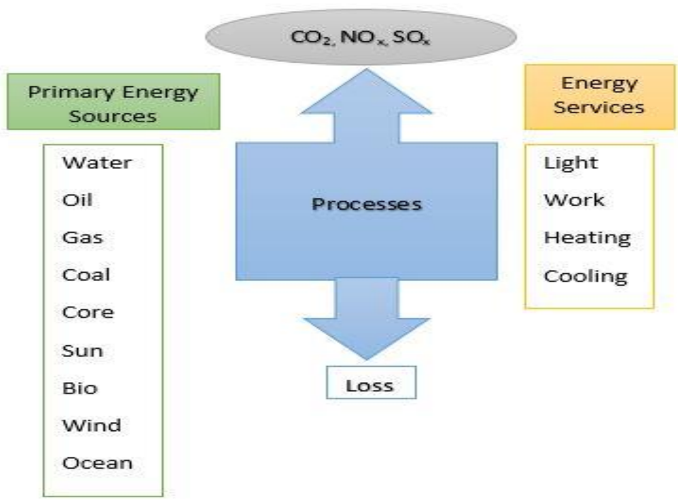


Figure 29: Primary energy sources, processes and energy services

6.2 WHY DISTRICT HEATING

District heating main purpose is to use energy sources that are left over in society and considered as losses. Their removal or treatment is often costly. Thus, these sources can be used instead of regular inputs that have an increasing demand. In this way, district heating systems reduce total use of energy resources increasing energy efficiency system level.

6.2.1 District heating utilizes surplus energy

District heating is about using energy that would otherwise have been lost, instead of contributing to increasing the extraction of primary energy resources. This is energy that remains due to another process or activity, such as forestry, industrial production or waste treatment. The better a district heating company succeeds in using such surplus energy, the more district heating contributes to reduced energy loss in society, and to reduced use of primary energy resources. Reduced use of primary energy resources results in reduced emissions and reduced nature interventions. District heating companies are virtually always established because there is surplus energy in a local community.

6.2.2 Bio fuel

Products from forestry, lumber, wood processing and agriculture are quite used in district heating. The type of biofuel is dependent on the sources available ant they vary from one place to another. It is always positive for the district heating plant to be near the biofuel source and so to eliminate the excessive cost. For example, a district heating plant that is near to a flour factory can use grain refiner as a fuel, or if it is near a forestry can use branches and peaks that are left over from industry or seasonal tree pruning. Another plant can use demolition and so on. In industrial companies waste from industrial processes can be used as a district heating source instead of being released in the atmosphere. In Norway, district heating companies use waste heat from smelters and metallurgical industry. In Europe, where fossil fuel power (gas, coal) are more common, heat is mostly generated from the surplus heat from power production. Such use of waste heat is called *CHP*, or *CHP* (Combined Heat and Power). In Norway, CHP is less common, because of less thermal power production.

6.2.3 Waste that cannot be recycled can be used for energy utilization

Waste heat is the most used type of heat in 8 major cities of Norway. Heat from wastes is the most common type of heat used in district heating systems in Norway (especially in eight major cities of Norway). Waste heat is the amount of heat that remains after incineration (waste burning). It represents currently about one third of the heat production in DH companies in Norway. The main reason behind this is that Norway have a well-arranged waste management structure will follows waste hierarchy principles.

Figure 30: Waste hierarchy order (Mavropoulos u.d.)

The core principle of this hierarchy is that waste must be captured as high as possible so that will be less wastes to be burned or to be landfilled. However, no matter how perfect this management is, there will be always a certain amount of waste that should be burned. As stated from Norway's waste and incineration policy at least 50% of energy extracted from this process should be used for useful purposes. This is done to increase energy recovery which is in that case to gain from what is already wasted.

6.2.4 Surplus heat from soil, bedrock, sea or sewage

Another type of surplus heat widely used from district heating is residue heat from soil, bedrock, sea or sewage. In Norway, many district heating plants are in areas where they can easily extract this excess heat and lift it to a level of temperature where it can be useful. The Norwegian district heating industry is also in the starting pit with investments and adaptations to be able to utilize several such types of ambient heat with lower temperatures.

6.3 District Heating Development

6.3.1 Evolution of DH systems

Future DH systems should absolutely be designed for the future system. One of the main challenges of the future is integrating district heating both with electricity sector and transport sector (Jiang XS 2014). In the upcoming years, this future system will be referred as a smart energy system. It can integrate smart electricity, smart thermal and smart gas grids in the same time and find the optimal solution for individuals and overall system.

To better understand the evolution of district heating systems let's look back to earlier generation and current application. The first generation of district heating systems were introduced in USA in 1880s. About all DH systems initiated between 1880 and 1930 used this generation technology. It is characterized by steam as the heat carrier. Distinctive elements of the technology used were pipes in concrete ducts, steam traps and compensators. Over years, negative aspects affected the work and maintenance of the system and brought it Over the years, negative aspects affected the work and maintenance of the system and brought it behindhand. Negative aspects like: high steam temperature (over 100 degrees) causes great heat losses and has considerable probability of steam explosions which have killed people, condensate returns pipes have often corroded lowering energy efficiency. Even so, steam as the main heat carrier is still used in

Manhattan and Paris, under stricter and modern control measures. In some other major cities like: Hamburg, Munich and Salzburg system were completely replaced, as is happening in Copenhagen. The establishment of first district heating systems was a method of replacing individual boilers. It would give them greater comfort and less risk from unpredictable incidents (Henrik Lund 2014).

The second generation of district heating systems was a technology used in large Soviet-based DH systems between 1930 and 1970. This technology used pressurized hot water as heat carrier and supply temperatures of the pressurized hot water reached over 100°C. Distinctive components were like in the previous generation pipes in concrete ducts, large tube and shell heat exchangers and large, heavy valves. In some areas of implementation this technology lacked heat demand due to bad quality of the system. While in other zones where quality was better this technology still can be found on some old parts of water-based DH systems. The reason of establishing this technology was to further increase comfort and save primary energy sources through greater energy savings.

The third generation of DH system were first introduced in 1970s and is often been referred as 'Scandinavian DH Technology'. Many if this technology components are being produced in Scandinavian countries. It has replaced older technologies and individual heaters in almost all countries of Central and Eastern Europe, former USSR, China etc. This technology still uses pressurized water, but temperatures are getting lower and lower. The trend throughout these three generations has been towards lower distribution temperatures, material lean components, and prefabrication leading to reduced manpower requirements at construction sites (Henrik Lund 2014). Following these identified directions, a future fourth generation of district heating technology should comprise lower distribution temperatures, assembly-oriented components, and more flexible pipe materials. The main reason of developing a third generation was protecting security of supply by replacing oil with other cheaper and clean fuels (after two oil crises).

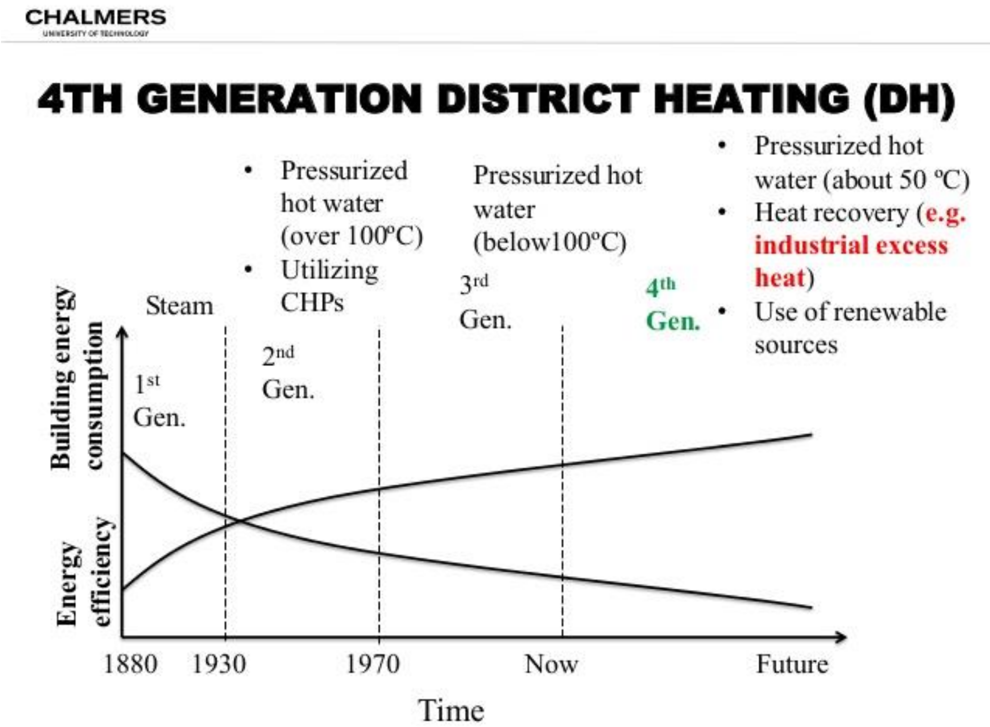


Figure 31: District Heating Technology Evolution (Akram Sandvall 2014).

The fourth generation of district heating has been developed recently but there is no practical system implemented yet (except small areas to test the technology). It has been referred as the technology of the future which will have a key role in the task of increasing energy efficiency and meeting the energy demand of the future.
Involving DH in future sustainable cities expand the use of CHP and heat from Waste-to - Energy. Future district heating technologies should, however, not be designed for the present energy system but for the future smart energy system.

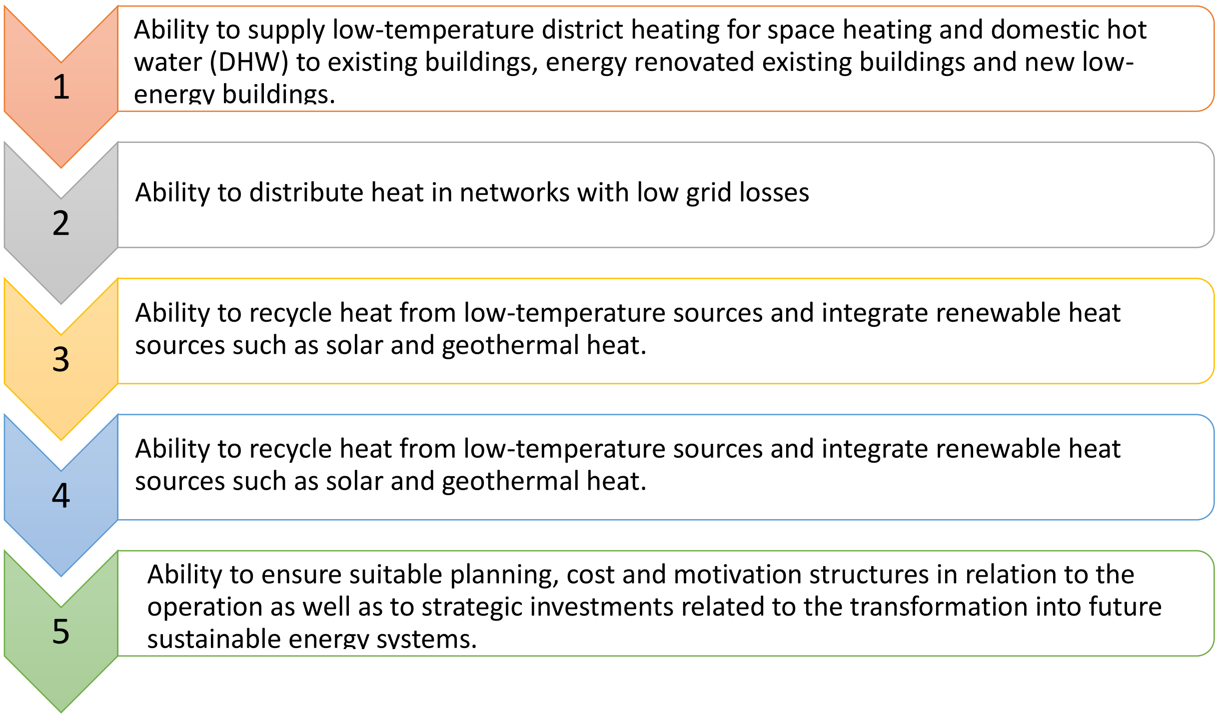


Figure 32: Five challenges of 4TH DH

METHODOLOGY

The purpose of this chapter is to explain the techniques and methods used in this master thesis. This is a study focusing on the analysis and forecasts of future values based on current trends and constraints. Quantitative indicators are successfully used to achieve evaluation in this scope and provide an effective platform for decision makers. The energy future is ambiguous. Thus, the determination of the current situation in the energy sector in Norway is the way to use the main indicators for observing sustainable development in the heating sector.

7.1 RESEARCH METHOD

The research method used in this master thesis is both quantitative and qualitative, so it is a mixed research method. As a definition, quantitative methods emphasize objective measurements and the statistical, mathematical, or numerical analysis of data collected through polls, questionnaires, and surveys, or by manipulating pre-existing statistical data using computational techniques. Quantitative research focuses on gathering numerical data and generalizing it across groups of people or to explain a phenomenon (Babbie 2010). In this study, quantitative research methods are utilized to analyze and forecast what the trend of energy indicators will be. Through individual research, documents review and email requests, numeric energy indexes are provided and used to discover the future development of energy system in Norway, especially in the heating sector. The software used to manipulate data towards required results is EnergyPlan. Thus, quantitative methods help to quantify a certain problem or a situation and escalate the quantitative results to a qualitative solution.

Meantime, qualitative research is a social-science research that allocates and analyzes non-numerical data. Qualitative methods used, interpret these data and give results to understand the problem of a targeted population or place. Qualitative methods were used to extend the understanding of the Norwegian energy system. In this master thesis, qualitative research was mainly used to find out constrains of the main idea of the study through two main qualitative methods: literature review and email correspondence.

When using qualitative and quantitative methods, we ensure that research is not limited to data collection and interpretation. Consequently, the limitations that these methods have when used separately will be reduced and the research will be more complete.
However, the use of two research methods is sometimes difficult. It contributes to more thorough research and therefore requires more research processes time (Nataliya V. Ivankova 2006).

The mixed research method is strongly related to triangulation measurement technique. The role of triangulation in mixed methods research at the analytic stage is on the combination or conversion of quantitative and qualitative data. Triangulation is a measurement technique often used by surveyors to locate an object in space by relying on two known points to ''triangulate'' on an unknown fixed point in that same space (Hesse-Biber 2012). Fielding argues that we mix not because there is something intrinsic or distinctive about quantitative or qualitative data. Quantitative and qualitative data can be mixed for illustrating a more complete understanding of the phenomenon being studied. This raises the specter of a new role for researchers who can provide quantitative and qualitative data in a mixed format through technology in real time as a basis for researching in contexts in which integration of such data can contribute to informed decision making.

7.2 Data collection

Data collection has a crucial role in the statistical analysis. The data used in a study can be classified in two frames: the source of the data and the nature of the data.

If we consider the source where the data come from they can be primary or secondary. As the name suggests, primary data is one which is collected for the first time by the researcher while secondary data is the data already collected or produced by others. The primary data are usually collected from experiments, interviews, surveys etc.

According the nature of the data they can be quantitative and qualitative. Qualitative data is a data concerned with descriptions, which can be observed but cannot be computed. On the contrary, quantitative data is the one that focuses on numbers and mathematical calculations and can be calculated and computed. Both types of data are used in this master thesis.

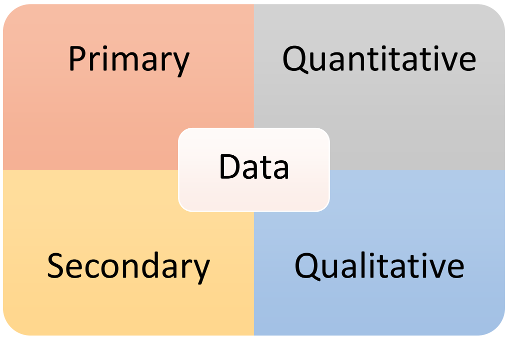


Figure 33: Classification of data

In this research secondary data are used. They have been previously collected, processed and analyzed by others. When studies are based on secondary data it is important for the researcher to verify the data or to gather only from reliable sources. Therefore, data taken into consideration in this research are found from various official and serious sources.

There are three main requirements that data should accomplish to be used in the research (Kothari 2004):

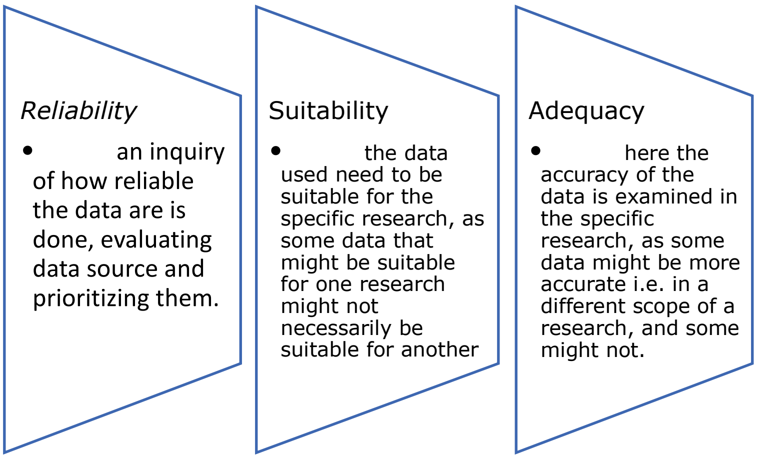


Figure 34: Three main characteristics that data should accomplish (Kothari 2004).

Sometimes it is not easy to obtain primary data. Contrarywise, getting material from other sources is simple and slight. The commitment to extracting data from the stakeholders is usually of a very high level. This means that secondary data usually have a pre-established degree of authenticity and reliability and usually do not need to be tested by the user who reuses for their authenticity. In addition, secondary data can also be helpful in the research design of subsequent primary research and can provide a baseline with which the collected primary data results can be compared to. Therefore, a wise way to start a research is reviewing and analyzing secondary data (Sigdel 2018).

The methods used in collecting data in this master thesis are mainly: literature review, internet articles research and statistical database.

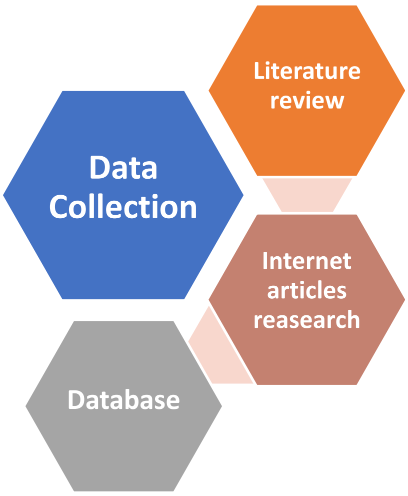


Figure 35: Data collection method chosen for this research. Own figure.

7.2.1 Literature review

The literature review is a method that works as an account of what has been published on a theme (subject) by accredited researchers and scholars. It gives the researcher a better understanding of a topic. This could be done to evaluate the research on a previous study, to find solutions to different problems or just to do a current research study.

Literature review can be traditional or systematic (Cronin 2011). Traditional review, also called narrative literature review, is more common to help the researcher gather a most generic information. Because a traditional literature review lacks a formal or reproducible means of estimating the effect of a treatment, including the size and precision of the estimate, a considerably more structured approach is needed. The "systematic review," also known as the "research synthesis," aims to provide a comprehensive, unbiased synthesis of many relevant studies in a single document. While it has many of the characteristics of a literature review, adhering to the general principle of summarizing the knowledge from a body of literature, a systematic review differs in that it attempts to uncover "all" of the evidence relevant to a question and to focus on research that reports data rather than concepts or theory (Edoardo Aromataris 2014).

For this research, traditional literature review techniques are used. The purpose of the traditional literature review used in this study is to demonstrate a gap or a problem in Norwegian heating sector that this research seeks to address. The importance of addressing the gap for heating sector and energy field in general must not be assumed but persuasively demonstrated. Indeed, explaining why there is a need for filling the gap helps us to justify our work's value, originality and significance.
There are no criteria for inclusion or exclusion of literature used in this study. All the books, published articles, article reviews and web sites that provide information within the framework of the topic are taken into account. The information gathered narrows down the problem and lead to a *research question*.
In addition, the sources of information selected for this study are qualitative or quantitative and subdivided primary or secondary. The information collected is taken from official research journals, study research and national statistical portals.

7.3 CHOICE OF MODELLING SOFTWARE

The choice of software suitable for this master thesis was done based on the publication of 26th January 2015 of David Connolly "Finding and Inputting Data in EnergyPlan" and a review made from him at 2009 over various modelling tools that could incorporate RE into different energy systems.

Analysis of several modelling tools and assessment of suitability with our study resulted in the choice of the most reliable tool. The following criteria were analyzed:

- ✓ Transparency, complexity and simplicity in the use of the model;
- ✓ Availability of data (database);
- ✓ Flexibility of the selected model in building scenario;
- ✓ Matching the results obtained with the user's aim
- ✓ International acceptance of the model (used by different Institutions);
- ✓ Cost of the model;

✓ The technical support provided;

These criteria secure that the chosen tool would include analysis of the overall energy system covering all sources and sectors of the energy at a national based level. Also, it should be able to perform on hourly bases analysis. The last fact is that it should be costless accessible.

In this master thesis we will analyze how a change in the heating sector will affect other sectors in Norway. Normally, an energy modelling tool that includes all affected sectors, can identify the changes in each sector and how they affect in the overall energy system. Norway is already with a high share based on renewable energies and the possibility of designing a 100% RES system should be considered.

7.3.1 EnergyPLAN

Choosing the most suitable software for conducting energy analysis is difficult because we are not competent and familiar with any existing software. Energy tools that can be used are of a broad range and they consider different regions, different technologies and have different scopes of study. Therefore, the first step I followed was finding the overall objective of my entire work. My overall objective of this master thesis is:

"To identify how Norway could integrate district heating system into its heating sector, as a new way of heating space and water in the residential sector"

After the formulation of the general objective of the study, which is the software that can lead us to our study goal can be evaluated by comparing energy tools with each other. Based on a publication titled "A review of computer tools for analyzing the integration of renewable energy into various energy systems" published in 2010 (Connolly 2015), where several energy tools are analyzed and compared to each other, the chosen software is EnergyPlan because:

EnergyPlan is *simple* to use. It is a user-friendly tool and its training period takes from a few days up to a month depending on the level of difficulty required. Related to this, everyone interested can access the online training materials and case studies available on EnergyPlan official web page (University u.d.). Moreover, this software is widely used and for any uncertainty can be found expository publications.

When using EnergyPlan *availability of data* is not a problem. The data required to build the energy plan model are easily accessible in the statistical portals in national, regional or global level. Finding data is often problematic in building accurate and valid models. Therefore, the ease of searching and finding them is a relief for a researcher who has based his/her research on secondary data.

EnergyPlan is *flexible* in building the desired scenarios. some other energy tools, EnergyPlan considers three important sectors of any national energy system. It includes electricity, heat and transport sectors. Since the heating sector at the national level is the mainstay of this work, this makes the selection of this energy model very preferable. Moreover, the heating sector in the country we are studying is closely related to the electricity sector. If the future follows the current trends, the transport sector will have a dominant effect on the electricity sector in the future. Precisely, the focus area of the model complies with the focus we have on designing energy scenarios and this is one of the main reasons for choosing EnergyPlan as the energy model in this master thesis.

One of the most possible methods of creating a flexible energy system is by integrating electricity, heat, and transport sectors in one single smart system. This can be realized by using technologies such as: Combined Heat and Power Plants (CHP), Heat Pumps, Electric Vehicles and Hydrogen.

EnergyPlan has a high *international acceptance*. The conclusions resulting from using EnergyPlan are increasingly being published in very well-known academic journals. Reading some of these journal papers make you understand that the contribution of these results is undisputed, like in the case of Denmark energy system (Lund H 2009).

The EnergyPlan software is *free* to download. Everyone can sign up and create an account at EnergyPlan official web page ask for a license. In this way, students or researchers have the right to use this software free of cost in a certain period.

The last but not the least, EnergyPlan *technical support* are fast with their answers and helpful any time the user has a problem.

EnergyPLAN is a deterministic input/output model made in Delphi Pascal. The tool is used to model national or regional energy systems. It works on an hourly basis and therefore distribution files used are also based on hourly values. Thus, they have 8 784 data entries according to every hour of a leap year. Distribution files for common years which lack this additional day have the same amount of entries. This is done by repeating the last 24 hours of the year twice (Lund 2014).

The full energy model flowchart in the EnergyPLAN model is presented in figure below.

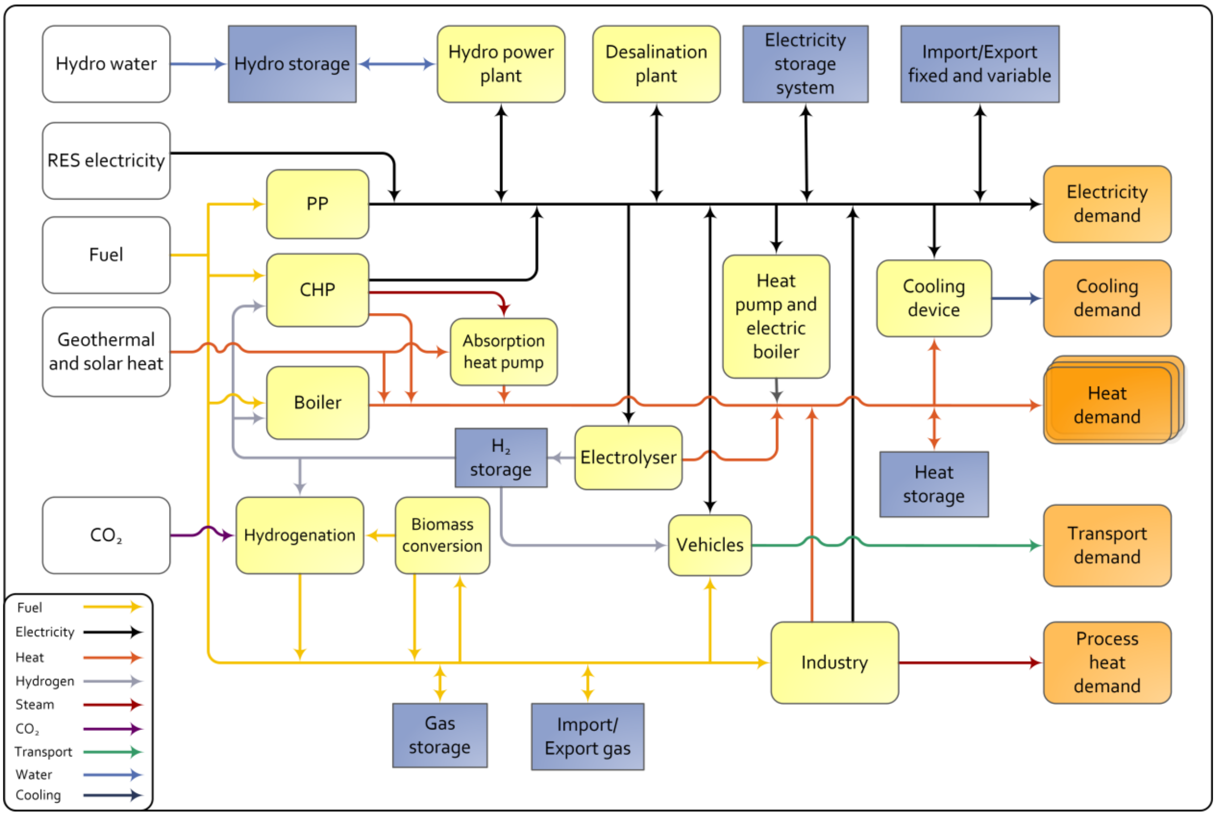


Figure 36: EnergyPLAN model flowchart (Lund, EnergyPLAN - Advanced energy systems analysis computer model. 2014).

7.3.2 Choice of simulation strategy

When we start building an energy model in EnergyPlan we need to know that this model ensures several simulation strategies but two of the are mainly used. These strategies determine the nature of the focus of the study, so if the study is geared towards new technologies or ways to minimize cost. These two types of simulation strategies that EnergyPlan mainly provides are:

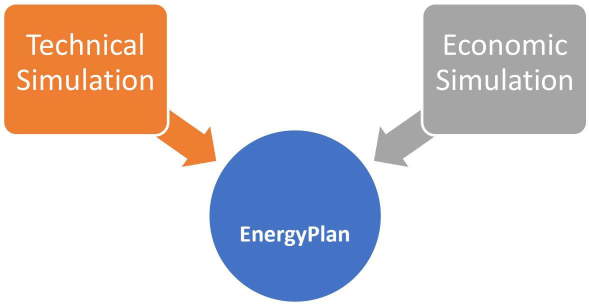


Figure 37: Two main options that EnergyPlan provides as simulation strategies (Connolly 2015).

The first strategy focuses primarily on meeting the targets of carbon emission reduction. Consequently, it focuses more on the withdrawal from the traditional technologies that use fossil fuels and the integration of renewable energy technologies to compensate the gap in the demand for energy. That's why, the technical simulation strategy in EnergyPlan is in the same time the total annual cost of the system. On the other hand, the market economic simulation strategy has the primary focus on minimizing the cost of the energy system operation. In principle, these two strategies oppose each other, as new and low carbon technologies are costlier. However, in the following, we will find the optimal point where these two strategies merge and give their most positive impact.

In this master thesis, we are mainly focused on suggesting the technology that contributes on the Norway's GHG emissions reduction objective for 2050. Thus, the simulation strategy that was chosen is technical simulation strategy, which has four sub-technical simulation strategies:

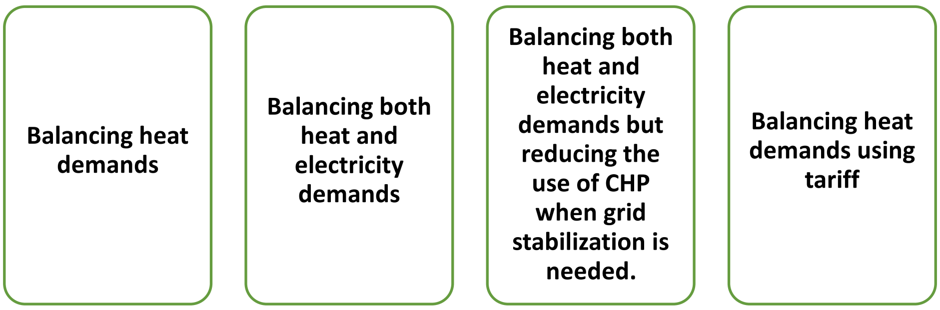


Figure 38: Four sub-technical simulation strategies

Under the '*Balancing Heat Demands'* sub-technical simulation strategy option, all units are producing solely according to the heat demand of the system. For district heating groups 2 and 3, the units are given priority on an hourly basis according to the following sequence:

Table 3: Units priority in district heating groups 2 and 3

Solar Thermal	q_{solar2}
Industrial CHP (CSHP)	$q_{industry\text{-}DH2}$
Heat production from waste fuel	q_{W2}
Heat plant CHP	q_{CHP2}
Heat pumps	q_{HP2}
Thermal Storages	q_{ths2}
Peak load boilers	q_{B2}

This model makes sure that no heat production becomes negative. Therefore, units that produce both heat and electricity rely on the heat demand and would not produce electricity if there is no need for heat.

In *'Balancing both heat and electricity demands'* strategy, the export of electricity is minimized by using heat pumps in CHP plants. This leads to a simultaneous increase and decrease respectively in the demand for electricity and in the electricity generation, since CHP units must reduce heat production. Utilizing the additional capacity in CHP plants combined with heat storages, production in condensation plants will be minimized as it is replaced by CHP plants. Also, according to this strategy the electricity produced from CHP, e_{CHP}, at any time should be lower or equal to the maximum capacity, CCHP. Also, e_{CHP} should meet the same condition corresponding to the capacity of heat demand that is not covered by industrial CHP (including waste and biomass conversion) and solar thermal production.

The third strategy '*Balancing both heat and electricity demands but reducing the use of CHP when grid stabilization is needed'* is the same as the second simulation strategy beside one element. In the previous simulation strategy, CHP will not be reduced if CHP units are needed for stabilization and the heat production will be replaced by heat pumps. While, in some cases when CHP stabilization factor is under 100%, surplus production can be minimized by reducing CHP and replacing heat production by heat pumps, boilers and stabilization demands by PP units. Hereupon, according to this strategy, CHP units can be reduced even when stabilization demand convene for replacement by PP units. The choice between the second strategy and the third strategy is the choice between a better efficiency and less surplus production. To summarize, the main difference between these two simulation strategies is that the use of CHP's is reduced not only when there is more than needed electricity produced but also when the system requires additional grid stabilization.

Strategy 'Balancing heat demands using tariff' is similar with simulation strategy one apart from one factor. The CHP units of the group 2 in this case do not operate according to heat demand but they follow the Danish triple tariff. The electricity produced from CHP units in group 2 is located according to an order of priority, i.e., peak load, high load and low load. The periods of the triple tariff are simply defined as:

-Peak load during weekdays between 8.00 and 12.00 (plus 17.00-19.00 in the winter)
-High load during weekdays between 6.00 and 21.00
-Low load during the remaining time.

Therefore, this strategy operates same as the first strategy with the change that the CHP units do not operate following the heat demand but following electricity demand. When they produce electricity during peak hours they earn three times (Connolly 2015).

In this master thesis, the technical simulation chosen was the second one. The main idea of this master thesis is to give a realistic model of Norwegian Energy System with focus on heating sector and electricity sector. However, some of the inputs for the Base scenario and DH scenarios are assumed by studying the trend of the related indicators.

PROBLEM EXPLANATION

The purpose of this chapter is to present the theoretical framework that helped us in modeling and determining the effects of shifting the heating sector toward district heating technology. In the previous chapters we have discussed, among others, about the evolution of the technology of district heating systems. In this master thesis, these systems will form the basis of the energy modeling of the Norwegian energy system and securing flexibility of the energy system will be the most important element in this transition.

8.1 HEAT DEMAND

This section contains a theoretical explanation of the term heat demand. According to Frederiksen and Werner in their 2013 edition, the heat demand has two main components: a heat energy and a demand for thermal energy. The demand for heat energy describes the required heating energy for a given time [kWh] while power describes the rate at which heating is needed [kW]. Therefore, the heat power demand describes the peak capacity necessary to cover a heat demand.

According to the same edition, heat demand is divided into these groups:

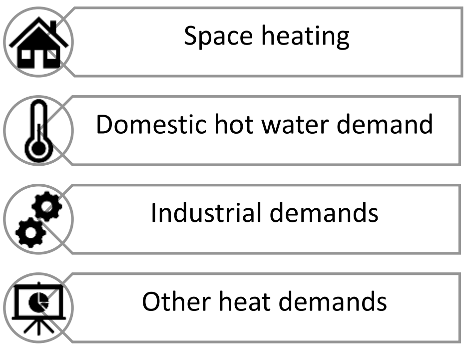


Figure 39: Heat demand categories (Werner 2013).

Space heating systems are designed to satisfy the thermal comfort requirements of building occupants. The interaction of the heating system with the fabric of the building is critical to the comfort achieved and the energy efficient operation of the system (Heikal 2011). The design of heating systems is dependent on the steady state of heat losses in the building. Differently, the design is based on the required heat output to retain indoor comfort conditions knowing the outdoor temperature. However, estimation of the energy required to provide these comfort conditions must be based on a dynamic assessment of the building during heating seasons. Another factor that must be considered is the hours of occupation.

Domestic hot water is needed in residential, industrial or commercial buildings for sanitary purposes. The demand for sanitary hot water does not depend on temperature but on personal consumption patterns. According to this pattern there is a tendency of demand for hot water according to which the demand for domestic hot water is higher during winter time and lower during summer time. As well, this demand is higher in certain hour periods during the day (in the morning and in the evening) and lower during the nights.

The demand for heat which is used in industry is distinct because it has different characteristics from heat used in residential buildings or service sector. Firstly, the heat demand in industrial buildings is well-defined by the temperature. Temperatures vary from below 100°C to above 400°C and this depends on the reason of use. Temperatures below 100°C are usually used for indoor space heating, hot water heating, washing, rinsing and food preparation processes. While higher temperatures are mainly used for evaporation, drying, manufacturing on mechanical industry etc.

The last group or other heat demands include (Werner 2013):

- Ground heating
- Agricultural heating
- Cold generation
- Process heating
- Domestic services

8.2 FLEXIBILITY

Flexibility is one of the most important values of an energy system. To understand this, let's first give the explanation of the term flexibility of an energy system. According to International Energy Agency (IEA), flexibility is the capability of a power system to cope with the variability and uncertainty that VRE generation introduces into the system in different time scales, from the very short to the long term, avoiding curtailment of VRE and reliably supplying all the demanded energy to customers. The definition also can be found: flexibility of a power system refers to "the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise" (Agency-IEA 2011).

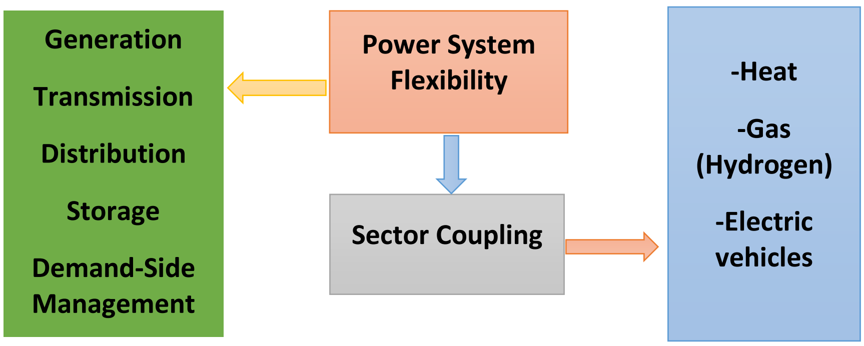


Figure 40: Power system flexibility enablers in the energy sector

Flexibility is a necessary term when talking about energy transition. Everyone agrees that future energy systems must be more flexible, while the biggest challenge is to find the way to achieve this flexibility when we need to abandon fossil fuels and turn to renewable energy sources, when power grids have currently a high level of losses in most of the countries. To move towards an energy system that will be dominated by renewable energy sources, flexibility increase should include all sectors of the energy system. Energy generation should be more flexible, transmission and distribution grids should have less grid losses. The use of energy storage systems should be higher as it helps in increasing flexibility of energy demand (demand-side management and sector coupling[4]).

Simultaneously, as shown by Remap 2015-2050 scenario, the share of RE in the power sector will need to change from 24% in 2015 to 85% in 2050, or approximately three times more compared to the current level. To achieve this result, every country will need to transform their power system as this transition will require a higher supply and demand balance.

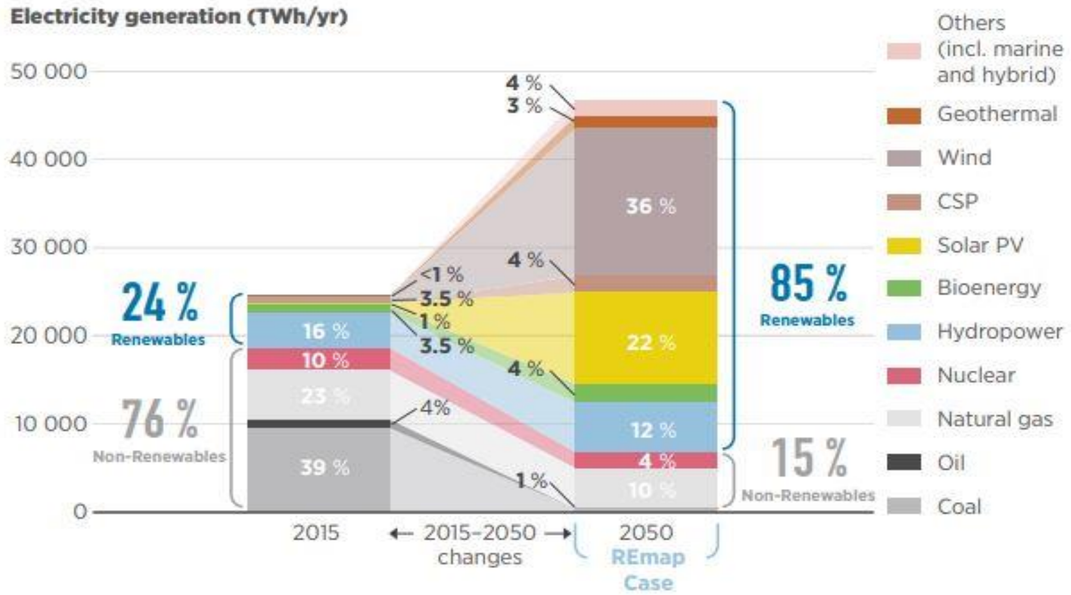


Figure 41: Remap case scenario for electricity generation 2015-2050 (IRENA, Renewable Capacity Statistics 2018).

Sources of flexibility can be technical or operational. Operational flexibility refers to how the assets in the power system are operated. It is dependent, in addition to the constraints of each technology's capabilities, on the regulatory and market environment that surrounds the physical system and drives system operations. Technical flexibility refers to the combination of technologies that determine

1) the ability of supply to follow rapid changes in net load

2) the ability of demand to follow rapid changes in supply

3) the ability of energy storage to balance mismatches between supply and demand at all time scales

[4] The process of interconnecting the power sector with the broader energy sector (e. g., heat, gas, mobility). It includes charging of battery-electric vehicles and production of heat and hydrogen from electricity.

4) adequate grid infrastructure to allow least-cost supply to reach demand always, anywhere in the power system.

8.3 DISTRICT HEATING MARKET IN NORWAY

In Norway, DH market is very tight compared to other Nordic countries. The historical reasons behind this limited market size are related to cheap prices of electricity and other alternative sources that provide heating.

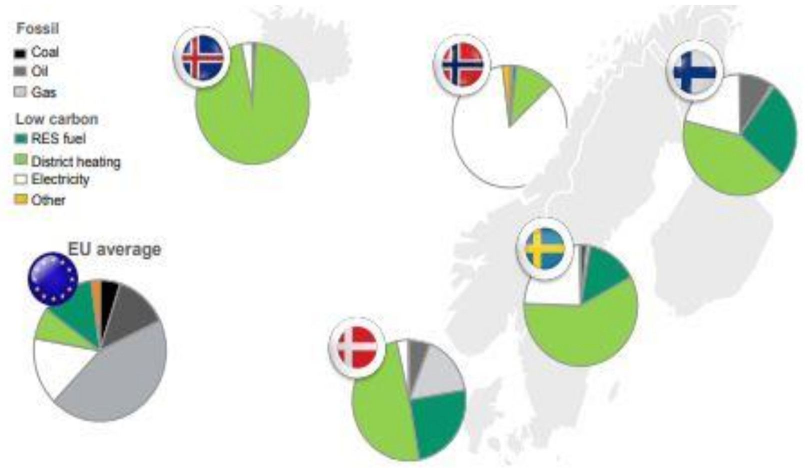


Figure 42: Energy sources used in households and service sector (Jenni Patronen 2015) [%].

When electricity price started increasing in the late 1990s, DH investments and subsidy policies were introduced to promote the build-up of buildings. Thus, the investments on DH systems have significantly increased from then to now. Service industry is by far the largest consumer of district heating with 3.3 [TWh] delivered to this sector. While households received 1.239 [TWh] in 2017. Summarizing this supplies together results that the DH heat delivered to these sectors is 82.8% of the total DH deliver.

Waste accounts for the major share of the source used as a DH input. The share is about 60% and waste have been the main input since 1980s. The first reason is that waste landfill was banned since 2009 in Norway. As a result, the investments on the waste incineration plants started increasing but the they only produce heat instead of heat and electricity. Due to low electricity prices it has been considered more cost efficient and convenient to use waste for heat production rather than electricity production. However, due to less DH systems and receivers of heat (partially and lack of infrastructure problem) some of these plants have tight possibilities to completely use the heat produced. This has led to a slowdown in the construction of new plants.

In industry, the use of oil, gas and electricity for heating purposes is still very high. The need of fulfilling 2050 targets will increase the must of finding new sources of heating in this sector. In 2015, there were 100 district heating companies in Norway delivering district heating to the market. The number of companies has increased rapidly, as in early 2000s there were only about 20 companies operating in this market (Jenni Patronen 2015). Many companies entered the market in 2009 and 2010, and this is also reflected in the sharp increase in production and infrastructure investments in this period. Large investments growth in this sector has mainly been the result of political ambitions and public funding of production and network facilities through ENOVA, and mandatory network connections to new buildings in areas with district heating network concession. District heating facilities are mainly located in city areas, and district heating is established in majority of all cities.

The potential for new facilities in densely populated areas is limited, and this explains the sharp decline in new production investment in the period 2013–2015. There is however still a need to expand existing district heating infrastructure capacity in cities with existing district heating as energy use per m2 of land area is on the rise in the larger cities. District heating capacity could also be established in new areas in the future, as smaller cities are experiencing densification of buildings areas as people from surrounding areas move in to the cities.

The Energy Act requires district heating operators to apply for concession in order to build and operate a district heating network. A concession gives the owner the right and a duty to build district heating network within its concession area. After a district heating facility has been granted concession the municipality within the concession area can decide on a mandatory connection for new buildings. In concession areas with mandatory connection, all new buildings have to be connected to the district heating network. The purpose of mandatory connection is to ensure better utilization of constructed district heating facilities, and to ensure profitability for district heating operators/owners. However, building owners with mandatory connection are not obliged to use district heating as heating source even if they are connected to the district heating network. As building owners are still required to take the investment cost to ensure that they meet the technical requirements in order to connect and receive heat from the district heating network, the cost burden of mandatory connection makes district heating use economic for most building owners.

Due to the partly mandatory connections, there are two types of agreements: voluntary and mandatory. The Energy Act regulates pricing and pricing structure for mandatory agreements. District heating cannot be priced higher that the alternative cost of other heating sources in the respective concession areas. The district heating price is therefore capped by electricity prices, including grid tariffs and electricity taxes. Metering of district heating is most commonly carried out when the hot water reaches the building – and the cost of district heating is then divided by floor area to the individual flats. Currently there is thus very limited number of individual meters on flat level. Regarding external heat delivery in district heating concession areas, a district heating concession does not grant the concession owner a monopoly on heat delivery within the concession areas. Thus, an end-user can enter into heat delivery contracts with other suppliers. Other suppliers however will not be allowed to construct district heating facilities with installed capacity ≥ 10MW unless they have a concession, and only one concession is granted for each area. The need to use heat pumps and electric boilers has been identified in Norway as well. The electricity tax for electricity used in energy production and in district heating/cooling production is reduced from the original 16.32 øre per kWh to 0.48 øre per kWh in 2017 (Skattedirektoratet 2017). There is also a tax deduction on the local grid tariff, decided by the energy authority if larger enterprises or a district heating company have a possibility for flexible loads in the energy production.

8.4 ELECTRICITY AND HEATING SECTOR

8.4.1 Electric vehicles and the power grid

In Norway – the stock of electric cars[5] has been expanding steadily since 2010. In Nordic region the number of electric cars reached almost 250 000 cars at the end of 2017 or 8% of the global total EVs in 2016 and it has the highest share of EVs/capita in the world.

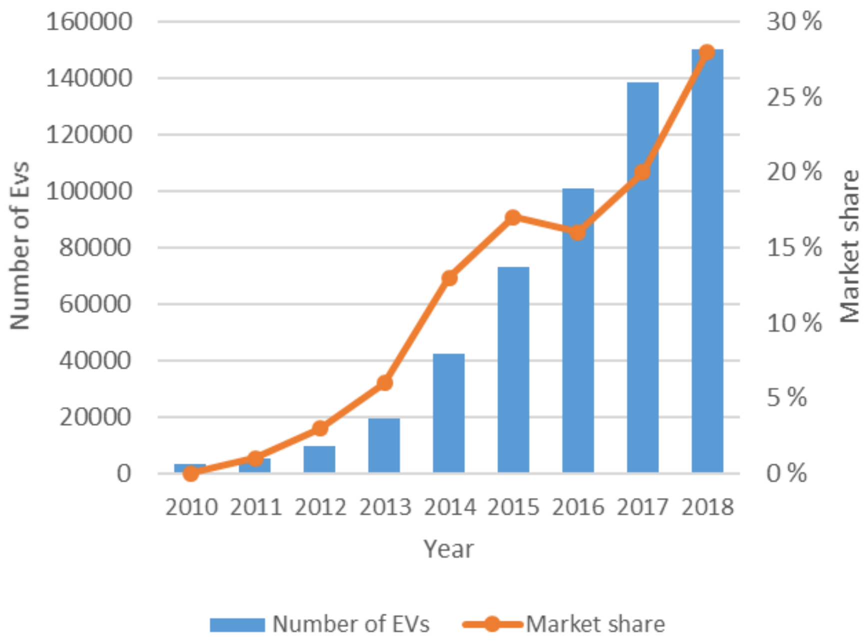


Figure 43: Change of the number of electric cars in Nordic countries in the period 2010-2018 (Norsk elbilforening u.d.).

As shown in te figure above, in Norway by the end of 2017 the total number of EVs in Norway was more than 142.000, including both private cars and vans. EVs represented approx. 5,6% of a total of 2,5 mill. private cars, and in 2018 EVs reached almost 30 % market share. Plug-in hybrids have a market share of 19 %. The development of the amount of private EVs in Norway, and their market share, is presented in the figure above (#SINTEF Blog 2018).

Since 2010, about 70% of the increased number of electric cars in the Nordic region located in Norway. Norway has the highest EVs share of market sales in the world and one of 16 vehicles is electric (when the average of the region is one of 50 vehicles is electric). Electric Vehicles can account for a high share of electricity consumption depending on the number of electric vehicles and their charging options. They can have a great impact on the grid by increasing peak demands and lowering grid flexibility if they operate in an uncontrolled manner. If growth follows the latest trends, it will be necessary to gradually transform the

[5] Electric cars include battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell electric vehicles (FCEV) in the category of passenger light-duty vehicles (PLDVs). BEVs and PHEVs are most electric cars in use today in the Nordic region and are the focus of this report.

energy system into a smart energy system. The security of electric power systems depends on three important requirements:

-Electricity generation and demand must be balanced in real time, keeping frequency close to its rated value.

-Real voltage levels must be kept inside a classical +/-5% range around the rated value.

- Maximum capacity of distribution equipment (transformers, lines) must be respected to prevent risks of over current or tripping.

The first requirement needs flexible generation to follow the demand. Hydro power plants and gas power plants are appropriate for this role. The current rapid increase in variable-generation renewable power sources is increasing the need for flexible generation or storage. Storage has the dual advantage of economically handling over-generation, not just under-generation, and is also generally carbon-free.

Changing to non-emission transport can result in approximately 1.5 mill. private electric vehicles by 2030, resulting in an energy need of 4 TWh. This represents a 3% increase of the Norwegian electricity consumption (IEA 2018).

8.4.2 Electricity Export

Another already existing options for increasing the flexibility within the European energy system is through the utilization of Norwegian hydro power capacity. Half of Europe's stored hydro capacity is located in Norway, and could provide a cheap, low-carbon solution to future European balancing needs. Norway has already controllable hydro power which could be used to add flexibility to the European energy system. This is often referred to as Norway functioning as a 'green battery' of Europe.

If Europe is to utilize Norway's flexible electricity production and use Norway as a 'green battery', it has to be taken into account that the Norwegian energy system is highly based on electricity, including both the electricity and heating sector. The electricity production in Norway is almost entirely based on hydro power, which despite being highly controllable, also depends on the water inflow to the hydro power reservoirs. Basing the heating sector on electricity, in particular dammed hydro power, makes the heating sector more vulnerable to cold winters in dry years. Furthermore, a large electricity consumption within the country may decrease the possibilities of utilizing Norwegian hydro power resources as balancing power for Europe. One way to do this shift is by following the EU Heating and Cooling strategy and looking into increasing of the DH sector in the country.
In order to investigate a potential shift from individual electric heating to DH, a further investigation of the Norwegian energy system, with specific focus on the Norwegian heating sector, is needed (Bozhkova 2017).

DESIGN OF A REFERENCE SCENARIO

In this chapter will be presented in detail the data collection and main steps used for the Reference Scenario. This scenario refers to 2017, since the latest available data pertained to this year. The built-in reference scenario is mainly based on the published EnergyPlan model for Norway built in 2015, making data upgrades timely. For the year that we are referring to, data that are not displayed on the official statistical web pages will be assumed based on upward or downward trends from previous years. Even though the base scenario is for 2017, published data for latest years that can be found will be presented in this material to be more objective in the results analyses and suggested scenarios. Distribution files in this model will be same as 2015 energy model for Norway.

The Reference Scenario is a projection of where our current set of policies coupled with market trends are likely to lead. The EU has set ambitious objectives for 2020, 2030 and 2050 on climate and energy, so the Reference Scenario allows policy makers to analyze the long-term economic, energy, climate and transport outlook based on the current policy framework.

9.1 REFERENCE SCENARIO

The Reference Scenario is a projection of where our current set of policies coupled with market trends are likely to lead. The EU has set ambitious objectives for 2020, 2030 and 2050 on climate and energy, so the Reference Scenario allows policy makers to analyze the long-term economic, energy, climate and transport outlook based on the current policy framework. In our case, it represents the current situation of Norwegian energy system.

As it is mentioned above, the main reason why Norway is chosen for this study is that its heating sector is uncommon in EU because it is mostly based on individual electric heating. Through this scenario, we understand better which composition of factors has led to this development. The built scenario is more focused on the sectors of electricity and heat, considering them as strongly related to each other. With the substantial increase in the number of electric cars in the last few years, a change in demand for electricity in heating sector will affect not only the electricity sector, but also the transport. Transport sector in a wider analysis will be affected by chain changes affecting the electricity and heat sectors. However, for this master thesis it will be kept same as the reference scenario as it is not within the study scope of this study. However, the future of this sector will be taken into account in our analysis, because it could negatively affect grid's flexibility.

9.2 Input for Reference Scenario

9.2.1 Demand

In this section are described all findings needed to complete the components in the demand category field.

9.2.1.1 Electricity

Electricity demand, required first, includes losses. According to Statistics Norway, in 2016 electricity demand was 132.679 [TWh] and in 2017 134.238 [TWh] or 1.3% higher. In the graph below, total electricity demand in last 10 years is presented.

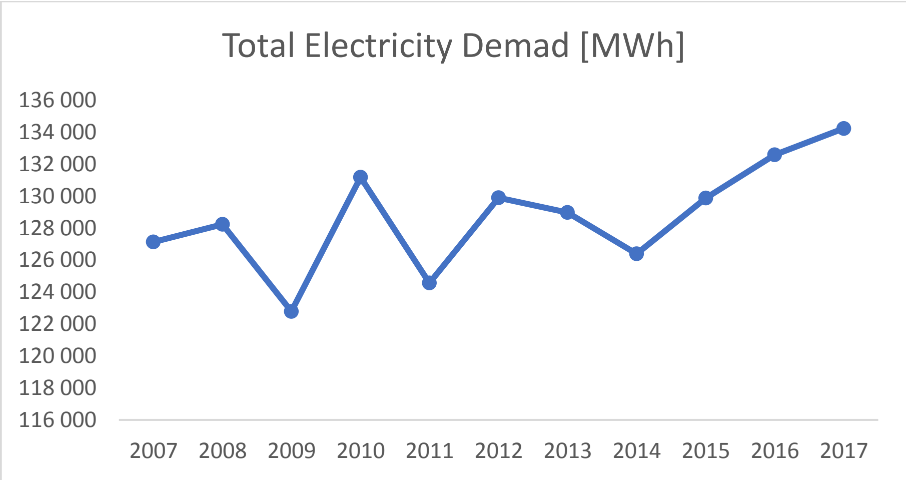


Figure 44: Total Electricity demand for the period from 2007-2017 (Statistics Norway 2017) [MWh].

If we analyze this 10 years period we can say that in the first years the demand trend for electricity has been unstable, while in the last years since 2014 the total demand for electricity has increasingly changed year after year.

9.2.1.2 Electric heating and cooling

Final use of energy in households was 47,6 [TWh] in 2017, or 22 % of total final energy consumption (EnergiFakta Norge 2017). Electricity is widely used for heating purposes in this sector and it is difficult to estimate heating demand in Norway. In 2016, the national heat market was estimated at 54.2 [TWh] (International Energy Agency 2016). According to EnergiFakta Norge electric heat accounts from 70% to 80% of the energy to heat buildings or approximately 32,3 TWh in 2017 (EnergiFakta Norge 2017). While electric cooling is assumed to be 1 [TWh] same as the total cooling demand subtracting district cooling (Havskjold 2011).

Table 4: Input for Demand-> Electricity

Total electricity demand [TWh]	**132.579**
Electric Heating [TWh]	32.3
Electric Cooling [TWh]	1

9.2.1.3 Heating

Heating tab is divided into three heating categories:

-Total Heat Demand

-Individual Heating

-District Heating

Total Heat Demand

Total heat demand is the sum of individual heating and district heating. Heat demand per building can be found from the following formula:

Heat demand per building = Total yearly heat demand/ Number of buildings in Norway

Heat demand per building=54.2/2’715’178

According to SSB last update, the number of residential building in 2017 in Norway is 2’715’178 including detached houses, houses with 2 dwellings, row houses and multi-dwelling buildings and excluding garages. Heat demand per building is calculated to be 19’961 [kWh/building].

Individual Heating

The main source of energy used for space heating and hot water in the residential and service sectors is electricity. It is estimated that 85% of space heating is based on electricity and more than 90% of dwellings have access to electrical ovens and other electric heating devices (ENOVA 2015). According to SSB, under category other, heat generation is mainly based in waste, biofuels, coal, gas and oil. It will be assumed that these fuels are used for heating purposes, since consumption purposes of these fuels are not specified.

Table 5: Share of installed heat boilers in Norway 2017- Input for Demand->Heating (Statistics Norway 2017).

Waste	**0.1 TWh**
Biofuels	6.2 TWh
Coal	0 TWh
Gas	0.8 TWh
Oil	8.1 TWh

Concerning heat pumps, their use gas become more widely used in recent years. In 2012, 27 per cent of all households had a heat pump, which is 9 percentage points more than in 2009 and they accounted for 1.1 million in Norway. In 2014, the production from heat pumps is estimated 15 [TWh] and the electricity use 6 [TWh]. The ratio between electricity input and heat output is the heat pump coefficient of performance (COP) and it is 2.5. Heat pumps generally extract heat from the air outside a building, from the ground, or from a river, lake or the sea. The most important difference between these three sources is that the ground or water temperature is much more stable over a 24-hour period and over the year than the air temperature. Cold weather means that the coefficient of performance of an air source heat pump is low in winter. The lower the air temperature, the less heat an air source heat pump can deliver. On cold days it will often be necessary to supplement a heat pump with other heating sources, for example wood-burning stoves or electric radiators (EnergiFakta Norge 2017).

The great majority of heat pumps in operation in Norway today are air source heat pumps. This is probably because they do not require a water-based heating system in the building and are therefore considerably cheaper to install (EnergiFakta Norge 2017). Due to lack of data it will be assumed that the use of electricity in heat pumps is already included in electric heating. The individual share of solar thermal heating can be calculated by the following formula:

Solar share= [Total area/Average installed area for house]/Total number of houses

Solar thermal share will be assumed 0.16% same as in 2015, and this share will be same in all households despite the heating source that they use. The distribution file used will be the same used in Denmark. Anyway, we should keep in mind that the total production from solar thermal should be lower in Norway compared to Denmark because of geographical position.

District heating

Net production of district heating in 2016 is 5.91 [TWh] and in 2017 6.149 [TWh] or 2,8% higher. Losses in the distribution net is 0.664 [TWh] or 11,23% in 2016 and 10.9% in 2017.

Table 6: District heating data- Inputs for Demand->Heating->District Heating (Statistics Norway 2017).

DH Group	Net Production of DH [TWh] in 2016	Network Losses [%]
Group 3	6.149	10.9

9.2.1.4 *Cooling*

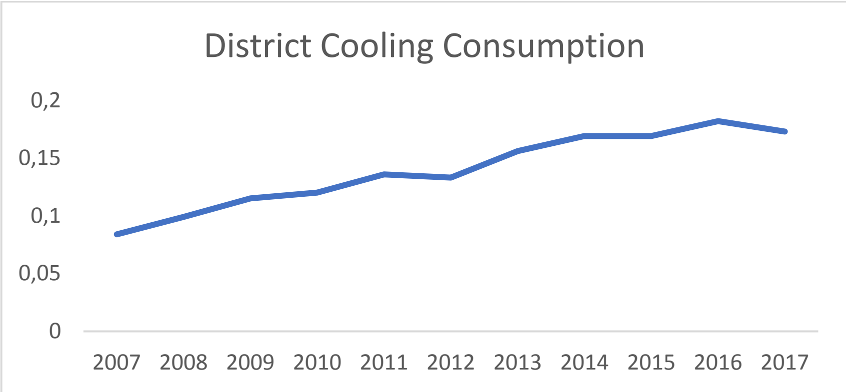


Figure 45: District cooling consumption (Statistics Norway 2017) [TWh].

District cooling consumption is 0,182 [TWh] in 2016 and 0,173 [TWh] in 2017. District cooling is supplied from compressing chilling, absorption chilling, free cooling and heat pumps. The larger technology used are heat pumps and so it will be assumed that all units are part of group two. Coefficient of performance is 1 for electric cooling and 2.4 for district cooling.

Table 7: District cooling data- Inputs for Demand->Cooling

District Cooling		
	COP	Cooling Production [TWh]
Electricity for cooling	1	1
DH for cooling Gr. 2	2.4	0.173

9.2.1.5 *Industry and fuel*

Industry fuel consumption is mainly based in coal, oil, gas, biomass and natural gas. Data are taken from SSB for 2017. Under 'various' column oil and natural gas energy industries own use is presented.

Table 8: Industry and other fuel consumption data- Inputs for Demand->Transport and Fuel (Statistics Norway 2017).

Industry and Other Fuel Consumption [TWh]			
Coal	Oil	Natural Gas	Biomass
7.9	10.6	3.4	3.9

The 'Various' input is only used when a consumption cannot be specified anywhere else or may need to be analyzed on its own. Therefore, this category will include energy industries own use and electricity. Fuel losses are not given from statistics and we will assume they are negligible.

9.2.1.6 *Transport*

Fuel shares used in transport can be found under category energy balance SSB. Regarding EVs, their number reached 138 983 by the end of 2017 (Statistics Norway 2017). Average road traffic volumes per electric vehicle (km) is 11 731 [km] in 2017 (Statistics Norway

2017) and average electricity consumption per km is 0.2 [kWh/km] (Norsk elbilforening u.d.). By multiplying all these values, we can find total electricity consumption in one year from electric vehicles if they are all dump charge vehicles.

Total electricity consumption by electric vehicles results 0.326 [TWh] in 2017 or 16.2% higher compared to 2016. The reason is the rapid increase of the number of electric vehicles in Norway. The number of hydrogen cars in 2015 was 23 and in 2018 was 120 cars. According to NTP, the sale traditional combustion engine cars should stop by 2025. They assume, if hydrogen cars have a rising market share from 30% to 50%, the number of these cars will reach 500 000 by 2030. These 500 000 cars are calculated to consume 75 000 tonnes of hydrogen or 4 [TWh]. If we do a quick calculation and assume that the number of hydrogen cars is 80 in 2017, the consumption will result 0.00064 [TWh] or 12 tonnes.

Table 9: Transport fuel consumption data-Input for Demand-> Transport (Statistics Norway 2017).

Transport	
Total fuel consumption [TWh]	
Jet Fuel	10.8
Diesel	46
Petrol	9.8
Natural Gas	1
LPG	0.03
Biofuels	5.9
Electric cars	0.326
Hydrogen cars	0.00064

9.2.2 Supply

In this section, all data findings for the supply tab will be presented.

9.2.2.1 Heat and Electricity Boilers

Combined Heat and Power plants

Thermal power plants or CHP accounted for 2.2 % of total electricity production capacity in 2017. These power plants are located near industry campuses and they use different source of energy such as: municipal waste, industrial waste, surplus heat, oil, natural gas and coal. According to (EnergiFakta Norge 2017) there are 32 thermal power plants with a total installed capacity of 1108 MW and with a stable production per year of 3.4 [TWh]. In the table below, we have gathered information for three most important CHP plants in Norway. As seen from the table, these plants are respectively phased out, decommissioned or not in use.

Table 10: Information for three CHP plants in Norway.

Station	Location	Co-ordinates	Capacity (MW)	Type	Status
Mongstad Power Station	Mongstad	60°48′32″N 5°2′13″E	280	Natural Gas	Phased out at the end of 2018
Kårstø Power Station	Kårstø	59°16′32″N 5°30′40″E	420	Natural Gas	Decommissioned in 2016

Tjeldbergodden Reserve Power Station	Tjeldbergodden	63°24’44”N 8°41’12”E	150	Natural Gas	Not in Use

For remained power plants we could not find information. Anyway, according to SSB 2017, the electric production from thermal power plants has been stable at the value of 3.436 [TWh] and the electric efficiency will be assumed 41% since most of them are gas fired plants. The maximum output from these plants is 1108 MW and the electric output 454.28 [MW-e].

Table 11: Input for Supply->Heat and Electricity->CHP condensing mode operation

CHP condensing mode operation	
	Group 3
Electric Capacity [MWe]	454.28
Electric Efficiency [%]	41

Under the category ‘CHP back pressure mode operation’ will be included one CHP plant biomass based with the following data:

Table 12: Inputs for Supply->Heat and Electricity-> CHP Back Pressure Mode Operation (Source: EnergyPlan Model for Norway 2015)

Electric Capacity [MWe]	**100**
Thermal Capacity [MJ/s]	275
Electric Efficiency [%]	24
Thermal Efficiency [%]	66

9.2.2.2 Central Power Production

Hydropower is the mainstay of Norwegian electricity system. The number of hydropower plants in Norway was 1 070 in 2017 with a maximum output or installed capacity of 31 912 [MW] (Statistics Norway 2017). The hydropower plants in Norway are both run of river hydropower plants and dammed hydropower plants. According to ENTSO, the installed capacity based on power plant is divided: 1045 [MW]-Hydro-run-of-river and poundage and 30 867 [MW]-Dammed Hydropower Plants. The yearly production from these power plants was 143.112 [TWh] in 2017.

Norway has more than 1000 Hydropower Storage Reservoirs. Their total capacity is 86.5 [TWh] and covers 70% of annual electricity consumption. Most of reservoirs are small and have a low capacity, while almost the half of the storage capacity is provided by 30 of them (EnergiFakta Norge 2017). The pumped storage (pump back capacity) was 1392 [MW] in 2016 and so it will be considered in 2017 (Association 2017).

Table 13: Inputs for Supply->Central Power Production

Central Power Production			
	Capacity [MW-e]	Annual production	Efficiency [%]
Dammed Hydro Power	30 867	143 112 [TWh]	90
Storage for dammed hydro	1 392	86.6 [TWh]	90

9.2.2.3 Variable renewable electric

Three types of variable renewable electric sources are included in this reference scenario: Wind Power, PV and River Hydro.

To start with, wind power farms were 33 by the end of 2017. Total installed capacity in the same year was 1207 [MW] (Statistics Norway 2017). This capacity corresponds to approximately 3.66 [TWh] in a year but the annual production in 2017 was 2.854 [TWh] (Statistics Norway 2017). Thus, the correction factor will be -0.64. By dividing the assumed annual production with real annual production, we can find that estimated capacity factor (CF) is 0.27 for wind farms.

Photovoltaics have a low share in Norway. According to (IRENA 2018), photovoltaics capacity in Norway is 42 [MW-e]. It is calculated that this capacity corresponds to an annual production of 0.03 [TWh] and the estimated capacity factor is 0.08.

As mentioned above, the pumped back capacity is 1392 [MW] (Association 2017). This corresponds to an annual production of 5.11 [TWh] and the capacity factor is 0.41.

Table 14: Input for Supply-> Variable Renewable Electric.

Variable Renewable Electric			
	Capacity [MW]	Production [TWh]	Estimated CF
Wind Power	1207	2.85	0.27
PV Power	42	3.03	0.08
River Hydro Power	1413	5.11	0.41

9.2.2.4 Heat Only

Heat only field includes four input categories. All these categories are related to district heating groups.

-Solar Thermal;

- Compression Heat Pumps;

-Geothermal from Absorption Heat Pumps;

-Industrial Excess Heat;

Solar Thermal

This category is part of DH group 2 since it represents DH systems based on small CHP plants. The use of solar collectors for district heating production started in 2013. Unable to provide data for 2017, we will use the results of 2015 arguing that the change will not be significant. In 2015, the total solar thermal production to DH was 4 [GWh], the storage 0.07 [GWh] and the losses 5% (Fjernvarme 2015).

Compression Heat Pumps

As is proceeded in the 2015 model of Norway, in the category of heat pumps we will consider the production of electric boilers. Based on the calculations in this model, the joint COP of Heat pumps and electrically boilers will be calculated by the following formula.

Capacity= [Production/COP]/Number of full load hours

Average COP= Net Production of DH by HP*COP HP/Net Production of DH by EB* COP EB

According to (Statistics Norway 2017), net production of district heating by heat pumps is 602.3 [GWh] and by electric boilers 788.6 [GWh] in 2017. Knowing that coefficients of performance of heat pumps and electric boilers are respectively 3 and 1 and the number of full load hours is respectively 3200 and 2500, the calculated average COP resulted.
From the calculations above resulted that:

Table 15: Input for Supply-Heat Only

Heat Only		
	Solar Thermal: Group 2	Units
Production	0.004	[TWh]
Storage	0.07	[GWh]
Loss	5	[%]
Share	0.7	[%]
Result	0	[TWh]
Compression Heat Pumps		
Electric Boiler Capacity	315.44	[MW]
HP's Capacity	62.73	[MW]
Total Capacity	378,17	[MW]
Average COP	1.33	

9.2.2.5 Fuel Distribution

Fuel distributions in accordance with their technologies are found from (Statistics Norway 2017) from the table 'Consumption of fuel used for gross production of district heating' under DH&C category.

Table 16: Input for Supply->Fuel Distribution

Fuel Distribution [TWh/year]		
Oil	Natural Gas	Biomass
0.0678	0.2828	2.1734

9.2.2.6 *Waste*

The primary energy production from waste resulted 4.7 [TWh] in 2017. The amount of wastes consumed for the gross production of district heating in 2017 was 3.8314 [TWh] (Statistics Norway 2017). It is assumed that the production remained of about 0.97 [TWh] from the primary production from waste is electricity and that all the amount of waste is used in decentralizes incineration plants that are under DH group 2. The heat or production efficiencies are calculated from the following formulas:

$$\text{Thermal Efficiency} = \text{DH production} / \text{Waste Input}$$

$$\text{Electric efficiency} = \text{Electricity Production} / \text{Waste input}$$

Thermal efficiency and electric efficiency are respectively 79.8% and 20.1%. In the table below are shown inputs for this section.

Table 17: Input for Supply->Waste

Waste			
	Waste Input [TWh]	DH Production [TWh]	Electricity Production [TWh]
DH Group 2			
Efficiency	100%	79.8%	20.1%

9.2.2.7 *Liquid and Gas Fuels*

There are no data provided from SSB or any other official statistical web page. Because the lack of data these plants are not taken into account.

CO_2

CO2 content in the fuels are taken the same as in 2015 model. The data are provided from (Energistyrelsen 2015). CCS and CSR are not considered since there are not onshore facilities that apply these technologies. Anyway, there is a project called Equinor’s storage project that will take CO2 captured from three onshore industrial facilities in eastern Norway and transport it by ship to a receiving plant onshore located on the west coast of Norway.

Table 18: Input for Supply->Liquid and Gas Fuels->CO2

Fuel type	CO_2	Unit
Coal	93.95	[kg/GJ]
Fuel oil / Diesel / Petrol / JP	73.58	[kg/GJ]
Ngas	56.95	[kg/GJ]
LPG	63.1	[kg/GJ]
Waste	36.79	[kg/GJ]

9.2.3 Balancing and Storage

9.2.3.1 Electricity

Norway enjoys high security of electricity supply, and the continuity of supply is close to 99,99% in years without extreme weather events. Consumers in Norway experience on average about two short interruptions and two long interruptions per year, where the average duration is less than two minutes for short interruptions and approximately two hours for long interruptions. However, the security of supply varies from region to region and is generally better at higher grid levels (NVE 2018).

Norway has the highest share of electricity produced from renewable sources in Europe, and the lowest emissions from the power sector. Additionally, more than 75% of the Norwegian production capacity is flexible, and Norway has half of Europe's hydro reservoir capacity. Norway is now developing more renewable power production capacity than in the last 25 years. Wind power currently accounts for a relatively modest share of production capacity, but dominates new investments and production is expected to increase.

Electricity in Norway is produced at a large scale from dammed hydropower plants which have a very flexible production when it comes to secure the stabilization of the grid. Investments are continuing for the expansion of wind farms, but their production is very low compared to hydropower plants. Thus, the share of total electricity production that must come from a grid stabilization unit is unknown and there is no information about electricity storages in Norway.

9.2.3.2 Thermal

Due to the lack of data regarding the thermal storage capacity, it was calculated the size of the thermal storage to minimize the production of DH on boilers and to increase the production of DH in heat pumps. The chose thermal storage size was 1 [GWh] that is optimized for 14 days, as suggested by the 2015 model. These are just small-scale storage units and not seasonal storage units.

9.2.3.3 Liquid gas and fuels

Liquid gas and fuels are not included in this reference scenario.

9.2.4 Cost

9.2.4.1 General

In this tab, CO_2 price is taken into account. CO_2 price is included in marginal production prices. According to (NVE 2017), CO_2 price in 2017 is 5 [€/tonn] or 48.7 [NOK/ton] in accordance with the currency exchange. The interest rate chose is 4% (NVE 2017) and it is especially recommended for socio-economic calculations that affect a business project. This master thesis is not part of any project. This project intends to study the trends of changing the energy parameters in the sectors affected by these changes.

9.2.4.2 Investment and fixed O&M

In this section are described all production units by their type, investments (capital costs), periods and O&M costs (variable costs). In this section, EnergyPlan does not take into account that the costs differ according to the size of the production units. The following costs are based on 2020 costs (Conolly 2015). The data input for this category are presented in the table below.

Table 19: Input for Cost-> Investment and fixed OM

Investment and fixed O&M				
Technology	Unit	Investment [MNOK/unit]	Lifetime	O&M [% of Inv.]
Heat and Electricity				
Small CHP units	[MW-e]	11.71	25	3.175
Heat Storage CHP	[GWh]	29.27	20	0.7
Waste CHP	[TWh/year]	2103.21	20	7.37
HP: Group 2	[MW-e]	33.17	20	2
Boilers: Group 2&3	[MW-th]	0.73	20	1.47
Renewable Energy				
Wind	[MW-e]	29.75	20	3.05
Photovoltaic	[MW-e]	20.39	30	2.09
River of Hydro	[MW-e]	19.51	50	2
Hydropower	[MW-e]	19.51	50	2
Hydro Pump	[MW-e]	14.63	50	1.5
Industrial Excess Heat	[TWh/year]	9.76	30	1
Heat Infrastructure				
Individual Boilers	[1000-Units]	0.05951	21	1.79
Individual HP	[1000-Units]	0.13657	20	0.98
Individual Electric Heat	[1000-Units]	0.07804	30	1

9.2.4.3 Fuel

In this section, fuel prices are taken from the EnergyPlan cost database. This document contains the costs about all necessary elements and taxes to complete the cost tab in the construction of energy models. The following table consists of fuel prices, handling costs, tax on fuel, and taxes on electricity from (Conolly 2015).

Table 20: Input for Cost->Fuel

Fuel						
	Coal	Oil	Diesel	Petrol	Natural Gas	Biomass
Fuel cost	30.24	116.09	146.33	148.28	88.77	93.65

Fuel Handling Costs					
Fuel	Centralized Power Plants	Decentralized Power Plants & Industry	Consumer	Transport (road & train)	Transport (air)
Coal	0.6	-	-	-	-
Oil	2.56	17.74	-	-	-
Diesel	2.56	18.58	20.33	-	-
Petrol	-	-	-	38.12	6.3

Natural Gas	4.02	20	30.69	-	-
Biomass	10.39	10.09	24.78	102.97	-

Taxes						
Fuel	Coal	Oil	Diesel	Petrol	Natural Gas	Biomass
Individual households	-	-	132.31	-	22.77	-
Industry	-	77.46		-	22.77	-
Boilers	-	77.46		-	22.77	-
CHP units	-	77.46		-	22.77	-

The missing data from this section are marked with [-]. The taxes listed above are taken from the document (Skattedirektoratet 2017). A CO2 tax is payable on mineral oil, petrol, gas, natural gas and LPG that's either imported into Norway or produced in Norway. A basic tax is also payable on mineral oils, along with a Sulphur tax on mineral oils containing more than 0.05 percent by weight of Sulphur. There are certain exemptions from these taxes. CO2 tax is not payable on mineral products used for the following:

- aircraft in international service
- shipping in international service

Reduced rates apply for certain areas of application, including certain types of industry. A reduction in the Sulphur tax is granted based on the purity rate of the emissions. Biodiesel is exempt from CO2, Sulphur and basic tax (Skattedirektoratet 2017). In addition to taxes on mineral products, there are also electricity taxes. Electricity taxes are not payable on the following:

- Growth industry
- Chemical reduction or electrolysis
- Metallurgical or mineralogical processes
- Energy recovery facilities
- Micro power plants

Table 21: Input for Cost->Fuel-Taxes on electricity for energy conversion.

Electricity Taxes		
[NOK/MWh]	DH	Individual
Electric heating	0.0048	0.16
HP-s	0.0048	0.16
Electrolysis	0.0048	0.16
Electric cars		0.16
Pump Storages	0.0048	

9.2.4.4 Variable operation and maintenance costs

In the Operation tab sheet, the user inputs the variable operation and maintenance costs for a range of technologies. Variable O&M costs account for the additional costs incurred at a plant when the plant must run such as more replacement parts and more labor.

Table 22: Input for Cost->Variable O&M

Variable O&M		
[NOK/MWh]	District heating and CHP systems	Individual
Boiler	1.46	15
CHP	26.34	-
HPs	2.63	2
Electric heating	4.88	1

9.2.4.5 External electricity market

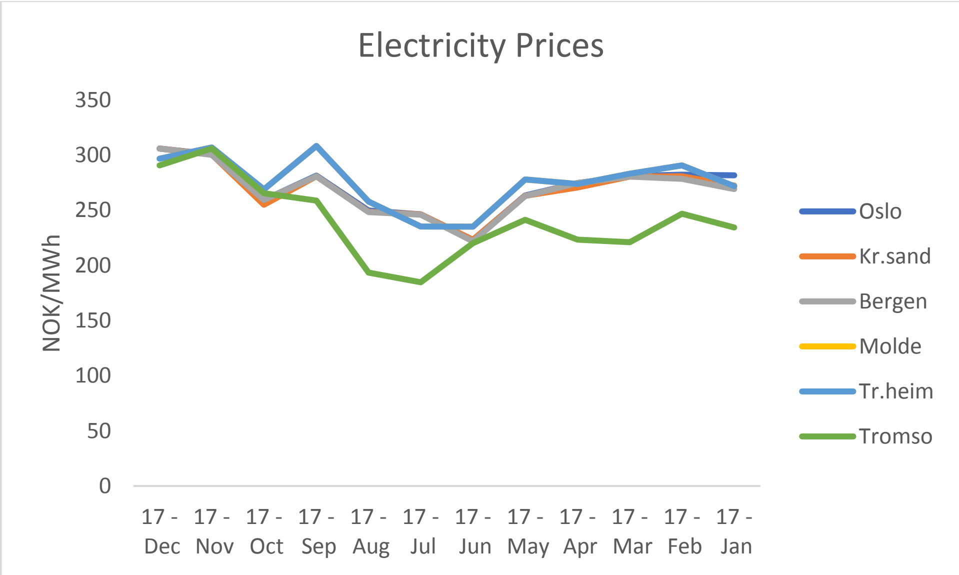


Figure 46: Elspot prices in 2017, by months (NordPool 2017).

According to (NordPool 2017) elspot (day ahead market), the highest price of electricity in 2017 was 184.72 [NOK/MWh] in July and the highest price was 308.85 [NOK/MWh] in September. Thus, by calculating the average electricity price we can find that it is 246.785 [NOK/MWh]. The addition factor used in the model is 0 and the multiplication factor is 1.385.

9.3 Results from Reference Scenario

After the reference scenario is build we will analyze its simulation results in some directions: electricity, individual heating, DH, thermal storage, electricity import/export, costs and emissions.

9.3.1 Electricity Production

In 2017, the total electricity produced was provided by these sources:

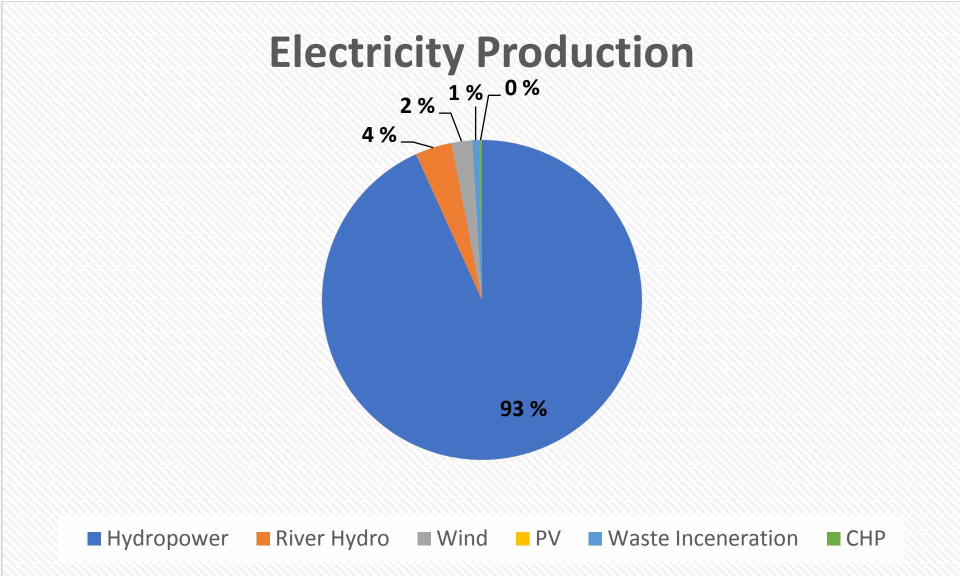


Figure 47: Electricity generation by type of power plant-reference scenario result [%].

From the electricity generation result we can see that dammed hydropower plants occupy a large share or 93% in the total final generation. Another considerable 4% is occupied by river hydro plants. While the left 3% incudes wind power plants (farms) with 2% and thermal power plant as waste incineration plants occupy the lower share or 1%. The last two categories are areas where investments have recently increased. PVs and CHP have the lowest production of electricity as it results 0% when is compared to others.

In TWh/year these percentages are presented in the table below:

Table 23: Output for electricity Production

Electricity Production-Reference Scenario		
Dammed Hydro	128.8	[TWh/year]
River Hydro	5.11	[TWh/year]
Wind Power	2.85	[TWh/year]
PV	0.03	[TWh/year]
Waste Incineration	0.97	[TWh/year]
CHP	0.39	[TWh/year]

If we compare the simulation results to the results published from SSB in 2017 we can see that hydropower share results 1% higher in the reference scenario. These insignificant differences exist because of very small values of PV and CHP which are calculated zero in the final share when they totaled 0.42 [TWh/year]. If we consider the fact that natural gas CHP is not included in the reference scenario, electricity production from this simulation has the same share as the one published from SSB.

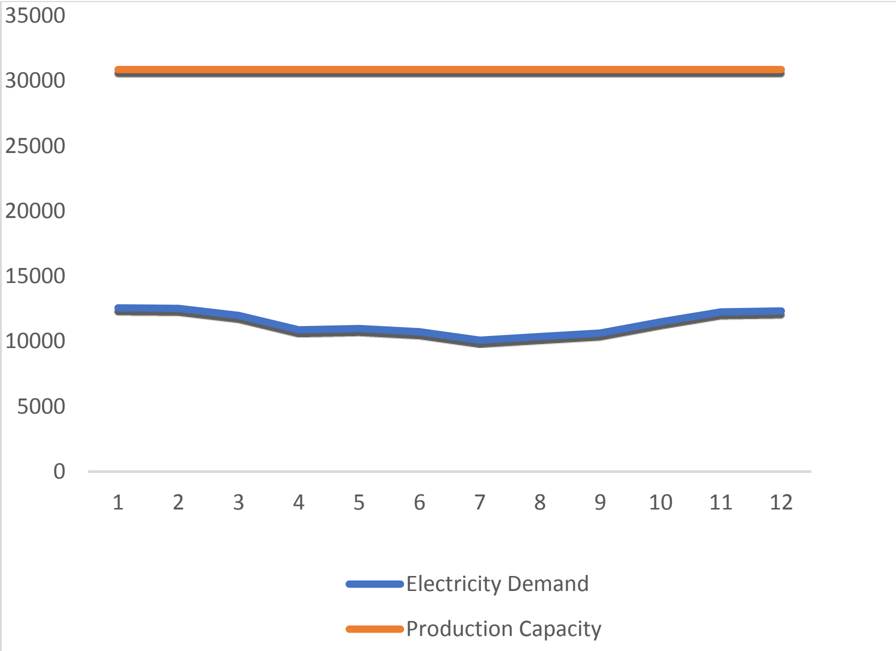


Figure 48: Monthly electricity demand and production capacity-reference scenario [MW].

Based on the above graph, it seems that the demand for electricity is lower during the summer season and the opposite in the winter. The reason for this variability is related to the effect that has on electricity demand the demand of individual electrical heating in dwellings. It is also noted that the electricity generation capacity is very flexible. It means that the current installed capacity, except that covers the domestic demand, can be responsive to the changes related to the electricity exports.

9.3.2 District heating production

From the reference scenario output the following share can be generated:

Table 24: District heating production from reference scenario

DH production		
Waste CSHP	4.01	[TWh/year]
CHP	1.06	[TWh/year]
HP	1.45	[TWh/year]
Boiler	0.02	[TWh/year]

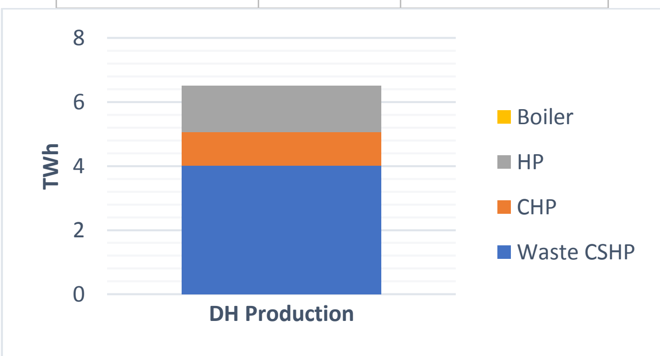


Figure 49: DH generation based on technology used -reference scenario result [TWh].

As we can see from the graph, incineration plants produce the larger part of the heat from DH systems. For the purposes of this study, the heat production from waste incineration plants is considered constant throughout the year, even though it can be variable depending on waste amount for each month. The share of waste incineration on the DH heating production constitutes 62% of the total production while from the statistics taken from SSB it has a smaller share resulting 50%. This can be somehow logical because SSB statistics are more focused on sources than technologies, as in output from the simulation of reference scenario. This technology is followed by HP (that are considered both with electric boilers with an average COP as explained on the "Inputs for Reference Scenario" section) that covers 22% on the reference scenario compared to 23% on the SSB statistics. HPs are further followed by CHP and boilers.

9.3.3 Individual Heating

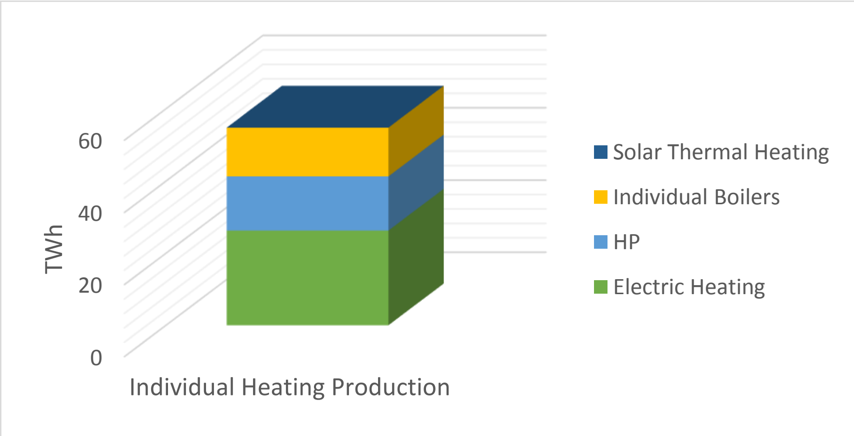


Figure 50: Individual heating generation-reference scenario output [TWh].

As we have been discussed before, electric heating has a significant share when it comes to individual heating production. Electric heating is followed by heat pumps. Then come individual boilers where are involved fossil fuel-based boilers and biomass boilers. Solar thermal heating has a small contribution on the individual heating production of about 0.01 [TWh/year].

9.3.4 Thermal Storage

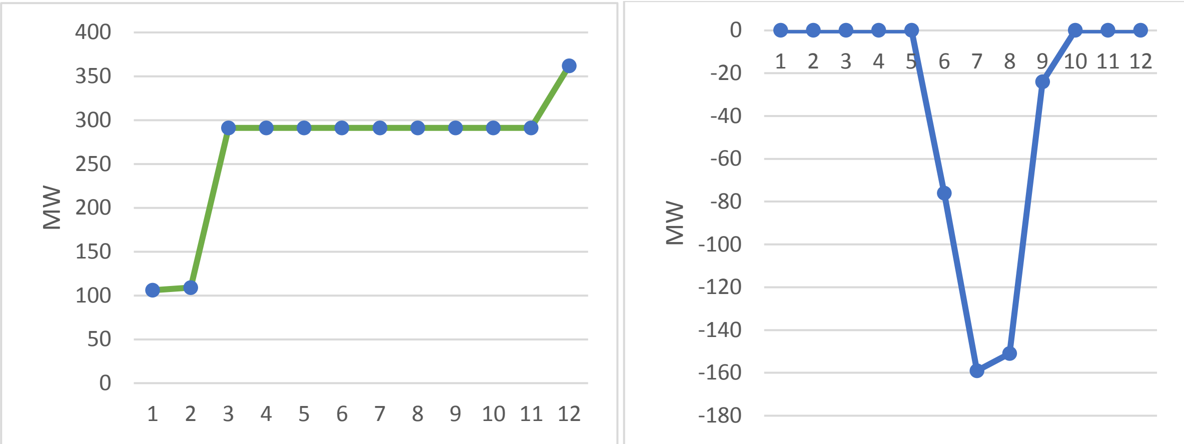


Figure 51: Thermal DH storage and heat demand balance- reference scenario output [MW].

In the graphs above, storage and balancing curves throughout the year are given. Numbers from 1 to 12 corresponds to months. As can be seen from the first graph, storage is constant only during the period from March to November. On this reference scenario the heat produced from waste incineration plants is considered constant along the year and these plants and the excess heat are not connected to the thermal storages. This is the reason why the difference between heat demand and heat production is negative meaning that the heat demand is lower than the heat produced from waste incineration plants and excess heat.

9.3.5 Emissions, Import/Export

Table 25: CO2 emissions

Emissions		Unit
CO_2 emissions	41.38	[Mt]
RES share of PES	39.2	[%]
RES share electricity	136.8	[%]
Total annual costs	160 206	[MNOK]

Table 26: Import/export in reference scenario

Total import [TWh/year]	**0**	**[TWh/year]**
Total export	4.15	[TWh/year]

DISTRICT HEATING (DH) SCENARIOS

District heating networks can be fed by various heat generation sources, including combustion plants (based on fossil fuel or biomass), CHP (combined heat & power) plants or renewable-based plants. The characteristics of each of these heat technologies are outlined in this section. The combination of multiple heat sources is beneficial, especially for large district heating schemes, as it allows shifting from source to source depending on specific conditions and market prices. The trend for last decade was to increase CHP and the objective for the following years is to inject renewable and waste heat sources.

The first part of this chapter will include a short description of the possible DH technologies to be implemented in the Norwegian energy system. Each technology will be accompanied by its advantages and disadvantages. The technologies chosen will follow EnergyPlan DH technologies prioritization.

10.1 CHP

CHP or combined heat and power plants have four main elements: engine or a drive system, heat recovery system, electricity generator and control system. CHP plants are usually classified by the application type, the drive system and the source it uses. There are several 'traditional' CHP plants operating by using reciprocating engines and turbines, while the newest ones that consist of fuel cells and Stirling engines are still being tested before commercialization.

Based on their scale, CHP plants can be small scale and or "campus'' scale. CHP plants can simultaneously produce electricity and heat and potentially cool by using thermally driven chillers. One of the main utility of these plants is that they can reduce CO2 emissions because they contribute to the power system. In case of Norway, this technology does not reduce CO2 emissions directly by affecting electricity sector. If we consider the indirect way, the logic is related mostly to the heating sector. By using less electricity for heating purposes, the growth of electric vehicles can be better covered by electricity sector and Norwegian power system can both meet the domestic electricity demand and export the excess of electricity to the neighbor's countries that still use fossil fuels on their power systems. This way of thinking leads to two changes in the system that help reducing CO2 emissions: reducing the use of traditional cars and reducing the use of traditional power plants.

Systems that can be used for producing both electricity and heat can use different technologies. Nowadays, the most traditional technologies used are: reciprocating engines, compression -ignited or internal combustion engines. These technologies are available in various sizes and, depending on that, various efficiencies. Normal efficiencies values are between 75% and 85%.

In Norway, the only large-scale CHP plant operating is going to be decommissioned 31st of December this year. After this plant being phased out the total electric capacity remained is about 100 MW divided into other small-scale CHP mostly based on biomass (except waste). The CHP plants considered in the DH scenarios are only biomass based since the ones that are fossil fuel based are being excluded from European energy system. The biomass available within the country will be considered as the only input for the plant. The biomass potential in Norway excluding waste incineration is estimated 23 [TWh] (EnergiFakta Norge 2017). The CHP's technologies in EnergyPlan are prioritized by electricity demand not heat demand that's why SCHP and excess heat have priority before CHPs.

In conclusion, the most important advantage of the system is that it produces two types of energy needs simultaneously thus providing a better total efficiency. The disadvantage is the investment costs which in the best cases ranges from about 870 M€/MW for the large-scale systems to between 1000 to 8000 M€/MW for the small-scale systems and there is not always a balance between the need for heat and power for example during summer when there might be a need for electricity for cooling but not for heating.

10.2 WASTE TO ENERGY DISTRICT HEATING PLANT

This system consists on the following elements: a waste reception area (1), a feeding system (2), a grate fired furnace interconnected with a hot or warm water boiler (4, 6, 7, 8), an extensive flue gas cleaning system and systems for handling combustion and flue gas treatment residues (10, 11, 12, 13,14). If the process is combined with electricity production a steam turbine (9) is used.

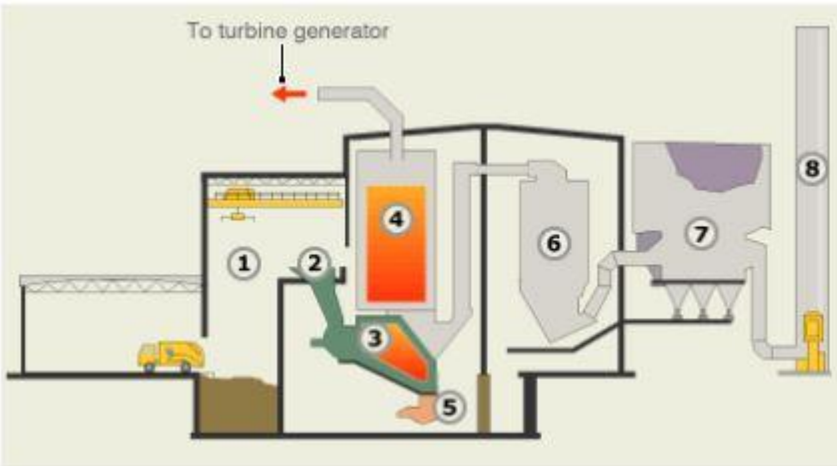


Figure 52: Diagram of the system (Nicolas Pardo Garcia u.d.).

Wastes used come from both residential and industrial sector and they are collected in a silo. After that a crane dumps waste inside incinerator, which is composed of a series of grates that constantly move to aid the combustion. Air under the grates and above the fire provides oxygen for the combustion process. The temperature in the incinerator is between 875 and 1100 °C. Pipes in the incinerator produce super-heated steam, which can be used in a turbine to produce electricity. Excess heat is processed in a heat exchanger to warm up water and produce district heating. The plant is primarily designed for incineration of municipal solid waste (MSW) and similar nonhazardous wastes from trade and industry.

Some types of hazardous wastes may, however, also be incinerated. It is convenient to incinerate waste due to the control of the emissions and due to the production of heat for district heating and in some cases also electricity (CHP).

The advantage of the system is that it uses waste as an energy source instead of using fossil fuels or other energy sources. As a significant part of the waste materials is renewable, that also leads to reduced CO2 emissions. The disadvantage is the investment costs and that the technology is limited to the amount of collected waste. There must be a systematic collection of waste, which should preferably be sorted to be incinerable by e.g. removing glass and metal bottles from the waste.

The waste potential in Norway will be considered the same as the input on Reference scenario, resulting 4.8 [TWh] in 2017. Currently, Norway has 3 Waste to Energy Plants – Haraldrud, Klemetsrud and Romerike Biogas. The Haraldrud Plant was the first waste to energy plant that was built in 1967. It has a recycling and sorting capacity of 100,000 tons of waste annually. The Klemetsrud Plant is the largest plant with a recycling capacity of 310,000 tons of waste annually. The Romerike Biogas plant was completed in 2012 as Oslo's largest biogas plant. It produces both biogas and bio-fertilizers based on food waste. The plant supplies 135 buses with biogas and 100 medium-sized farms with nutritious bio-fertilizer. In EnergyPlan, the priority order of waste-to-energy plants is after CHP plants.

10.3 Heat Pumps

The use of heat pumps has increased in recent years. In 2016 their installed capacity was 85 MW and Norway is ranked in the third place after Sweden and Finland for the greatest heat pumps installed capacity. The graph below presents the year of establishment in each country and it shows how has the growth of become during years. As seen, the largest increase in the use of heat pumps coincides with the period from 2006 to 2010. There are two main observations that we can find out from this graph: the heat pumps in Sweden are old, and it is unclear how many years these respective units will continue to function and in the rest of the countries, new investments for large-scale heat pumps were made, and many projects were commissioned in or after 2006, which was chosen as a border year between the new and older generation of heat pumps.

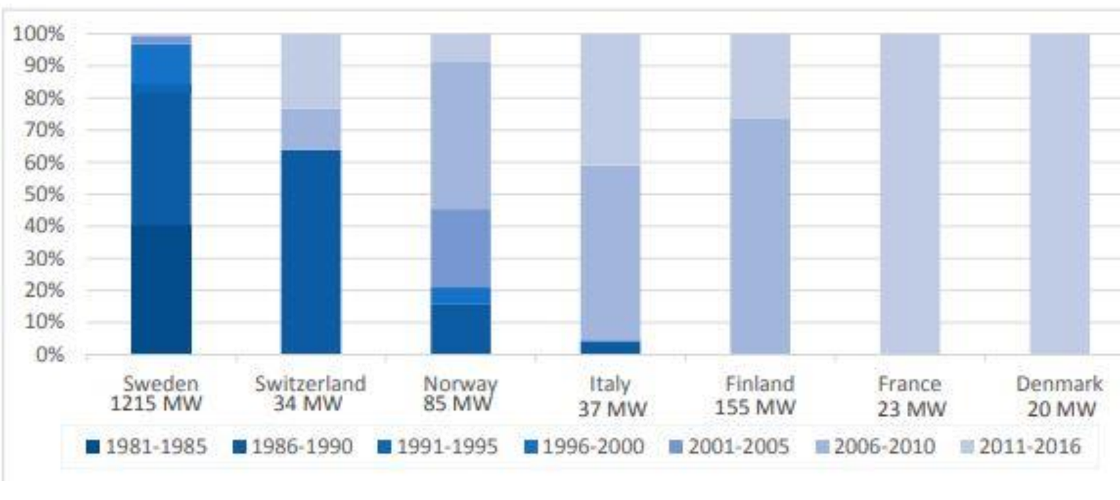


Figure 53: Establishment years and capacities of heat pumps in seven countries with the greatest capacities installed and currently operating (Andrei David 2017).

In this master thesis the reduction of the direct electric heating in the Norwegian heating sector is the main idea. That's the reason why heat pumps as an efficient way of using electricity will be considered to use only to cover heating peak demand.

In Norway, the large-scale case of a heat pump plant is in Drammen. The average water temperature of the fjord in winter is 8°C; this drops to 6°C in summer due to melting glacier water. Because of its constant temperature, the water is extracted at around one kilometer from the shore at a depth of 35 m, and then filtered and transported to the heat pump system. The thermal energy of the water is transferred to a closed circuit here, and successively heated to 90°C by three two-stage heat pumps connected in series and designed for 65 bar. Each heat pump only needs a fill of 1,000 kg NH3. Thanks to the intelligent system design, the ammonia heat pumps achieve a COP of 3.05. The nearly boiling water then passes through a 22 km pipeline system to Drammen and supplies the connected buildings with hot water and heating via a heat exchanger. And at an unbeatable price: one megawatt hour costs just 11 euros. With its capacity of 43 MW, the plant covers about 70% of the district's total energy needs. In 2013, 'Drammen district heating' supplied a total of 90 GWh – and the heat pumps generated nearly three-quarters of this (67 GWh), in a sustainable and cost-efficient manner (Eurammon 2018).

However, the first technologies chosen to cover the heat demand are those that do not use electricity. Such technologies, heat pumps or electric boilers will be part of the system proposed in DH scenarios only in peak loads. Otherwise, the other technologies will be preferred. In EnergyPlan heat pumps and electric boilers have the same prioritization.

10.4 EXCESS HEAT FROM INDUSTRY

The most recent study related to excess heat from industry was published by the Norwegian utility Enova in 2009. This study determined the usable waste heat potential of the Norwegian industry by sending out questionnaires to the most energy intensive sectors, which 72 of 105 companies answered. According to this report, the excess heat potential from industry was around 9.8 [TWh]. There are no data for the cost or the temperature of this surplus heat. Anyway, for this master thesis it will be considered free. EnergyPlan prioritize Excess Heat from Industry before CHPs and after STH units.

10.5 DESIGN OF DH SCENARIOS

As described in the section 3.3.1 Electricity in 2030, it is estimated that the electricity demand in 2030 will grow with 10% or from 130 [TWh] in 2015 to 143 [TWh] in 2030. NVE by using future trends of population and all sectors that use electricity has come with this result. Then if we consider electricity export trend and the EU targets for 2030 we will assume a growth of 30% because the exports are increased 66,3% in the period from 2001 to 2017 (in 16 years). We are not taking into account the built of new interconnection lines because this assumption is only considered on how it affects the total production of electricity in the future.

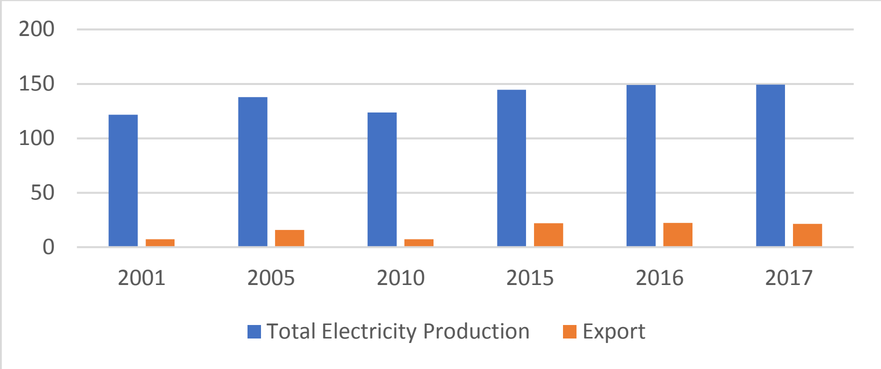


Figure 54: Total electricity production and electricity export from 2002 to 2017 in Norway (Statistics Norway 2017) [TWh/year].

Then the export electricity demand will grow from 21.276 [TWh] in 2017 to 27.658 [TWh] in 2030 or with 6.38 [TWh]. Considering both increasing electricity demand within the country and for export we can say that overall electricity demand will increase to approximately 20 [TWh] in about 10 next years. The above assumptions are only based on current trend they do not represent the reality. This analyze in made to show how important is to shift from individual electric heating to other DH technologies.

In 2017, electric heating from reference scenario is estimated to be 32.3 [TWh]. If the electricity demand from the heating sector is reduced, this would result in a positive balance contributing to meet the future electricity demand and improving system flexibility.

To start with the DH scenario design, electric heating will be reduced in 3 levels: 20%, 60%, 100%.

Table 27: Electricity shift from Individual Electric Heating to DH in three levels.

	Electricity Demand	**Electric Heating**	**Individual Electric Heating**	**District Heating**	**Units**
Base Scenario	132.579	32.3	26.3	6.149	[TWh/year]
20%	126.119	25.84	19.84	12.609	[TWh/year]
40%	119.656	19.42	13.38	19.069	[TWh/year]
60%	113.199	12.92	6.92	25.529	[TWh/year]
100%	100.279	0	0	38.449	[TWh/year]

As is evident from the above displacements, the shift from individual electric heating to DH technologies doubles, triples and quadruples the DH production needed for each level compared to the reference scenario.

The heat displacements are completed in EnergyPlan by adjusting total electricity demand, individual electric heating and DH production. The relevant distribution files are kept the same as in the base scenario as it is assumed that these files will not change.

The most appropriate DH technologies that we will suggest together with the potential capacity of their use in Norway will be summarized in the table below. It should be noted that these technologies will serve to understand the effects in general on the Norwegian energy system when electricity is virtually unused for heating purposes. The results of the proposed scenarios will attempt to analyze the state of the energy system if it approaches the way for expected changes in the overall electricity demand.

Table 28: DH technologies with their potential and storage option in Norway.

DH Technologies	Potential Input [TWh/year]	Storage
Biomass	21.1	Yes
Waste Incineration	4.86	No
Excess Heat from Industry	9.8	Yes
HP-Peak Loads Only	-	Yes

When sizing these technologies for the use of DH scenarios two important elements are considered. First, if the technology chose is possible to relate to a thermal storage and second if the technology that the proposed scenario is used to cover base heating load or peak load. In the description of DH technologies above it is found approximately the potential of each to contribute to the heating demand.

10.5.1 Biomass based scenario

Increased production and use of bioenergy is a high priority in Norway. Bioenergy is recovered from several types of biomass - among them forest-generated raw materials. Forest resources represent the major potential for increased bioenergy production in Norway. The potential increase varies in different studies according to assumptions. A doubling of the current production is possible within the current sustainability policies. The theoretical potential, if all biomass resources where used for energy production would be around 180-210 PJ (50-55 TWh).
Based on the two first shifting levels above we will represent DH demand ai its base load, average load and maximum (peak) load.

Table 29: Biomass scenario DH demand by shifting levels.

DH Demand [MW]			
	20%	40%	60%
Base Load	508	762	1016
Average Load	1444	2179	2915
Peak Load	2908	4389	5874

Based on the above requirements for each level, the capacity of each biomass-based production unit will be determined. Then, the resulting sizes will be compared to the real capacities in Norway. If these capacities can cover DH demand, then the analyze will continue with the total annual costs and emissions so that we can choose the best scenario available.
If we go back to reference scenario results again we can find the capacities of each biomass-based technology. After that, the same capacities should be found on the

proposed scenarios. Differences between these capacities will be tested if they can be covered by the resulting biomass potential capacities in Norway. If the capacities are too high to be covered from the potential sources within Norway the scenario will not be considered as relevant for further analyses.

Table 30: Production units in the reference scenario

	Reference Scenario	Units
Waste	457	[MW]
Boilers	518	[MW]
Heat Pumps	437	[MW]
Biomass CHP	275	[MW]
Excess Heat	22	[MW]

If only production units from reference scenario are considered, we can see that the available capacities can only cover a little more than base load. If we want to cover the total demand capacities should be proposed on the technologies that use sources with more potential in Norway.

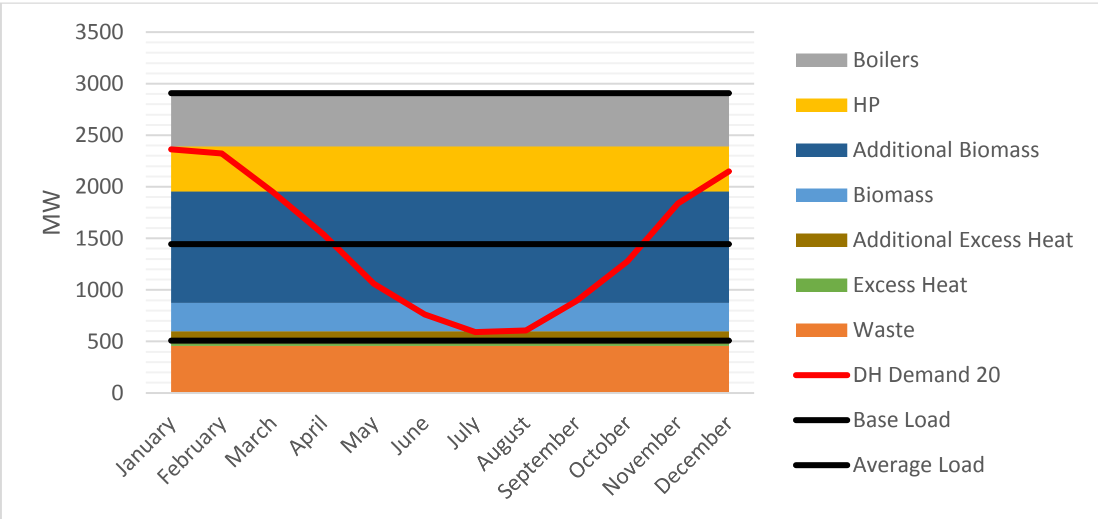


Figure 55: DH demand from reference scenario and available Biomass capacities on biomass 20% scenario [MW].

If hourly DH demand values were presented on the graph, the peak load would be more visible. However, for simplicity of the interpretation of the graph we have chosen the monthly values of DH demand. To cover DH demand was decided to calculate the additional capacities that will cover and excess the peak load in this scenario. If we start interpreting the graph we can see that current available capacities can meet about half of the DH demand. From the available capacities we will chose those which was greater potential within the country.

From calculations result that the available capacity from the reference scenario is 1708 [MW] while the peak load resulted in 2017 is 2904 [MW]. So, there is 1199 [MW] more capacity to be added. In this scenario, additional technologies will be as below. Biomass will cover needed to cover DH demand. Thermal storages are implemented in all scenarios to maximize the use of HP's and minimize the use of boilers for DH production.

Table 31: Additional capacities proposed for the 20% shift

Additional Capacities (20%)		
Biomass	1080	[MW]
Excess Heat	120	[MW]
Storage Size	4	

The suggested units above should be ordered according to the priority of production set by EnergyPlan. However, for visual effect on building the graph they are ordered according they values. In this case, EnergyPlan prioritizes the production units as bellow:

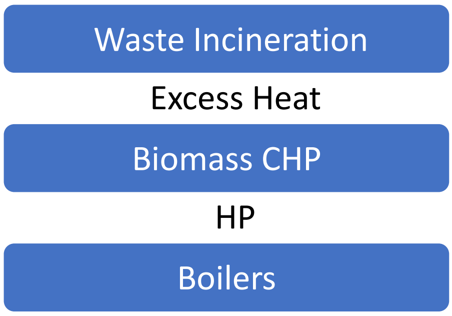


Figure 56: Units production prioritization according to EnergyPlan

From reference scenario we can see that the base load is covered by waste incineration plants and excess heat. While CHPs and HPs are not enough to cover the average load. The load left is covered by existing boilers and other additional boilers used to cover peak demand. While we can propose additional small biomass CHPs and HPs. To create a more secure supply system additional production units will be proposed.

Considering the available capacities introduced above we will propose additional units that will help increase the security in winter seasons when heat demand is greater. The availability of sources is the most important element when proposing other technologies. The second important element is the production unit prioritization as showed above. Combining both these qualities results that the first technology to be proposed is based on biomass CHPs. For the first shift (20%) it is needed 1 199 [MW] additional capacity. The greater heat supply to cover this load is proposed to be covered from additional biomass CHPs or about 1080 [MW]. The reason why small biomass CHPs plants are proposed is that Norway have now inconvenient experiences with large-scale biomass CHP plants. Properly maintained biomass CHP systems should benefit from around 8000 hours operation in a year and so the additional production we propose is 8.65 [TWh] in a year. The additional capacity covered by excess heat is around 120 [MW]. The storage included in the reference scenario is 1 [GWh] while in this shift the storage size is 4 [GWh].

In this master thesis another shift will be considered. As results from EnergyPlan, the peak load in the second shift (40%) is 4389 [MW] or more than two times higher compared to the 25% shift scenario. Again, if we refer to reference scenario the capacity implemented is 1708 [MW] the difference between this load and peak load is 2 681 [MW].

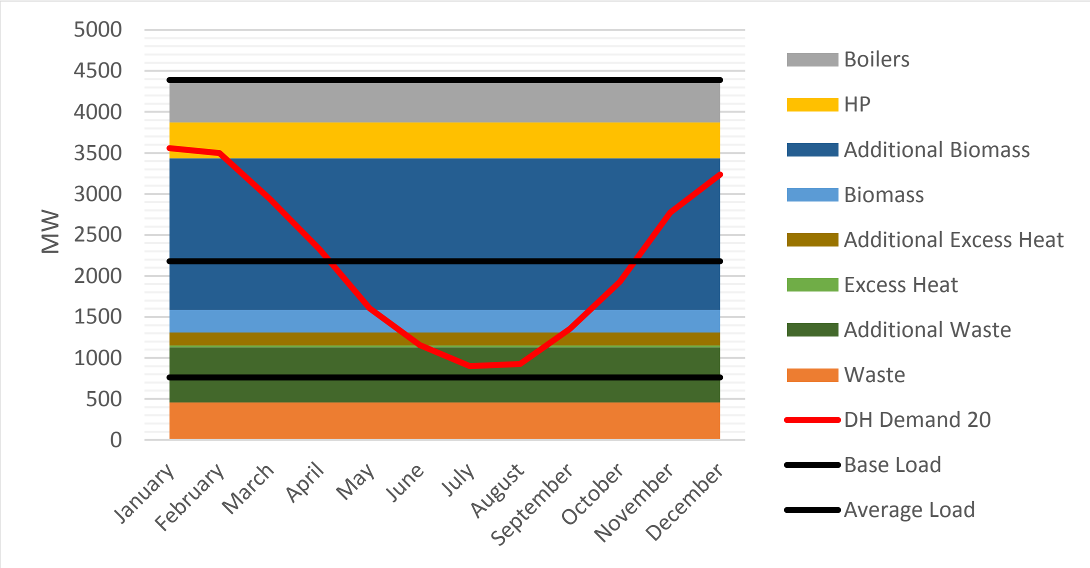


Figure 57: DH demand from reference scenario and available biomass capacities on the biomass 40% scenario [MW].

For this case depending on the units prioritization and the source availability the additional capacity proposed is a followed:

Table 32: Additional capacities proposed for the 40% shift

Additional Capacities (40%)		
Waste Incineration	673	[MW]
Excess Heat	158	[MW]
Biomass	1 850	[MW]
Storage Size	5.2	

In this shift, the additional required capacity is covered by waste incineration units, excess heat from industry and biomass units. Biomass units consist of small biomass-based units and biomass boilers. Coefficient of performance (COP) resulted 5.2.

The last electric heating shift is considered on the reduction of electric heating with around 60%. This shift uses the above-mentioned units almost to their capacity limits. That is why this combination will be taken into consideration, but its implementation presents a difficulty as the proposed model assumes many elements that are likely to divert the reality. This is done to simplify the system for study simplicity purposes.

After implementing changes in EnergyPlan for the 60% shifting the additional capacity needed to cover the peak demand is suggested as below:

Table 33: Additional capacities proposed for the 60% shift

Additional Capacities (60%)		
Waste Incineration	1035	[MW]
Excess Heat	234	[MW]
Biomass	2897	[MW]
Storage Size	6.4	

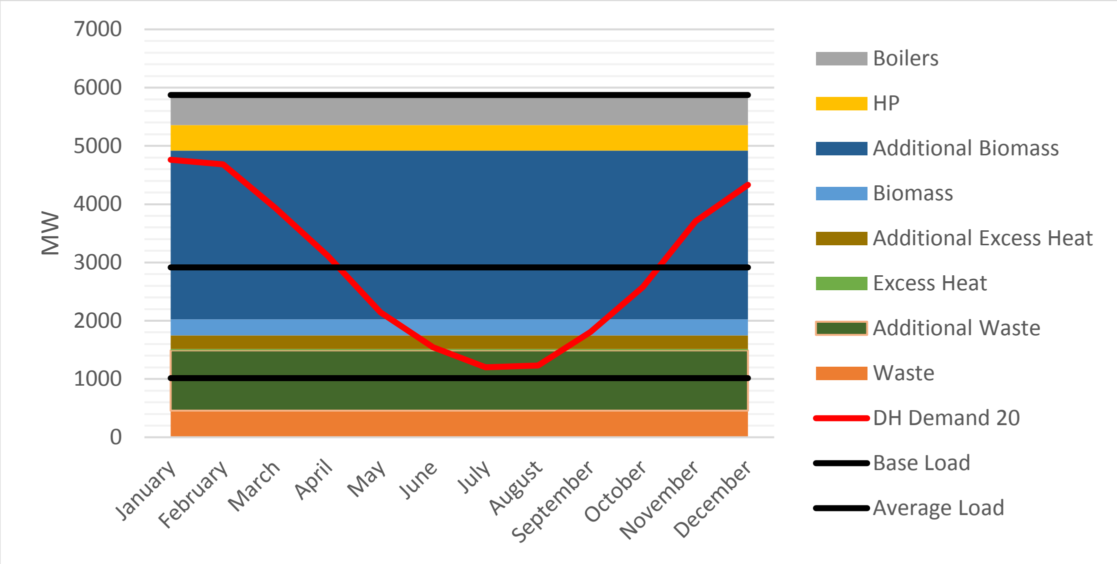


Figure 58: DH demand from reference scenario and available biomass capacities on the biomass 60% scenario [MW].

The combined use of these resources is in accordance with the conditions outlined above. The results section will show the comparative results of these two biomass-based scenarios. Comparison analyses will include the change in CO2 and cost accompanied by arguments related to other relevant components.

In the 100% shift case, the implementation of technologies that only use biomass sources is not possible because it exceeds the amount of resources available within the country. Scenarios based on the replacement of individual electric heating systems with district heating systems based on renewable biomass sources are based on real data and the assumptions made are not far from reality. However, in the implementation of these production units there are several factors that are not taken into account but that for the purpose of the study they will be consider on the following chapter. The main barriers are related to the lack of infrastructure and estimated operational efficiency of the units. System improvements taking into account these obstacles require some additional inputs and data regarding the characteristics of dwelling and distribution requirements in DH distribution system.

10.5.2 Optimized scenario

In this section other combination of DH scenarios will be proposed and analyzed. A very important issue when proposing scenarios is to consider sources be they order of availability, efficiency and acceptance from internal energy directives and international targets. When proposing biomass-based scenarios, we considered the total available capacity within the country and our scenarios were analyzed until there were free available capacity.

However, if the biomass is not enough to cover the total heat demand we will shift to other scenarios that consider other efficient ways. That is why is decided to include heat pumps in this section of DH scenarios. Heat pumps a very efficient way of using direct electricity and converting it with a coefficient of performance (2.2-3.5) to heat. It is way more efficient compared to the use of direct electricity. First proposed scenario will include heat pumps integrated to DH network and individual heat pumps as well.

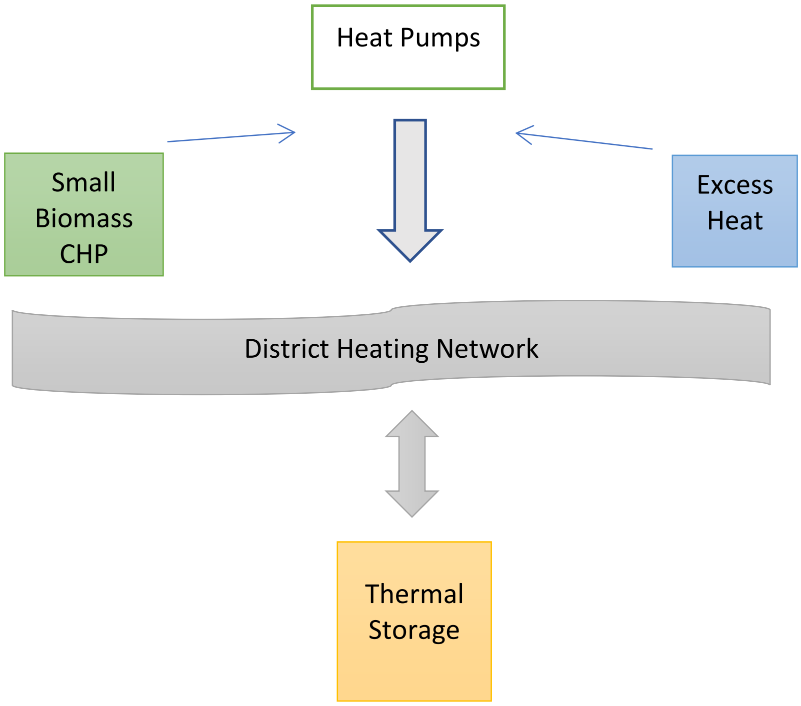


Figure 59: Heat pumps integrated in the district heating system

It is well known that biomass sources are limited. To avoid insecurities because of that the above system is proposed. Heat pumps will be used to cover the peak load. The proposed scenarios so far have available capacity only to meet peak load but in the next years if the heat demand will increase they will not be able to cover more than peak demand. That is why we decided to optimize the scenario that will use a combination of available resources and overcome the expected demand for the required heat by increasing the security of supply for the heating sector. Also, it is known that the demand for heating is expected to increase in the future as forecasts and the population will also increase.

According to this scenario, we have reduced electric individual heating to 0.5 [TWh] per year from 26.3 [TWh] per year that it was before. This value of electricity is not set to zero, so it can cover the demand for heat in those areas where other technologies will not be possible, since Norway has almost 100% coverage with electricity across the country. This change will be reflected in the total demand for electricity and the total demand for electricity used for heating purposes in other sectors. Referring to the reference scenario

Electricity Demand and Electric Heating will decrease respectively from 132.579 [TWh] to 106.279 [TWh] and from 32.3 [TWh] to 6.5 [TWh].

Table 34: Additional capacities on the optimized scenario

	Combined Scenario	Reference Scenario	Unit
Electricity Demand	106.279	132.579	[TWh/year]
Electric Heating	6.5	32.3	[TWh/year]
Individual Electric Heating	0.5	26.3	[TWh/year]
Excess Heat	9.8	0.181	[TWh/year]
Waste	4.8	4.8	[TWh/year]
Heat Pumps	15	15	[TWh/year]
Biomass	6.3	6.3	[TWh/year]

As we simulate these inputs in EnergyPlan, we will get satisfactory results both in terms of reducing electricity and lowering the total cost of the system. Excess heat from industry has a considerable potential in Norway but unfortunately it is not possible to find information about the temperature and the cost of this heat. Such information would help us build a clearer heat supply scenario, but this will be a priority in future work. Heat pumps have remained at the same levels and in this scenario to not increase more initial costs. Also, more capacity implemented in heat pumps means more consumed electricity if other sources are not available.

RESULTS FROM DH SCENARIOS

In this chapter we will show the effects carried out from the implementation of proposed scenarios in the current energy system presented in the reference scenario in EnergyPlan. Each shift has its own effects that affects different elements of energy balance. In district heating scenarios we have used the same simulation strategy as in the reference scenario.

Furthermore, all the changes in the proposed scenarios are explained above in detail because the shift from electric heating to other heat production units is a very complicated transformation that takes into account all the possibilities and limitations of the system. All the proposed changes suggest the adaption of the heating sector as a small electricity consumer. The significant reduction in the amount of electricity consumed by the heating sector brings to Norway a favorable situation in the energy situation in and outside the country. In summary, below will graphically depicted the differences between the baseline scenario and the proposed scenarios to further select the best possible scenario.

11.1 ELECTRICITY

The first energy indicator we will focus on will be electric heating (EH). If we make a comparison between the baseline scenario and the proposed scenarios we will notice a decrease in demand for electricity. Electric heating consumes a considerable amount of electricity. From one scenario to another, the change of electricity used for heating purposes is distinct. Such a change results because of the increase in the percentage of biomass used as part of the heating systems. This implies that the proposed technologies give effect to the fulfillment of the purpose we have in this master thesis.

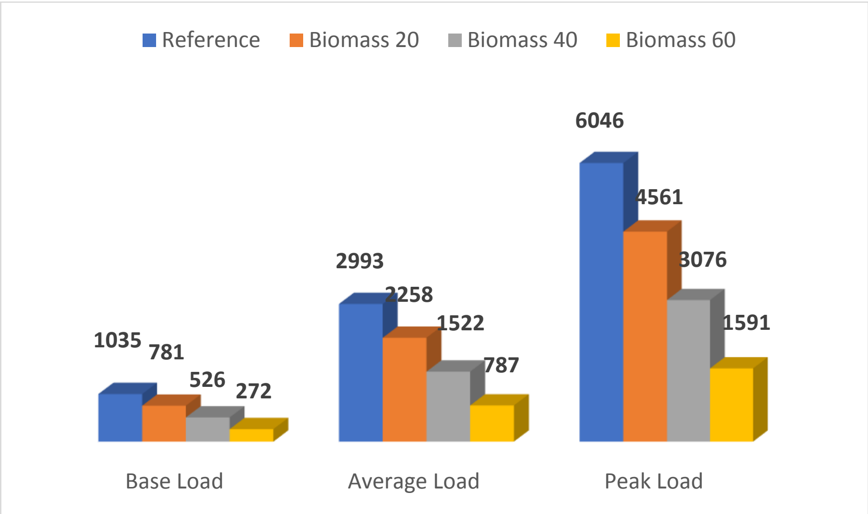
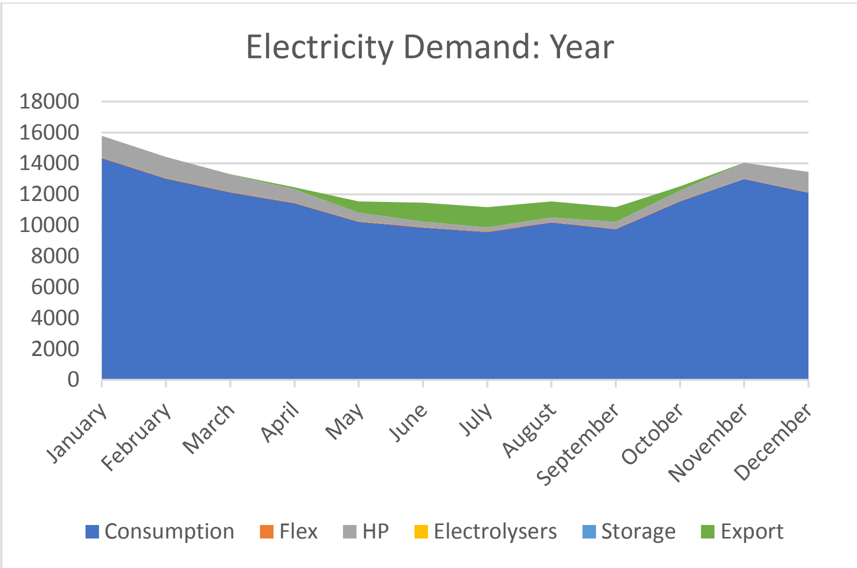
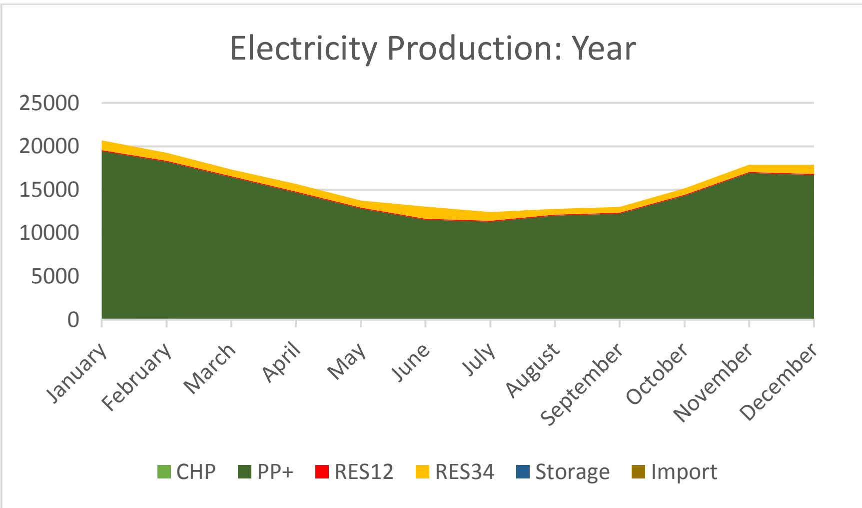


Figure 60: The change in electric heating from reference scenario to the proposed scenarios [TWh/year].

Below we will present the changes in electricity due to the changes according to the graphs generated by EnergyPlan. The graphs below show the change in electricity demand, electricity production and energy balance referring to year 2017. In the following it will be explained the elements presented on each graph that may be difficult to understand. CHP, mentioned on the electricity production represents CHP in group two and three and industrial, micro and waste CHPs. In this master thesis all the CHPs included are small-scale CHPs based mostly on biomass. Thus, CHPs suggested on the proposed scenarios are part of group two and so the generated results will be available only for group two. RES12 are renewable energy sources from wind and photovoltaic and RES34 are renewable energy sources from river hydro and CSP solar power. While PP+ includes different power plants including nuclear, geothermal and hydro power plants.





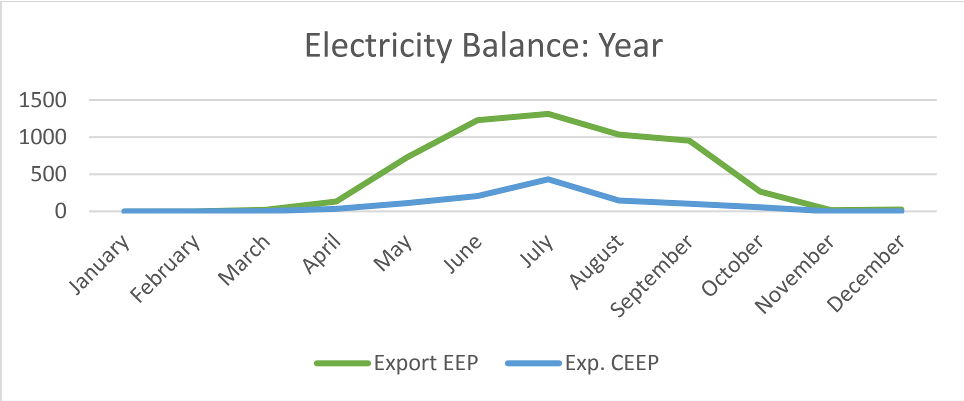
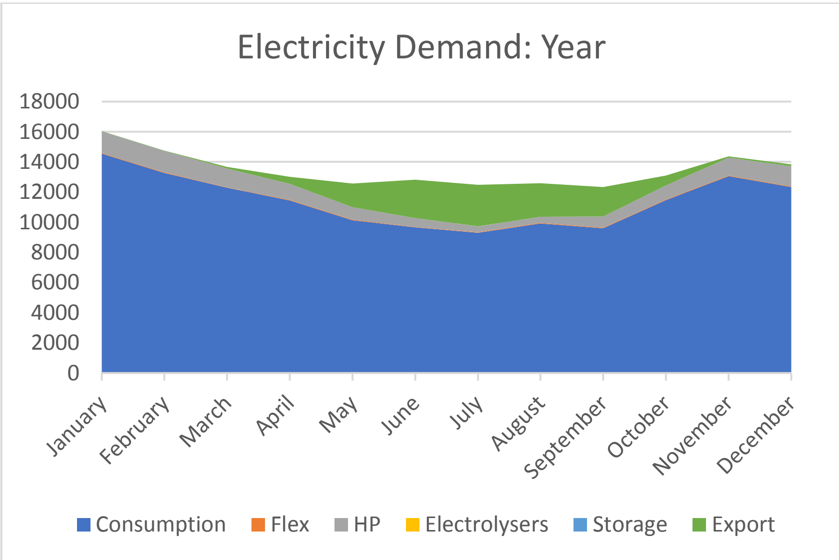
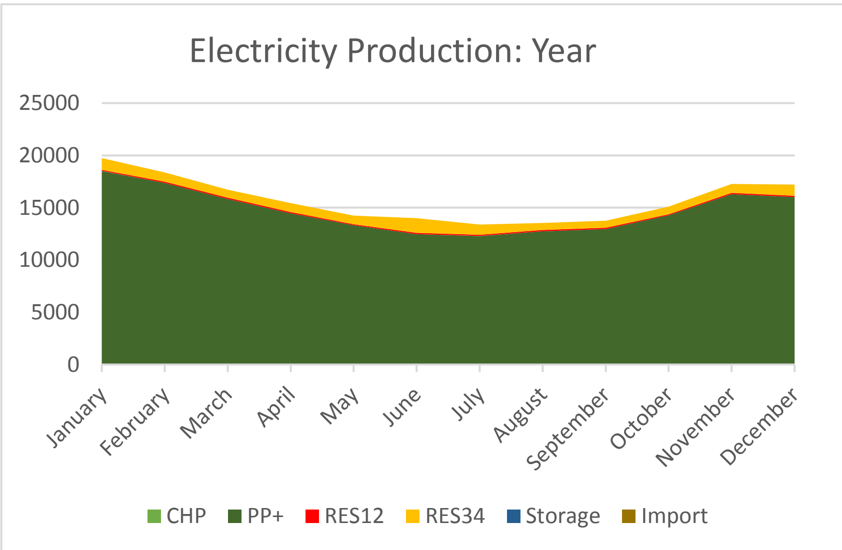


Figure 61: Electricity Demand (1), Electricity Production (2) and Energy Balance (3) from EnergyPlan: Reference Scenario [MW].





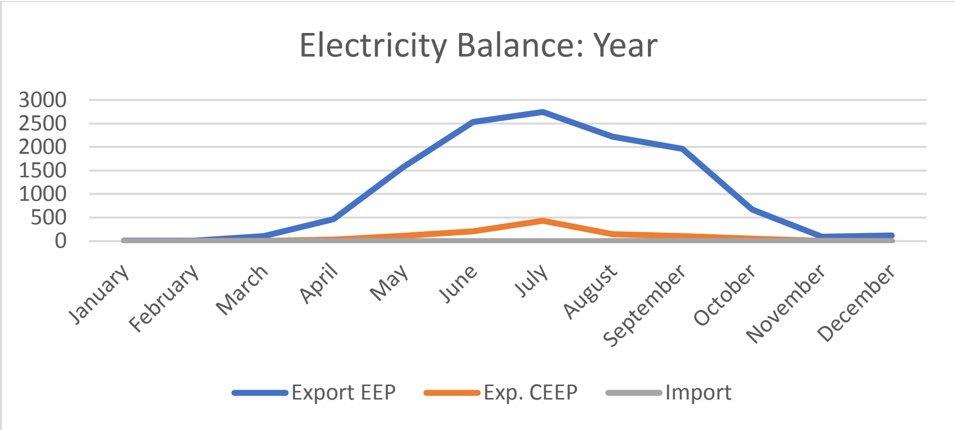
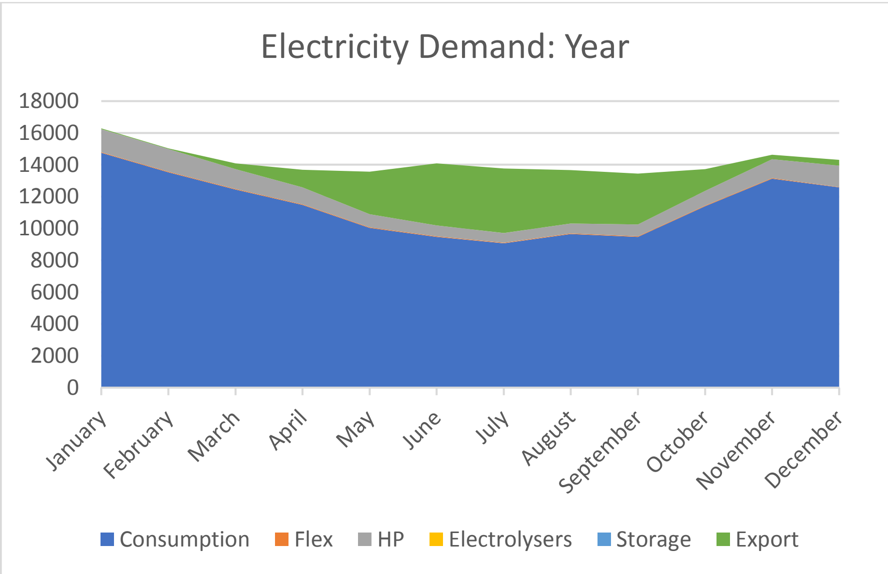
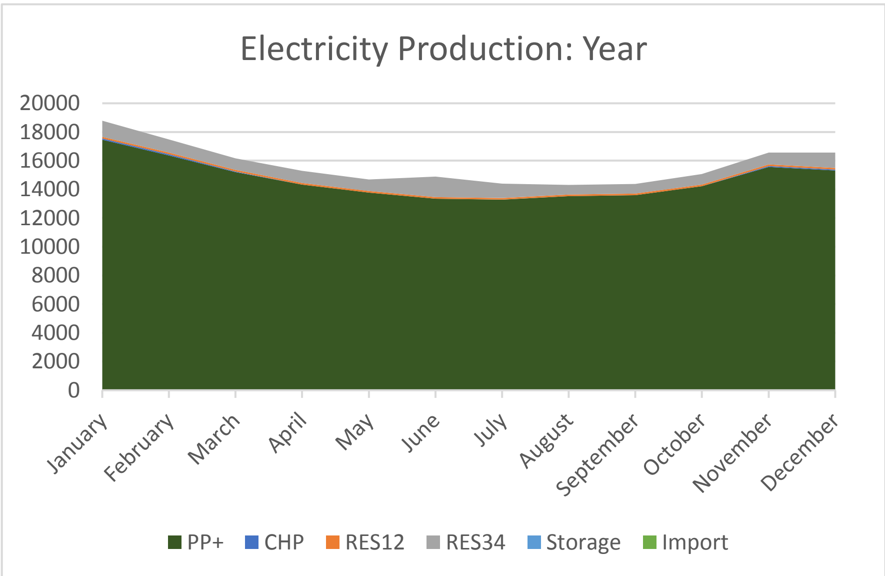


Figure 62: Electricity Demand (1), Electricity Production (2) and Energy Balance (3) from EnergyPlan: Biomass 20% Scenario [MW].





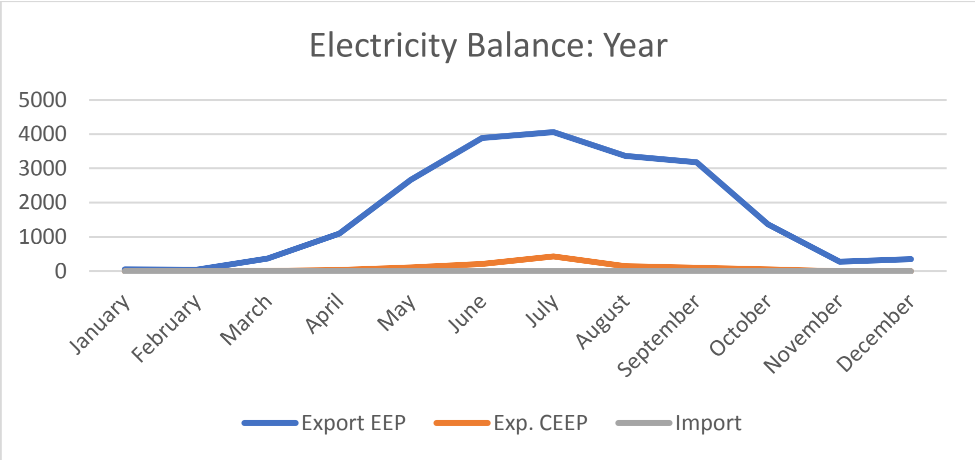
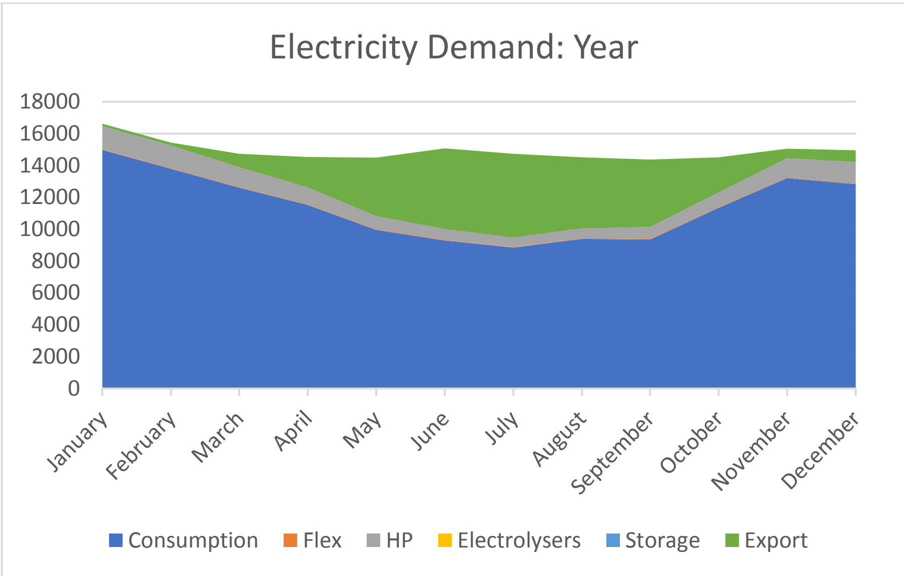
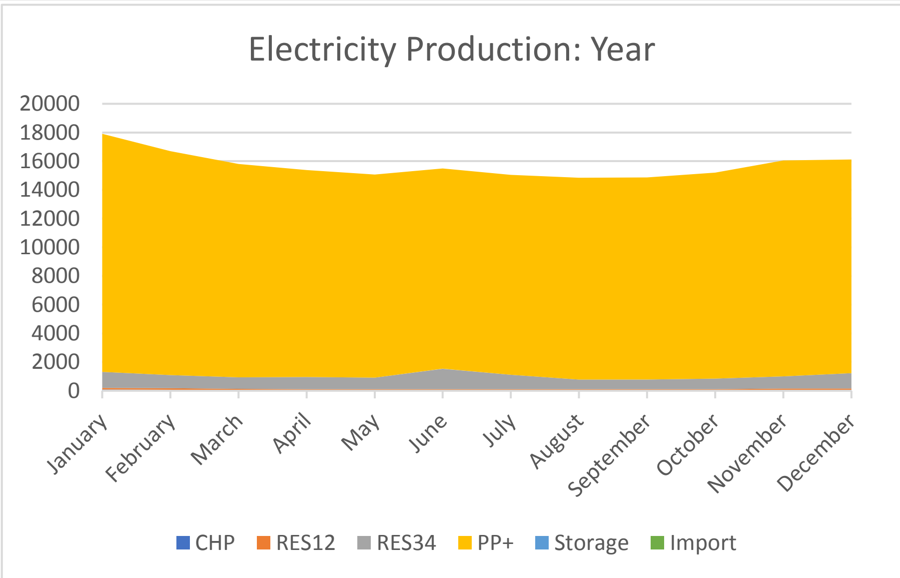


Figure 63: Electricity Demand (1), Electricity Production (2) and Energy Balance (3) from EnergyPlan: Biomass 40% Scenario [MW].





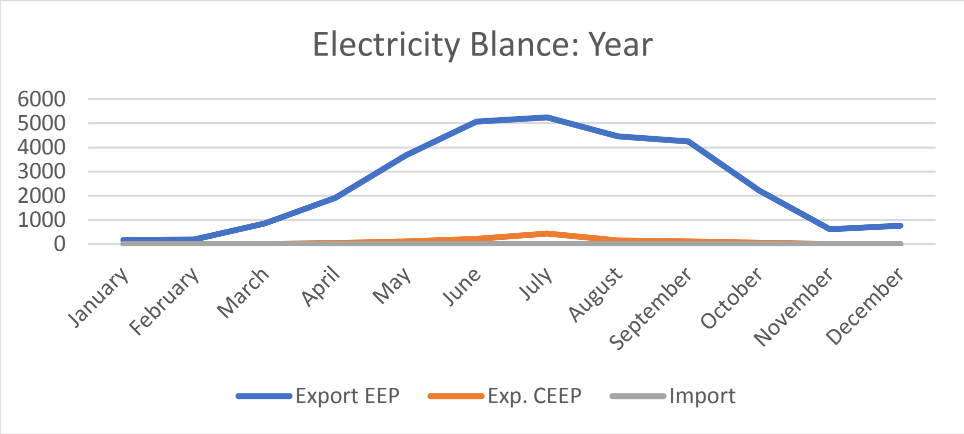


Figure 64: Electricity Demand (1), Electricity Production (2) and Energy Balance (3) from EnergyPlan: Biomass 60% Scenario [MW].

The comparison of the graph gives us the overview of the changes for all scenarios. If we compare electricity consumption it remains the same because of the increasing demand of electricity on other sectors (ex. Transport). Electricity production becomes constant during the year, so it can be stored. While the amount of electricity exported have become higher as the share of biomass sources increases electricity import become lower.

As mentioned above, Norway currently uses hydro sources to produce electricity, the electricity sector does not contribute to the amount of CO2 emissions in atmosphere. Also, recent investments in Norway include wind farms which also do not pollute. Switching from electric heating to systems mainly supported on biomass, waste and excess heat is not accompanied by visible changes in the amount of carbon emitted.

Norway is different compared to other countries in the region and Europe, where a shift that results in a reduction in the amount of electricity consumed results in a very sensitive positive effect on the amount of carbon emitted. This is because most of these countries rely on electricity generation in traditional power plants using fossil fuels. Therefore, the proposed scenarios will affect CO2 emissions in Norway, but this will be due to chain effects. Reduction of electricity used by the heating sector will increase available power capacities to cover electricity consumption by electric vehicles (EVs) in transport sector.

Norway can also influence carbon emissions in other countries by exporting electricity. Countries that do not have large renewable energy sources will face the need for electricity imports to meet the carbon emission reduction targets in the upcoming years. The electricity export has begun for years and Norway exports a large part of domestically produced electricity. This is expected to continue as 2030, 2040 and 2050 are coming. This substantial changes except for positive effects will be associated with significant cost of interconnection network lines.

11.2 Heat

The outputs from district heating section will be discussed as we have on our scenarios shifted a significant amount of heat from electric heating to DH systems. District heating systems can heat supply on large areas by increasing the final total efficiency. In some extent, the use of DH systems results positive for the country and other neighbor countries for the reasons that we have discussed above. If we take a look on the DH demand represented by months according to different scenarios we can notice that this demand increases as the biomass share is higher. This happens because of the reduced electricity amount used for heating purposes.

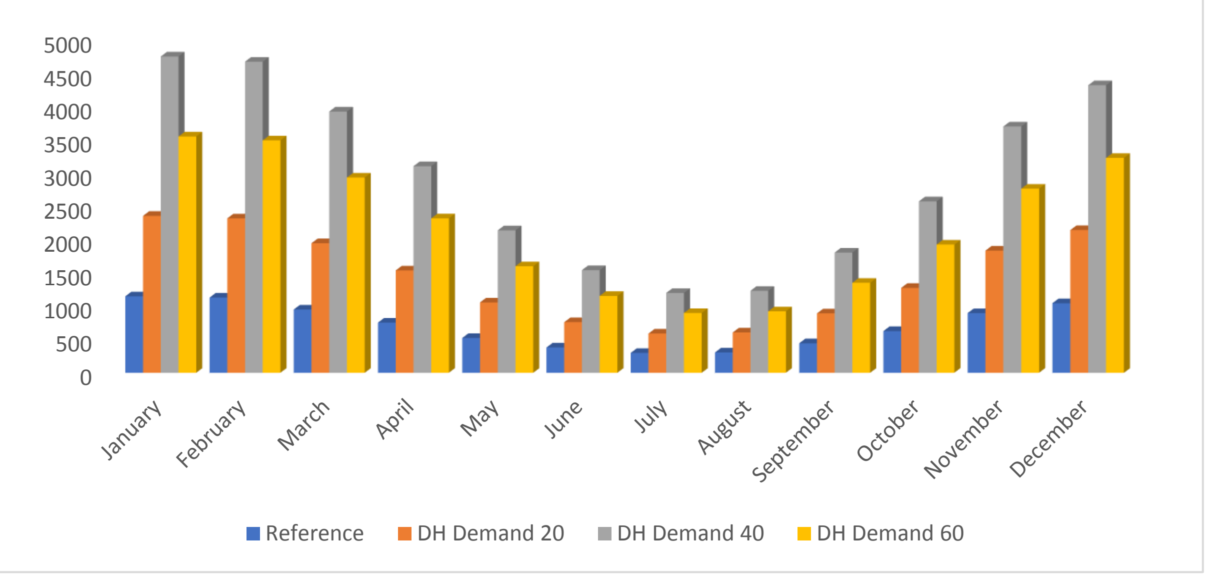


Figure 65: DH demand change in different scenarios [MW]

Below we will show results generated by EnergyPlan and try to understand what the effects of proposed scenarios are. On the DH demand it will be divided between DH used for biogas, heating and cooling. Among different scenarios, we can notice that DH systems are mainly used for heating purposes in Norway. There is approximately no DH for biogas and cooling purposes because Norway has gas reserves and it is a cold country. District heating for heating increases about 1000 MW if we shift from reference scenario to 20% and from 20% to 40% biomass. If we look at the other shift from 40% to 60% the DH for heating will start to increase but less than two first shifts. This can be explained by DH network losses. More DH network implemented, higher DH network losses are. This means that the production will be higher compared to the case when direct electricity from electric heaters is used.

If we take a look on DH production graph we can see that on the reference scenario the heat is produced to an extend share from waste incineration, small CHPs, HPs and electric boilers. If we consider all the production units carefully it is evident that production here is less than real heat demand. This is because the direct electricity used for heating purposes it’s not included in this graph. The amount of electricity consumed for heating purposes is very difficult to be defined. However, based on statistics from EnergyFakta this amount is significant.

On the suggested scenarios we decide to reduce electricity used for heating purposes and it affects the total electricity consumption but increases DH production. As we move from 20% to finally 60% we can see that the production based on different production units but not direct electricity becomes higher and higher. The amount of electricity used before now is replaced by biomass, waste, excess heat etc.

Apart from the results generated by EnergyPlan, we will analyze some energy balance noted. The distribution of production technologies varies in different scenarios. This is accomplished based on the software distribution itself. We see that scenarios include technologies within the limits of resource utilization and including balance [MW]. DH production increases by passing through each scenario and is growing steadily and storage size.

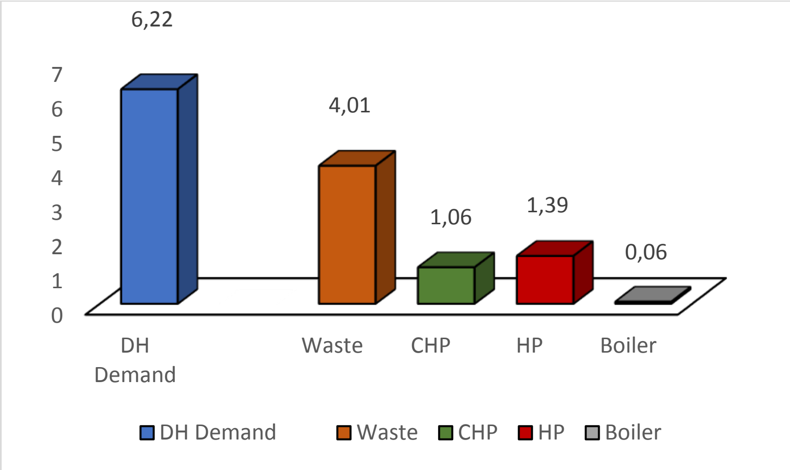


Figure 70: DH production by production technology-Reference Scenario

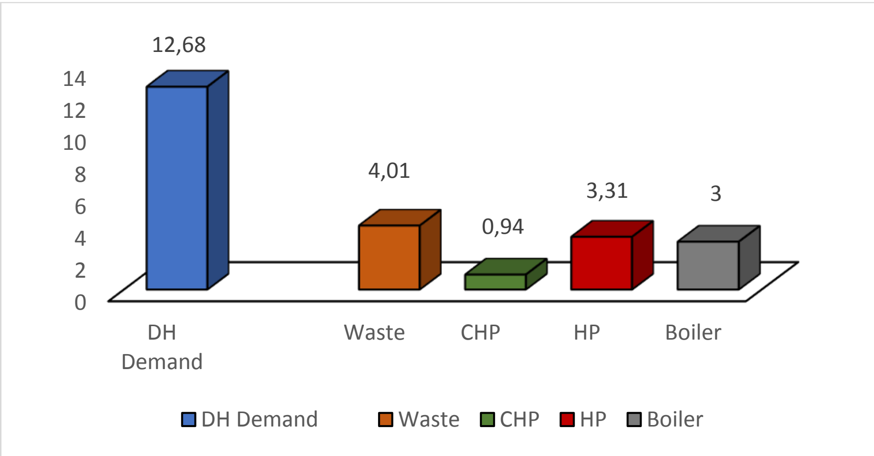


Figure 71: DH production by production technology-Biomass 20% Scenario.

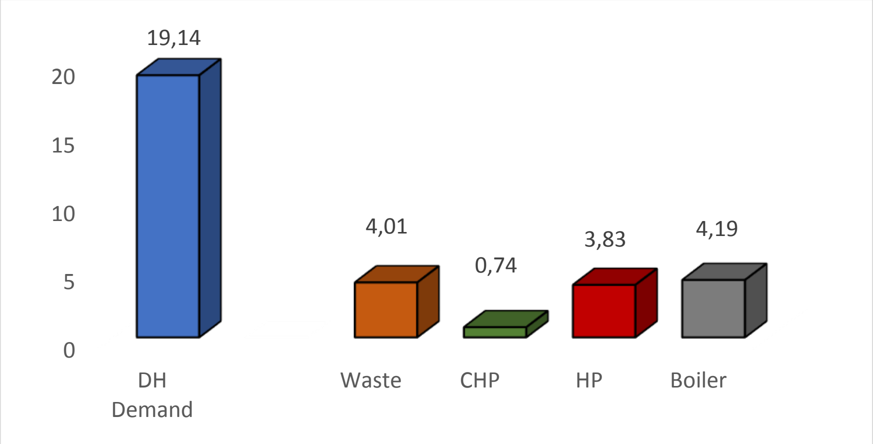


Figure 72: DH production by production technology-Biomass 40% Scenario.

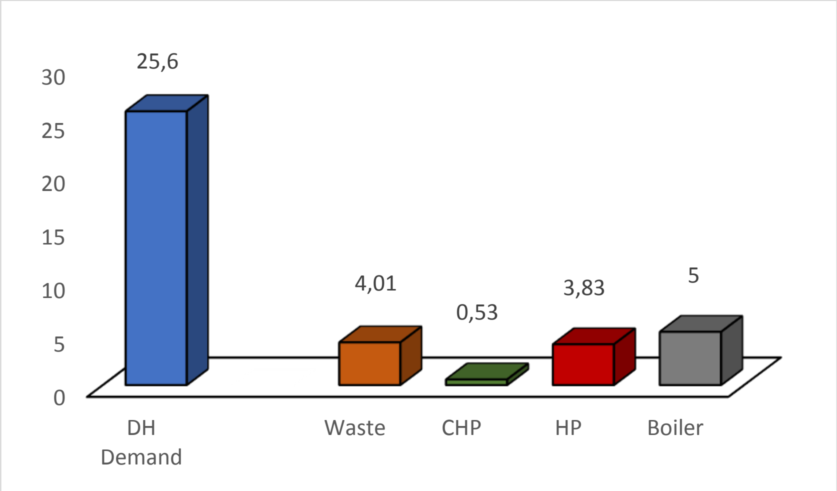


Figure 73: DH production by production technology-Biomass 60% Scenario.

From the depicted graphs above it is clearly observed that the additional capacities suggested helps to better cover the heat demand when electricity used is lower. The maximum of these sources is used on the 60% shifting and we can see that the heat demand is well covered in absence of electricity. More biomass-based systems we propose higher will storage size be for those technologies that can have a storage.

11.3 COST

In this section the effects on the cost will be analyzed. The focus will be on the total annual cost and on the marginal operational cost.

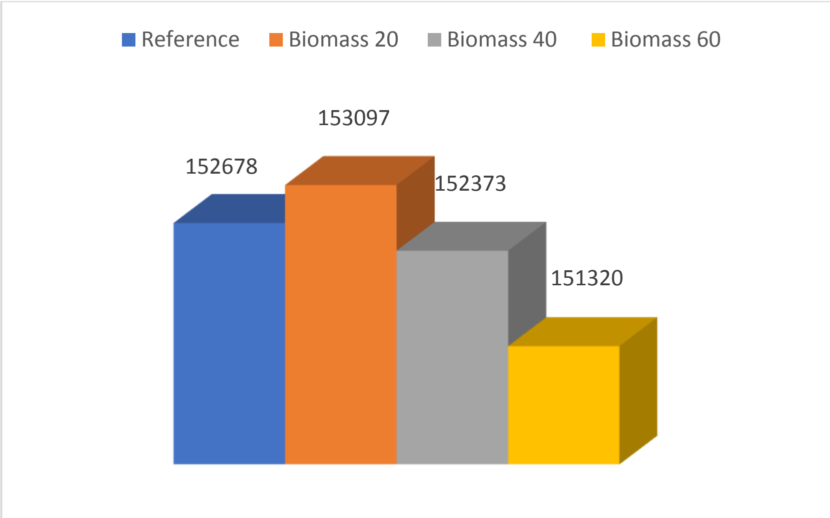


Figure 74: The comparison of cost for different scenarios (Million NOK).

Software optimizes all variants and generates total annual costs of implementing scenarios. Referring to the baseline scenario, the total initial annual cost increases compared to 20% biomass and then comes down to two other shifts. The explanation for this lies in the fact that initially the implementation of changes is accompanied by high investment costs. Also, the proposed technologies produce fewer units and this affects the marginal operational cost for each heat production unit. Then, the following scenarios propose capacity enhancements that are associated with a significant cost falling down compared to initial costs. Also, the design of larger production systems reduces unit cost and is associated with lower losses.

As we have previously mentioned, the last scenario uses the limit of biomass, waste, and heat surplus resources so it is not considered as the most suitable for implementation. Therefore, even though it results in the lowest cost, further analysis will be carried out.

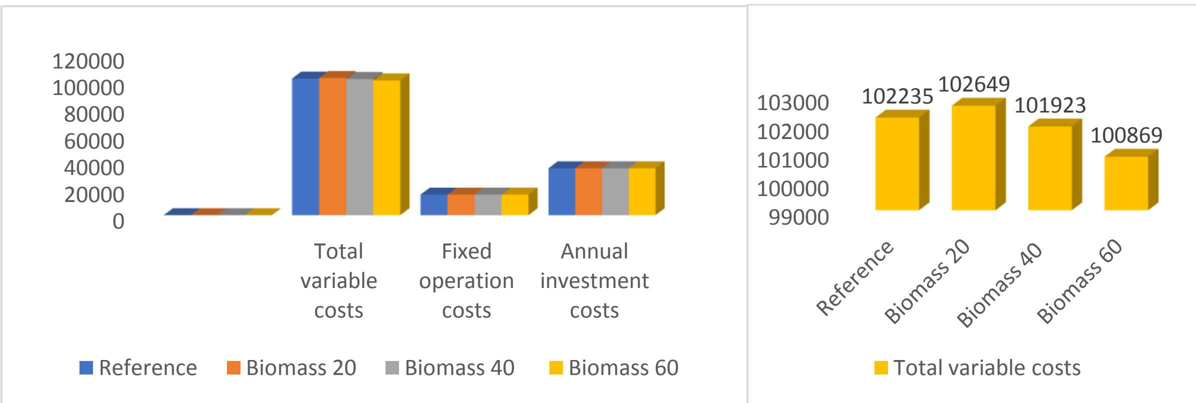


Figure 75: Total annual costs [Million NOK].

To argue what is said above, we are presenting the elements that make up the total annual cost to understand where the biggest difference is. As seen the biggest change is in the total variable cost that is directly related to the cost per unit of energy produced. According to economies of scale, with the increase of production capacity at a certain level, the unit production cost decreases.

CONSTRAINS

Replacement of electric heaters with district heating systems besides the benefits it brings along with some barriers. These barriers can be considered in two groups: barriers outside the system and barriers within the system. The first type includes all the obstacles that result in the selection of other heating technologies rather than the district heating systems. These are obstacles that are not related to the technology used in district heating systems or with internal elements of the system. While the second type of obstacles are related to the disadvantages of implementing this system due to its technological features and resources available within the country.

12.1 EXTERNAL BARRIERS

Due to the nature of the energy system and resources used, Norway has a very high use of electricity for heating purposes. This is because the electricity price is affordable for Norwegian households and domestically produced electricity is enough for the entire energy system, resulting in excess electricity.

In 2019, electricity price in Norway, excluding taxes and grid rent is 55.2 [øre/KWh] where grid rent, and taxes are respectively 34.4 [øre/KWh] and 38.7 [øre/KWh] respectively. While, the average district heating price is 68.9 [øre/KWh] excluding taxes or 5% higher compared to 2016 (Statistics Norway 2017).

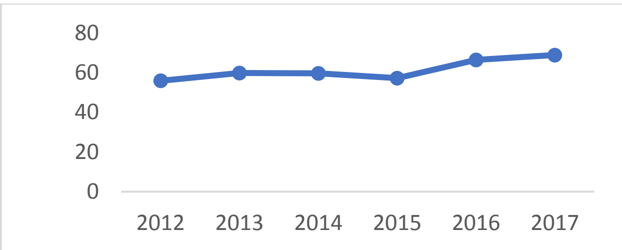


Figure 76: Average district heating price for households (Statistics Norway 2017).

The direct use of electricity for heating purposes therefore has two advantages that attract consumers into its use. First the price and access to electricity. Access to electricity (% of total population) in Norway was reported at 100 % since 2012, according to the World Bank collection of development indicators, compiled from officially recognized sources.

If we consider zero losses in transforming electricity into heat from electrical equipment, the efficiency is 1. While heat pumps have a COP that varies from 2.2 to 3, meaning that the amount of electricity used will decrease if indirect electricity is used on the heating sector. This is the reason that HPs market have been significantly growing. Norwegian heat pump market has been growing steadily since 2001. In 2006 the market reached 78,300 units. The most popular heat pump system in Norway is single unit air-to-air heat pumps. These heat pumps are replacing electric baseboard heaters and thereby reducing the dependency of electricity for space heating. In 2012, 27 per cent of all households had a heat pump, which is 9 percentage more than in 2009. In 2017, the number of heat pumps in Norway reached While today, there are 1.1 million heat pumps installed in Norwegian homes. The use of heat pumps reduces the amount of electricity used, but it has additional investment and maintenance costs. However, the use of efficient heat pumps for heating is positive compared to the direct use of electricity.

Considering the legal framework, it is concluded that the responsibility between institutions is problematic when it comes to making decisions about district heating infrastructure. The important role to provide district heating infrastructure is belongs to municipalities as it is part of the local infrastructure. While NVE, as licensing authority, has often similar responsibilities. This problem can be solved by removing the actual national licensing schemes and better specify decision making responsibilities in the energy act.

In Norway, there are no available support schemes for consumers that want to be connected to DH system. This can be a barrier by limiting potential consumers on the district heating system. The implementation of supporting schemes is thus an additional element that contributes to the financial acceptability.

In Norway, the implementation of large-scale plants that supply the DH network has resulted non-efficient and inconvenient. A very important factor when projecting a large-scale CHP or incineration plant in a certain area is the population density. If the density of population is optimal the plant will result cost-efficient. This means that the amount of heat delivered will be acceptable to provide profit and to justify the losses from distribution system. There are 15 P/km2 while is predicted to be 19 P/km2 in 2050. Norway is a vast country with a relatively small population compared to its geographical size. This could be a constrain for the CHP and incineration plants expansion because the linear heat density is low. The principle of "linear heat density" can be used to help identify potential areas for district heating. The Linear density of a heat network is the total heat demand, divided by the total length of pipe. The resultant figure serves as a useful marker for financial viability because the high capital costs of heat network infrastructure must be offset by sufficient heat sales through the network over a reasonable period of time (Partnership 2017).

Furthermore, the Norwegian residential sector is highly made up of individual houses and not apartment complexes. Out of 1 534 929 residential buildings in Norway 2017, only 3.4% were multi-dwelling buildings. While detached buildings, house with two dwellings and row houses have the largest share (Statistics Norway 2017).

12.2 Internal Barriers

In the proposed scenarios of district heating systems, we are limited to some elements that are the result of the objectives that Norway must achieve in the future. In this master thesis, electricity used for heating purposes should be reduced and instead the use of DH systems should be implemented. DH systems using biomass resources are first prioritized to cover the base heat load and if it is not sufficient the system will automatically use the most electricity efficient technologies. In this selection, the use of fossil fuels will not be considered while it is against the fulfillment of the objectives. When proposing district heating systems, we focus on the resources that will be used. Any source will be used based on what is available within the country. Therefore, we can say that availability of resources is the element that limits the range of potential DH technologies.

Lack of DH infrastructure in the existing buildings is another internal barrier for the DH expansion. Investigated by (Bozhkova 2017) the main heating sources used from the households mostly have airborne due wide use of solar collectors and heat pumps air to air that are airborne heating systems.
According to SSB, only 16% of the households may use waterborne heating systems because they are connected to central heating systems, oil boilers, heat recovery geothermal HPs and district heating systems. So, to be able to connect to DH network this households should invest on waterborne systems and this can be a barrier as it means additional cost.

DISCUSSION

The suggestion of district heating scenarios is very difficult to be completely analyzed for countries that do not have in countries that do not have a widespread use of DH technology. This is a true fact about Norway. In this study, we have referred to DH systems in a general way without including some features of this technology. When we discussed district heating systems updates we have argued that the fourth generation of these systems is very efficient. Also, systems belonging to this generation have many advantages over the use of renewable energy sources due to the lower temperatures applied in these systems.

Furthermore, to not remain in a solution that uses resources that are somewhat limited is proposed a combination of technologies that complement each other. Reduction of the electricity used by the heating sector is the main focus of this research. However, when this reduction is not possible we decided to apply technologies that use electricity efficiently e.g. heat pumps. Again, within this proposal, is decided that HP would be used for large installed capacities connected to the district heating network. Then in cases when it is not possible can be applied individual heat pumps, that are a more efficient solution than direct use of electricity from electric heaters.

The cost aspect is another field that can be discussed. Some of the costs the we have been able to find from official sources are considered in this model. Other are taken from EnergyPlan cost database updated recently. These costs may not represent real costs due to the various elements influencing markets in different countries. However, these costs represent a general overview of the current situation and the effects that cause different scenarios. On this basis, we have considered the generated results and argued the changes compared to each other.

13.1 FUTURE WORK

The theme chosen for this master thesis includes a broader study aspect. The lack of data sources has affected and limited some aspects of the analysis. Therefore, I will continue to improve and update this model, including more detailed data. Some of the research aspects where the future study will be focused are going to include additional inputs due to the problems with the infrastructure (including the lack of infrastructure on residential buildings) and the lack of considerations of the new generation of DH system. Inclusion of these elements will give a more realistic situation and will have a socio-economic impact in the future.

CONCLUSION

The main purpose of this master thesis is to investigate the effects of transforming heating sector in Norway from a sector that is mainly based on electricity to the sector that uses alternative heat production technologies and sources that help on reducing electricity consumption nationally. Smart energy systems are defined as an approach in which smart electricity, thermal and gas grids are combined and coordinated to identify synergies between them to achieve an optimal solution for individual sector as well as for the overall energy system (Lund 2014).

In the future, there are two main expected developments that will require Norway to have electricity surplus at higher levels than currently: further increase in the number of electric vehicles (incl. V2G technology) & the growing need for export of electricity. These developments have both the same reasons. First, Norway is investing in increasing the number of electric vehicles to reduce carbon emissions in the country and to achieve energy targets in the future. Second, role of Norway as the main exporter of electricity will become more important because other countries that are currently lacking renewable sources will not reach their final energy intensity targets, as one of the main solutions to reduce energy consumption in different energy sectors, as activity level grows exponentially. Environment and development, with an emphasis on climate change is the third reason that has become a key issue since 1990s and has an increasing social importance along with the rising discussions on global warming. As European countries, especially Nordic countries should be converted into low- carbon economy (LCO), their priority will be displaced on purchasing electricity from countries that have energy surpluses and produce it from carbon free sources. To reach the above-mentioned reduction of electricity consumption for heating purposes within residential sector, it is crucial to identify excess heat in different industry levels. The remain heat demand with be supplied by designing CHP 2, excluding CHP 3 as they have some barriers to be applied in Norway because of country context[6].

Based on the Choice of Awareness Theory, which advocated counterstrategies involving the design of technical alternatives, feasibility studies based on institutional economic thinking, and the design of public regulation measures seen in light of conflicting interests as well as changed in the democratic decision-making infrastructure, we need radical technological changes especially in DH sector based on socio-economic impact.

In order to assess the effects of heat relocation mainly in the residential sector a reference scenario is designed. This scenario represents the current stage of operation of the energy system in Norway and only by starting from a baseline scenario we can understand the effects of the displacement of heating technologies on the overall system. Then, assessing the availability of low carbon energy sources within the country, some suggested scenarios have been designed:

[6] Norway is a vast country with a relatively small population compared to its geographical size.

• Biomass 20
• Biomass 40
• Biomass 60
• Optimized Scenario

Initially, in the district heating scenarios we applied a reduction on the electricity consumed from individual electric heating by 20%, 40% and then 60%. For consumption reductions of electricity greater than 60% we should have to consider sources outside the capacity of the country and therefore this alternative was not taken into consideration. After running the proposed changes from the base-case scenario on EnergyPlan, the results generated for each new simulation were analyzed regarding: the possibility of reducing total final electricity consumption and the respective effects on the heating demand, coverage of the heating demand from the additional capacities proposed, electricity export and total annual cost. All the proposed scenarios provided a reduction of consumed electricity at national level, the export level increased, and based on the increase in demand for heat in the district heating sector the proposed technologies met the demand for heating. But the total annual cost was affected by the economy of scale effect, which caused its increase to 20% shift and after that this cost decreased progressively.

The interpretation of these outputs orientated us towards the selection of the scenario which results more cost-efficient but needs further optimization. The ideal scenario to be optimized resulted in 40% Biomass because it has a decreasing cost and is within the availability of resources, while Biomass 20% has higher total annual cost and Biomass 60% is on the limits of the resources available. In order to achieve at lower costs, several possible resource combinations were tested, and the optimal model resulted in a 3.7 % annual cost reduction.

Concerning CO_2 emissions, Norway is a different case compared to most of other neighbor and European countries, where a shift that results in a reduction in the amount of electricity consumed is followed by a very sensitive effect on the amount of carbon emitted. This is because most of these countries rely on fossil fuel-based power plants. Therefore, the proposed scenarios have not directly effect on the CO2 emissions in Norway, but they will affect emissions due to chain effects. Reduction of electricity used by the heating sector will increase available power capacities to cover electricity consumption by electric vehicles (EVs) in transport sector. Norway can also influence carbon emissions in other countries by exporting electricity. Countries that do not have large renewable energy sources will face the need for electricity imports to meet the carbon emission reduction targets in the upcoming years. The electricity export has begun for years and Norway exports a large part of domestically produced electricity. This is expected to continue as 2030, 2040 and 2050 are coming. This substantial changes except for positive effects will be associated with significant cost of interconnection network lines.

To conclude, if we bring to the attention the research question that led this study in this master thesis we can say that it is entirely possible to transform the heating sector in Norway. Norway is a country that is blessed with hydro power sources. In the meantime, over the years, this country has well managed its energy system and for this reason has achieved a high investment capability. Thereby, I believe its role as Europe's green battery will continue to grow and its contribution will be the best aid for certain countries

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ENERGYPLAN RESULTS

Input Reference_Scenario_2017.txt The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	99.28	Fixed imp/exp.	0.00
Electric heating + HP	32.30	Transportation	0.33
Electric cooling	1.00	Total	132.90

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	6.15	0.00	6.15
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	6.15	0.00	6.15

Wind	1207	MW	2.85	TWh/year	0.00	Grid
Photo Voltaic	42	MW	0.03	TWh/year	0.00	stabili-
River Hydro	1413	MW	5.11	TWh/year	0.00	sation
CSP Solar Power	0	MW	0	TWh/year	0.00	share
Hydro Power	30867	MW	128.8	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	100	275	0.24	0.66	
Heat Pump	326	437			1.34
Boiler		624		0.83	
Group 3:					
CHP	0	0	0.36	0.45	
Heat Pump	0	0			3.00
Boiler		0		0.83	
Condensing	454		0.41		

Heatstorage: gr.2: 1 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.97
Gr.3:	0.00	0.00

Regulation Strateg	Technical regulation no. 2	
CEEP regulation	210000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	1.00	
Maximum import/export	8895	MW

Energinet_no_NOKprices_2015.txt

Addition factor	0.00	NOK/MWh
Multiplication factor	1.39	
Dependency factor	0.00	NOK/MWh pr. MW
Average Market Price	246	NOK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:		0.000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	66.60	1.00	0.00
Household	0.00	8.10	0.80	6.30
Industry	7.90	10.60	3.40	3.90
Various	0.00	11.30	54.00	56.20

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance						
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp Million NOK	Exp Million NOK
January	1150	0	457	0	270	386	0	37	0	0	14336	37	1406	0	4901	0	0	1123	19351	0	110	98	0	100	0	1	0	1	0	0
February	1132	0	457	0	272	374	0	29	0	0	13011	37	1378	0	4819	0	0	909	18128	0	110	99	0	100	0	0	0	0	0	0
March	952	0	457	0	238	256	0	1	0	1	12126	37	1113	0	4044	0	0	790	16353	0	110	86	0	100	0	19	0	19	0	4
April	755	0	457	0	110	189	0	0	0	-1	11412	37	870	0	3195	0	0	854	14645	0	110	40	0	100	0	134	0	134	0	28
May	524	0	457	0	3	64	0	0	0	0	10224	37	549	0	2197	0	0	807	12815	0	110	1	0	100	0	726	0	726	0	133
June	381	0	457	0	0	0	0	0	0	-76	9839	37	360	0	1579	0	0	1419	11515	0	110	0	0	100	0	1228	0	1228	0	141
July	298	0	457	0	0	0	0	0	0	-159	9548	37	279	0	1224	0	0	995	11297	0	110	0	0	100	0	1313	0	1313	0	104
August	306	0	457	0	0	0	0	0	0	-151	10181	37	287	0	1259	0	0	679	12010	0	110	0	0	100	0	1035	0	1035	0	108
September	444	0	457	0	0	10	0	0	0	-24	9738	37	431	0	1853	0	0	674	12225	0	110	0	0	100	0	951	0	951	0	107
October	628	0	457	0	87	84	0	0	0	0	11540	37	667	0	2649	0	0	737	14282	0	110	32	0	100	0	266	0	266	0	44
November	898	0	457	0	241	200	0	0	0	0	12979	37	1020	0	3813	0	0	840	16828	0	110	88	0	100	0	17	0	17	0	3
December	1047	0	457	0	233	345	0	11	0	1	12106	37	1274	0	4455	0	0	1080	16621	0	110	85	0	100	0	24	0	24	0	2
Average	708	0	457	0	121	159	0	6	0	-34	11416	37	801	0	2993	0	0	908	14663	0	110	44	0	100	0	478	0	478	Average price	
Maximum	1419	1	457	0	275	437	0	251	0	201	18356	72	1705	0	6046	0	0	2414	23722	0	110	100	0	100	0	1943	0	1943	(NOK/MWh)	
Minimum	253	0	457	0	0	0	0	0	0	-203	7573	0	236	0	1035	0	0	243	9680	0	110	0	0	100	0	0	0	0	-	161
TWh/year	6.22	0.00	4.01	0.00	1.06	1.39	0.00	0.06	0.00	-0.30	100.28	0.33	7.04	0.00	26.29	0.00	0.00	7.98	128.80	0.00	0.97	0.39	0.00		0.00	4.19	0.00	4.19	0	675

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	7.90	7.90	0.00	7.90	2.67	2.67
Oil	-	-	-	0.00	-	0.00	-	-	-	-	-	-	-	-	-	-	-	66.60	8.10	21.90	96.60	0.00	96.60	25.59	25.59
N.Gas	-	1.61	-	0.01	-	0.00	-	-	-	-	-	-	-	-	-	-	-	1.03	0.80	57.40	60.84	0.00	60.84	12.47	12.48
Biomass	-	-	-	0.06	-	0.00	-	-	4.80	-	-	-	-	-	-	-	-	-	6.30	60.10	71.26	0.00	71.26	0.64	0.64
Renewable	-	-	-	-	-	-	-	128.80	-	-	-	-	2.85	0.03	-	133.91	0.01	-	-	-	136.79	0.00	136.79	0.00	0.00
H2 etc.	-	0.00	-	0.00	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-5.90	-	-	-	-	-	-	5.90	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	1.61	-	0.07	-	0.00	-	128.80	4.80	-	-5.90	-	2.85	0.03	-	133.91	0.01	73.53	15.20	147.30	373.40	-10.23	363.17	41.37	41.38

02-June-2019 [23:02]

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW
January	0	0	0	0	1150	0	457	270	386	0	37	0	731	0
February	0	0	0	0	1132	0	457	272	374	0	29	0	725	0
March	0	0	0	0	952	0	457	238	256	0	1	0	658	1
April	0	0	0	0	755	0	457	110	189	0	0	0	926	-1
May	0	0	0	0	524	0	457	3	64	0	0	0	998	0
June	0	0	0	0	381	0	457	0	0	0	0	0	998	-76
July	0	0	0	0	298	0	457	0	0	0	0	0	998	-159
August	0	0	0	0	306	0	457	0	0	0	0	0	998	-151
September	0	0	0	0	444	0	457	0	10	0	0	0	998	-24
October	0	0	0	0	628	0	457	87	84	0	0	0	998	0
November	0	0	0	0	898	0	457	241	200	0	0	0	996	0
December	0	0	0	0	1047	0	457	233	345	0	11	0	680	1
Average	0	0	0	0	708	0	457	121	159	0	6	0	892	-34
Maximum	0	0	0	0	1419	1	457	275	437	0	251	0	1000	201
Minimum	0	0	0	0	253	0	457	0	0	0	0	0	0	-203
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	6.22	0.00	4.01	1.06	1.39	0.00	0.06	0.00		-0.30

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage MW	Gr.3 Balance MW	RES1 Wind MW	RES2 Photo MW	RES3 River MW	RES 4-7 MW	Total MW
January	0	0	0	0	0	0	0	0	0	0	452	0	671	0	1123
February	0	0	0	0	0	0	0	0	0	0	387	1	520	0	909
March	0	0	0	0	0	0	0	0	0	0	307	2	481	0	790
April	0	0	0	0	0	0	0	0	0	0	289	5	560	0	854
May	0	0	0	0	0	0	0	0	0	0	375	6	427	0	807
June	0	0	0	0	0	0	0	0	0	0	271	7	1140	0	1419
July	0	0	0	0	0	0	0	0	0	0	290	6	698	0	995
August	0	0	0	0	0	0	0	0	0	0	208	6	465	0	679
September	0	0	0	0	0	0	0	0	0	0	262	4	408	0	674
October	0	0	0	0	0	0	0	0	0	0	232	2	503	0	737
November	0	0	0	0	0	0	0	0	0	0	304	1	536	0	840
December	0	0	0	0	0	0	0	0	0	0	508	0	572	0	1080
Average	0	0	0	0	0	0	0	0	0	0	324	3	581	0	908
Maximum	0	0	0	0	0	0	0	0	0	0	1207	42	1413	0	2414
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	6	0	243
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	2.85	0.03	5.11	0.00	7.98

Own use of heat from industrial CH0.00 TWh/year

ANNUAL COSTS (Million NOK)

Total Fuel ex Ngas exchange =	81005
Uranium =	0
Coal =	860
FuelOil =	9830
Gasoil/Diesel=	34377
Petrol/JP =	12586
Gas handling =	253
Biomass =	23790
Food income =	0
Waste =	-693
Total Ngas Exchange costs =	19434
Marginal operation costs =	456
Total Electricity exchange =	-675
Import =	0
Export =	-675
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	2015
Total variable costs =	102235
Fixed operation costs =	15362
Annual Investment costs =	35081
TOTAL ANNUAL COSTS =	152678

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	5	409	0	149	114	6535	7212	0	0	0	0	0	0	7212	7212	0
February	4	412	0	147	114	6535	7211	0	0	0	0	0	0	7211	7211	0
March	0	360	0	123	114	6535	7132	0	0	0	0	0	0	7132	7132	0
April	0	166	0	97	114	6535	6912	0	0	0	0	0	0	6912	6912	0
May	0	5	0	67	114	6535	6720	0	0	0	0	0	0	6720	6720	0
June	0	0	0	48	114	6535	6696	0	0	0	0	0	0	6696	6696	0
July	0	0	0	37	114	6535	6686	0	0	0	0	0	0	6686	6686	0
August	0	0	0	38	114	6535	6687	0	0	0	0	0	0	6687	6687	0
September	0	0	0	56	114	6535	6705	0	0	0	0	0	0	6705	6705	0
October	0	132	0	81	114	6535	6861	0	0	0	0	0	0	6861	6861	0
November	0	365	0	116	114	6535	7129	0	0	0	0	0	0	7129	7129	0
December	1	353	0	135	114	6535	7139	0	0	0	0	0	0	7139	7139	0
Average	1	183	0	91	114	6535	6923	0	0	0	0	0	0	6923	6923	0
Maximum	34	417	0	184	114	6535	7283	0	0	0	0	0	0	7283	7283	0
Minimum	0	0	0	31	114	6535	6680	0	0	0	0	0	0	6680	6680	0
Total for the whole year TWh/year	0.01	1.61	0.00	0.80	1.00	57.40	60.81	0.00	0.00	0.00	0.00	0.00	0.00	60.81	60.81	0.00

RES Share: 55.7 Percent of Primary Energ 114.3 Percent of Electricity 137.7 TWh electricity from RES

Input Biomass_20.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	99.28	Fixed imp/exp.	0.00
Electric heating + HP	25.84	Transportation	0.33
Electric cooling	1.00	Total	126.44

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	12.61	0.00	12.61
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	12.61	0.00	12.61

Wind	1207	MW	2.85	TWh/year	0.00	Grid
Photo Voltaic	42	MW	0.03	TWh/year	0.00	stabili-
River Hydro	1413	MW	5.11	TWh/year	0.00	sation
CSP Solar Power	0	MW	0	TWh/year	0.00	share
Hydro Power	30867	MW	128.8	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	100	275	0.24	0.66	
Heat Pump	326	437			1.34
Boiler		624		0.83	
Group 3:					
CHP	0	0	0.36	0.45	
Heat Pump	0	0			3.00
Boiler		0		0.83	
Condensing	454		0.41		

Heatstorage: gr.2: 4 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.97
Gr.3:	0.00	0.00

Regulation Strategy	Technical regulation no. 2	
CEEP regulation	210000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	1.00	
Maximum import/export	8895	MW

Energinet_no_NOKprices_2015.txt

Addition factor	0.00	NOK/MWh
Multiplication factor	1.39	
Dependency factor	0.00	NOK/MWh pr. MW
Average Market Price	246	NOK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	66.60	1.00	0.00
Household	0.00	8.10	0.80	6.30
Industry	7.90	10.60	3.40	3.90
Various	0.00	11.30	54.00	56.20

Output

District Heating: Demand (Distr. heating); Production (Solar, Waste+CSHP, DHP, CHP, HP, ELT, Boiler, EH); Balance. Electricity: Consumption (Elec. demand, Flex.&Transp, HP, Electrolyser, EH, Hydro Pump); Production (Turbine, RES, Hydro, Geothermal, Waste+CSHP, CHP, PP); Balance (Stab-Load, Imp, Exp, CEEP, EEP). Exchange: Payment (Imp, Exp).

	Distr. heating MW	Solar MW	Waste+CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp (Million NOK)	Payment Exp (Million NOK)
January	2354	0	457	0	264	437	0	624	0	573	14548	37	1444	0	3697	0	0	1123	18411	0	110	96	0	100	0	13	0	13	0	3
February	2316	0	457	0	265	437	0	624	0	532	13272	37	1425	0	3635	0	0	909	17263	0	110	96	0	100	0	9	0	9	0	2
March	1946	0	457	0	194	437	0	620	0	239	12287	37	1248	0	3051	0	0	790	15761	0	110	70	0	100	0	108	0	108	0	24
April	1540	1	457	0	70	437	0	547	0	29	11450	37	1055	0	2410	0	0	854	14428	0	110	26	0	100	0	465	0	465	0	99
May	1064	1	457	0	3	436	0	166	0	2	10134	37	827	0	1657	0	0	807	13310	0	110	1	0	100	0	1573	0	1573	0	291
June	769	1	457	0	0	315	0	0	0	-4	9654	37	596	0	1191	0	0	1419	12477	0	110	0	0	100	0	2529	0	2529	0	291
July	599	0	457	0	0	142	0	0	0	0	9310	37	385	0	923	0	0	995	12294	0	110	0	0	100	0	2743	0	2743	0	217
August	615	0	457	0	0	160	0	0	0	-1	9919	37	406	0	949	0	0	679	12744	0	110	0	0	100	0	2221	0	2221	0	233
September	899	1	457	0	0	426	0	14	0	1	9608	37	741	0	1397	0	0	674	12958	0	110	0	0	100	0	1959	0	1959	0	222
October	1279	0	457	0	73	436	0	309	0	4	11470	37	930	0	1999	0	0	737	14230	0	110	27	0	100	0	667	0	667	0	114
November	1835	0	457	0	213	437	0	583	0	146	13055	37	1196	0	2876	0	0	840	16226	0	110	78	0	100	0	89	0	89	0	18
December	2141	0	457	0	206	437	0	624	0	418	12344	37	1342	0	3361	0	0	1080	15940	0	110	75	0	100	0	121	0	121	0	13
Average	1444	0	457	0	107	377	0	342	0	161	11416	37	964	0	2258	0	0	908	14663	0	110	39	0	100	0	1045	0	1045	Average price	
Maximum	2904	2	457	0	275	437	0	624	0	1111	18305	72	1705	0	4561	0	0	2414	22527	0	110	100	0	100	0	3838	0	3838	(NOK/MWh)	
Minimum	508	0	457	0	0	51	0	0	0	-171	7552	0	274	0	781	0	0	243	11322	0	110	0	0	100	0	0	0	0	-	166
TWh/year	12.68	0.00	4.01	0.00	0.94	3.31	0.00	3.00	0.00	1.41	100.28	0.33	8.47	0.00	19.83	0.00	0.00	7.98	128.80	0.00	0.97	0.34	0.00		0.00	9.18	0.00	9.18	0	1527

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and Wind off CSP	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	7.90	7.90	0.00	7.90	2.67	2.67
Oil	-	-	-	0.10	-	0.00	-	-	-	-	-	-	-	-	-	-	-	66.60	8.10	21.90	96.70	0.00	96.70	25.61	25.61
N.Gas	-	1.42	-	0.41	-	0.00	-	-	-	-	-	-	-	-	-	-	-	1.03	0.80	57.40	61.06	0.00	61.06	12.52	12.52
Biomass	-	-	-	3.11	-	0.00	-	-	4.80	-	-	-	-	-	-	-	-	-	6.30	60.10	74.31	0.00	74.31	0.64	0.64
Renewable	-	-	-	-	-	-	-	128.80	-	-	-	-	2.85	0.03	-	133.91	0.02	-	-	-	136.80	0.00	136.80	0.00	0.00
H2 etc.	-	0.00	-	0.00	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-5.90	-	-	-	-	-	-	5.90	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	1.42	-	3.62	-	0.00	-	128.80	4.80	-	-5.90	-	2.85	0.03	-	133.91	0.02	73.53	15.20	147.30	376.76	-22.38	354.38	41.44	41.45

Output specifications Biomass_20.txt The EnergyPLAN model 14.1

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW	RES1 Wind MW	RES2 Photo MW	RES3 River MW	RES 4-7 MW	Total MW
January	0	0	0	0	2354	0	457	264	437	0	624	0	1482	573	0	0	0	0	0	0	0	0	0	0	452	0	671	0	1123
February	0	0	0	0	2316	0	457	265	437	0	624	0	1482	532	0	0	0	0	0	0	0	0	0	0	387	1	520	0	909
March	0	0	0	0	1946	0	457	194	437	0	620	0	1482	239	0	0	0	0	0	0	0	0	0	0	307	2	481	0	790
April	0	0	0	0	1540	1	457	70	437	0	547	0	1482	29	0	0	0	0	0	0	0	0	0	0	289	5	560	0	854
May	0	0	0	0	1064	1	457	3	436	0	166	0	1037	2	0	0	0	0	0	0	0	0	0	0	375	6	427	0	807
June	0	0	0	0	769	1	457	0	315	0	0	0	2876	-4	0	0	0	0	0	0	0	0	0	0	271	7	1140	0	1419
July	0	0	0	0	599	0	457	0	142	0	0	0	2978	0	0	0	0	0	0	0	0	0	0	0	290	6	698	0	995
August	0	0	0	0	615	0	457	0	160	0	0	0	3149	-1	0	0	0	0	0	0	0	0	0	0	208	6	465	0	679
September	0	0	0	0	899	1	457	0	426	0	14	0	1997	1	0	0	0	0	0	0	0	0	0	0	262	4	408	0	674
October	0	0	0	0	1279	0	457	73	436	0	309	0	399	4	0	0	0	0	0	0	0	0	0	0	232	2	503	0	737
November	0	0	0	0	1835	0	457	213	437	0	583	0	90	146	0	0	0	0	0	0	0	0	0	0	304	1	536	0	840
December	0	0	0	0	2141	0	457	206	437	0	624	0	90	418	0	0	0	0	0	0	0	0	0	0	508	0	572	0	1080
Average	0	0	0	0	1444	0	457	107	377	0	342	0	1545	161	0	0	0	0	0	0	0	0	0	0	324	3	581	0	908
Maximum	0	0	0	0	2904	2	457	275	437	0	624	0	4000	1111	0	0	0	0	0	0	0	0	0	0	1207	42	1413	0	2414
Minimum	0	0	0	0	508	0	457	0	51	0	0	0	0	-171	0	0	0	0	0	0	0	0	0	0	0	0	6	0	243
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	12.68	0.00	4.01	0.94	3.31	0.00	3.00	0.00		1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	2.85	0.03	5.11	0.00	7.98

Own use of heat from industrial CHP 0.00 TWh/year

ANNUAL COSTS (Million NOK)

Total Fuel ex Ngas exchange =	82199
Uranium =	0
Coal =	860
FuelOil =	9876
Gasoil/Diesel=	34377
Petrol/JP =	12586
Gas handling =	261
Biomass =	24931
Food income =	0
Waste =	-693
Total Ngas Exchange costs =	19502
Marginal operation costs =	456
Total Electricity exchange =	-1527
Import =	0
Export =	-1527
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	2018
Total variable costs =	102649
Fixed operation costs =	15363
Annual Investment costs =	35086
TOTAL ANNUAL COSTS =	153097

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	84	399	0	149	114	6535	7281	0	0	0	0	0	0	7281	7281	0
February	84	402	0	147	114	6535	7281	0	0	0	0	0	0	7281	7281	0
March	84	293	0	123	114	6535	7148	0	0	0	0	0	0	7148	7148	0
April	74	107	0	97	114	6535	6926	0	0	0	0	0	0	6926	6926	0
May	22	4	0	67	114	6535	6742	0	0	0	0	0	0	6742	6742	0
June	0	0	0	48	114	6535	6696	0	0	0	0	0	0	6696	6696	0
July	0	0	0	37	114	6535	6686	0	0	0	0	0	0	6686	6686	0
August	0	0	0	38	114	6535	6687	0	0	0	0	0	0	6687	6687	0
September	2	0	0	56	114	6535	6707	0	0	0	0	0	0	6707	6707	0
October	42	111	0	81	114	6535	6881	0	0	0	0	0	0	6881	6881	0
November	79	323	0	116	114	6535	7166	0	0	0	0	0	0	7166	7166	0
December	84	311	0	135	114	6535	7180	0	0	0	0	0	0	7180	7180	0
Average	46	162	0	91	114	6535	6947	0	0	0	0	0	0	6947	6947	0
Maximum	84	417	0	184	114	6535	7333	0	0	0	0	0	0	7333	7333	0
Minimum	0	0	0	31	114	6535	6680	0	0	0	0	0	0	6680	6680	0
Total for the whole year TWh/year	0.41	1.42	0.00	0.80	1.00	57.40	61.03	0.00	0.00	0.00	0.00	0.00	0.00	61.03	61.03	0.00

RES Share: 56.0 Percent of Primary Energy 134.3 Percent of Electricity 137.7 TWh electricity from RES 02-June-2019 [23:01]

Input Biomass_40.txt

The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	99.24	Fixed imp/exp.	0.00
Electric heating + HP	19.38	Transportation	0.33
Electric cooling	1.00	Total	119.94

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	19.07	0.00	19.07
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	19.07	0.00	19.07

Wind	1207	MW	2.85	TWh/year	0.00	Grid
Photo Voltaic	42	MW	0.03	TWh/year	0.00	stabili-
River Hydro	1413	MW	5.11	TWh/year	0.00	sation
CSP Solar Power	0	MW	0	TWh/year	0.00	share
Hydro Power	30867	MW	128.8	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	100	275	0.24	0.66	
Heat Pump	326	437			1.34
Boiler		624		0.83	
Group 3:					
CHP	0	0	0.36	0.45	
Heat Pump	0	0			3.00
Boiler		0		0.83	
Condensing	454		0.41		

Heatstorage: gr.2: 5 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.97
Gr.3:	0.00	0.00

Regulation Strate(	Technical regulation no. 2	
CEEP regulation	210000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	1.00	
Maximum import/export	8895	MW

Energinet_no_NOKprices_2015.txt

Addition factor	0.00	NOK/MWh
Multiplication factor	1.39	
Dependency factor	0.00	NOK/MWh pr. MW
Average Market Price	246	NOK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:		0.000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	66.60	1.00	0.00
Household	0.00	8.10	0.80	6.30
Industry	7.90	10.60	3.40	3.90
Various	0.00	11.30	54.00	56.20

Output

	District Heating										Electricity													Balance					Exchange	
	Demand	Production									Consumption						Production												Payment	
	Distr. heating MW	Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million NOK	Exp Million NOK
January	3558	0	457	0	246	437	0	624	0	1795	14752	37	1444	0	2493	0	0	1123	17462	0	110	89	0	100	0	57	0	57	0	14
February	3499	0	457	0	247	437	0	624	0	1735	13526	37	1425	0	2451	0	0	909	16373	0	110	90	0	100	0	42	0	42	0	9
March	2939	0	457	0	136	437	0	624	0	1285	12441	37	1248	0	2057	0	0	790	15206	0	110	50	0	100	0	372	0	372	0	83
April	2325	1	457	0	22	437	0	624	0	785	11483	37	1055	0	1625	0	0	854	14331	0	110	8	0	100	0	1103	0	1103	0	238
May	1604	1	457	0	1	437	0	604	0	105	10040	37	827	0	1117	0	0	807	13768	0	110	0	0	100	0	2663	0	2663	0	500
June	1157	1	457	0	0	437	0	263	0	0	9465	37	686	0	803	0	0	1419	13354	0	110	0	0	100	0	3892	0	3892	0	451
July	900	1	457	0	0	436	0	7	0	-1	9071	37	605	0	622	0	0	995	13291	0	110	0	0	100	0	4060	0	4060	0	323
August	925	1	457	0	0	437	0	33	0	-2	9655	37	613	0	640	0	0	679	13524	0	110	0	0	100	0	3368	0	3368	0	354
September	1354	1	457	0	0	437	0	455	0	6	9475	37	749	0	942	0	0	674	13595	0	110	0	0	100	0	3176	0	3176	0	362
October	1930	0	457	0	19	437	0	624	0	393	11396	37	930	0	1348	0	0	737	14223	0	110	7	0	100	0	1366	0	1366	0	245
November	2772	0	457	0	185	437	0	624	0	1069	13125	37	1196	0	1940	0	0	840	15557	0	110	67	0	100	0	277	0	277	0	55
December	3235	0	457	0	164	437	0	624	0	1553	12575	37	1342	0	2266	0	0	1080	15325	0	110	60	0	100	0	354	0	354	0	41
Average	2179	0	457	0	85	437	0	477	0	724	11411	37	1009	0	1522	0	0	908	14663	0	110	31	0	100	0	1733	0	1733	Average price	
Maximum	4389	3	457	0	275	437	0	624	0	2596	18246	72	1705	0	3076	0	0	2414	21322	0	110	100	0	100	0	5663	0	5663	(NOK/MWh)	
Minimum	762	0	457	0	0	436	0	0	0	-132	7482	0	562	0	526	0	0	243	12758	0	110	0	0	100	0	0	0	0	-	176
TWh/year	19.14	0.00	4.01	0.00	0.74	3.83	0.00	4.19	0.00	6.36	100.24	0.33	8.86	0.00	13.37	0.00	0.00	7.98	128.80	0.00	0.97	0.27	0.00		0.00	15.22	0.00	15.22	0	2675

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	7.90	7.90	0.00	7.90	2.67	2.67
Oil	-	-	-	0.14	-	0.00	-	-	-	-	-	-	-	-	-	-	-	66.60	8.10	21.90	96.73	0.00	96.73	25.62	25.62
N.Gas	-	1.12	-	0.57	-	0.00	-	-	-	-	-	-	-	-	-	-	-	1.03	0.80	57.40	60.92	0.00	60.92	12.49	12.50
Biomass	-	-	-	4.34	-	0.00	-	-	4.80	-	-	-	-	-	-	-	-	-	6.30	60.10	75.54	0.00	75.54	0.64	0.64
Renewable	-	-	-	-	-	-	-	128.80	-	-	-	-	2.85	0.03	-	133.91	0.02	-	-	-	136.80	0.00	136.80	0.00	0.00
H2 etc.	-	0.00	-	0.00	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-5.90	-	-	-	-	-	-	5.90	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	1.12	-	5.05	-	0.00	-	128.80	4.80	-	-5.90	-	2.85	0.03	-	133.91	0.02	73.53	15.20	147.30	377.89	-37.12	340.77	41.42	41.43

28-May-2019 [15:24]

Output specifications Biomass_40.txt The EnergyPLAN model 14.1

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage MW	Gr.3 Balance MW	RES1 Wind MW	RES2 Photo MW	RES3 River MW	RES 4-7 MW	Total MW
January	0	0	0	0	3558	0	457	246	437	0	624	0	1864	1795	0	0	0	0	0	0	0	0	0	0	452	0	671	0	1123
February	0	0	0	0	3499	0	457	247	437	0	624	0	1864	1735	0	0	0	0	0	0	0	0	0	0	387	1	520	0	909
March	0	0	0	0	2939	0	457	136	437	0	624	0	1864	1285	0	0	0	0	0	0	0	0	0	0	307	2	481	0	790
April	0	0	0	0	2325	1	457	22	437	0	624	0	1864	785	0	0	0	0	0	0	0	0	0	0	289	5	560	0	854
May	0	0	0	0	1604	1	457	1	437	0	604	0	1864	105	0	0	0	0	0	0	0	0	0	0	375	6	427	0	807
June	0	0	0	0	1157	1	457	0	437	0	263	0	1849	0	0	0	0	0	0	0	0	0	0	0	271	7	1140	0	1419
July	0	0	0	0	900	1	457	0	436	0	7	0	2030	-1	0	0	0	0	0	0	0	0	0	0	290	6	698	0	995
August	0	0	0	0	925	1	457	0	437	0	33	0	2082	-2	0	0	0	0	0	0	0	0	0	0	208	6	465	0	679
September	0	0	0	0	1354	1	457	0	437	0	455	0	1866	6	0	0	0	0	0	0	0	0	0	0	262	4	408	0	674
October	0	0	0	0	1930	0	457	19	437	0	624	0	1538	393	0	0	0	0	0	0	0	0	0	0	232	2	503	0	737
November	0	0	0	0	2772	0	457	185	437	0	624	0	1538	1069	0	0	0	0	0	0	0	0	0	0	304	1	536	0	840
December	0	0	0	0	3235	0	457	164	437	0	624	0	1538	1553	0	0	0	0	0	0	0	0	0	0	508	0	572	0	1080
Average	0	0	0	0	2179	0	457	85	437	0	477	0	1813	724	0	0	0	0	0	0	0	0	0	0	324	3	581	0	908
Maximum	0	0	0	0	4389	3	457	275	437	0	624	0	4052	2596	0	0	0	0	0	0	0	0	0	0	1207	42	1413	0	2414
Minimum	0	0	0	0	762	0	457	0	436	0	0	0	0	-132	0	0	0	0	0	0	0	0	0	0	0	0	6	0	243
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	19.14	0.00	4.01	0.74	3.83	0.00	4.19	0.00		6.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	2.85	0.03	5.11	0.00	7.98

Own use of heat from industrial CH0.00 TWh/year

ANNUAL COSTS (Million NOK)
Total Fuel ex Ngas exchange = 82672
Uranium = 0
Coal = 860
FuelOil = 9895
Gasoil/Diesel= 34377
Petrol/JP = 12586
Gas handling = 256
Biomass = 25390
Food income = 0
Waste = -693

Total Ngas Exchange costs = 19459

Marginal operation costs = 451

Total Electricity exchange = -2675
Import = 0
Export = -2675
Bottleneck = 0
Fixed imp/ex= 0

Total CO2 emission costs = 2017

Total variable costs = 101923
Fixed operation costs = 15363

Annual Investment costs = 35087

TOTAL ANNUAL COSTS = 152373

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	84	372	0	149	114	6535	7254	0	0	0	0	0	0	7254	7254	0
February	84	374	0	147	114	6535	7253	0	0	0	0	0	0	7253	7253	0
March	84	207	0	123	114	6535	7062	0	0	0	0	0	0	7062	7062	0
April	84	34	0	97	114	6535	6864	0	0	0	0	0	0	6864	6864	0
May	82	1	0	67	114	6535	6798	0	0	0	0	0	0	6798	6798	0
June	35	0	0	48	114	6535	6732	0	0	0	0	0	0	6732	6732	0
July	1	0	0	37	114	6535	6687	0	0	0	0	0	0	6687	6687	0
August	4	0	0	38	114	6535	6691	0	0	0	0	0	0	6691	6691	0
September	61	0	0	56	114	6535	6766	0	0	0	0	0	0	6766	6766	0
October	84	29	0	81	114	6535	6842	0	0	0	0	0	0	6842	6842	0
November	84	281	0	116	114	6535	7129	0	0	0	0	0	0	7129	7129	0
December	84	249	0	135	114	6535	7117	0	0	0	0	0	0	7117	7117	0
Average	64	128	0	91	114	6535	6932	0	0	0	0	0	0	6932	6932	0
Maximum	84	417	0	184	114	6535	7333	0	0	0	0	0	0	7333	7333	0
Minimum	0	0	0	31	114	6535	6680	0	0	0	0	0	0	6680	6680	0
Total for the whole year TWh/year	0.57	1.12	0.00	0.80	1.00	57.40	60.89	0.00	0.00	0.00	0.00	0.00	0.00	60.89	60.89	0.00

RES Share: 56.2 Percent of Primary Energ 112.7 Percent of Electricity 137.7 TWh electricity from RES 28-May-2019 [15:24]

Input Biomass_60.txt

The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	99.28	Fixed imp/exp.	0.00
Electric heating + HP	12.92	Transportation	0.33
Electric cooling	1.00	Total	113.52

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	25.53	0.00	25.53
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	25.53	0.00	25.53

Wind	1207	MW	2.85	TWh/year	0.00	Grid
Photo Voltaic	42	MW	0.03	TWh/year	0.00	stabili-
River Hydro	1413	MW	5.11	TWh/year	0.00	sation
CSP Solar Power	0	MW	0	TWh/year	0.00	share
Hydro Power	30867	MW	128.8	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	100	275	0.24	0.66	
Heat Pump	326	437			1.34
Boiler		624		0.83	
Group 3:					
CHP	0	0	0.36	0.45	
Heat Pump	0	0			3.00
Boiler		0		0.83	
Condensing	454		0.41		

Heatstorage: gr.2: 6 GWh gr.3 0 GWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3: 0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.97
Gr.3:	0.00	0.00

Regulation Strategy	Technical regulation no. 2	
CEEP regulation	210000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	1.00	
Maximum import/export	8895	MW

Energinet_no_NOKprices_2015.txt

Addition factor	0.00	NOK/MWh
Multiplication factor	1.39	
Dependency factor	0.00	NOK/MWh pr. MW
Average Market Price	246	NOK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	66.60	1.00	0.00
Household	0.00	8.10	0.80	6.30
Industry	7.90	10.60	3.40	3.90
Various	0.00	11.30	54.00	56.20

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Electrolyser MW	EH MW	Hydro Pump MW	Turbine MW	RES MW	Hydro MW	Geothermal MW	Waste-CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million NOK	Exp Million NOK
January	4762	0	457	0	223	437	0	624	0	3020	14972	37	1444	0	1289	0	0	1123	16592	0	110	81	0	100	0	164	0	164	0	40
February	4683	0	457	0	194	437	0	624	0	2972	13795	37	1425	0	1268	0	0	909	15619	0	110	70	0	100	0	183	0	183	0	41
March	3933	0	457	0	82	437	0	624	0	2333	12608	37	1248	0	1064	0	0	790	14871	0	110	30	0	100	0	843	0	843	0	189
April	3110	1	457	0	5	437	0	624	0	1586	11525	37	1055	0	840	0	0	854	14404	0	110	2	0	100	0	1912	0	1912	0	416
May	2144	1	457	0	0	437	0	624	0	626	9954	37	827	0	578	0	0	807	14155	0	110	0	0	100	0	3676	0	3676	0	696
June	1545	1	457	0	0	437	0	576	0	75	9282	37	686	0	415	0	0	1419	13962	0	110	0	0	100	0	5071	0	5071	0	591
July	1201	1	457	0	0	437	0	307	0	0	8835	37	605	0	322	0	0	995	13938	0	110	0	0	100	0	5244	0	5244	0	418
August	1234	1	457	0	0	437	0	340	0	0	9395	37	613	0	331	0	0	679	14047	0	110	0	0	100	0	4460	0	4460	0	470
September	1810	1	457	0	0	437	0	624	0	292	9348	37	749	0	487	0	0	674	14077	0	110	0	0	100	0	4241	0	4241	0	485
October	2581	0	457	0	1	437	0	624	0	1062	11330	37	930	0	697	0	0	737	14358	0	110	0	0	100	0	2211	0	2211	0	410
November	3708	0	457	0	126	437	0	624	0	2064	13207	37	1196	0	1003	0	0	840	15056	0	110	46	0	100	0	609	0	609	0	122
December	4330	0	457	0	100	437	0	624	0	2712	12820	37	1342	0	1172	0	0	1080	14902	0	110	36	0	100	0	757	0	757	0	95
Average	2915	0	457	0	61	437	0	569	0	1391	11416	37	1009	0	787	0	0	908	14663	0	110	22	0	100	0	2454	0	2454	Average price	
Maximum	5874	3	457	0	275	437	0	624	0	4089	18203	72	1705	0	1591	0	0	2414	20136	0	110	100	0	100	0	7070	0	7070	(NOK/MWh)	
Minimum	1016	0	457	0	0	437	0	122	0	0	7302	0	562	0	272	0	0	243	13686	0	110	0	0	100	0	0	0	0	-	184
TWh/year	25.60	0.00	4.01	0.00	0.53	3.83	0.00	5.00	0.00	12.22	100.28	0.33	8.86	0.00	6.91	0.00	0.00	7.98	128.80	0.00	0.97	0.19	0.00		0.00	21.56	0.00	21.56	0	3973

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and Wind off CSP	Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	7.90	7.90	0.00	7.90	2.67	2.67
Oil	-	-	-	0.16	-	0.00	-	-	-	-	-	-	-	-	-	-	-	66.60	8.10	21.90	96.76	0.00	96.76	25.63	25.63
N.Gas	-	0.81	-	0.68	-	0.00	-	-	-	-	-	-	-	-	-	-	-	1.03	0.80	57.40	60.71	0.00	60.71	12.45	12.45
Biomass	-	-	-	5.19	-	0.00	-	-	4.80	-	-	-	-	-	-	-	-	-	6.30	60.10	76.39	0.00	76.39	0.64	0.64
Renewable	-	-	-	-	-	-	-	128.80	-	-	-	-	2.85	0.03	-	133.91	0.01	-	-	-	136.80	0.00	136.80	0.00	0.00
H2 etc.	-	0.00	-	0.00	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-5.90	-	-	-	-	-	-	5.90	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	0.81	-	6.03	-	0.00	-	128.80	4.80	-	-5.90	-	2.85	0.03	-	133.91	0.01	73.53	15.20	147.30	378.55	-52.58	325.97	41.39	41.39

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Output specifications Biomass_60.txt The EnergyPLAN model 14.1

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	RES1 Wind MW	RES2 Photo MW	RES3 River I MW	RES 4-7 o MW	Total MW
January	0	0	0	0	4762	0	457	223	437	0	624	0	0	3020	0	0	0	0	0	0	0	0	0	0	452	0	671	0	1123
February	0	0	0	0	4683	0	457	194	437	0	624	0	0	2972	0	0	0	0	0	0	0	0	0	0	387	1	520	0	909
March	0	0	0	0	3933	0	457	82	437	0	624	0	0	2333	0	0	0	0	0	0	0	0	0	0	307	2	481	0	790
April	0	0	0	0	3110	1	457	5	437	0	624	0	0	1586	0	0	0	0	0	0	0	0	0	0	289	5	560	0	854
May	0	0	0	0	2144	1	457	0	437	0	624	0	0	626	0	0	0	0	0	0	0	0	0	0	375	6	427	0	807
June	0	0	0	0	1545	1	457	0	437	0	576	0	0	75	0	0	0	0	0	0	0	0	0	0	271	7	1140	0	1419
July	0	0	0	0	1201	1	457	0	437	0	307	0	0	0	0	0	0	0	0	0	0	0	0	0	290	6	698	0	995
August	0	0	0	0	1234	1	457	0	437	0	340	0	0	0	0	0	0	0	0	0	0	0	0	0	208	6	465	0	679
September	0	0	0	0	1810	1	457	0	437	0	624	0	0	292	0	0	0	0	0	0	0	0	0	0	262	4	408	0	674
October	0	0	0	0	2581	0	457	1	437	0	624	0	0	1062	0	0	0	0	0	0	0	0	0	0	232	2	503	0	737
November	0	0	0	0	3708	0	457	126	437	0	624	0	0	2064	0	0	0	0	0	0	0	0	0	0	304	1	536	0	840
December	0	0	0	0	4330	0	457	100	437	0	624	0	0	2712	0	0	0	0	0	0	0	0	0	0	508	0	572	0	1080
Average	0	0	0	0	2915	0	457	61	437	0	569	0	0	1391	0	0	0	0	0	0	0	0	0	0	324	3	581	0	908
Maximum	0	0	0	0	5874	3	457	275	437	0	624	0	0	4089	0	0	0	0	0	0	0	0	0	0	1207	42	1413	0	2414
Minimum	0	0	0	0	1016	0	457	0	437	0	122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	243
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	25.60	0.00	4.01	0.53	3.83	0.00	5.00	0.00		12.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	2.85	0.03	5.11	0.00	7.98

Own use of heat from industrial CH0.00 TWh/year

ANNUAL COSTS (Million NOK)
Total Fuel ex Ngas exchange = 82992
Uranium = 0
Coal = 860
FuelOil = 9907
Gasoil/Diesel= 34377
Petrol/JP = 12586
Gas handling = 249
Biomass = 25705
Food income = 0
Waste = -693

Total Ngas Exchange costs = 19392

Marginal operation costs = 443

Total Electricity exchange = -3973
Import = 0
Export = -3973
Bottleneck = 0
Fixed imp/ex= 0

Total CO2 emission costs = 2015

Total variable costs = 100869
Fixed operation costs = 15363

Annual Investment costs = 35088

TOTAL ANNUAL COSTS = 151320

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	84	339	0	149	114	6535	7220	0	0	0	0	0	0	7220	7220	0
February	84	293	0	147	114	6535	7173	0	0	0	0	0	0	7173	7173	0
March	84	124	0	123	114	6535	6979	0	0	0	0	0	0	6979	6979	0
April	84	8	0	97	114	6535	6838	0	0	0	0	0	0	6838	6838	0
May	84	0	0	67	114	6535	6800	0	0	0	0	0	0	6800	6800	0
June	78	0	0	48	114	6535	6774	0	0	0	0	0	0	6774	6774	0
July	41	0	0	37	114	6535	6727	0	0	0	0	0	0	6727	6727	0
August	46	0	0	38	114	6535	6733	0	0	0	0	0	0	6733	6733	0
September	84	0	0	56	114	6535	6789	0	0	0	0	0	0	6789	6789	0
October	84	1	0	81	114	6535	6814	0	0	0	0	0	0	6814	6814	0
November	84	192	0	116	114	6535	7040	0	0	0	0	0	0	7040	7040	0
December	84	151	0	135	114	6535	7019	0	0	0	0	0	0	7019	7019	0
Average	77	92	0	91	114	6535	6908	0	0	0	0	0	0	6908	6908	0
Maximum	84	417	0	184	114	6535	7333	0	0	0	0	0	0	7333	7333	0
Minimum	16	0	0	31	114	6535	6696	0	0	0	0	0	0	6696	6696	0
Total for the whole year TWh/year	0.68	0.81	0.00	0.80	1.00	57.40	60.68	0.00	0.00	0.00	0.00	0.00	0.00	60.68	60.68	0.00

RES Share: 56.3 Percent of Primary Energ 118.9 Percent of Electricity 137.7 TWh electricity from RES

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