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# Integrating a high share of EV in an energy system with high share of renewable energy.

## A case study of Norway

MASTER’S THESIS IN SUSTANABLE MANUFACTURING

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# Abstract

In April 2016, Norway has ratified the Paris Agreement on climate changes by pledging to reduce GHG emission with 40 percent by 2030 (Ministry of Climate and Environment, 2015). This compared to 1990 levels in order to limit the temperature increase with over 2 degrees Celsius above pre-industrial levels (Ministry of Climate and Environment, 2014b). Moreover, the Norwegian government has undertaken the ambitious goal of becoming a low-emission society that requires 80-95 percent emission reduction by 2050. According to Statistics Norway, the transport sector in 2018 contributed to 22% of the total final consumption of energy and 31.15% of the total greenhouse gas emission emitted. Only road traffic emitted around 17% of the total domestic emission in the Norwegian territory. Historically, the transport sector has had a high dependence on fossil fuel and a potential transition towards an electrified transport sector would result in significant emission reduction. Even further when supplied by a power system like Norway's that generates electricity almost one hundred percent with RES.

The main objective of this study is to discover in what extent a potential shift of passenger vehicles from conventional to electric vehicles would contribute in the fulfillment of the ambitious goal of becoming a low emission society by 2050. Two different scenarios are built for this purpose, EV 2050 Existing and EV 2050 Wind Optimum, for the Norwegian energy system in 2050. Both scenarios assume a total shift from petrol and diesel passenger cars in electric and alternative fuel vehicles and consider the increase in the number of passenger vehicles, influenced by the population growth. In the first scenario it is assumed that only the energy demand by the transport sector will change and is based on the existing power supply of the reference scenario. Therefore, the increase in electricity demand beyond domestic production is covered through export. The second scenario besides the increase of electricity demand by transport sector considers an increase of energy demand by residential sector with 9.84 TWh. This due to the population growth and it is assumed that all the added energy demand would be covered with electricity. An optimum value of wind power capacity is added to the power supply in order to fulfill the increase of electricity demand and export the remaining electricity production. The deterministic modeling approach EnergyPLAN is chosen to simulate the future scenarios for the Norwegian energy system, in order to evaluate the potential reduction of $CO_2$ emissions in 2050.

The findings of this study suggest adding an optimum wind power capacity in 2050. This would result in the incase the share of renewable energy in the primary energy supply of the country from 50.4% to 56.1%, and it would reduce the $CO_2$ emissions with 13.9% compared to the levels of the reference scenario. Furthermore, it would increase the energy security of the Norwegian energy system and would generate more electricity than the domestic demand by keeping the role of Norway as a net exporter of green electricity in the European power market.

**Keywords:** Paris Agreement, Climate change, low emission society, Electricity demand, greenhouse gas, EnergyPLAN, transport sector, Wind optimum, alternative fuel, electric vehicles, CO2 emission, energy security.

# Sammendrag

I april 2016, signerte norge en avtale som skulle sørge for å redusere GHG utslipp med 40 prosent, innen 2030. Dette i forhold til utslipp på 1990 og for å redusere temperaturstigningen med over to grader celsius, sett i forhold til tiden før industrialiseringen. Denne avtalen heter «paris avtalen for klimaendring». I tillegg til dette, har den norske regjerinen ambisiøse mål om å bli et lavutslipp samfunn. Dette krever at Norge reduserer utslipp med 80-95 prosent innen 2050

I følge statistisk sentralbyrå, har transportsektoren skyld i 22 prosent av det totale energiforbruket og 31,15 prosent av utslipp av klimagasser i 2018. Hvis vi kun ser på veitransport, utgjør dette 17 prosent av det totale utslippet på norsk landjord. Historisk sett, ser vi at transportsektoren har hatt høy forbruk av fosilt brennstoff. Dette medfører at overgangen til elektriske alternativ, vil kunne ha en enorm gevinst med tanke på reduksjon av utslipp. Enda mer når Norge kan vise til en strømproduksjon, hvorav inntill 100 prosent er i fra fornybare energikilder.

Det som jeg i førgeomgang ønsker å finne ut med dette studiet, er om overgangen i fra konversielle kjøretøy og over på elektriske kjøretøy, og hvor mye dette vil redusere klimautslipp. Jeg vil også se på om dette er en stor nok bidragsyter, til at Norge når det ambisiøse målet om å bli et lavutslippsamfunn innen 2050.

Jeg har laget to forskjellige scenarier for norges energisystem, EV 2050 Existing og EV 2050 Wind Optimim. Disse senariene, er begge laget med tanke på tilstanden i 2050 og har en totalomvenning i fra forbrenningsmotorer og over på alternativ drevne kjøretøy. Jeg har også tatt i betraktning en økning i folketall, dette bassert på statestikk i fra statistisk sentralbyrå.

Begge senariene tar utgangspunkt i en helomvending i fra benisn- og dieseldrevne kjøretøy, for så å gå over på alternativt drivstoff. Likedan, tatt i betraktning en økning i antall biler på norske veier, dette et resultat av folketallet.

Det første scenarioet, beholder alle variablene i fra andre sektorer, utenom transportsektoren. Dette betyr at altså at en har tar utgangspunkt i det norske energisystemet som er i 2018, mens transportsektoren skilles ut. På grunn av dette, er energibehovet utover den norske produksjonen dekket igjennom eksport.

Det andre scenarioet, da sett bort i fra det økte energibehovet til transportsektoren, tar også i betraktning en økning på 9,84TWt til oppvarming. Dette kommer igjen av en økning i folketall, og går ut ifra at den økte forespørselen blir dekket av elektrisk energi.

Her har jeg lagt inn optimale verdier av energi i fra vindkraft for å dekke energibehovet til 2050, dette fordi Norge skal fortsette å være en eksportør av den overskytende grønne energien. Jeg har brukt EnergyPLAN som verktøy for å simulere de fremtidige scenariene for det norske energisystemet, dette for å få evaluere den potensielle reduksjonen i co2-utslipp i 2050. Resultatet av dette studiet, viser at en ved å dekke energibehovet ved hjelp av vindkraft, vil føre til en økning av fornybare energi resurser i fra 50.4% til 56,1%. I tillegg vil vi kunne redusere CO2 utslipp på hele 13,9% i forhold til tallene fra det refererte scenarioet. Videre, vil dette ha positive ringvirkninger på energisikkerheten til det norske energisystemet. Og til slutt, men ikke minst, vil Norge opprettholde sin rolle som nett eksportør av grønn energi til det europeiske markedet. Dette ettersom Norge vil produsere mer energi enn det som benyttes.

# Preface

This thesis is submitted in fulfillment of the requirements of the course TØL4902, Master's Thesis-Sustainable Manufacturing at the Norwegian University of Science and Technology (NTNU), Gjøvik. It was written during the period 15 January – 7 August 2019 under the supervision of Professor Alemayehu Gebremedhin and Dr. Lorenc Malka.

I want to thank my supervisor, professor Alemayehu Gebremedhin for the great support and guidance during all the process of writing the and the co-supervisor, Dr. Lorenc Malka for assisting with help regarding the modeling approach EnergyPLAN.

I would like to thank my family and friends for all the support they have given me during my studies. Many thanks to all the staff of NTNU Gjøvik and especially the International Office for all the support given this last year. Finally, a very special thank goes to all the people that were part of my journey in Norway this last year.

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# List of Abbreviations (or Symbols)

| | |
|---|---|
| AC | Alternative Current |
| AF | Alternative Fuels |
| bcm | Billion cubic meters |
| BEV | Battery Electric Vehicle |
| CEEP | Critical Excess Electricity Production |
| CNS | Carbon Neutral Society |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| $CO_2$-eq | Carbon Dioxide equivalent |
| $CH_4$ | Methane |
| COOP 21 | Conference of Parties |
| DC | Direct Current |
| EEA | European Environmental Agency |
| EU | European Union |
| EU-ETS | European Union Emission Trading Scheme |
| EV | Electric Vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| FCEV | Fuel Cell Electric Vehicle |
| FIDE | Find and Input Data into EnergyPLAN |
| HEV | Hybrid Electric Vehicle |
| ICE | Internal Combustion Engine |
| IEA | International Environmental Agency |
| IRENA | International Renewable Energy Agency |
| GHG | Greenhouse Gas |
| LDV | Light Duty Vehicles |
| Li-ion | Lithium Ion Batteries |
| LULUCF | Land Use, Land Use Change and Forestry |
| Mt | Million ton |
| MWh | Megawatt hours |
| Na/S | Sodium Sulfur |
| Ni-Cd | Nickel-cadmium |
| Ni-MH | Nickel metal hybrid battery |
| Ni-Zn | Nickel-zinc |
| NTP | National Transport Plan |
| NVE | Norwegian Water Resources and Energy Directorate |
| $NO_x$ | Nitrogen oxides |
| $N_2O$ | Nitrous Oxide |
| PEV | Pure Electric Vehicle |
| PM | Particular Matter |
| PHEV | Plug-in Hybrid Electric Vehicle |
| RES | Renewable Energy Sources |
| SDG | Sustainable Development Goals |
| SSB | Statistics Norway |
| $SO_2$ | Sulfur Dioxide |
| TFC | Total Final Consumption |
| TPES | Total Production Energy Supply |
| TWh | Terawatt hours |

| | |
|---|---|
| UN | United Nations |
| VOC | Volatile Organic Compounds |
| V2G | Vehicle to Grid |
| WTW | Well-to-wheel |

# 1 Introduction

The heavy reliance of today's society on energy is threating the long-term existence of the humankind. The high level of fossil fuel consumption is making it difficult to control the concentration of GHG (Greenhouse Gas) emissions in the atmosphere. The rising concerns about energy security and high ambition of the Paris Agreement on climate changes are changing the development of the energy sector nowadays (INTERNATIONAL ENERGY AGENCY (IEA), 2016). The shape of the future energy system is uncertain. With this uncertainty, several patterns are coming up. The long process of electrification is probably going to continue and quicken.

It was in the 18th century when for the first time the term "Environmental Limits" rose by questioning the continuity of our existence. The famous economist Thomas Robert Malthus (1766 – 1834) was the first who predicted the restrictions of development as a result of limited resources. His theory known as Environmental Limits Thinking states that: "As a result of limited agricultural lands on earth the growth of population will reduce the food supply per capita" (Saadatian, 2012). The Environmental Limit anticipated the term of SD (Sustainable Development) that appeared later in 1969 in an official document that was signed by thirty-three countries in Africa under IUCN (International Union for Conservation) guidance. According to the National Environmental Policy Act of 1969, the definition of SD was: "The economic development that may have benefits for current and future generations without harming the planet's resources or biological organisms " (acciona.com, 2018).

The most famous definition for Sustainable Development is the one from Our Common Future, a book-length report of 1987 known as the "Brundtland Report" in honor of the Norwegian Prime Minister, Gro Harlem Brundtland, who was the chair of the World Commission on Environment and Development (Pezzoli, 1997). This report states that "SD is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Mebratu, November 1998). The Norwegian Kingdom was one of the earliest birds in the politics for sustainable development.

In 2007-2008 the world faced an economic crisis that was predictable and inevitable at the same time. This crisis gave a fundamental break from the past decades - the period when most of the economists embraced the unrealistic view that the endless economic growth is necessary and possible to accomplish. Presently there are plenty of boundaries in the ongoing economic development, and the world is crashing into those boundaries. Although, as we will see in the following chapters there are three primary factors that define future economic growth:

- The consumption of natural resources such as fossil fuels and minerals;
- The environmental impact that rises from the extraction and usage of resources (among other things the burning fossil fuels) – leading to sky-high costs in efforts to avoid or try to clean them up;
- Financial interruptions because of the lack in the existing banking, monetary, and investment system to adapt with both the shortage of resources and the rising environmental costs – and their failure on servicing the huge government clusters

and the private debt that has been produced in the recent decades. (Heinberg, 2011)

The economic crisis of 2007-2008 which rose the concerns about energy security alongside with high ambition of the Paris Agreement on climate changes are changing the development of the energy sector nowadays. (INTERNATIONAL ENERGY AGENCY (IEA), 2016).

Transport is one of the most important drivers for social and economic development, it opens doors for people and empowers economies to be competitive. Transport infrastructure connects people with everything they need in life (job, education, health services, good supplies and every other kind of service). This sector is the core of decisive development challenges that consist of:

- Climate change: Transport consumes about 64% of global oil consumption, 27% of the total energy use, and 23% of $CO_2$ energy-related emissions.
- Fast urbanization and motorization: With the increase of the population that lives in cities (5.4 billion predicted by 2050) the number of cars is predicted to double and reach 2 billion.
- Road safety: According to statistics in a year 1.25 million people are killed and more than 50 million are injured in road accidents all over the world.
- Air pollution: The pollution from motors has been related to many health conditions, among others cardiovascular and pulmonary diseases. The air pollution caused by vehicles is an extra factor that contributes to the death of around 185,000 people every year. (The World Bank, 2018)

Transport is nowadays one of the main energy consumers and the most important drivers for social and economic development. It opens doors for people and empowers economies to be competitive. The infrastructure connects us with everything we need in our life. In a national level, the transport sector is essential for the decrease of the level of poverty, encourage prosperity and reach the SDG (Sustainable Development Goals) for each country as the core of decisive development challenges.

The European target 3x20 has a specific requirement that the increase of RES (Renewable Energy Sources) in EU countries must record a share of at least 10% in the transport sector (Eurpoean Commission, 2018). The goal of the Norwegian government is to reduce greenhouse gas emissions with 30% of 1990-levels by 2020 (Norwegian Ministry of the Environment, 2007). According to SSB, the transport sector accounts in 21.7% of the total energy consumption for 2018 and 31.5% of the total greenhouse gas emissions are emitted by the transport sector (SSB, 2019).

The high energy consumption and the continuous increase of the energy demand from the transport sector in Norway give at the same time an opportunity and a challenge for improvement. This sector is having some essential changes in recent years with the high expansion of electric vehicles. This kind of transition has a significant impact in both GHG emission and energy demand reduction since the efficiency of the new electric battery motor is three to four times more than the actual combustion engine. While the number of vehicles in the future will increase the overall energy consumption by the transport sector will be reduced.

## 1.1 Personal motivation

Energy is running the world nowadays. The increase in energy demand is directly connected with the welfare and prosperity all over the world. Providing the growing energy demand requires the usage of global natural resources, and this brings the engagement and obligation of using it with responsibility so that future generations can meet their needs. Population growth and economic development will continue to increase energy demand. The world is now aware that the uncontrolled increase of the energy demand is questioning the ability of our planet to meet the energy demand for this and future generations with natural resources.

The biggest challenge now is to find the way how to meet the increasing energy demand and reduce energy consumption. This challenge now is giving an opportunity to every country to improve their manners of development and walking in the path of Sustainable Development by taking actions to protect the environment from the degradation. The growing energy demand requires the growth of installed generation capacity and this is something we cannot avoid but, what can be done is the improvement of the existing supply by ensuring a more efficient energy use. Furthermore, to keep the focus on renewable energy sources while adding new aggregate for electricity generation. Nowadays, the aim of is to ensure sustainable energy production and efficient energy consumption.

The global level of GHG emissions from the transport sector is increasing rapidly. Between 2000 and 2016 the GHG emitted by this sector grow with 29% (reaching 7.5 Gt $CO_2$-eq from 5.8 Gt $CO_2$-eq) by contributing in this way with around 23% of total global energy-related $CO_2$ emissions and 14% of the worldwide greenhouse gas emissions in 2014 (SLoCaT, 2018).

In the transport sector nowadays, the consumption of fossil fuels can be replaced by other alternative fuels such as electricity, hydrogen, and biofuel. The number of vehicles that use alternative fuels is very low at the moment and their lifetime is around 15 to 20 years, so the road towards the emission-free transport sector will still take time. Considering the technology that is developed nowadays, the category of vehicles that can use an electric motor that is supplied by a battery is mostly passenger cars and vans. The future railway network will definitively operate with electricity. The heavy tracks and the vehicles that are projected to travel long distances with the existing technology will have problems in applying the electric motor and battery. So, the best choice for this category would be the usage of biofuels and hydrogen.

In a long term thinking and systematic studies, the expansion of the electric motor will not only decrease the usage of the fossil fuels, but it will in the same time reduce the energy consumption from transport sector because the effectiveness of the electric motor is three to four-time higher than the actual combustion engine. Depside the fact that the number of the vehicles and the volume of transportation will continue to increase if the number of EV would increase in considerable amounts the overall energy consumption and emission emitted by transport sector can increase.

According to SSB, the transport sector accounts in 21.7% of the total energy consumption for 2018 and 31.5% of the total greenhouse gas emissions are emitted by the transport sector (SSB, 2019). Therefore, the high expansion of EV in the transport sector will bring essential changes in the Norwegian energy system. It will affect both the decrease of the fossil fuel consumption of the country and the total energy consumption. Moreover, it would result in the increase of the total GHG emissions emitted in the Norwegian territory.

## 1.2 Problem definition

Norway is one of 174 countries that have ratified the Paris Agreement on climate change in April 2016 and committed to limiting the increase of temperature to a maximum of 2 degrees Celsius compared to the pre-industrial levels. Furthermore to put efforts on limiting the temperature growth up to 1.5 degree Celsius (Ministry of Climate and Environment, 2014b). The climate obligation that the Norwegian Government committed implies the reduction of greenhouse gas emissions with 40 percent compared with the levels of 1990 by 2030(Ministry of Climate and Environment, 2015). With a power supply based on renewable sources and almost emission-free, a residential and commercial building sector that is mainly based on electricity consumption, and an individual electrified heating system the interventions on transport sector remain crucial for the fulfillment of the Paris Agreement commitments.

Transport is one of the largest sources of greenhouse gas emissions in Norway with around one-third of the total emissions, and road traffic gives the major contribution. In twenty-eight years since 1990, the tendency of growth of GHG emission from the transport sector has been inclining and declining. The period between 1990 and 2010 was the period with significant growth of emissions from the transport sector. After 2010 the GHGs were stabilized and had a significant decrease until 2017, and then rose again in 2018 with 4.4 percent. The increase from road traffic was 2.8 percent, and other modes of transport increased by 6.4 percent. In 28 years starting from 1990, the emissions by the transport sector had an overall increase with 27 percent. (Miljødirektoratet, 2019)

The trends of emissions are strongly related to the economic and the population growth. The transport volume in Norway increased by 55 percent from 1990- 2017, while the population increased by approximately 25 percent (Miljødirektoratet, 2019). The larger the population the higher the requirement for both passenger and freight transport. According to SSB the population of Norway will continue increasing and will reach six million inhabitants by 2030 and will be over 7 million in 2060 (SSB, 2019). The indicators for the future show that the traffic volume will continue increasing in the future. According to NTP (National Transport Plan) for 2018-2029 the projections for the future show that the increase of passenger and freight transport volumes will continue towards 2050 (Norwegian Ministry of Transport and Communications, 2017a).

For 2017 the total greenhouse gas emissions emitted in the Norwegian territory were 52.74 Mt $CO_2$-eq, and transport sector contributed with 15.81 Mt $CO_2$-eq that is equivalent with 30 percent of the total emissions (Miljødirektoratet, 2019). The government has continuously taken efforts towards the reduction of greenhouse gas emissions by road transport but the energy consumption and the level of GHGs emitted by this sector remain high. The emissions emitted by transport sector cover around one-third of the total greenhouse gas emissions of the country. The reduction of emissions by this sector has to be done rapidly in order to contribute in the achievement of the goal of emission reduction with 40 percent by 2030 and becoming a low emission society by 2050 (Ministry of Climate and Environment, 2014b).

From what said above the emissions from the transport sector will continue to increase and transport will remain one of the sectors with the highest greenhouse gas emissions, air pollution, and noise even in the future. The aim of the Norwegian Government is to make the transport sector more environmentally friendly and to reach this aim their policy is supported in two principles that are:

1. The reduction of transport volume and transition to lower-emission transport modes such as public transport, cycling, and walking. For example, the substitution of freight transport from road transport to sea or rail.
2. Transition to low- and zero-emission technology such as electric vehicles. (Miljødirektoratet, 2019).

The climate changes are driving the reduction of both energy consumption and emissions emitted and increasing the share of renewable energy sources used. Transport sector remains one of the sectors with the highest energy consumption and emissions emitted and the lowest share of renewable energy share. This because of the dependence on fossil fuel. The high share of fossil fuel gives the transport sector high potential for emission reduction when increasing the share of renewable sources. In order to increase the share of RES in the transport sector and make it more efficient electricity is the solution. The shift towards an electrified transport sector has already started. Norway is one of the pioneers of this change and the supportive incentives towards electrification have started in early 1990. Nowadays, Norway is a leader on the electric vehicles market and the supportive incentives have given their fruits. For several years now, even in 2018, Norway was the global leader for the market share of the electric vehicles that reached 46 percent.

As a result of the shift from the traditional to an electrified transport sector, the national energy system will have essential changes. The electricity consumption will increase while the consumption of oil will have the opposite tendency. The curve the electricity demand will change the shape and the peak load may change the value or period or both. The need for new generating units may arise demanding on the scale of electrification. This in order to keep the self-sufficiency of electricity consumption. If the need for new generating sources rises, it is a great opportunity for the diversification of the generating sources of electricity. Norway is abundant on natural resources and wind is one of the sources with high potential for electricity production. The opportunities for the implementation of the innovative V2G technology in the future makes the interest of investing in wind power generation even more tempting.

Shortly, given that the Norwegian power system is mainly based on RES and the residential and commercial building sector have a high share of electricity and low emissions, the dependence of transport sector on fossil fuels is risking the fulfillment of Norwegian climate obligation within the Paris Agreement.

## 1.3 Research aim and objective

The increasing number of electric vehicles in Norway is changing the structure of energy demand and consumption. The share of electricity in the total energy consumption is 47.5% (SSB, 2019), and in the upcoming years, the electricity demand will increase. Two main factors that are expected to have a great impact on the increase in the electricity demand are the population growth and the increasing number of electric vehicles. According to NVE in Norway, the population will grow to about 5.9 million inhabitants in 2030 and further to 6.6 million inhabitants by 2050 (The Norwegian Water Resources and Energy Directorate, 2018, October 8). The growth rates of the population will increase the energy consumption in all the sector including the transport sector. The transport sector is responsible for one-third of GHG emissions. Therefore, in order to reduce the total GHG emissions, it is very important to intervene in this sector. By aiming the accomplishment of the climate target for 2030 "At least 40% reduction of greenhouse gas emissions compared to 1990 levels"(Ministry of Climate and Environment, 2015).

The Norwegian EV policies are among the best and the Norwegian EV market is nowadays one of the largest. According to the statistics, one in three vehicles that were sold in 2018 was electric (SSB, 2019). When it comes to the emission reduction by the increase of electric vehicles, it is needed to highlight that: "EV is as free emission as the energy they use". While most of the countries all over the world are trying to increase the percentage of the renewable energy in their power system, Norway already has a good starting point since 98% of the electricity is produced by hydropower plants. Therefore, the EV in Norway are totally free emission since the energy they use is generated by RES. While there is only one decade left to complete the climate target for 2030 the electrification of the transport sector is one of the pillars that will lead towards the accomplishment of the target.

The main objective of this study is to discover in what extent a potential shift of passenger vehicles from conventional to electric vehicles would contribute in the fulfillment of the ambitious goal of becoming a low emission society by 2050. The aim of the thesis is to design a possible model of the Norwegian energy system in 2050 based on the replacement of the conventional passenger vehicles with electric vehicles and the integration of a higher scale of wind power in the generation supply. In order to fulfill the aim of the thesis, the modeling approach EnergyPLAN is going to be used.

In order to address the main objective, the following sub-objectives are taken into consideration:

The study sub-objectives are:

- To define in what extent will the growing number of electric vehicles affect the decrease of greenhouse gas emissions in Norway.
- To identify how will the population growth impact passenger transport volume.
- The identification of the effects that the increasing number of electric vehicles could bring in a power system with high RES penetration.
- The evaluation of social-economic and environmental impact.

For this purpose, the segment of passenger cars (Category M1) is chosen to be analyzed. The focus of the analysis is the identification of individual elements and the development of a suitable structure in the environment of the Norwegian market.

To sum up, this master thesis will give an evaluation in the area of sustainable energies by rising some research questions, that will be listed in the section below. These research question will be the guide of orientation for this study.

## 1.4 Research questions

To shed light on the background for writing this thesis I want to look closely on how the potential transition from conventional passenger cars to electric passenger cars would affect an energy system with high RES penetration, like Norway's energy system.

Therefore, the research question I have chosen is:

*How a potential transition from conventional passenger cars to electric passenger cars would affect an energy system with high RES penetration like Norway's energy system?*

To address the research question given above there are three important sub-issues that are relevant to the topic of the thesis:

1. How the increase of population would affect the growth of the passenger transport volume?
2. In what extent the growing number of the EV would affect the decrease of GHG emissions in Norway?
3. What impact could have a high penetration of RES (Wind) power generation in the Norwegian Energy System?

## 1.5 Project outline

This master thesis is structured into nine chapters as listed below:

1. Introduction- In this chapter is described the personal motivation for choosing this topic. The research question that is addressed the main issue that is studied in this master thesis and the objectives that I seek to fulfill are listed in this chapter.
2. Background- The chapter of Background gives a brief overview of the global energy system. It is mainly focused on historical data on GHG emission and energy consumption and future trends.
3. The Norwegian energy system- as it can be seen by the name the intention of this chapter is to describe the Norwegian energy system. The main focus is on the power sector since the data for electricity consumption and the tendency that this element has had over the years later on is going to be used in the modeling tool.
4. The transport sector in Norway – A brief description of the Norwegian transport infrastructure is given in this chapter. Moreover, the historical trends of the energy consumption and GHG emissions and future trends for energy demand and GHG emission reduction based on the electrification of this sector are studied. The pollutants emitted by ICE are listed in this chapter. Furthermore, the expansion of the EV in the Norwegian market is described. Since this is a key element of this study.
5. Electric vehicles – The main objective of this study was modeling a potential model for the Norwegian energy system in 2050 with the focus on the shift of passenger vehicles from conventional to electric. Therefore, a short summary of the EV development over the years is given in this chapter. The main elements of EV technology together with the advantages and advantages that in the end will influence the future model. By looking into the limitations of the technology a better understanding of the challenges of the electrification of the transport sector is given.
6. Methodology – This chapter outlines the research strategy used in this study. It describes the modeling tool used in this study and underlines some of the main reasons that made me chose this modeling tool instead of any other energy modeling approach. The process of data collection is another important issue treated in this chapter.
7. Scenarios – Five different scenarios are simulated with energyPLAN in order to answer the research question that is chosen for this master thesis. The Scenario Reference is based on the Norwegian energy system in 2018. All the input data for this scenario are explained and calculated in this chapter. An activity analysis of the transport sector is been done. A possible projection of the future passenger transport that considers the national targets and incentives, as well as the historical trend of the activity, is represented. Therefore, based on this projection

for the future number of the total and electric passenger cars four different future scenarios are built.

8. Results – in this chapter are given the results taken for each scenario after the simulation with the energy modeling tool EnergyPLAN. A comparison between different elements of the same scenario, as well as between different scenarios, is done in order to see how the trend of one element can influence the other elements.
9. Discussion and Conclusion – in this chapter are summarized the main findings of this master thesis. In order to see if the objectives set for this thesis are fulfilled, an assessment of the work is done. Finally, recommendations for further work are given.

# 2 Background

The purpose of this chapter is to give a brief overview of the actual Global Energy System. When it comes to analyzing a national energy system, it is very important to see the system from a wide perspective. This in order to identify how the system we are studying interfere with the surrounding systems. The energy system can be divided into four levels that are: Global, Continental (in our case the European), Regional (in our case the Nordic), and National (in the current case the Norwegian). The development of a national system will always be affected by how the bigger systems are developing. On the other hand, different countries develop their energy systems differently depending on the natural resources they have and the economic opportunities. Their goals are different depending on their unique natural resources and opportunities. What connects all the counties of the World is the fact that we all have a planet and we all contribute to destroy or to keep this planet safe for the future generations.

## 2.1 Overview of the actual energy system

The rising concerns about energy security and the high ambition of the Paris Agreement on climate changes are changing the development of the energy sector nowadays (International Energy Agency (IEA), 2018). The shape of the future energy system is uncertain. With this uncertainty, several patterns are coming up. The long process of electrification if probably going to continue and quicken. The electrification process has already started. This is shown by the record level of 19% of electricity in the total global energy consumption in 2018. The development of low-emission technologies is transforming the electricity generation by making it more sustainable and environmentally friendly. (World Economic Forum, 2018)

The energy sustainability according to the World Energy Council is measured by three main dimensions:

- Energy Security – effective administration of primary energy supply, reliability of energy infrastructure, and the capability of energy providers to meet the actual and future demand.
- Energy Equity – The energy supply should be accessible and affordable for the whole population.
- Environmental Sustainability – including the accomplishment of supply and demand-beside the energy efficiencies and the development of RES energy supplies and low-carbon sources and technologies. (World Energy Council and WYMAN, 2018)

These dimensions establish the Energy Trilemma, and the accomplishment of high performance on all the dimensions requires interaction between different public and private actors, economic and social factors, natural resources, environmental concerns, and consumer behaviors. The dimensions of the Energy Trilemma are evaluated in a rate from A to D, where A is the strongest result and D the lower. For 2018 the top ten countries with the highest values of the trilemma dimensions ranked in a declining scale according to World Energy Council are Denmark, Switzerland, Sweden, Netherlands, United Kingdom, Slovenia, Germany, New Zealand, Norway and France (World Energy

Council and WYMAN, 2018). The schematic view of the Energy Trilema is illustrated in figure 2-1.

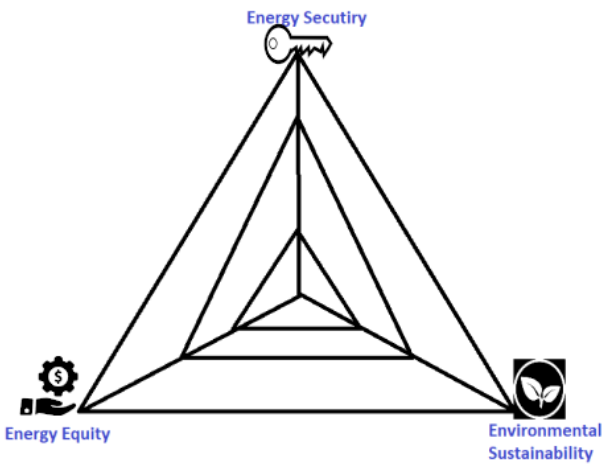



**Figure 2-1. The dimensions of Energy Trilemma**

### 2.1.1 Total Final Consumption of Energy

The Global Total Final Consumption (TFC) for 2016 according to the International Energy Agency (IEA) was 111128 TWh. This is approximately 45% higher than the TFC in 1990 when the TFC was 72931 TWh. Oil and electricity are the sources that historically have had the highest share of the total energy consumption worldwide. The share of electricity consumption in the TFC between 1990 to 2016 increased from 13% of the TFC or 9481 TWh in 19% of the TFC or 20863 TWh. The industry has been and remains the biggest consumer of electricity over the years. In recent years, it is noticed an important growth in electricity consumption by the transport sector. Between 1990 and 2016 the consumption of electricity in the transport sector increased by 32% (from 244 TWh to 357 TWh). This is mainly caused by the high expansion of electric vehicles in road transport recently. (International Energy Agency (IEA), 2018)

The figure 2-2 gives full data for the global TFC by source and the TFC of electricity by sector for 2016.

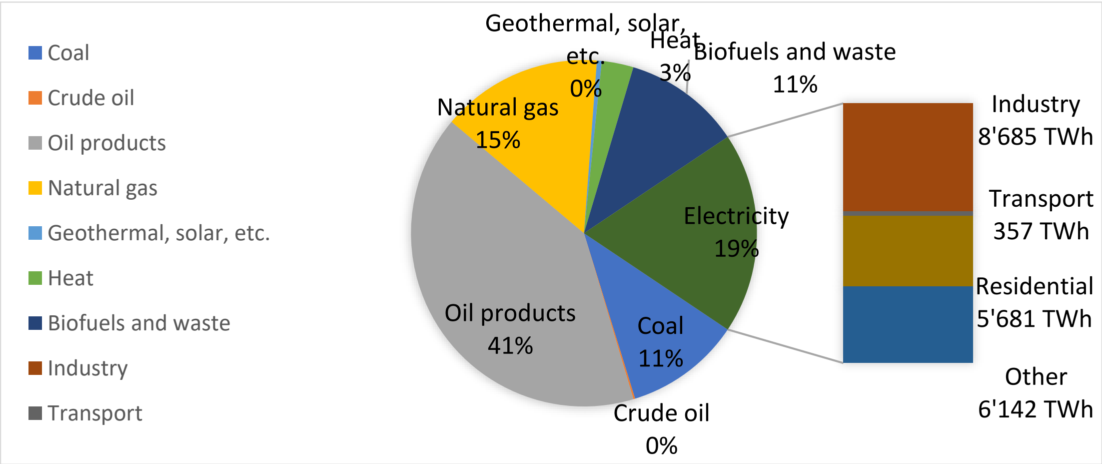



**Figure 2-2. Global TFC by sources and Electricity consumption by sector (2016)**

Source: (IEA, 2019b)

The goal of EU countries is to archive a reduction the of greenhouse gas emissions with at least 20% comparing to 1990 levels, to incline the share of RES to at least 20% of the total consumption, and to increase the energy efficiency with 20%. A specific for the increase of the RES is that EU countries must record a share of at least 10% on the transport sector (Eurpoean Commission, 2018). For 2018 the transport sector consumed 31.6% of the world final energy consumption (International Energy Agency (IEA), 2018) and 21.7% of the final energy consumption in Norway (SSB, 2019).

The TFC in the European Union-28 for 2016 was 13232 TWh or 11.9 percent of the global TFC. The level of consumption hasn't changed much from 1990 when it was 13191 TWh or 13.19 percent of the global TFC. As illustrated in the figure 2-3 a change in the share of energy sources in the final consumption is clearly noticed between 1990 and 2016. The decrease in coal consumption from 1400 TWh in 401 TWh is the most evident change between these years. The reduction in coal consumption is replaced with an increase in the consumption of biofuels, waste, and electricity. Thereby, these sources have had a significant increase in the TFC of EU-28.

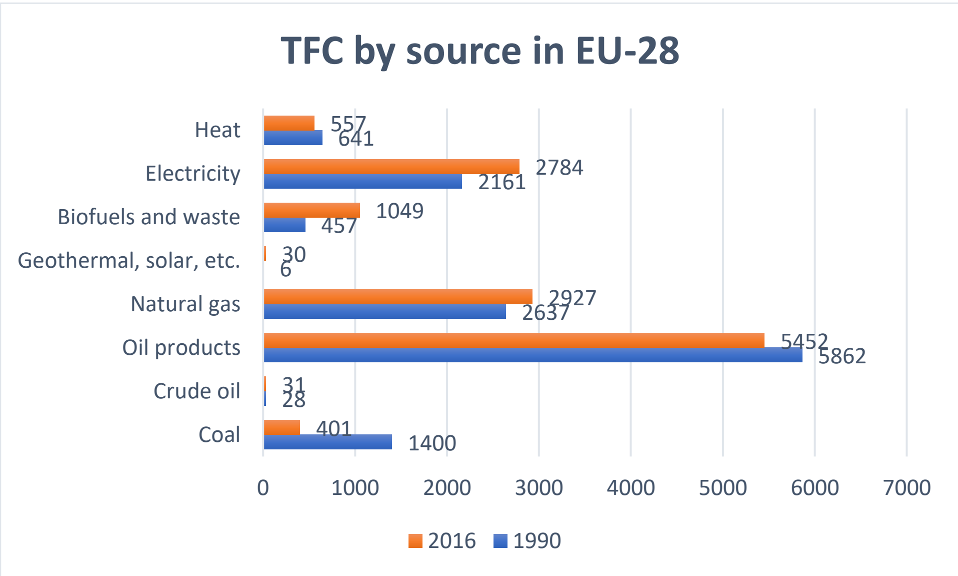



**Figure 2-3. TFC by source - EU28 (1990-2016)**

**Source: (IEA, 2019b)**

The Nordic countries have a low reliance on fossil fuels. That is why comparing to other developed counties the emissions emitted by these countries is very modest. The energy consumption per capita in the Nordic countries is among the highest in the world caused by the cold climate and the use of electricity on space heating (except Iceland that uses mainly geothermal) and industry. Norway and Iceland are the countries that lead the electricity consumption in the Nordic region. Transport, industry, and buildings have around one-third of the final energy consumption each. In the past 20 years in the Nordic region, the greatest increase with around 20% of the final energy use has happened in the transport and commercial building sectors. (IEA et al., 2016)

In the figure 2-4 is given the final energy demand in the Nordic Region for 1990, 2000, and 2013. The sector with the highest energy demand during 1990 and 2000 is the industrial sector but in 2013 the sector of buildings leads the energy demand with a total demand of 389 TWh, that corresponds with 33% of the total final demand. The total energy demand in the transport sector has increased since 1990. The increase in this sector was more visible from 1990 till 2000. In a period of ten years from 1990 till 2000 the total final energy consumption in the transport increased with 15%, from 260 TWh to 304 TWh. (IEA et al., 2016)

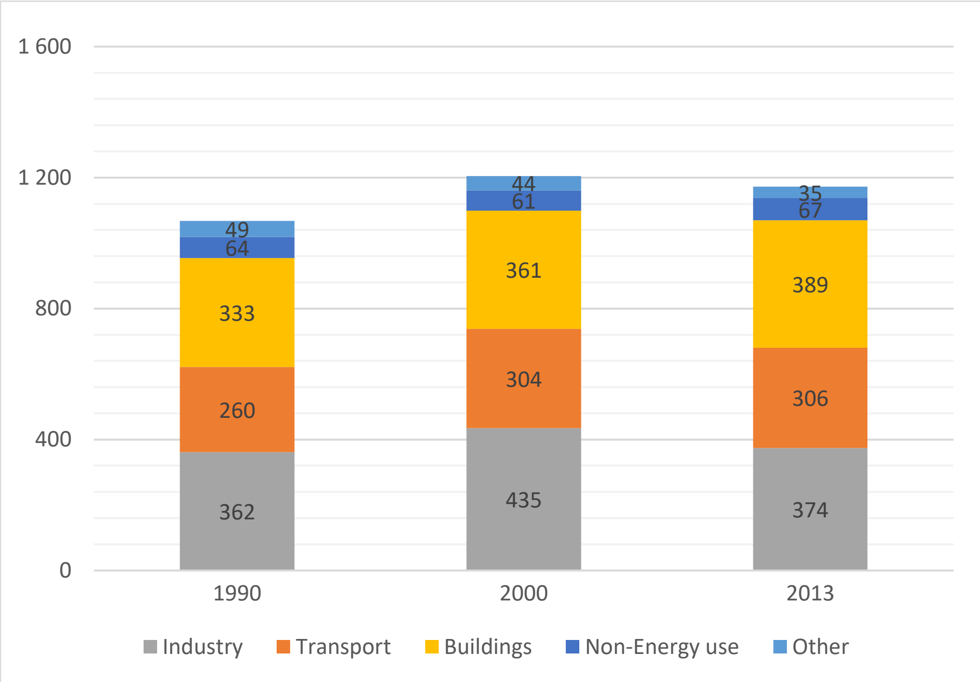



**Figure 2-4. Final energy demand in Nordic Countries (TWh)**

**Source: (IEA et al., 2016)**

The Nordic countries are among the countries with the lowest reliance on fossil fuels and with the highest energy consumption per capita in the world. The goal of the Norwegian government is to reduce greenhouse gas emissions with 30% of 1990-levels by 2020 (Norwegian Ministry of the Environment, 2007).

The TFC of energy in Norway grow from 203 TWh in 1990 into 239 TWh in 2016. The two main sources of energy consumption in Norway are Oil products and Electricity. The highest share in the TFC of energy for 2016 in Norway was covered by electricity with 48% of the total final consumption. The electricity consumption for this year was 114 TWh, 15% higher than the consumption of the same source in 1990. Another important change is the increased consumption of natural gas from zero conceived 4% of the TFC in 2016. In TWh, the usage of natural gas for 2016 was 10 TWh that is a considerable amount for a TFC that has the value of 239 TWh. In the share of TFC of energy by sectors, transport and industry sector cover the higher percentage for 2016. TFC for this year was covered 32.3% by industry and 26.3% by the transport sector. The consumption of the transport sector for 2016 was around 63 TWh from which mostly used source is oil products that cover around 80% (50 TWh) of the TFC of energy from this sector.

In the figure 2-5 is given the full overview of the TFC in Norway by sources for 1990 and 2016.

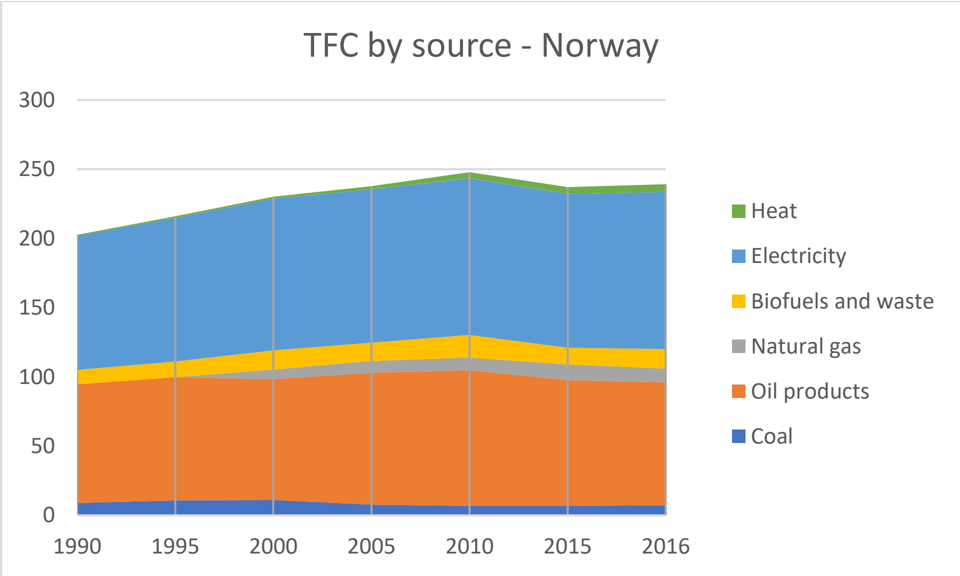



**Figure 2-5. The tendency of TFC by sources in Norway (1990-2016)**

**Source: (IEA, 2019b)**

The transport sector is one of the main consumers of energy globally. Recently the transport volumes and consequentially the energy consumption by this sector are increasing. This is an indicator of economic growth and welfare. The number of personal cars and road traffic is having a growing tendency. The opposite is happening with public transport that is becoming less preferable nowadays.

In the figure 2-6 is given the percentage of energy used by the transport sector in the total final consumption globally, EU-28 and Norwegian. In 2016 the share of energy consumption globally and in EU-28 had a higher percentage than in Norway. In the global TFC, the energy consumption by the transport sector in 2016 was 35116.5 TWh or 32% of the global TFC. The energy consumed by transport in EU-28 and Norway was respectively 4181 GWh or 31% and 63 GWh or 26% for the same year. (IEA, 2019b)

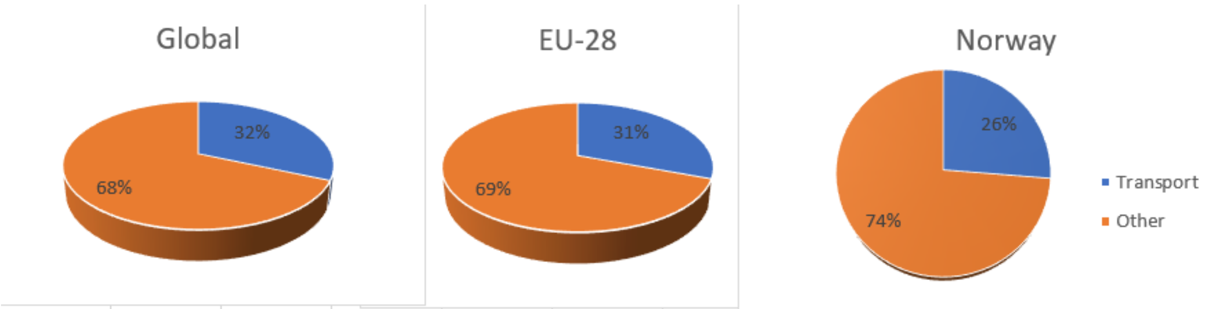



**Figure 2-6. The consume by the transport sector in TFC for 2016**

Source: (IEA, 2019b)

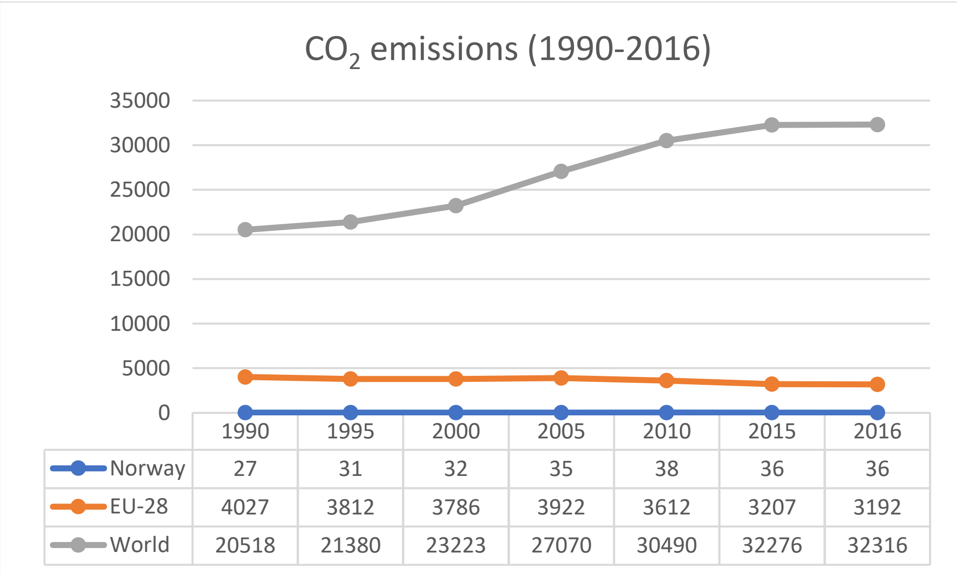
## 2.1.2 Emissions

Globally the level of $CO_2$ emissions between 1990 and 2016 has been growing. Between these years the growth rate was 36.5% by reaching the level of 32316 Mt $CO_2$ emissions only from fuel combustion in 2016. If we compare the growth rate of global TFC and global emissions they have both positive growth rate but the TFC has been growing in greater values than the emission, respectively 48% the growth rate of TFC and 36.5%

the growth rate of $CO_2$ emissions. The inconsistency of the values is caused by the increasing level of RES in global energy consumption and the production of electricity. Furthermore, the electricity consumption is doubled between 1990 and 2016. (IEA, 2019b)

In EU-28 the tendency of $CO_2$ emissions is negative, and this is the only region in the world that has decreased the amount of $CO_2$ emitted in the atmosphere during this period of time. While the TFC in this region has had a very small increase from 13191 TWh that was in 1990 into 13232 TWh in 2016. The reasons behind this change are the decrease in coal consumption in the TFC and the replacement of it with the consumption of biofuels, waste, electricity and geothermal energy. By the other hand, electricity production has had significant changes with the improvement of technology and the increased share of RES in electricity production. Between 1995 and 2015 the emitted $CO_2$ emissions by EU -28 countries decreased from 4 012 million ton in 3 472 million ton by constituting 10% of the total $CO_2$ emissions of the World while the TFC covers 12% of the global TFC. (IEA, 2019b)

In Norway, emissions have been increasing[2] from 1990 till 2010 when the level of $CO_2$ emitted reached the record value of 38 Mt from 27 Mt that was in 1990. After that year the amount of $CO_2$ decreased to 36 Mt in 2015 than remained at the same levels even for 2016. The sectors with the highest energy consumption are transport, industry and residential sector. Around 50% of GHG emissions in the Norwegian territory are emitted from Oil and gas extraction (14.5 million tonnes $CO_2$-equivalent), and manufacturing industries and mining (12.1 million tonnes $CO_2$-equivalent) and 17% from road traffic ( 9 million tonnes $CO_2$-equivalent). (IEA et al., 2016)




| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|
| Norway | 27 | 31 | 32 | 35 | 38 | 36 | 36 |
| EU-28 | 4027 | 3812 | 3786 | 3922 | 3612 | 3207 | 3192 |
| World | 20518 | 21380 | 23223 | 27070 | 30490 | 32276 | 32316 |

**Figure 2-7. $CO_2$ emissions from fuel combustion (1990-2016)**

Source: (IEA, 2019b)

In the Nordic region, the energy-related $CO_2$ emissions represent around two-thirds of the total greenhouse gas (GHG) emissions. As shown in figure 2-8 in 2010 in the total amount of greenhouse gas (GHG) emissions only the energy sector contributed to 57% of the total amount. The most important sectors that contributed are industry, power generation and transport sector. Only the transport sector accounted for 21% of the total amount (IEA et al., 2016).

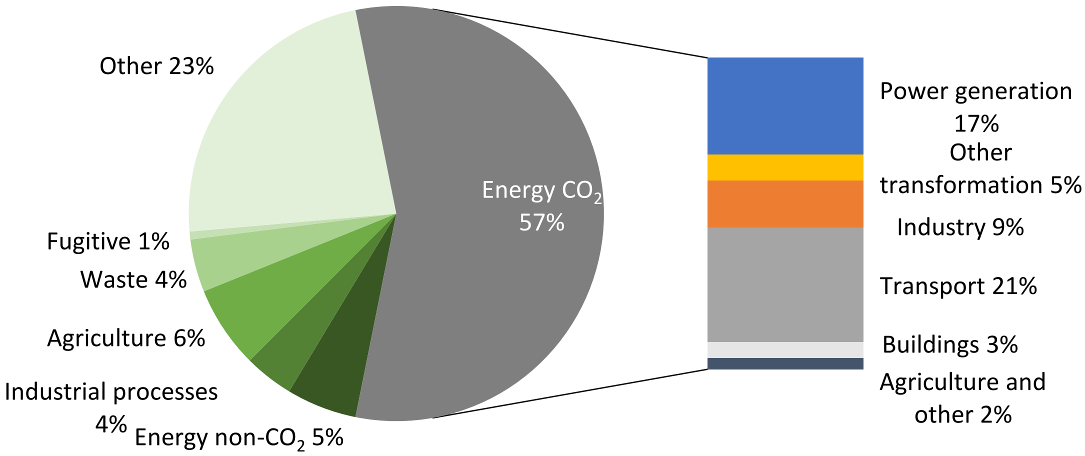



**Figure 2-8 Direct GHG emissions in the Nordic Region (2010)**

**Source: (IEA et al., 2016)**

For 2016 the level of $CO_2$ emissions from fuel combustion was 32.3 $GtCO_2$ and the largest source of emission were the fossil fuels (oil, natural gas, and coal) that emitted 99% of the total global $CO_2$ emissions and from the other side represent 81% of the global TPES (190962 TWh). Oil leads in the list for the higher share of energy sources in the global TPES for 2016 with 32% followed by coal with 27%. The situation is reversed in the total global emission were due to its high carbon intensity the emission from coal combustion cover 44% of the total $CO_2$ emissions for 2016. The sectors with the highest carbon emissions are transport, buildings, and industry. The industry had the highest percentage of the total $CO_2$ emissions for 2016 with 36% followed by buildings and tansport with 27% and 25% each. The contribution of transport in the total $CO_2$ emissions for 2016 was 7866 $MtCO_2$ of which 5853 $MtCO_2$ were emitted by road transport. In the total $CO_2$ emissions from road transport, the oil combustion contibuted in 98%. (International Energy Agency, 2018a)

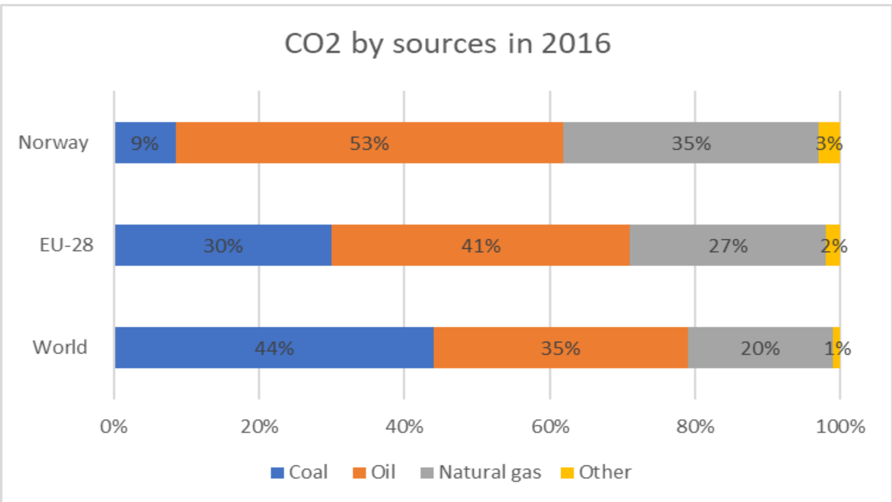



**Figure 2-9. CO2 emitted from the fuel combustion by sources in 2016**

Source: (International Energy Agency, 2018a)

In the global level, the emissions emitted by coal combustion are the highest, while in EU-28 and Norway oil is the first source of $CO_2$ emissions. This is an indicator that globally the power plants that run with coal have a high percentage while in EU-28 the electricity production from coal is decreasing continuously with the rising concerns for climate changes that are driving the increase of RES share in the power system. In Norway, the production of electricity is almost 97% from hydropower and this is the factor behind the low percentage of coal that covers only 9% of the $CO_2$ emissions emitted by fuel combustion. From 1990 until 2016 emissions from fuel combustion have had a growing tendency in the global level where they increase with 57.5% while in EU-28 they decrease with 20.7%. In the Norwegian territory the emissions from fuel combustion increased but not in the same levels with the global growth rate, the difference between the level of emission in 1990 and 2016 was plus 29.3%. (International Energy Agency, 2018a)

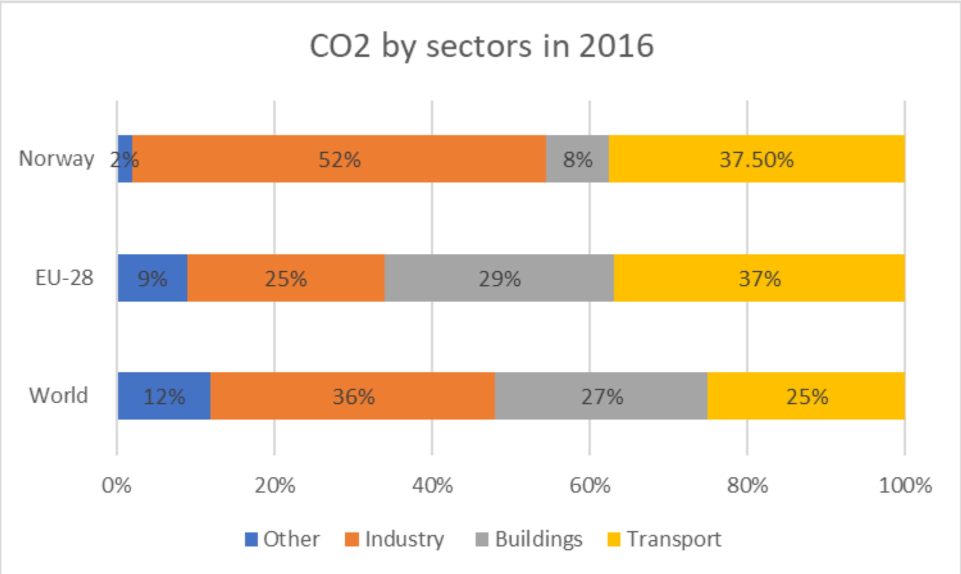



**Figure 2-10. CO2 emissions from fuel combustion by sectors in 2016**

Source:(International Energy Agency, 2018a)

The share of $CO_2$ emissions by fuel combustion emitted by the industrial sector dominated convincingly in World and Norway respectively with 36% and 52% in 2016 (see figure 2-10). For the same year in EU-28, the share $CO_2$ emissions emitted by fuel combustion occupies the third place with 25% and comes after transport that leads with 37% and buildings with 29%. For 2016 in Norway the most dominants sectors in term of emissions emitted by fuel combustion are industry and transport with 52% and 37.5%. The sector of buildings has a modest contribute compared with the two first sectors because of the high use of electricity in this sector. Moreover, electricity is produced by renewable sources, mainly hydropower than covers around 97% of the total production of electricity. As mentioned above, the transport sector is one of the biggest emitters of $CO_2$ emission. From 1990 till 2016, it has had a positive growth rate with 71% on the global level and 20% in EU-28. (International Energy Agency, 2018a)

The share of renewable energies on this sector remains a global issue and the first precautions are now undertaken. The consumption of electricity and biofuels is the best options to reduce the dependence of the transport sector from fossil fuels and to reduce the emissions emitted. The share of electricity in public transport is now increasing, and the promotion of electric and hybrid vehicles with different tax incentives in different counties is giving now the first positive feedbacks. Norway is one of the first countries that has started the tax incentives and has now the highest sales of electric vehicles on the overall sales.

In the table 2-1 are given three main energy indicators for the global, continental and national level. These indicators are energy and electricity consumption per capita and emissions per capita. The energy consumption per capita in Norway is one of the highest in the world. It is two times more than in EU-28. This is an indicator of the high living standard. Electricity has a very high share in Norway's TFC, this as a consequence of the high consumption form the sector of buildings that uses it mainly for heating due to very long and cold winters. The use of electricity is ten times more than the global electricity consumption per capita and five times more than in EU-28. The level of $CO_2$ emissions per capita is lower at the global level than in EU-28 even though they are the ones that are taking more precautions for the emission reduction. The level of emissions per capita is lower in the world than in EU-28 because the energy consumption per capita in EU-28 is three times more than the energy consumption per capita in the world. Norway and EU-28 have almost the same levels of emissions per capita but the energy consumption in Norway is two times more than in EU-28. The difference consists of the high electricity consumption that is almost emission-free.

**Table 2-1. The comparation on energy consumption, electricity consumption and emissions emitted per capita in 2016**

| | **Energy consumption/capita (MWh)** | **Electricity consumption/capita (MWh)** | **Emissions/capita (t $CO_2$)** |
|---|---|---|---|
| **World** | 11.63 | 3.11 | 4.35 |
| **EU-28** | 36.4 | 6.01 | 6.24 |
| **Norway** | 60.5 | 32.69 | 6.78 |

Source: (International Energy Agency, 2018a)

## 2.2 The future of the energy system

The period of historical changes has already started for the worldwide energy system. The development of new energy technologies is opening doors with new opportunities by changing the face of the system. The future energy system aims for high energy security and sustainability. These aims can be accomplished if the actual fossil fuel supply would be replaced by a supply that is based on renewable energy. The barrier of this potential change has started to fall with the declining cost of renewable energy and the increase of technology efficiency. While the energy production is having remarkable progress the use of energy by the end-users remains an issue. The use of renewable sources by this category can play an important role to accelerate the progress in this category of users. The considerable share of electricity consumption by end-users can improve the end-user's efficiency progress if accompanied by the inclining share rate of RES in electricity supply. Furthermore, the electrification of the transport sector opens the opportunity of future decarbonized road transport. Only in 2017 the number of electric vehicles sold reached 1.2 million that is around 1.5% of the total number of cars sold that year (International Renewable Energy Agency (IRENA), 2018).

### 2.2.1 Roadmap to 2050

Roadmap 2050 has projected two possible scenarios for the global energy system. These scenarios are:

- Reference Case that is based on the current situation and future plans of the national energy systems worldwide.
- Remap Case is based on the potential development of low-emission technologies, the high share of renewable energy and increase of energy efficiency, to drive a potential transformation of the global energy system. This new and transformed energy system aims to reach the predetermined goal of keeping the rise of the global temperature to below 2°C above pre-industrial temperature levels by the end of the century. (International Renewable Energy Agency (IRENA), 2018)

The projected changes in the Remap Case scenario are supported in the inclining growth rate of renewable energy in the total global energy supply from 15% in 2015 up to 66% in 2050. The planned policies of the countries, that are analyzed in the Reference Case, suggest a potential increase in the share of renewable energy with around 27%. The power sector will have the most radical changes where the share of renewable energy in electricity generation is expected to reach 85% of the total electricity production in 2050 from 25% that is was in 2017. On the other hand, the end-users will be more attracted by electricity as it becomes low-emission, and the predicted share of electricity consumption by this sector will grow from 20% in 2015 to 40% in 2050. The growth of electric vehicles in the transport sector, in general, has a very specific role in the fulfillment of the defined targets. (International Renewable Energy Agency (IRENA), 2018)

In 2016 the share of RES in TFC was 17%, where the largest amount was the direct use of RES in industry and buildings. The future will be electrified, and this is now a fact. In both scenarios of Roadmap 2050 the greatest increase in renewables in TFC is in electricity. According to these scenarios, the share of renewables in the global TFC for 2050 is 25% in the Reference Case and 66% in REmap Case as it is illustrated in the figure 2-11. On 2050 the generation of electricity will come 86% from RES, and the share of electricity in TFC of energy from the transport sector will rise by 43% according to REmap Case.

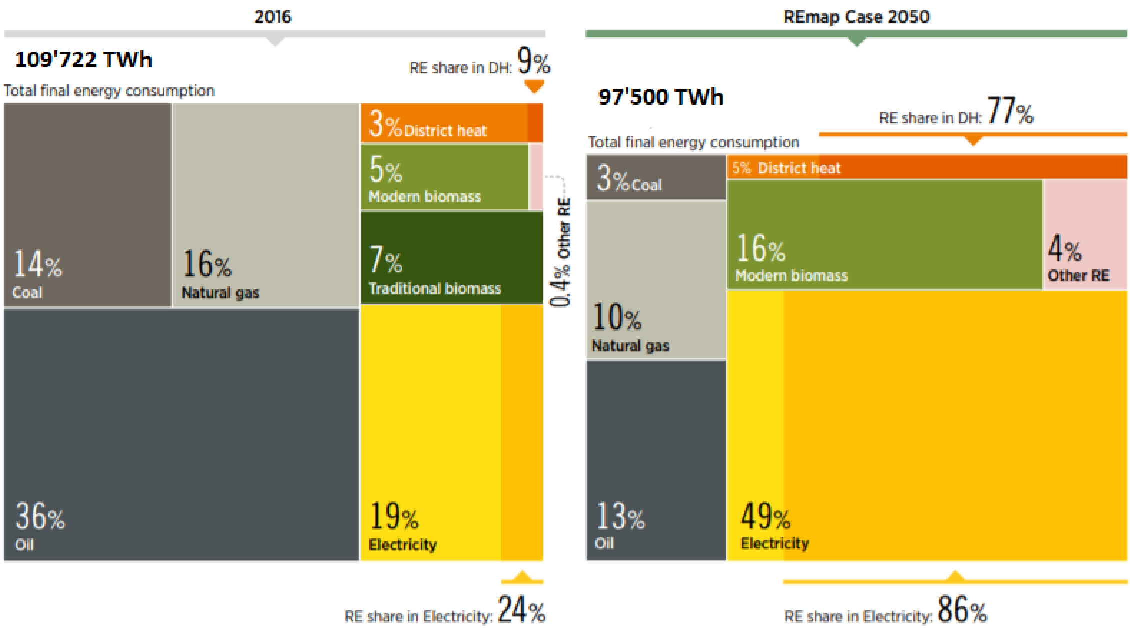



**Figure 2-11. Electricity as the main energy source in 2050 and the share of RES in electricity**

**Source: (IRENA, 2019a)**

In REmap Case scenario the level of electricity consumption by end-use sectors will double by 2050 compared with 2016 levels. The generation of electricity will be 86% by renewable sources and the most radical change will happen in the transport sector where the electrification will continue and quicken during this period of time and the electricity consumed by the transport sector will become 22% from 2% that is was in 2016. (IRENA, 2019a)

The transport sector is the sector with the highest dependence on fossil fuels. The policies for a more sustainable and less pollutive future of this sector are relying on:

- RE-Electrification (BEV and Hydrogen in fuel cells)
- Renewables (direct-users)
- Energy efficiency (improvement of technology, shift to public transport)

From the analysis, if REmap Case scenario will be archived in 2050 the amount of $CO_2$ released annually by this sector would become 3 Gt that is equal with 70% of the actual emissions from this sector. The share of renewable energy use in transport is predicted to become 58% and the share of electricity 33%. (International Renewable Energy Agency (IRENA), 2018) While the volume of transportation will continue increasing the energy use and emissions emitted by transport sector are predicted to have the opposite trend in the REmap Case scenario for 2050. The increase of the number of EV and growth of biofuel used will help in the same time on emission reduction and will reduce the energy consumption because the efficiency of the new electric motors is from two to three times more than the efficiency of the actual combustion engines. The full comparison between 2015 and the expected future based on REmap Case 2050 is given in the figure 2-12.

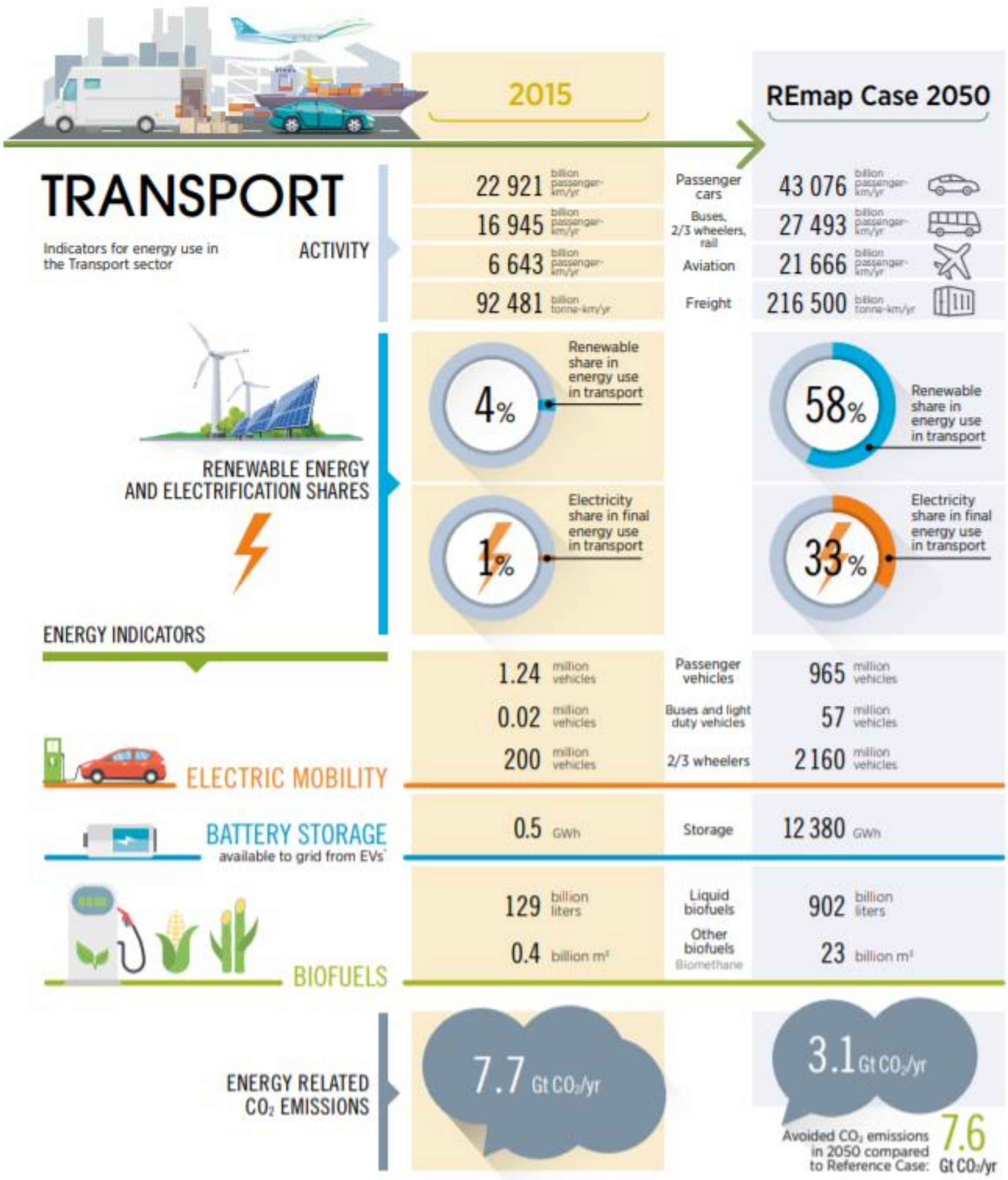



**Figure 2-12. The transport sector in 2015 and 2050**

**Source: (International Renewable Energy Agency (IRENA), 2018)**

## 2.2.2 EU targets for 2020 and 2030

Europe has nowadays three different targets on energy and climate objectives. The short-term target that EU countries aim to archive is the 3x20 target that has three important indicators that are:

- The reduction of greenhouse gases with 20% compared to 1990 levels.
- Increasing with 20% the share of RES in final energy consumption in the EU, with an obligatory increase in the transport sector with 10% in the share of renewables.

- The improvement in energy efficiency and a 20% reduction of the final energy consumption.

Meanwhile, the track of the indicators for the short-term target of 2020 continues, EU has set the new targets for mid and long-term periods. The targets for 2030 are more ambitious and set a reduction on domestic GHGs with at least 40% compared with the levels of 1990, the increase of RES share on 32% and the reduction of the consumption with 32.5%. After 2030 the long-term goal of the EU is the achievement of the wide target of 80-95% of greenhouse gas emissions by 2050 compared with the levels of 1990. The ambitious goal of emission reduction for 2050 will require high progress on energy efficiency, technology improvement and a high share of renewables. (EEA, 2018)

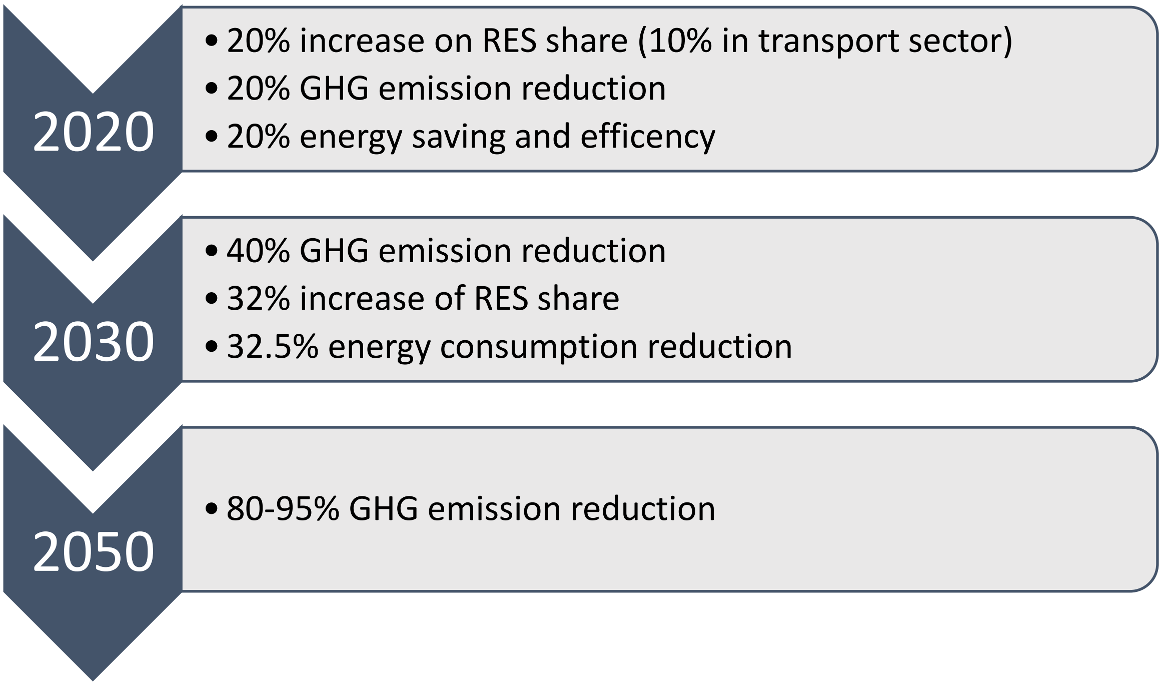



**Figure 2-13. EU energy targets for 2020, 2030 and 2050.**

The transport sector has an important status on the projection of energy and climate targets in the EU because of its high dependence on fossil fuels and the continuous growth of the energy demand. The improvement in energy efficiency and the increase in the share of RES would be of a great contribution at the achievement of the energy and climate targets of the European energy system. The expansion of EV and the increase of biofuel consumption would in the same time increase the renewables share and improve the efficiency because of the high efficiency on the new electric motors. On the other hand, the technological development continues and in the recent years, the V2G (Vehicles to Grid) technology is helping in terms of energy security by being an energy storage that could be used during the peak hours demand. Another great opportunity that has started to be tested in recent years is the usage of hydrogen for cars. To sum up what written above: The future of a sustainable transport sector is supported by the electrification, biofuels, hydrogen and V2G technology.

# 3 The Norwegian energy system

Norway has a key role in the global energy systemas one of the biggest producers and exporters of oil and gas. The Norwegian reserves of water, oil, and gas are very important for the security of the European and global energy system. While the population of Norway is only one percent of the total population in Europe, this country has abounded natural resources. Norway has 50% of the water storage, 20% of hydropower, 40% of gas and 60% of oil resources in Europe.  Bolster the high development oil and gas industry, this country has a very strong environmental sustainability. Electricity is mainly generated by hydropower. In 2016 around 96.4% of the electricity was produced by hydropower and for the same year, the share of electricity on the TFC of the country was around 47.5%. The targets of Norway on GHG emission reduction are above the EU targets. The reduction of emissions with 30% and 40% from 1990 levels respectively by 2020 and 2030 are the actual targets. Norway aims to be one of the first carbon-neutral countries by adding to the actual targets of the emission reduction the contribute that the clean energy exported by Norway gives abroad. The target for 2050 remains unknown while the goal is to become a low-emission society, but the definition of a low-carbon society is yet something to discover. (IEA, 2019b)

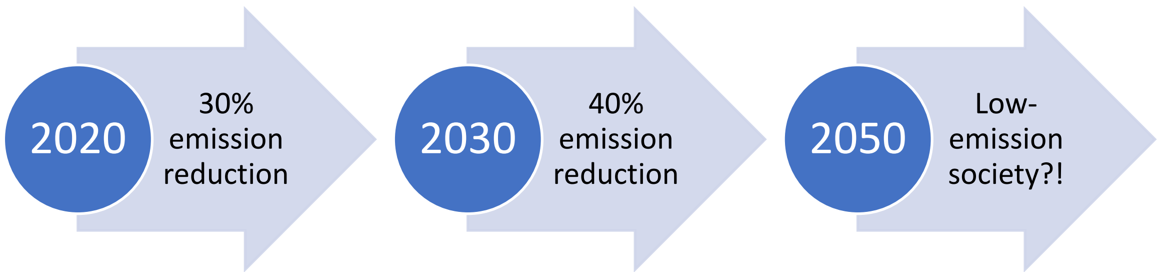



**Figure 3-1. The emission reduction target compared with 1990 levels**

The achievement of the emission target is very challenging for Norway because electricity production is emission-free, and the building sector has a large use of electricity. Anyway, due to the stable economic development and the high income from gas and oil exportation, Norway has the opportunity to invest in new technologies. On the other hand, the growing energy demand in the transport sector and a large amount of fossil fuels consumed by this sector turn on a green light as a sector with great potential for emission reduction. The number of EV has experienced rapid growth in the resent year because of the taken incentives, such as: excluding EV from toll charges and some other taxes, and free public parking. For countries like Norway that have a power sector based on renewable sources, the increase of the number of EV is one of the most attractive options for the fulfillment of the emission reduction targets.

As mentioned in the sections above the Energy Sustainability is measured by three dimensions that represent the Energy Trilemma. The dimensions of the Energy Trilemma are Environmental Sustainability, Energy Equity (affordability and accessibility to energy) and Energy Security. In 2018 Norway was ranked the 9th country in the world for the performance of the three dimensions of the Energy Trilemma. The score of Norway was AAB (Environmental Sustainability, Energy Equity, Energy Security). Norway has declined the position of the global Energy Trilemma ranking with two positions from 2016 till 2018 because of the bad ranking on Energy Security. (World Energy Council and WYMAN, 2018)

A power system with high dependence on hydropower gives in the same time advantage for the Environmental Sustainability dimension but in the same time a disadvantage for the dimension of the Energy Security because of the dependence on the climate conditions. The climate changes have given their effects in Norway with dry years that have had a very negative impact on the power system by rising concerns related to the energy security of the country, this fact has shown its effects in the index rank of Energy Trilemma. By being one of the biggest exporters of clean electricity the diversification of sources in the power system is becoming an urgent need, not only for the security of the Norwegian power system but even for the security of the European power system. And it is important to mention that Norway is rich in other renewable energy resources such as tidal, wave and wind power, among others the development for the wind power exploitation is more advanced. Recently as a consequence of the increasing electricity demand and the urgent need to diversify the electricity generation sources, Norway has started with the exploitation of the wind power and has built some wind farms in the coastal line. A simple illustration of the Energy Trilemma for Norway is given in figure 3-1.

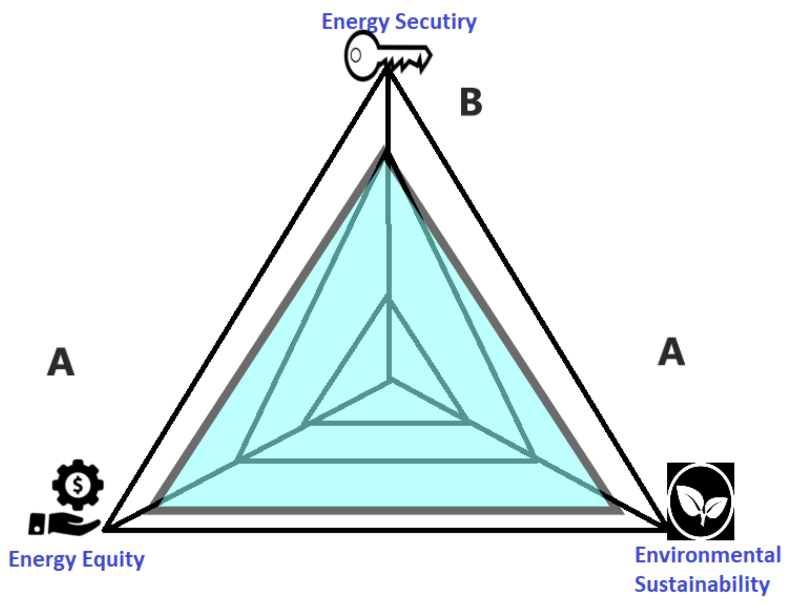



**Figure 3-2. The Energy Trilemma for Norway**

## 3.1 The Norwegian Energy System

Norway has a very special energy system. The Norwegian energy system is based on three main elements: electricity, oil, and natural gas. The electricity is generated almost entirely by renewable sources, mainly hydropower. As one of the biggest exporters of oil and natural gas, and one of the leaders on clean electricity exporters the Norwegian energy system has an important role in the global and European energy system.

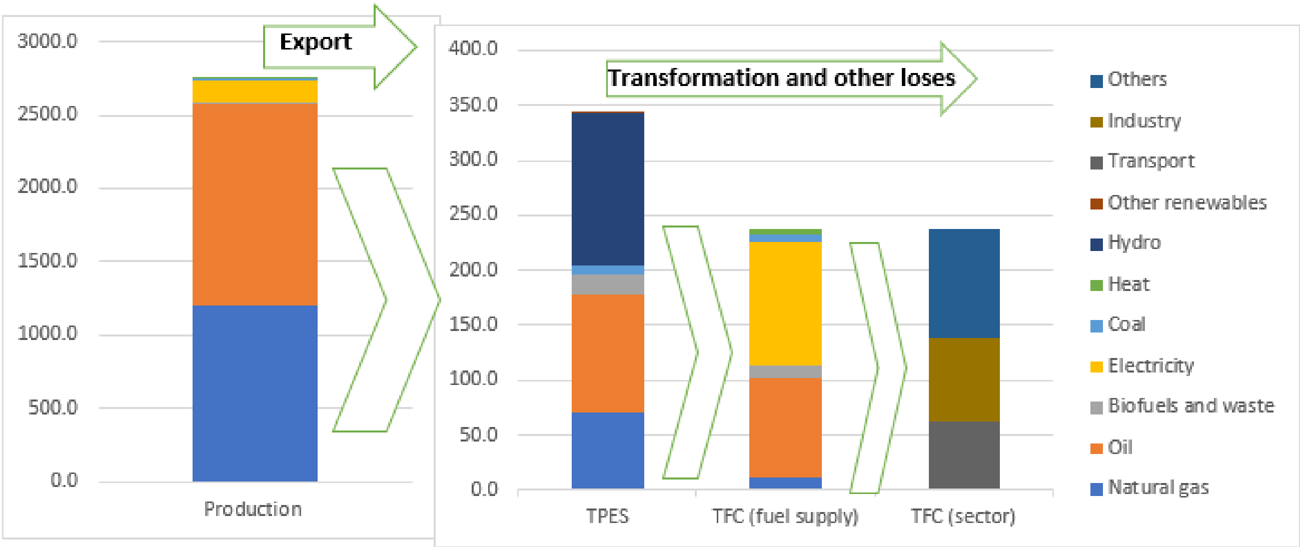



**Figure 3-3. Energy system transformation for 2015**

**Source: data from (SSB, 2019) and (IEA, 2019b)**

For 2015 the total energy production in Norway was 2636610 GWh and the major contribution was given by natural gas with 1196326 GWh, oil with 1268381 GWh and electricity with 137077 GWh (SSB, 2019). The total primary energy supply for the same year was 2553 GWh and the sources that gave the higher contribution on the TPES were: hydro with 1015 GWh, natural gas with 525 GWh and Oil with 788.5 GWh. The TFC in Norway for 2015 was 1753 GWh and the main used sources were: oil with around 673 GWh and electricity with 821 GWh.  The sectors with the higher contribution on the TFC were industry and transport that represent in the same time the sectors with the higher level of pollution because of the high dependence on fossil fuel, especially oil and oil products. (IEA, 2019b)

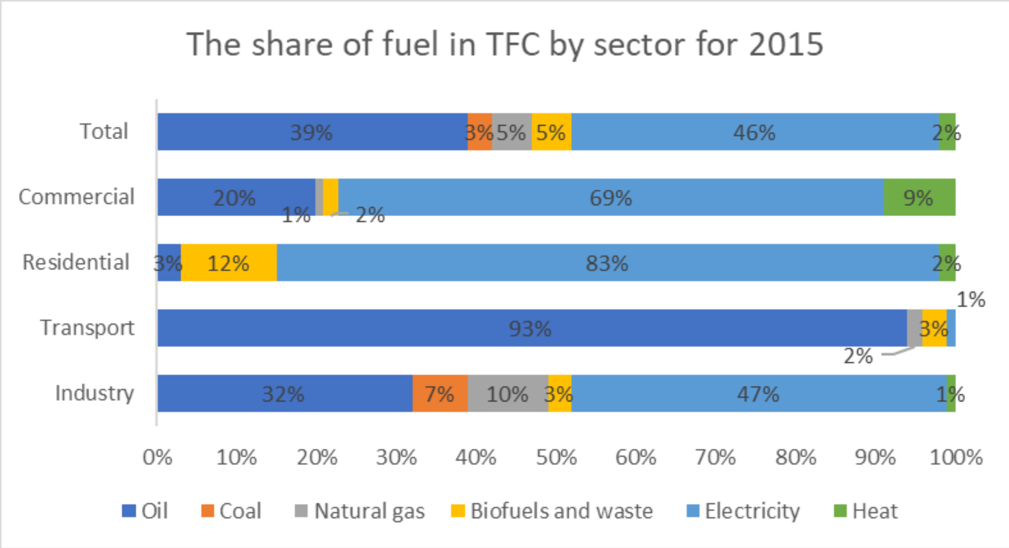



**Figure 3-4. The share of fuel in TFC by sector for 2015**

Source:(IEA, 2017)

As mentioned previously and as it can be seen in the figure above electricity and oil have the highest share in TFC in the Norwegian energy system. Oil covered 39% of TFC in 2015 and the sectors with the largest share of oil on their TFC were transport, industry, and commercial respectively with 93, 32 and 20%. Electricity has been historically and was even for 2015 the dominant energy source with 46% in TFC. Electricity covered the majority of TFC in commercial, residential and industrial sectors. An inclining tendency of electricity use in transport is noticed in recent years with the efforts done towards the electrification of this sector with the supportive scheme for EV and the increase in electricity use in railway transport. (IEA, 2017)

A more detailed overview of the power system and the industry of gas and oil will be given in the following sections.

Norway has developed a strong power system that relies on renewable energy, with a high percentage of hydropower that is supported by a large number of water reservoirs across the country. As a consequence, the amount of electricity generated varies from year to year. The capacity of the cross-border transmission lines is the key for the operation with efficiency and the security of the power system. Between 1998 and 2013 the annual average amount of electricity produced in Norway has been 135 TWh. (Rindal et al., 2016)

The annual production of electricity in 2018 was 141 TWh and the installed capacity was 33755 MW. In the total annual production of electricity for 2018 hydropower covers, 94.3% of the production with 1609 hydro powerplants and wind turbines in the 33 wind farms over the country cover 3.4% of the total production. In Norway, there are more than 1000 storage reservoirs that have a total capacity of 86.5 TWh that corresponds with 70% of the total electricity consumption in a year. (Norwegian Ministry of Pertoleum and Energy, 2019)

The production of electricity consumption is higher during the wintertime because of the high demand for heating due to very low temperatures. The production during this time is highly dependent on water storage because of the low water flow. The price of electricity during this period is higher. The production in hydropower plants changes with the change of the water flow, and during the spring and summertime the production of electricity increase while the opposite happens with the electricity demand that decreases with the decrease in the household sector.

The potential of wind power is very high, but this resource is exploited at a very small scale. The total installed capacity of wind power was 1188 MW at the end of 2017 and new wind farms with an approximate production of 5.4 TWh were under construction. The security of the power system and sustainability have had an inclining trend in the recent year and the investments on wind power have had a great impact on these changes. (Norwegian Ministry of Pertoleum and Energy, 2019)

On the other hand, with the increase of the installed power capacity, some new challenges show up. If the production will grow, what to do with the amount of electricity that remains after covering the domestic electricity demand of the country?

Some potential options that answer that question are:

- To increase the domestic electricity demand
    - Electrification of transport (10 TWh)
    - Electrification of offshore oil and gas industry (20 TWh)
    - To encourage the development of more power-hungry industries
- To grow the power export in Europe
- To use electricity for hydrogen production. (Svendsen, 2015)

For 2015 the total production of electricity was 141590 GWh. The main production was given by hydropower with 138450 GWh and wind 2515 GWh. (SSB, 2019) The total final consumption of electricity for the same year was 122 TWh. The difference between the total production and TFC of electricity represents the own consumption of the power stations, pump storage consumption and the loses in the distribution and transmission grid. In figure 3-5 is given the electricity generation by sources and the consumption by sectors.

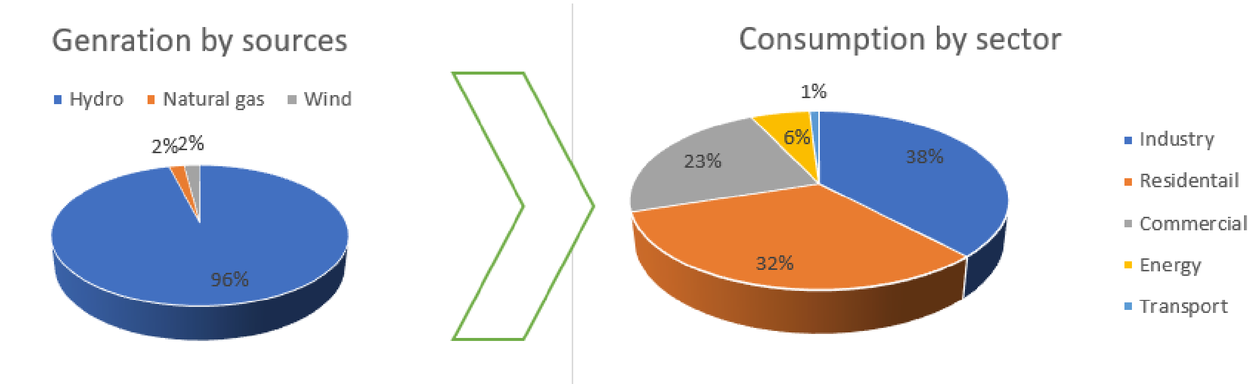



**Figure 3-5. Generation by sources and consumption by sectors in 2015**

Source: (IEA, 2019b)

As can be seen from the in figure 3-5 in 2015 the electricity was produced 96% by hydropower. The contribute of wind and natural gas was very modest, but what is important to underline is the fact that the production by wind power is having an increasing trend in the recent years and the installed capacity of wind power is grown from year to year. In 1990 the generation of electricity by wind power was zero and it reached the maximal level in 2015 with 2515 GWh. From 2010 till 2015 it has been a golden period for wind power where the generation grows with three times. (IEA, 2019b)

Electricity is the most important energy source in every except for transport. The sectors with higher electricity consumption in Norway are industry, residential and commercial. For 2015 the share of electricity consumption is higher in the industrial sector with 46.5 TWh, followed by residential and commercial respectively with 39 TWh and 28 TWh. The share of electricity consumption in the transport sector is very modest, it represents only 1% (1 TWh) of TFC in 2015, but the increase of the number of electric vehicles and with the electrification of the railway transport the trend of electricity use in this sector is growing. (IEA, 2019b)

The data for electricity production, import, export, and consumption are published monthly at Statistic Norway. In the table below is the summary of some of the most important indicators for 2018 that come as a result of information processing from the monthly values published in SSB for this year.

**Table 3-1. Yearly electricity production, Import, Export, Gross and Net electricity consumption for 2018 (in TWh)**

| **Electricity production** | | | **Import** | **Export** | **Gross electricity consumption** | **Net electricity consumption** |
|---|---|---|---|---|---|---|
| Hydro power | Thermal Power | Wind power | | | | |
| 139.51 | 3.46 | 3.88 | 8.34 | 18.49 | 136.7 | 126.06 |

Source: (SSB, 2019)

### 3.1.1 Oil and gas industry

The sector of oil and gas is the sector which gives the higher revenue and the main pillar of the Norwegian economy. The Norwegian exports of gas and oil are among the highest in the world. Norway is the third country in the world for the export of gas and the tenth for oil exports. The export of gas and oil for 2015 were respectively 114.7 bcm (billion cubic meters) and 12 Mt. Since 2005 the export of oil has decreased with 42.4% while the opposite has happened with gas that has increased with 39%. For 2015 oil and gas contributed with 36.8 and 18.2% of TPES. The consumption of oil was around 127 TWh and the share was higher in transport and industry with 52.6 and 30.6%. The consumption of gas was around 63 TWh from which 74.8% was used by energy industries.(IEA, 2017)

In the figure 3-6 is given TFC of oil by products and by sectors. As it can be seen the product with the highest share in TFC is gas/diesel with 68% and the sector that covers the higher share is transport with 57%. In the transport sector that is divided into road, domestic navigation and domestic aviation. The road transport covers 44% of the TFC.

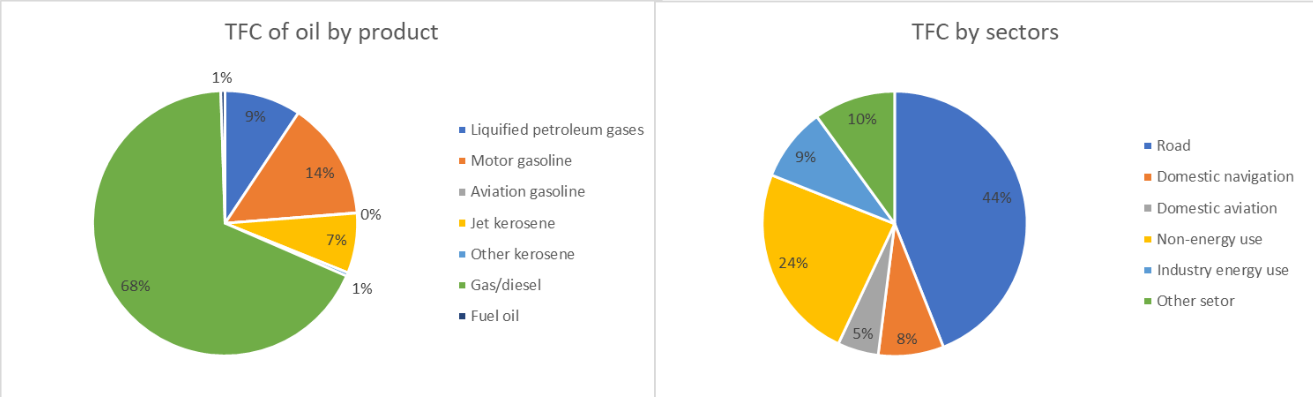



**Figure 3-6. TFC of oil by product and sectors for 2015**

Source: (SSB, 2019)

## 3.2 Greenhouse gas emissions

In Norway as well as in worldwide total greenhouse gas emissions, $CO_2$ is the gas that accounts the higher amount of GHG. In 2018 the amount of GHG emissions emitted in Norway was 52.9 $MtCO_2$-eq (million tonnes of carbon dioxide equivalent) from which 83% were $CO_2$ emissions. Carbon dioxide emissions have been growing between 1990 and 2018 with around 20%. In 2018 the emissions from oil extraction were 14.5 $MtCO_2$-eq that is equal with 27.5% of the total emissions. The transport sector has the highest amount of emissions released in 2018, with 16.5 $MtCO_2$-eq from which 9 $MtCO_2$-eq are emitted by road traffic and 7.5 $MtCO_2$-eq from aviation, navigation, fishing, and motor equipment. (SSB, 2019)

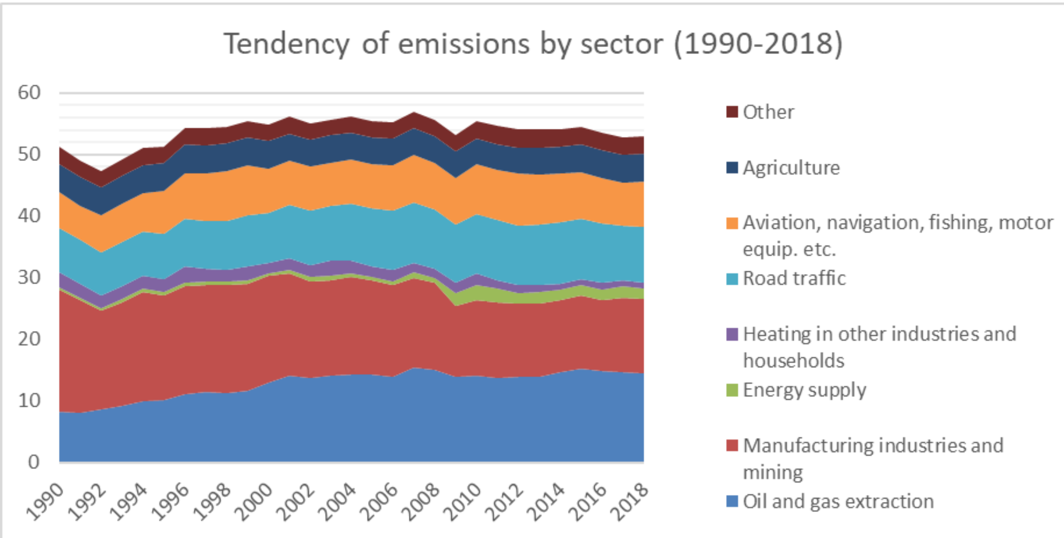



**Figure 3-7. The tendency of greenhouse gas emissions by sector (1990-2018)**

Source: (SSB, 2019)

Between 1990 and 2018 the amount of greenhouse gas emissions emitted to air in the Norwegian territory increased by 3.4%. This results from the increase and decrease of the total emissions from different sector. The most significant changes have happened in the sector of oil and gas extraction that experienced an increase with 75.6% since 1990. Driven by the increase of the oil and gas for the domestic needs and export purpose. The transport sector has had a significant increase in emissions emitted from 1990. This is caused by the increase in the number of vehicles and the increase in the volume of transport that comes both from the increase of welfare and the growing number of the population. This sector is represented by road traffic and aviation, navigation, fishing and motor equipment that had respectively 25.8 and 29% increase compared with 1990 levels.

Oil has been and remains the major contributor in the total CO2 emissions by fuel combustion, but from 1971 where emissions emitted by oil combustion covered 83% of the total emissions from fuel combustion in 2016 this percentage was 53%. This change was influenced by the increase of the consumption of natural gas, and consequently, its contribution to emission production. From zero in 1971 the share of CO2 emissions emitted by the combustion of natural gas in Norway reached the level of 35% in 2016. The full data for CO2 emission trends by fuel is given in figure 3-8.

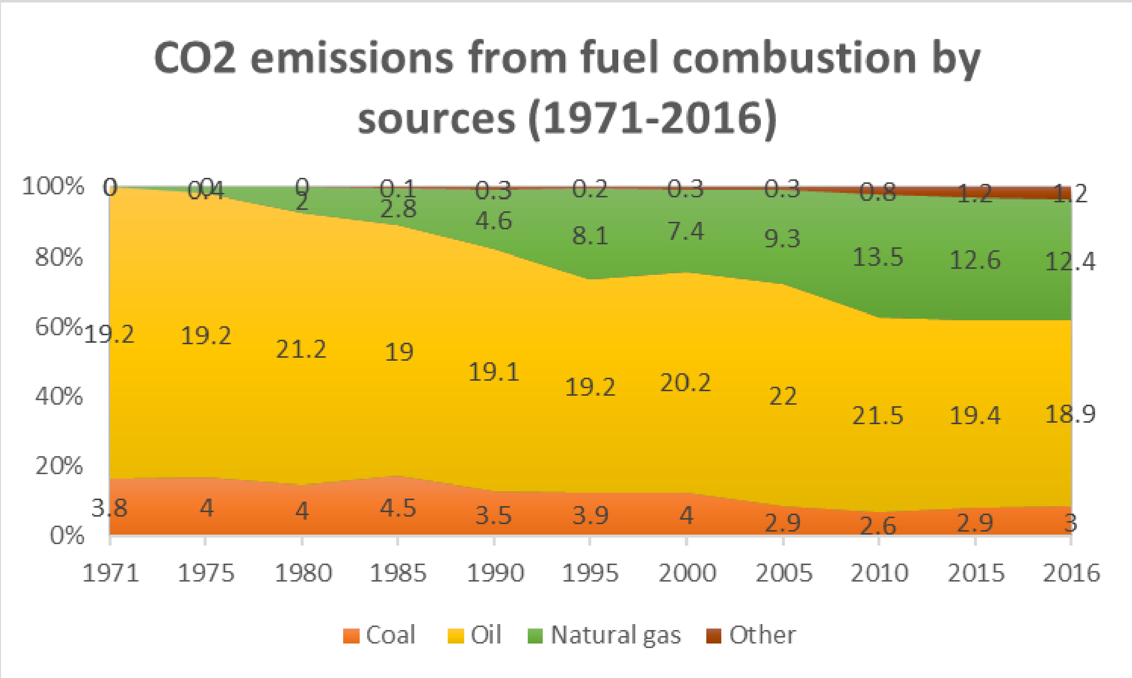



**Figure 3-8. $CO_2$ emissions from fuel combustion by sources in Norway (1971-2016)**

Source: (International Energy Agency, 2018a)

The Norwegian targets on emission reduction under the Paris Agreement are very ambitious. The reduction of emissions will be accomplished by the combination of domestic emission reduction and by EU Emissions Trading Scheme (EU-ETS), their contribution that the Norwegian energy gives in the emission reduction of other countries. The target for 2020 is the reduction with 30% below 1990 levels and for 2030 the target is to archive 40% below 1990 levels. The EU-ETS and CO2 tax cover around 80% of the total amount of greenhouse gas emission of the country. The electrification of the transport system and the increase of renewables in this sector are seen as one of the greatest potentials for the emission reduction in the future.(IEA, 2017)

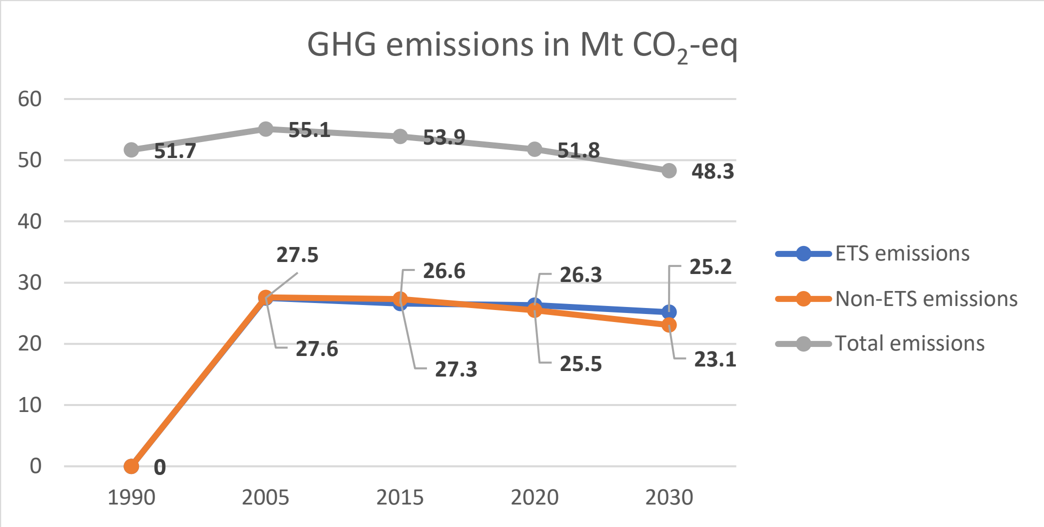



**Figure 3-9. The tendency and future projections for ETS and non-ETS emissions in Norway**

Source: (DET KONGELIGE KLIMA-OG MILJØDEPARTEMENT, 2017)

The level of GHG emissions in 2015 was 53.9 Mt CO2-eq from which 27.3 Mt CO2-eq were not included in ETS. The projections for the future predict the reduction of emissions with 0.75% per year between 2015 and 2030. In amount, the decrease in emissions during this period is expected to be 5.5 Mt CO2-eq. From these 5.5 Mt CO2-eq, the major contribution is expected to come from non-ETC emission reduction, with 4.25 Mt CO2-eq. The emission reduction until 2030 is estimated to be 1.9 Mt CO2-eq, and this is assumed to be only the first phase of the increasing number of low and emission-free vehicles. (DET KONGELIGE KLIMA-OG MILJØDEPARTEMENT, 2017)

# 4 Transport sector in Norway

The transport sector is globally one of the main consumers of energy and main contributors to air pollution. With the increase of welfare level, the number of vehicles and transport volume increases and so do the energy consumption and GHG emissions. The development of the economy has both positive and negative effects. From the other side, economic development gives more founds for technological innovations. The increase in transport volumes and the number of vehicles is at the same time predictable and inevitable.

The population growth is one of the main factors that together with the economic growth have contributed to the development of the transport sector. Since the population growth is hard to keep under control the answer towards the increase of energy consumption and emission release is the increase of the share of renewable sources in this sector. The option that is having more incentives in Norway is the increase in electricity use in transport. The electrification of transport would decrease the usage of fossil fuels in the national level and would reduce significant amounts of greenhouse gas emissions, because of the high efficiency of the electric motor and the generation of electricity almost hundred percent with renewable sources.

## 4.1 The Norwegian transport infrastructure

Norway has a very special transport infrastructure with a high number of airports, seaports and fishing ports. The large distances between cities make air transport preferable even for domestic travel. Due to the geographical aspects, the sea transport for passengers and goods is very high in domestic and national level. Regardless of what said above road transportation remains the most important and the one with the higher energy consumption and GHG emission release.

The transport infrastructure in 2016 had this situation:

- 94600 km public roads of which:
    - 10700 km national roads
    - 44500 km country roads
    - 39400 km local roads
- More than 1100 road tunnels
- 4208 km railway network of which
    - 2459 km electrified
    - 269 km double track
- 49 airports
- 32 seaports connected with the national grid transport
- 700 fishing ports (Norwegian Ministry of Transport and Communications, 2017a)

The map of the Norwegian national infrastructure that shows the road, railway, maritime, and road-ferry network as well as the location of ports, railway terminal/station, and airports, is given in figure 4-1.

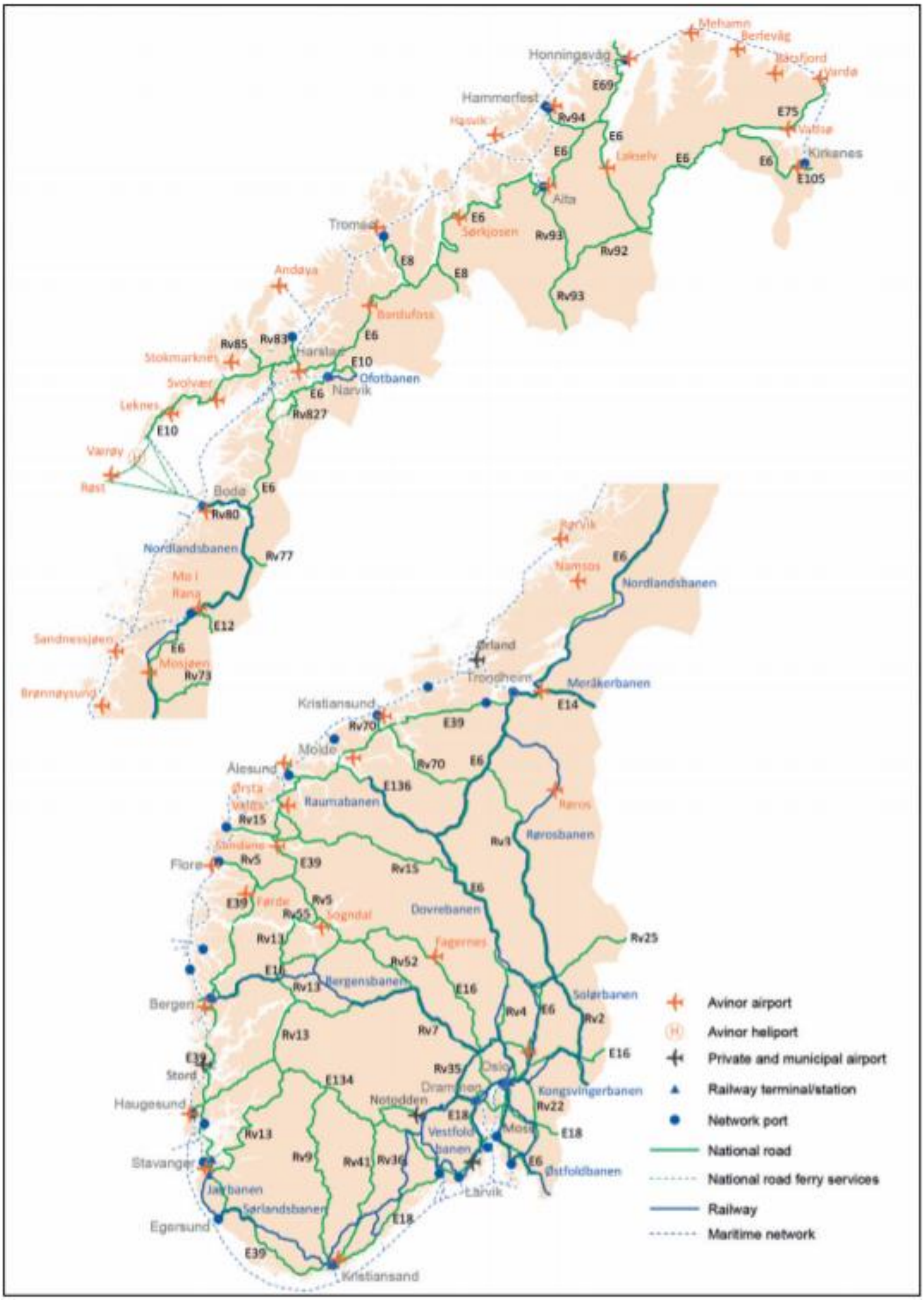



**Figure 4-1. The map of the Norwegian infrastructure**

Source:(Norwegian Ministry of Transport and Communications, 2017b)

The total final consumption of energy in the Norwegian territory for 2018 was 244 TWh. The share of energy consumed by the transport sector was around 22%. It has a slight decrease with 0.8 % from the previous year. TFC form transport sector in 2018 was 53.68 TWh. In figure 4-2 is given the share on energy consumption by the transport sector in TFC (left) and the share of energy products for 2018. Oil and oil products are the sources with the highest distribution on the total consumption in the transport sector, it covered 88% of the total energy consumption by this sector. After oil and oil products that led with 47.2 TWh come biofuels, natural gas, and electricity with 4.5 TWh, 1.2 TWh and 0.6 TWh each. (SSB, 2019)

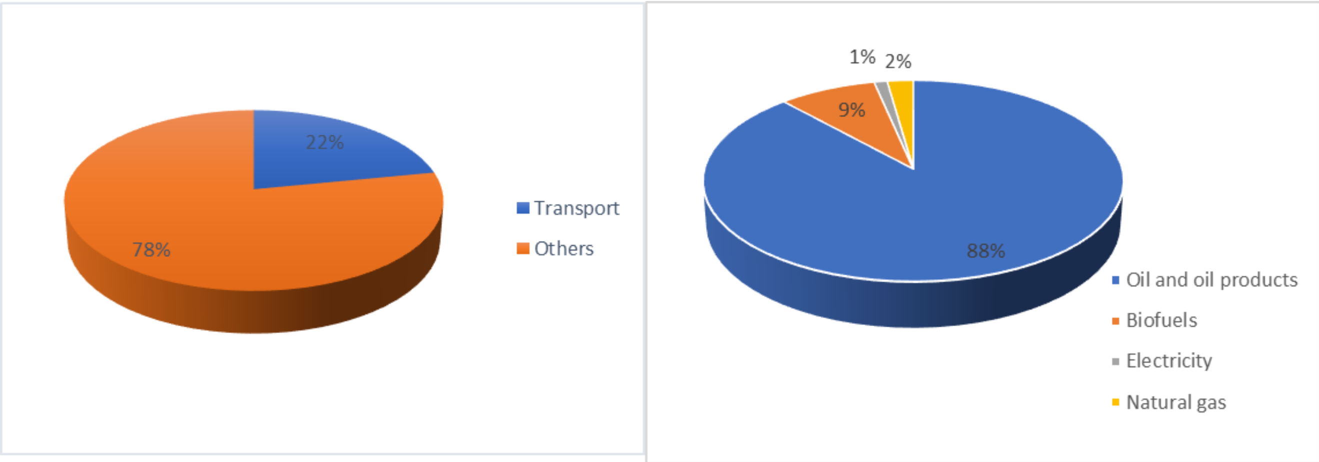



**Figure 4-2. The share of energy consumption by transport in TFC and the share of TFC from transport by energy products for 2018**

Source: Data available at (SSB, 2019)

The total final energy consumption has been increasing continuously. Between 1973 and 2016 the increase of TFC was around 43%. The tendency of TFC by transport sector has had also growing tendency during this period of time but the growth rates are different. Between 1973 and 2016 TFC by transport sector grow with 63% and reached the level of 55 TWh.

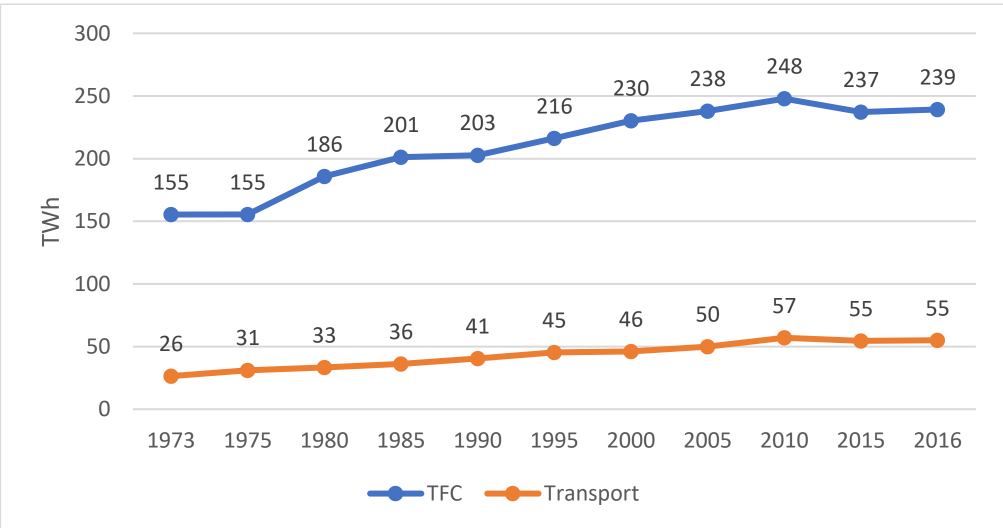



**Figure 4-3. The progress of TFC and energy consumption by transport sector (1973-2016)**

Source: Data available at (IEA, 2019a)

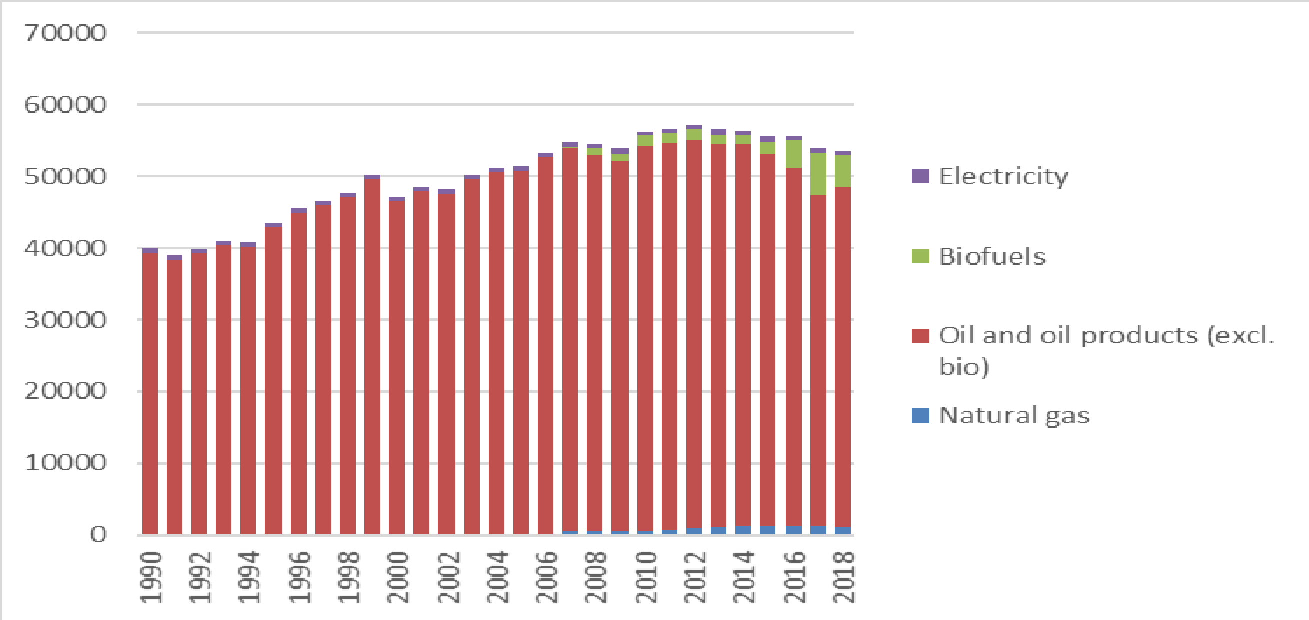



**Figure 4-4. Energy consumption from the transport sector by energy sources (1990-2018)**

Source: Data available at (SSB, 2019)

In recent years, the usage of biofuel and natural gas in the transport sector has been increasing in significant amounts. In 2018 the consumption of natural gas and biofuels by transport sector was 1189 GWh equivalent with 2.22% of the total consumption by transport, and 4471 GWh, equivalent with 8.36% of the total consumption by transport (SSB, 2019). While the process of electrification started very early in Norway the progress has not been very satisfactory so far. The usage of electricity remains in low amount even though the number of journeys made by electric trains has increased from 115 million in 1990 to 225 in 2017 the electricity consumption decreased from 640 GWh to 632 GWh, equivalent with 1.25 % decrease (Norwegian Ministry of Pertoleum and Energy, 2019). The decrease in electricity is an indicator of significant progress on energy efficiency.

In figure 4-5 is given the progress in the share of renewable energy sources in the transport sector during the period 2005-2016 for EU-28 and Norway. Since 2005 the share of renewable energy sources in transport in EU-28 rose three times while in Norway it rose with around six times. The increase in RES share in transport has quickened in recent years in Norway. Between 2014 and 2016 it doubled, these changes are driven by the rapid expansion of the EV in the Norwegian market. From 3.1 percent that the share of RES was in Norway in 2005 in 2016, it rose to 17%, while in EU-28 from 1.8 percent it reached 7.1 percent. (European Union, 2018)

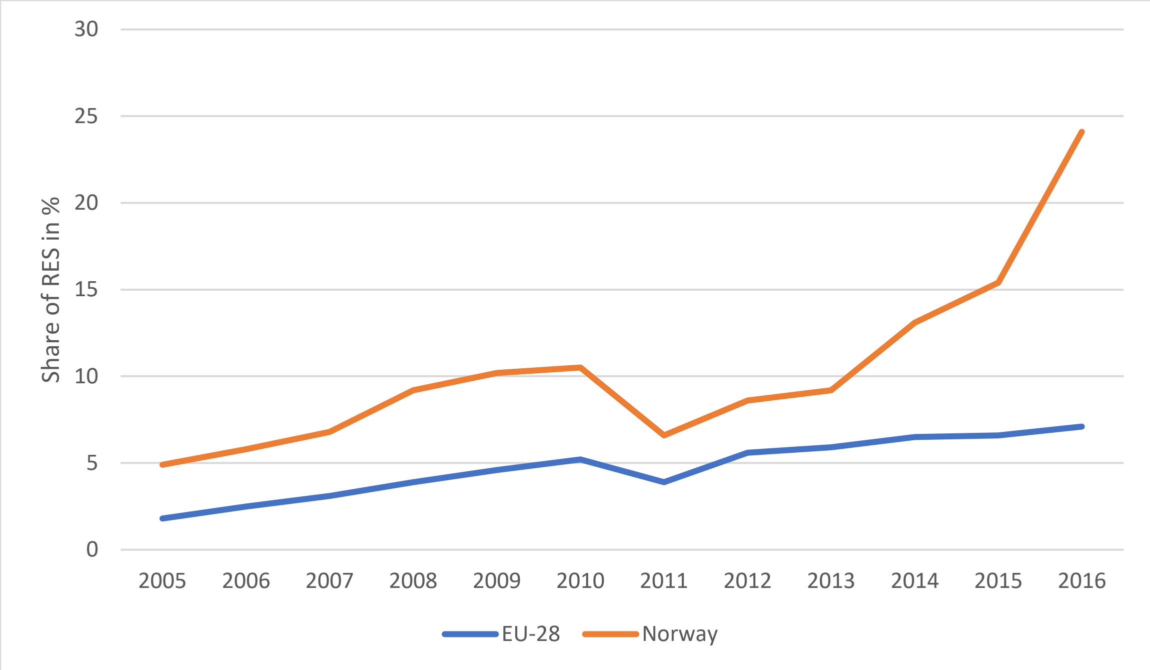



**Figure 4-5. The progress of RES share in the transport sector in EU-28 and Norway (2005-2016)**

Source: Data available at (European Union, 2018)

The total consumption of energy by transport sector for 2015 was around 55.5 TWh (SSB, 2019) from which 69% was consumed by road transport, car transport for passengers covered 36% (around 20 TWh) and road freight 33% (around 18 TWh) (ODYSSEE-MURE, 2019). The remaining part was covered by air and water transport.

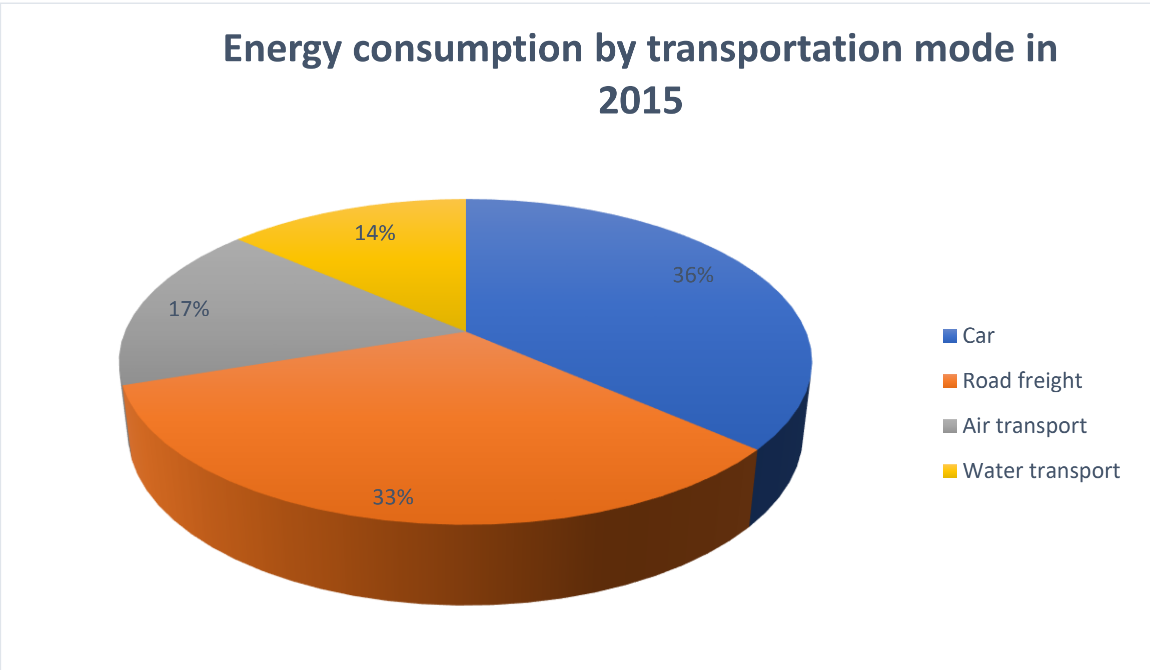



**Figure 4-6. Energy consumption by transportation mode for 2015**

Source: Data available at (ODYSSEE-MURE, 2019)

The total consumption of energy by transport sector for 2015 was around 55.5 TWh (SSB, 2019) from which 69% was consumed by road transport, car transport for passengers covered 36% (around 20 TWh) and road freight 33% (around 18 TWh) (ODYSSEE-MURE, 2019). The remaining part was covered by air and water transport.

To sum up, the energy consumption by the transport sector in Norway has been increasing over the years. Oil and oil products are the main energy source used by this sector and road transport for passenger and goods covers around 70% of the energy used by the transport sector in 2015. While energy consumption is very high, differently from the other sectors in the Norwegian energy system, the transport sector is the sector with the lowest share of renewable energy. The efforts to increase the share of RES in this sector have started with electrification in the railway network but the tendency of the electricity use has been declining because of the improvements in energy efficiency. Norway aims to electrify not only public transport but private transport too. Several supportive policies are taken to reach this aim. In the following section will be given an overview of these policies over the years.

## 4.2 GHG emissions

The amount of total GHG emissions released in the Norwegian territory in 2015 was 53.9 million tonnes $CO_2$-eq. From 1990 the amount of GHG emissions grow with 4.2 percent that is equivalent with approximately 2.2 million tonnes of $CO_2$-eq. From 1990 emissions has been inclining to reach the peak value at 56.8 million tonnes of $CO_2$-eq in 2007. After 2007 the tendency of emission has had a slight decrease. (Norwegian Environment Agency et al., 2017)

The net emissions have had a significant decrease between 1990 and 2015 where the amount decreased from 41.3 million tonnes of $CO_2$-eq to 29.6 million tonnes of $CO_2$-eq. In 2009 net emissions were 24.2 million tonnes of $CO_2$-eq that is the lower value reached between 1990 and 2015. Thanks to the great contributions of LULUCF (Land Use, Land-Use Change, and Forestry)[1] in emission removal, the amount of net emissions has had a significant reduction with around 28% during this period of time. (Norwegian Environment Agency et al., 2017)

Energy emissions have had a different trend from net emissions. Since 1990 Norway has experienced great economic growth that has resulted in inclining emissions trend in the total amount and the amount of energy-related emissions. The energy emissions increased with around 30% between 1990 and 2015, and the greater contribute was by industry and transport that are the main fossil fuel consumers in Norway.

Transport sector gives a great contribution to the total energy-related emissions. In 2015 the emissions emitted by transport sector were 33.4% of the total energy-related emission. Emissions from the transport sector have increased with around 28% from 1990 to 2015 and their share grows with 4.7%, from 19.8% to 24.5% of the total energy emissions. Road transport gives the outweigh amount of emissions emitted by the transport sector. In 2015 road transport contributed with 77.8 percent of the total emissions by the transport sector, that is equal with 19.1 percent of the total emissions released in the Norwegian territory. Between 2007 and 2010 the amount of emissions by road transport has slightly downward due to the switch from petrol to diesel driven by

[1] The emissions and removals of $CO_2$ from land and forests are measured separated by fusil fuels.

the implementation of a new CO2 tax in 2007.(Norwegian Environment Agency et al., 2017)

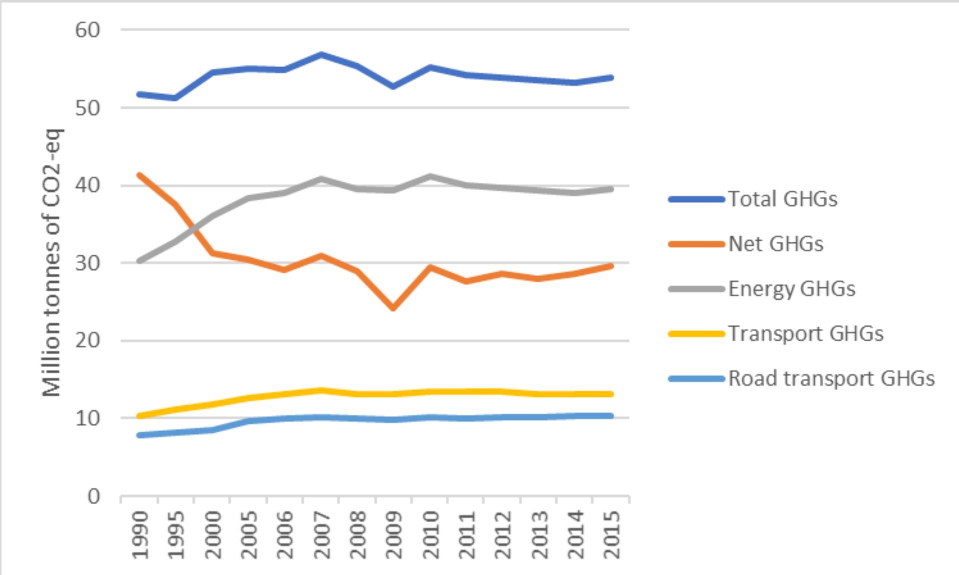



**Figure 4-7. The progress of GHG emissions in Norway (1990-2015)**

Source: Data available at (Norwegian Environment Agency et al., 2017)

### 4.2.1 Emissions from road transport

Road transport gives the outweigh amount of emissions emitted by the transport sector. In 2015 road transport contributed with 77.8 percent of the total emissions by the transport sector, that is equal with 19.1 percent of the total emissions released in the Norwegian territory. Road traffic contributed with 32.1 percent in the total amount of $CO_2$ emissions and 2.8 percent of the total $N_2O$ emissions in 2015. The overall growth of emissions between 1990 and 2015 in road transportation was 32.5%. (Norwegian Environment Agency et al., 2017)

Due to the generation of electricity almost one hundred percent by renewable sources, mainly hydropower, the Norwegian $CO_2$ emissions have two important sources:

- Road traffic that in 2015 contributed by 22.8% of the total $CO_2$ emissions
- Oil and gas industry that in 2015 contributed with 32.1% of the total $CO_2$ emissions (Norwegian Environment Agency et al., 2017)

$CO_2$ emission is the dominant contributor to the total greenhouse gas emissions. In 2015 the amount of $CO_2$ emissions covered 82.9% of the total national emissions in Norway followed by $CH_4$ with 9.6%, $N_2O$ with 4.9% and fluorocarbons [2] with 2.7%. In figure 4-8 is shown the progress of $CO_2$ emissions in the Norwegian territory during the period 1990-2015. Road transport $CO_2$ emissions during this period of time increased with around 33.5 percent. Meanwhile, the total amount of $CO_2$ emissions increased more slowly, the overall growth of $CO_2$ emissions from 1990 till 2015 was around 25%. (Norwegian Environment Agency et al., 2017)

[2] Fluorocarbons or fluorinated gases are PFCs, SF6, and HFCs gases.

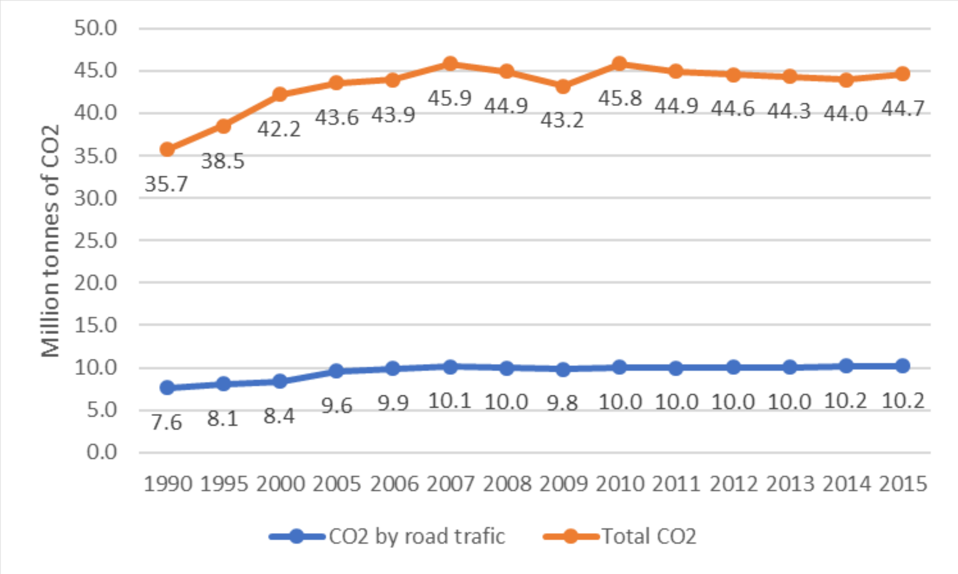



**Figure 4-8. The progress of the total CO2 emissions and CO2 by road traffic**

Source: Data available at (Norwegian Environment Agency et al., 2017)

In figure 4-8 is showed the progress of the road traffic volumes from passenger cars by fuels during the period 2005-2018. Passenger cars that use petrol dominate the traffic volumes with great advantage in 2005. The road traffic volume from passenger cars that use petrol has been declining since 2005 while the opposite has happened with diesel passenger cars the volume of which has been inclining. Only in 2018, the traffic volume of diesel passenger vehicles has declined slightly, while the total volume of kilometers by passenger cars has increased. This has happened due to the rapid increase of the volume from electric passenger vehicles.

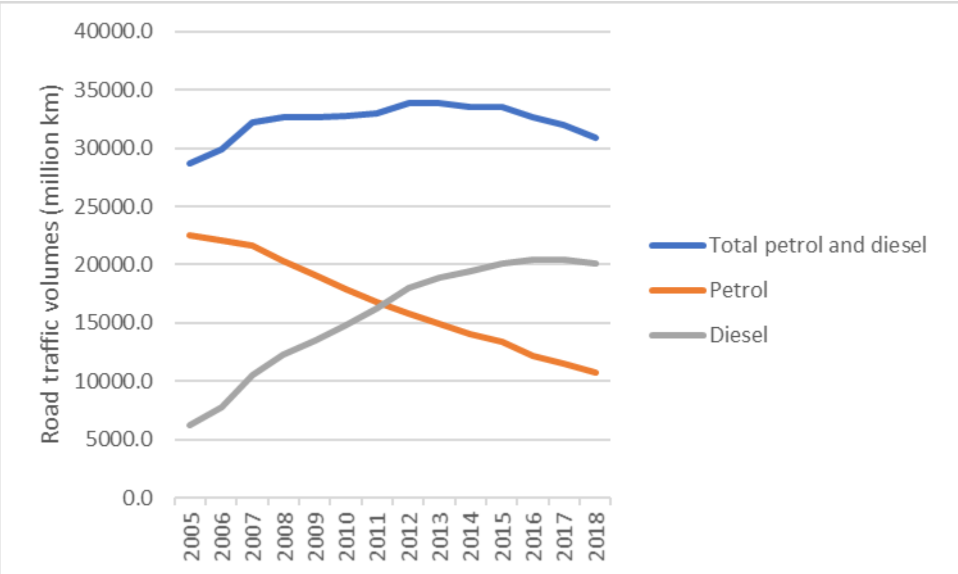



**Figure 4-9. The progress of road traffic volumes in Norway (2005-2018)**

Source: Data available at (SSB, 2019)

Since 2005 the $CO_2$ emissions from diesel and petrol passenger cars has decreased with one percent while the total road traffic volumes by the same type of passenger cars has increased with around 17 percent (Norwegian Environment Agency et al., 2017). The different trends on traffic volume and $CO_2$ emissions are driven by the use of more fuel-efficient passenger cars, by the increase of the number of diesel passenger cars and the decrease of the number of petrol passenger cars. The road traffic volume of petrol passenger cars during the period 2005-2015 decreased with around 46% meanwhile the road traffic volume of diesel passenger cars rose with more than three times the amount of 2005 (SSB, 2019).

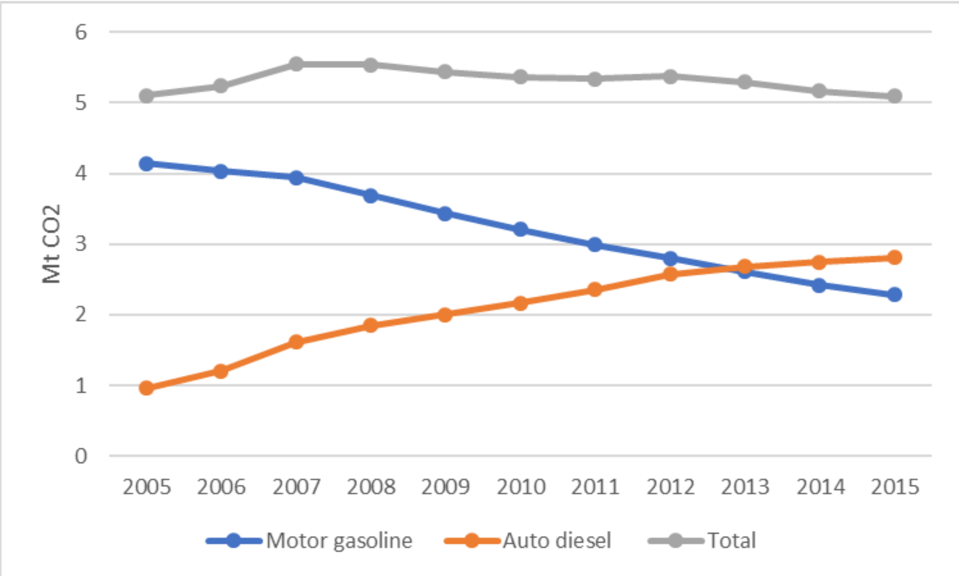



**Figure 4-10. CO2 emission progress by motor gasoline and auto diesel (2005-2015)**

Source: Data available at (Norwegian Environment Agency et al., 2017) and (SSB, 2019)

### 4.2.2 The emission from ICE (internal combustion engine)

ICE (Internal Combustion engine) is the most widespread type of heat engines and it works on the principle of the ideal gas law [3]. ICEs are used in all types means of air, sea and road transportation such as vehicles, ships, airplanes, boats, and trains. The name of ICE comes from the fact that the fuel combustion does work inside the engine. After the combustion process, the mixed composition of air and fuel is emitted in the environment as exhaust. (Janson et al., 2018)

ICE has two main parts that are a fixed cylinder and a moving piston. The two main types of ICE in production are: the spark ignition gasoline and the compression ignition diesel engine. Both types are mainly four-stroke cycle engines. The difference between the engines stands in the way the fuel is supplied and ignited. In the diesel engine, the fuel and air are mixed together and enter the cylinder during the intake process. This mixed fuel-air composition after is compressed by the piston and in the end ignited from a spark by causing the combustion. The piston is pushed by the expansion of the combustion gases. In the compression ignition diesel engine, the air is inducted and

[3] Ideal Gas Law is expressed with the equation $PV= nRT$

compressed in the cylinder. The fuel is sprayed at a measured rate into the hot air by causing the combustion. (Energy Efficiency & Renwable Energy, 2013 )

The air pollution by transport means is divided into:

- primary pollution is the pollution emitted directly into the atmosphere
- Secondary pollution that comes because of chemical reactions between different pollutants in the atmosphere.

The main pollutants emitted by ICE are:

1. Particulate matter (PM) is a serious threat for human health because it can penetrate in the lungs through the respiratory process. it can be both primary and secondary pollutant, and the highest amount of it comes by diesel exhaust.
2. Volatile Organic Compounds (VOCs) cause the formation of ground-level ozone when in the presence of the sunlight react with nitrogen oxides. VOCs include toxic air pollutants such as benzene, acetaldehyde, and 1.3-butadiene that are related to several types of cancer.
3. Nitrogen oxides (NOx) can cause both primary and secondary pollution. It contributes to the formation of the ground-level ozone and PM (secondary pollution). NOx is harmful to human health because they irritate the lungs and increase the body's defense from against the infections of the respiratory system. (pneumonia and influenza).
4. Carbon monoxide (CO) is a poisonous gas formed by fossil fuel (gasoline) combustion. The inhale of this gas blocks the oxygen circulation from the brain, heart, and other organs.
5. Sulfur dioxide ($SO_2$) is formed by the combustion of fossil fuels that content sulfur (ex. diesel). The reaction of sulfur dioxide in the atmosphere can form fine particles. It is a great health risk for children and asthmatics.
6. Greenhouse gases (GHGs) emitted by the combustion process of fossil fuels in the ICE. The predominant greenhouse gas is carbon dioxide that from the other hand is the main contributor in the global climate change. (USCUSA, 2018 )

One of the main priorities of the European Commission is the protection of air quality and the decrease of GHGs. The exhaust emission standards in the automotive sector were introduced for the first time in 1970 for the category of passenger cars. In 1992 in the standard "Euro 1" was introduced the new invent for the reduction of carbon monoxide (CO) emissions that was the fitting of catalytic converters for petrol vehicles. The latest standard is "Euro 6" that reduces the limits of some pollutants with 96% of the 1992 limits. The full list of Euro standards is given in the tables below for both petrol and diesel cars. In EURO 1 the emission limits are the same for petrol and diesel the only difference is that diesel cars have a limit on PM while petrol cars do not have a limit on PM. From EURO 2 onwards the emission limits for petrol and diesel were different.

The Euro emission standard for both diesel and petrol vehicles can be seen in figure 4-11

| Stage | Date | CO | HC | HC+ NOx | NOx | PM | Stage | Date | CO | HC | HC+ NOx | NOx | PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Compression Ignition (Diesel)** | | | | | | | **Positive Ignition (Petrol)** | | | | | | |
| Euro 1† | Jul 1992 | 1.0 | - | 0.97 (1.13) | - | 0.14 (0.18) | Euro 1† | Jul 1992 | 2.2 | - | 0.97 (1.13) | - | - |
| Euro 2, IDI | Jan 1996 | 1.0 | - | 0.7 | - | 0.08 | Euro 2 | Jan 1996 | 2.3 | 0.20 | 0.5 | - | - |
| Euro 2, DI | Jan 1996[a] | 0.64 | - | 0.9 | - | 0.10 | | | | | | | |
| Euro 3 | Jan 2000 | 0.50 | - | 0.56 | 0.50 | 0.05 | Euro 3 | Jan 2000 | 1.0 | 0.10 | - | 0.15 | - |
| Euro 4 | Jan 2005 | 0.50 | - | 0.30 | 0.25 | 0.025 | Euro 4 | Jan 2005 | 1.0 | 0.10[d] | - | 0.08 | - |
| Euro 5a | Sept 2009[b] | 0.50 | - | 0.23 | 0.18 | 0.005[f] | Euro 5 | Sept 2009[b] | 1.0 | 0.10[d] | - | 0.06 | 0.005[e,f] |
| Euro 5b | Sept 2011[c] | 0.50 | - | 0.23 | 0.18 | 0.005[f] | | | | | | | |
| Euro 6 | Sept 2014 | 0.5 | | 0.17 | 0.08 | 0.005[f] | Euro 6 | Sept 2014 | 1.0 | 0.10[d] | - | 0.06 | 0.005[e,f] |

* At the Euro 1..-4 stages, passenger vehicles > 2,500 kg were type approved as Category N1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×1012 1/km within first three years from Euro 6 effective dates

**Figure 4-11. EURO emissions standard for petrol and diesel passenger cars**

Source: (European Parliament, 2016 )

## 4.3 Current energy policies and future plans

The Norwegian government has set very ambitious short, mid and long-term targets on emission reduction. The current objectives of the climate policy in Norway are:

- ✓ To overcome the Kyoto commitment with ten percent at the end of the first period.
- ✓ To reduce with 30 percent under 1990 level the greenhouse gases until 2030.
- ✓ To become a carbon-neutral society (CNS) by 2050.
- ✓ To become carbon neutral by 2030 as part of a potential global agreement with other developed countries. (Ministry of Climate and Environment, 2014a)

The fulfillment of these objectives can be achieved by reducing emissions from both the ETS and non-ETS sectors. The transport sector is the sector that accounts around one-third of the total emissions in Norway (Ministry of Climate and Environment, 2014b) and is part of the non-ETC sector. Transport is the sector with the highest potential emission reduction but at the same time, the traffic volume keeps increasing and is very difficult to be kept under control. Knowing that the tendency of traffic volume would have an inclining tendency for a long period the Norwegian government has approved several incentives to promote a potential shift towards a sustainable transport sector with a high share of RES and free from the fossil fuel dependence. Nowadays Norway is mentioned as a success story towards the zero-emission transport sector with 230000 battery electric cars (BEV) registered until May 2018 (Norsk elbilforening, 2018).

The supportive scheme for the promotion of emission-free vehicles in the Norwegian market has started in the early 1990s and is an on-going process that is driving the transition of the transport system from fossil fuel to renewable energy sources. In figure 4-12 are given in chronological order all the EV policies taken in Norway since the 1990s.

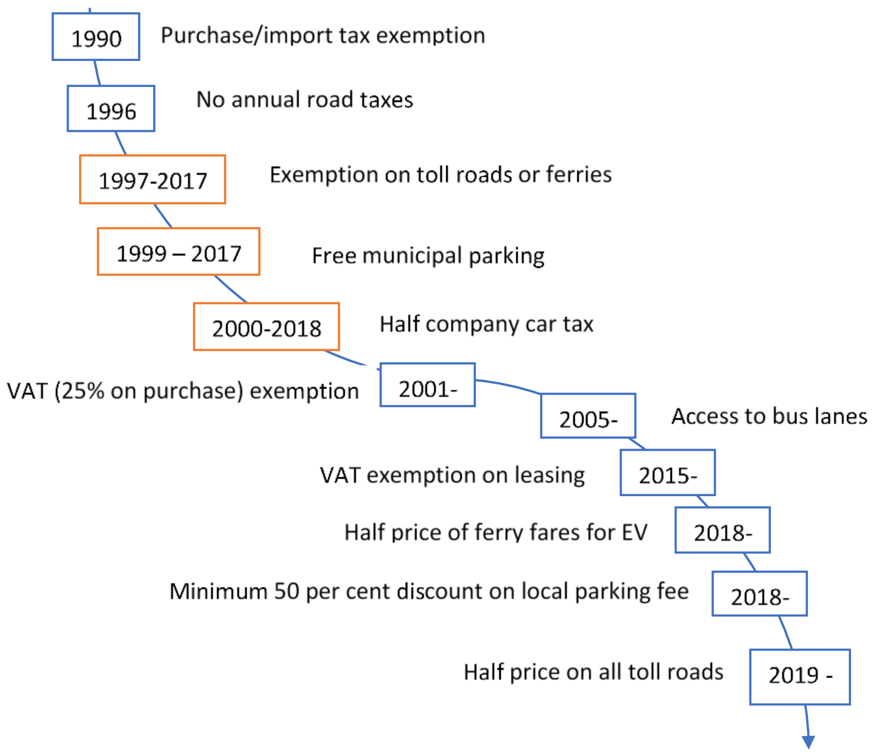



**Figure 4-12. Norwegian EV policy**

Source: (Norsk elbilforening, 2018)

With the incentives already implemented in the market, the targets for the transport sector are very ambitious. Part of the Norwegian national climate strategy are two targets for the expansion of low and zero-emission vehicles. These targets are:

- All the new passenger cars and urban buses bought must be BEV or FCEV by 2025
- All new vans, three-quarters of the new interurban buses, and fifty percent of the new trucks for good transportation must be BEV or FCEV by 2030. (Fridstrøm et al., 2018)

While EU has the target is to keep the average emission target 95 $gCO_2/km$ for the new cars (European Commision, 2019b), the Norwegian target is to keep this average in the level of 85 $gCO_2/km$ by 2020 (IEA, 2017).

The main strength of the Norwegian energy system is the free-emission electricity generation. The transport sector is the next sector that aims to have significant GHG emission reduction in the near future. The change has already started with ambitious targets on biofuels and the rapid increase in the number of EV. In March 2018, 37% of the total new vehicles in Norway were EV. The target of the Norwegian government on transport sector is to reduce the amount of emission emitted from this sector with fifty percent from 2005 to 2030. Figure 4-13 gives the historical emissions from transport between 2005 and 2015 and a sketch of the future emission reduction until 2030. (Hertzberg, 2019)

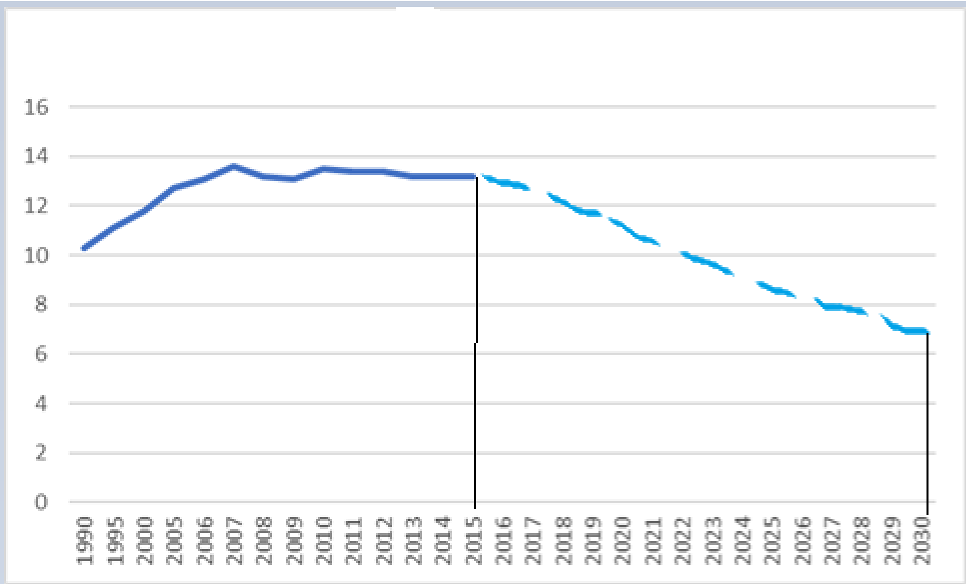



**Figure 4-13.The reduction of the transport emissions with 50% by 2030**

## 4.4 The expansion of EV in the Norwegian market

Due to the strong support that the Norwegian government has given to EV with all the policies that are mentioned in the section above, now for several years Norway is leading country in the deployment of EV in a global level. The incentives taken to support the EV expansion have made their price competitive with the prices of the normal cars.

In 2017 around 10 percent of the total passenger cars road traffic volume was covered by BEV and PHEV, by noting in this way an increase with 40 percent from the previous year. EV covered 4 percent of the total road traffic volume in 2017 from 3 percent that the driven distance by EV constituted in 2016. The growing number of kilometers driven by EV and other fuels power cars are causing the decrease of the driven kilometers by diesel- and petrol-powered cars. The decrease on the driving kilometers only by passenger cars was respectively 0.4 and 6 percent for both categories. (Statistics Norway, 2018b)

According to Statistics Norway the number of registered passengers EV in the beginning of 2019 was 195351 and it is 40.6 percent higher than the previous year. Since 2013 the number of EV increased with 999.3 percent. (SSB, 2019) Oslo is the city with the highest number of passengers EV in Norway. In 2017 the number of registered passengers EV in Oslo was around 50 percent higher than ne previous year and for every 1 000 inhabitants there were 37 electric cars in Oslo. The stock of passenger EV in the biggest cities in Norway was leaded by Oslo like mentioned above with 24 808 followed by Bergen with 12 782 and Bærum with 10 950 cars. (Statistics Norway, 2018a)

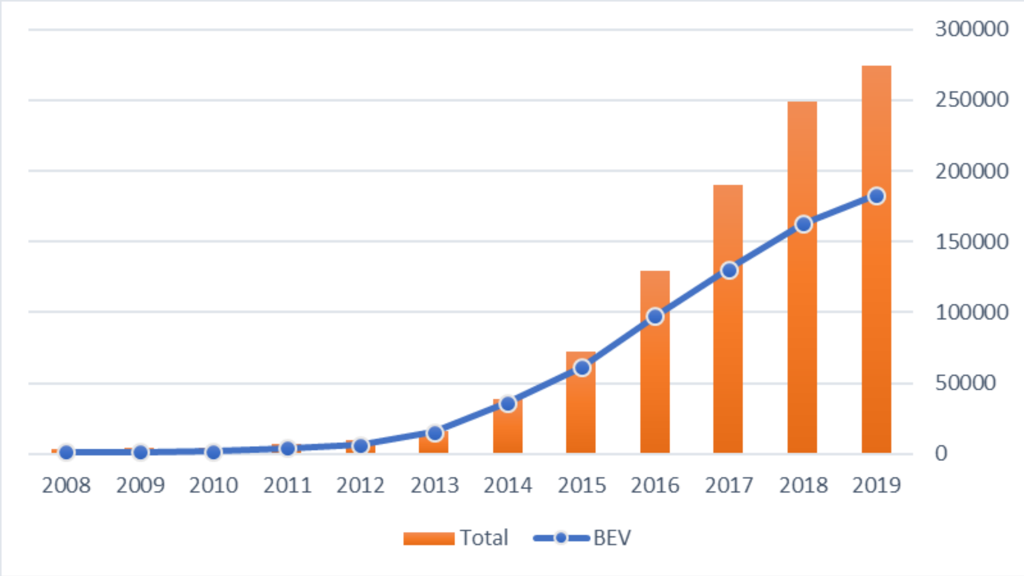



**Figure 4-14. The increase of the number of passengers BEV compared with the total AF passenger cars (2008-2019)**

Source: (European Commision, 2019a)

As it is represented in figure 4-14, the expansion of electric vehicles in Norway started in 2010, even though the supportive incentives for EV have started in 1990. The share of passenger BEV is the highest in the total number of AF (alternative fuel) passenger cars. In less than a decade, the number of BEV is reaching two hundred thousand followed by PHEV that have around half the amount of BEV in the total number of AF passenger vehicles.

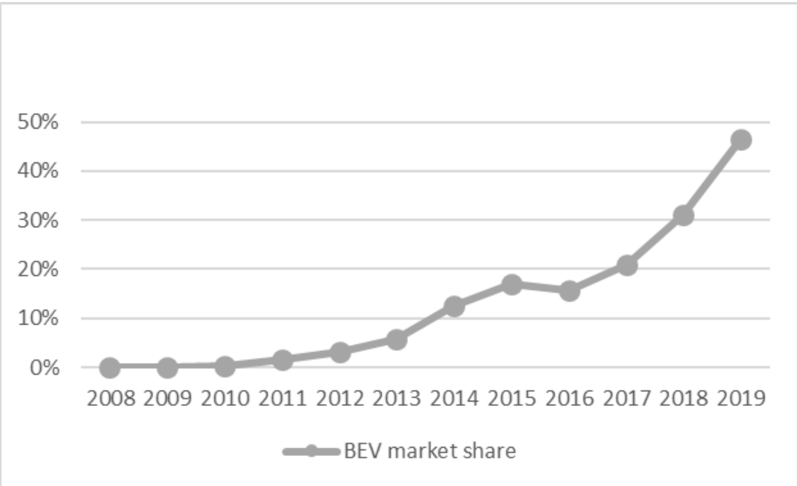



**Figure 4-15. The market share of new passenger BEV relative to the total[4] number of new passenger cars**

(European Commision, 2019a)

The Norwegian EV market is one of the most developed worldwide. In 2017 the electricity consumption by electric vehicles is Norway was more than two-third of the total electricity consumption by EV in the Nordic Region. The total consumption of electricity

[4] The total number of cars includes ICE (internal combustion engine).

for EV in Norway that year was around 355 GWh, while the total consumption for the Nordic region was 500 GWh. Nowadays the number of EV is still modest when compared with the total number of vehicles in circulation but if all the passenger vehicles in Norway were electrified the electricity demand of the country would rise with around 6.5 TWh. (International Energy Agency, 2018b)

The structure of the market share of EV in Norway is different from the other countries. In Norway BEV is the dominant type of the total EV fleet, in 2016 it accounted for 75 percent of the total share of electric vehicles. In other counties such as Sweden and Netherland that have had aggressive supportive schemes for electric vehicles the tendency is reversed, these counties have a large share of PHEV. While with the last battery technological innovation BEV has become more competitive other obstacles are showing up with the increase of their share. The actual challenge of BEV is access in the charging infrastructure. The majority of BEV owners charge their vehicles at home over the night, but in order to be suitable for longer trips, they should have access to public charging stations. Norway is trying to follow up on the increasing trends of the BEV share by building new public charging points. From 2011 till 2016 the number of public charging points increased from 3000 to 8000 but still the growing rate of the charging points and BEV number is not in the same rhythms. The growing rate of charging points is far below the growing rate of BEV for the same period of time by causing the decline of the availability level of the public chargers. The availability of the public chargers in Norway for 2016 was 0.6 per 10 BEV while the recommendation of  EU directives is that one charger should correspond to 10 BEV. (International Energy Agency, 2018b)

# 5 Electric vehicles

The purpose of this chapter is to give a brief summary of the history of the electric vehicles evolution that is changing the face of the today's energy sector. Since the transport sector remains one of the sectors with the highest level of pollution, with continuous growth on energy consumption and with less share of RES the development of electric vehicles technology is turning on a green light for the future of this sector that is the electrification. The classification of electric vehicles and the reasons why to use electric vehicles where we list some of the major benefits of this technology are also an important part of this chapter.

## 5.1 The history of Electric Vehicles

The technology of EV is nowadays one of the most energy-efficient technologies for vehicles that has a high potential to reduce the consumption of energy and emissions emitted by the transport sector. The first EV prototype powered by non-rechargeable batteries dates in 1834 and was invented by Robert Anderson. During 1890-1920 EV were very popular and in 1912 the share of EV in the global market was 28% of the total number of cars on the road. The development of ICE technologies accompanied by the mass production that resulted in low-prices of vehicles together with the availability of affordable oil resources vanished the development of EV. The domination of petrol cars was determined by a factor of enormous importance that was the ability to travel a long distance. So, the evolution of EV market eventually collapsed. (Vidyanandan, 2018)

The first mass-production model of EV was introduced in the market by Ford Motor Company in 1910 and was named Model T, and it became one of the most popular vehicles for the middle class. (International Economic Development Council, 2013) After the period of bloom that the introduction of the first mass-production EV model gave the next 30 years were quite dark for EV and the technology had modest development. The turning point of this dark age of EV came after the immediate rise of oil prices and gasoline shortages in 1973 caused by Arab Oil Embargo. This event grew the interest of the US in decreasing the level of foreign fuels dependence. In 1976, the Energy Department approved the Electric and Hybrid Vehicle Research, Development, and Demonstration in order to support the research of hybrid and electric vehicles. With all the efforts done the vehicles produced in the 1970s were not good enough to compete with petrol-powered vehicles. Two main challenges were the speed which did not pass 45 miles per hour and fact that they could travel only in short distances before needing to be recharged again and the availability of charging stations was limited. (Rebeca, 2014)

It took only a few decades from then that the high price of oil and rising concerns on climate changes would renew the interest in EVs. New regulatory acts on emission reduction were implemented and the gold period with supportive schemes for EV started. While the price of oil kept increasing the same trend had the interest and effort of vehicle manufacturers on producing hybrid vehicles and in 1996 the EV1 model was produced by General Motors. One year later Toyota promotes Prius, which was the first HEV in the world and only in the first year it recorded 18000 sales. Since 2010 gigantic automobile manufacturers have started to introduce new models of HEV and BEV to the market such as Mitsubishi i-MiEV, Nissan Leaf, Tesla Model S, Chevrolet Volt, etc. (Yong et al., 2015)

A brief history of the evolution of electric vehicles is illustrated in picture 5-1. The history of EV is a prof of the global emphatic ingenuity and integration in transportation. The future will be written in based on the lessons learned from the past periods. Nowadays two centuries after the beginning of the electric mobility age we have entered in the third age of the electric mobility in 2001 that is focused on the electrification of the vehicles and the entire transportation sector (Clean Energy Ministerial et al., 2013). More than one hundred years after the period of the boom and bust of electric mobility the world is experiencing rapid growth on the market share of electric vehicles driven by the energy security and climate change issues.

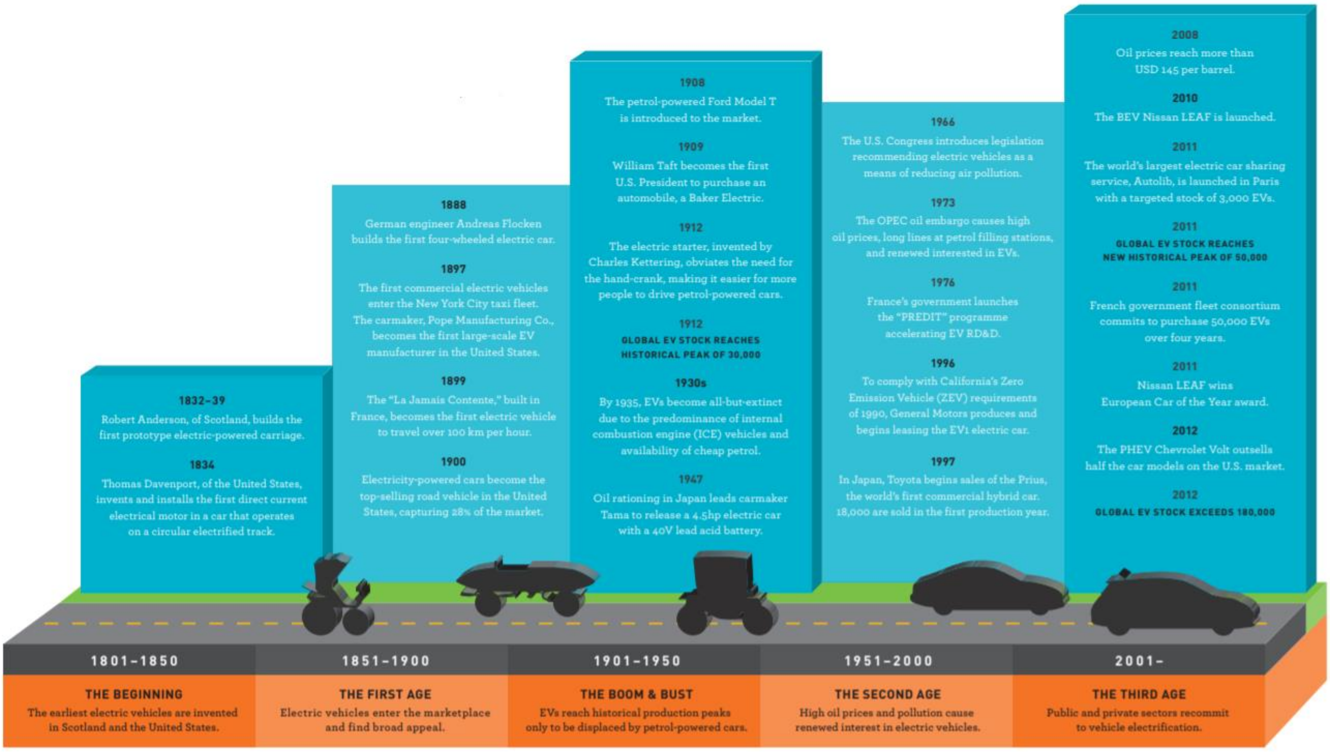



**Figure 5-1. Walking in the roadmap of electric mobility development**

Source: (Clean Energy Ministerial et al., 2013)

## 5.2 Types of Electric Vehicles

Firstly, let's explain the concept of Electric Vehicles. EVs are the vehicles that ensure propulsion via one or multiple motors that could be an electric motor or traction motor. The scale of electrification is not the same in all types of electric vehicles. It can vary from zero (conventional vehicles) to 1 (BEV). (Flah et al., 2014)

Nowadays with all the evolution and improvement of electric vehicles technology in the market exist several different types of EVs. There are some different classifications for electric vehicles. The first classification is done on the basis of power supplement and propulsion devices. In these bases the electric vehicles are divided into three different types that are:

- PEV (Pure electric vehicles) the driving system is powered by an electric motor and are fed with electricity by the battery (the power storage unit)

- HEV (Hybrid electric vehicles) the propulsion is provided by the combination of an electric motor together with an ICE consequently the source of power is both electricity and diesel or gasoline.
- FCEV (Fuel cell electric vehicles) are driven by an electric motor that is powered by hydrogen, ethanol, methanol or gasoline in a direct or indirect way. (Basu et al., 2019)

### 5.2.1 The characteristics of electrical vehicles

The propulsion mode and the characteristics of different types of electric vehicles are not the same. In table 5-1, is given a short comparison between the characteristics of three main types of electric vehicles: PEV (widely known as BEV), HEV and FCEV.

| | **BEV** | **HEV** | **FCEV** |
|---|---|---|---|
| **Propulsion** | • Electric motor | • Electric motor<br>• ICE | • Electric motor |
| **Energy system** | • Battery<br>• Ultracapacitor | • Battery<br>• Ultracapacitor<br>• ICE | • Fuel cells |
| **Characteristics** | • Emission free<br>• Short driving range<br>• Crude oil independence<br>• Available commercially<br>• High initial cost | • Low emission<br>• Crude oil dependence<br>• Long driving range<br>• Complex system<br>• Available commercially | • Emission free or ultra-low emission<br>• Energy efficiency<br>• Electricity independent<br>• Independence on crude oil<br>• Satisfying range of driving<br>• Under development |
| **Main issues** | • Range<br>• Charging infrastructure<br>• Battery capacity | • Battery sizing<br>• The dependence on driving cycle<br>• Energy sources management | • The high cost of fuel cells<br>• Lack of the fueling system<br>• Feasible hydrogen production |

**Table 5-1. Comparison of different EV characteristics**

Source: (Basu et al., 2019)

As mentioned at the beginning of this section the electrification scale of vehicles varies from zero to one. The traditional conventional vehicles are vehicles with the scale zero of electrification and battery electric vehicles are the vehicles with the highest scale of electrification they are totally dependent on electricity and their scale of electrification is one. In between the minimum and maximum scale of electrification stays the type of hybrid vehicles that includes PHEV and FCEV. In figure 5-1, is given the illustration of the basic working of the different vehicle types as well as the arrow that shows the trend of electrification of three main vehicle types: Conventional, Hybrid and Battery Electric Vehicles.

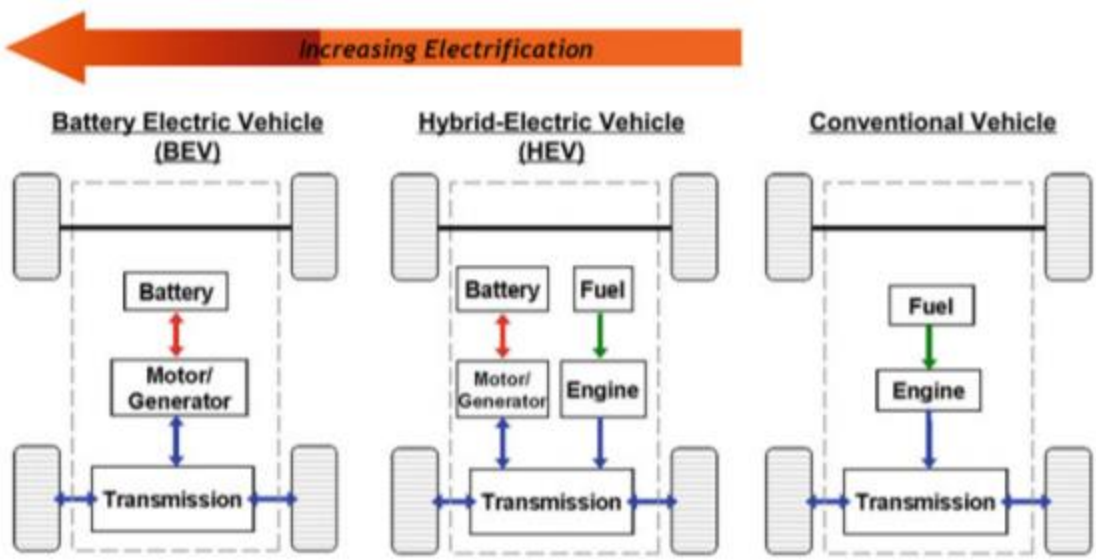



**Figure 5-2. The basic working principle of different type of vehicles and the scale of electrification**

Source: (Basu et al., 2019)

### 5.2.2 The structure of BEV

The structure of a BEV is very simple when compared with the traditional conventional vehicles. BEV do not have a lubrification system, no exhaust vessel, and no starting system. A battery-electric vehicle has four main components that are: the electric battery, the electric engine, motor controller and charger (as shown in figure 5-3). The working principle of BEV is simple the power is taken by the controller from the battery and delivered to the electric motor that converts it into torque that moves the vehicle. (Un-Noor et al., 2017)

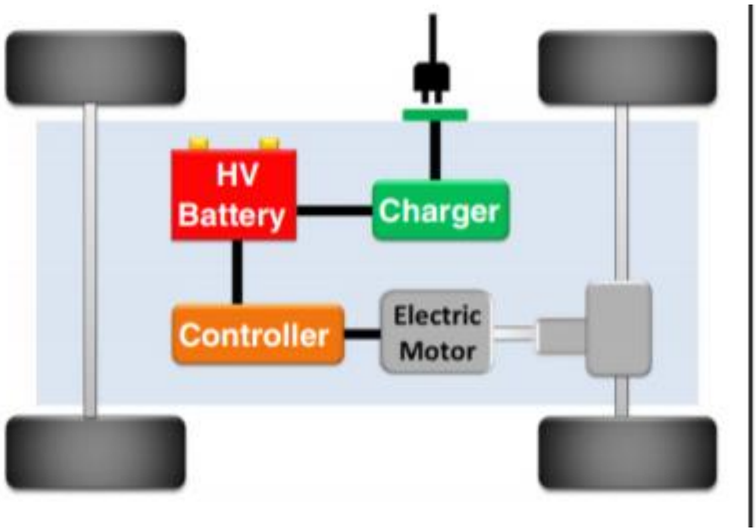



**Figure 5-3. The main components of a Battery Electric Vehicle**

Source: (Un-Noor et al., 2017)

The battery of a battery electric vehicle can be charged by plugging it in a power station of through the breaking through the system. The working principle of this type of vehicles is very simple. Electrical power can enter the vehicle as alternative or direct current depending on the type of charger used (see figure 5-4 for the difference between AC and DC chargers). The DC power stored in the batteries is converted in AC with the help of the controller (inverter) by giving the motor the energy needed to move the vehicle. The working principle of BEV is illustrated in figure 5-3 . (Un-Noor et al., 2017)

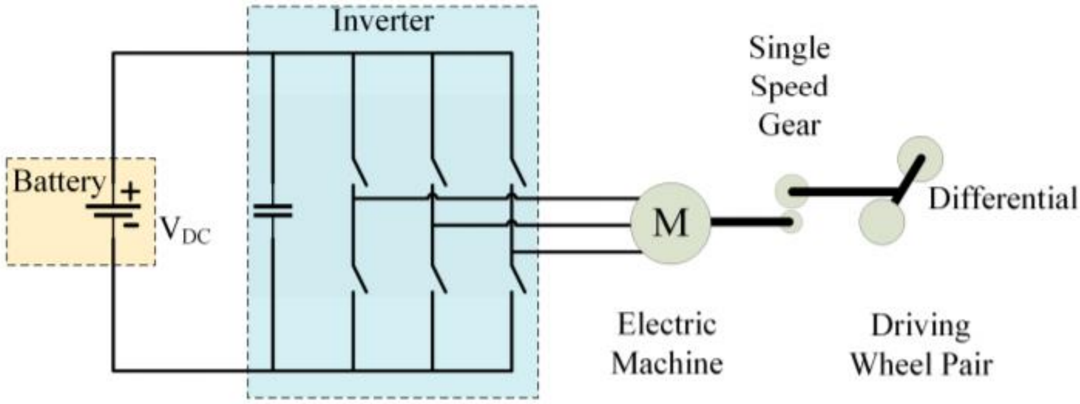



**Figure 5-4. BEV configuration**

Source: (Un-Noor et al., 2017)

Electric vehicles are flexible, and no mechanical arrangements are required to run them. The only moving part of this type of vehicle is the motor. The system of an EV can be divided into three sub-systems:

- The energy source – which includes these elements: the source, the recharging system and the system that manages the energy.
- The propulsion – which includes the electric motor, converter, controller, transmission (than includes driving wheels as one of its components)
- Auxiliary – includes the system of temperature control, the auxiliary power supply and the unit of power steering. (Un-Noor et al., 2017)

## 5.2.3 The charging system

The power source for electric vehicles is the power grid that depending on the country can be single phase 90-240 Vac or three-phase 208Vac/400Vac/480Vac/600Vac. The EVSE (electric vehicle supply equipment) that is the charger of the electric vehicle is the infrastructure that connects the battery and the power source with the intention of restoring charge. The battery of the electric vehicles must be charged with DC while the grid delivers AC. Here comes the need of having an on-board charging that from the other side is sized in a way that fits the space inside the car and keeps the price of the vehicle at a competitive level. So, the onboard converters are relatively small in size and constantly the power delivered to the battery is low between 3 kW and 6 kW by making the charging process slow. On the other hand, the DC chargers are fast since they are an external element that is not sized in any limitations of cost and space. The technology used is smart and the power is three phases. In figure 5-5 below is illustrated the difference between AC and DC charging. (Tisley, 2017)

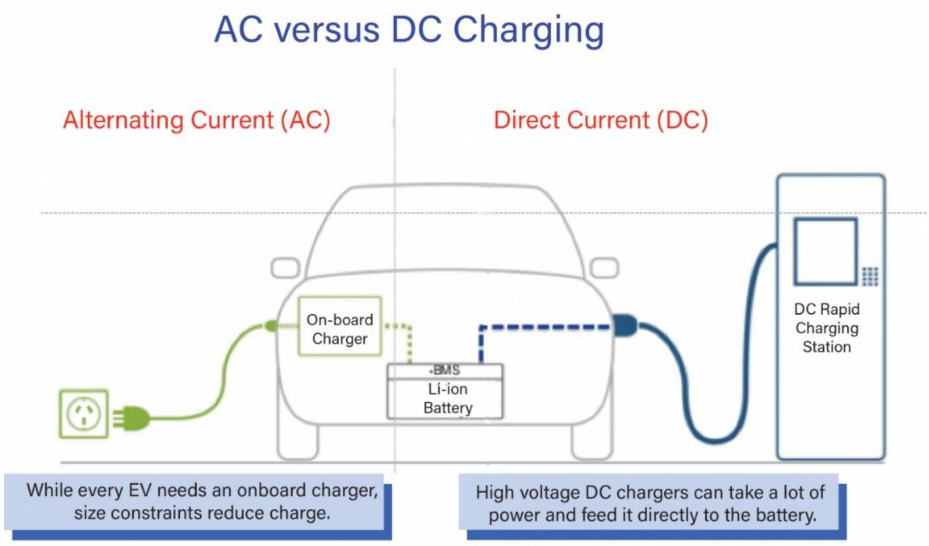



**Figure 5-5. The difference between AC and DC charging.**

Source: (Tisley, 2017)

### 5.2.4 The types of batteries

As one of the most important elements of electric vehicles, and the major energy source the technology of batteries has been under continuous development in order to obtain the desired performance and is still an ongoing process. Some of the battery types used in electric vehicles are: lead-acid, Ni-Zn, Zn/air, Ni-Cd, Ni-MH, Li-Polymer, Na/S and Li-ion. (Un-Noor et al., 2017).

All the types of batteries mentioned above have their advantages and disadvantages that have to be considered when selecting one of them. The choice of the battery has a great effect in the final cost of the vehicles, therefore it is important that in the vehicles of small range that are constructed for low driving range the operation to be done with a cheap type of batteries (e.g. Lead-acid). Li-ion batteries offer an increased energy density that is one of the advantages that are required for further expansion of electric cars. (Helmes and Marx, 2012 )

Lead-acid and nickel metal batteries (NiMH) are the types that were used in the earlier ages of the electric vehicle’s evolution. Nowadays this type of batteries is rarely used as the source of energy storage of BEV. The specific energy of lion-acid batteries is poor (34 Wh/kg) while the NiMH have better specific energy (68 Wh/kg) when compared to them. So, the vehicles that use NiMH are lighter in weight and consequentially this reduces the cost of energy for propelling. NiMH is appropriate for a hot environment because of the high level of self-discharge (12.5% per day in the normal room conditions).  The standard batteries for today’s BEV are Lithium-Ion Batteries (Li-ion). Some of the benefits of this battery technology are: excellent specific energy (140 Wh/kg), high energy density, low self-discharge level (5% per month). The disadvantages of this technology are the high price and safety concerns connected with overcharging and overheating of the batteries. (Mok, 2017)

An illustration of the energy density of different battery technologies used in electric cars is given in figure 5-6.

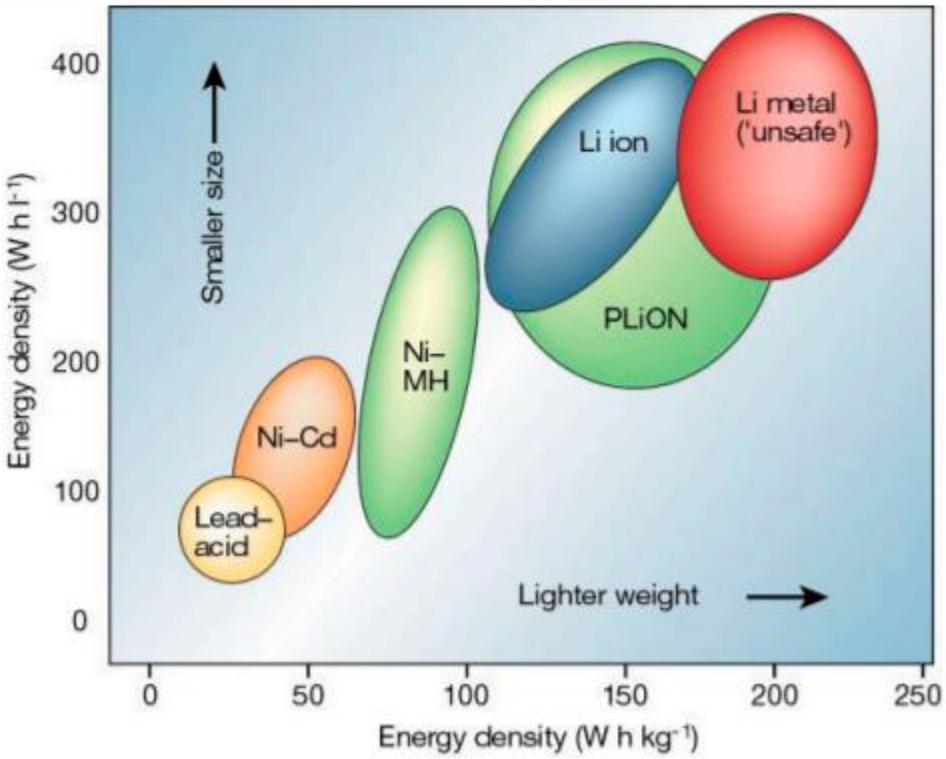



**Figure 5-6. The energy density of battery technologies used in EV by weight and size.**

Source: (Miao et al., 2019)

## 5.3 Why electricfication is the future of the transport system?

The common global target to prevent the average temperature rise by more than 2 degrees Celsius compared with the temperature levels of the pre-industrial period is defined as one of the necessary objectives that have to be accomplished in order to avoid the dangerous consequences of the climate change. In 2015 at COP 21 (Conference of Parties) UN Climate Change Conference held in Paris, 195 countries agreed on the goal mentioned above. One of the pillars of this change is the transport sector that has a very high level of pollution and high energy consumption. As mentioned even in the sections above part of the 20/20/20 EU target is the increase of the share of renewable energy sources in the final energy consumption, where an increase with at least 10 percent of the 1990 levels is obligatory for the transport sector (EEA, 2018). Nowadays exists a global motivation for the electrification of this sector. Some of the reasons that are leading towards the electrification are: the increase of the air quality, the decrease of the energy consumption and GHG emission reduction potential. (European Commission, 2017 )

The increasing number of BEV has a great contribution to the shift of the transport system into a sustainable system. The electric motors have less noise and greater energy efficiency when compared with traditional ICE. One of the main barriers of a higher market share of BEV is the high initial cost. To decrease the initial cost of BEV and to make them more competitive against traditional conventional vehicles several incentive programs are launched all over the world. From the technical perspective, two are the reasons that make BEV more energy efficiency comparing to ICV. The efficiency of the electric motors is very high in all the range of operating states (above 90 percent), while the ICE has an efficiency that reaches a maximum level of 40 percent and this not in all the range of speed and torque. Furthermore, the BEV has the ability to recuperate energy from breaking. With the increasing share of RES in electricity, production EV is an attractive option from the perspective of climate change mitigation. (Braun and Rid, 2017)

Some of the benefits of electric vehicles are listed in figure 5-7.

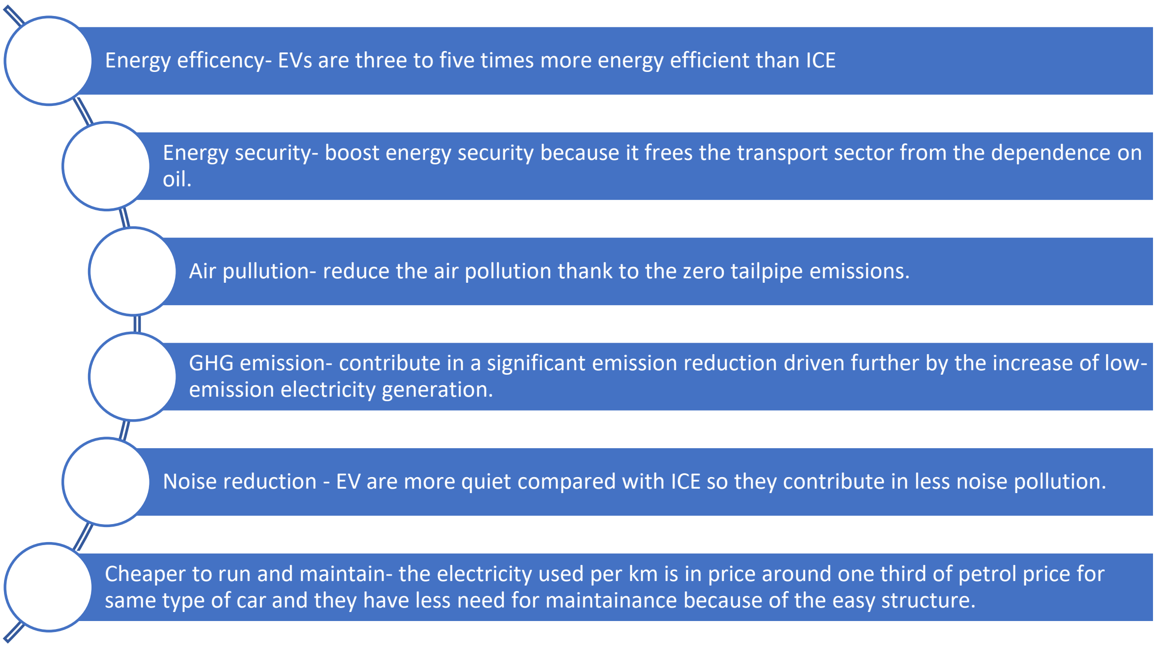



**Figure 5-7. The main benefits of electric vehicles**

Source: (Clean Energy Ministerial et al., 2013)

## 5.4 Current status of the global EV market

The increase of the EV share boost the energy efficiency, doesn't require direct fuel combustion and rely on the most diversified energy carrier, electricity. The expansion of EV enhance energy security, contributes to better air quality, decreases the noise pollution, contributes to emission reduction in arrangement with a low-emission

### 5.4.1 New sales and stock fleet

The expansion of electric mobility is a process that is having rapid growth. The total global number of electric cars on the road for 2018 reached 5.1 million, by increasing with two million from the previous year that is equivalent to an increase of 63%. The growth did not have many differences from the previous years, in 2016 the yearly growth was 60 percent, and in 2017 with 57 percent. The amount of BEV in the total global EV stock is 64 percent.(Electric Vehicles Initiative et al., 2019)

China has the largest EV fleet that is equal with 45 percent of the total global EV fleet. Only the one-year period between 2017 and 2018 the stock of EV almost doubled to reach 2.3 million. After China, the European EV stock is the second largest with a total number of 1.2 million EV that is equivalent to 24 percent of the total global fleet of EV. In this 1.2 million EV the countries that are part of the European Union contribute with 0.96 million. The EV stock fleet of the United States covers 22 percent of the total global EV stock and the rest of the world contributes 9 percent in the total global EV stock. (Electric Vehicles Initiative et al., 2019)

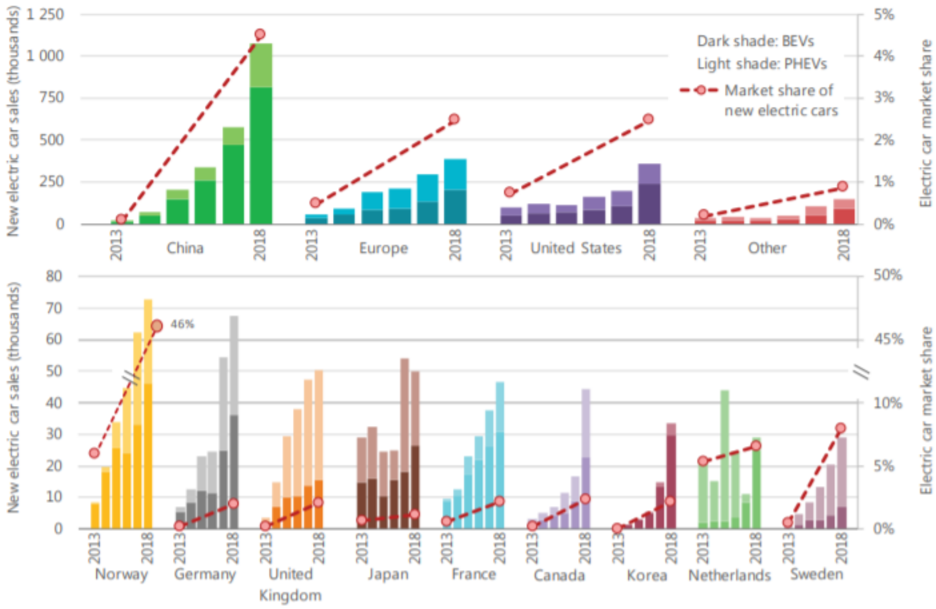



**Figure 5-8. The global electric vehicles sales and market share for 2013-2018**

Source: (Electric Vehicles Initiative et al., 2019)

The number of new sales of electric vehicles in Europe was 385000 followed by the United States with 361000 electric cars sold. The relative increase of sales from the preview year was 31 percent that was 10 percent lower than the relative yearly increase of 2016-2017. While the growth rate of EV sales for 2018 in Europe was below the global levels the market of the United States had the opposite tendency by increasing with 82 percent of the global levels. (Electric Vehicles Initiative et al., 2019)

The global leader of EV stock share for 2018 was Norway. The percentage of the Norwegian stock share in this year was equal to 10 percent of the total national vehicle stock. In global level the stock share of EV for 2018 is higher than one percent of the total vehicle stock, only in five countries: 10 percent in Norway; 3.3 percent in Iceland; 1,9 percent in the Netherlands; 1.6 percent in Sweden and 1.1 percent in China. (Electric Vehicles Initiative et al., 2019)

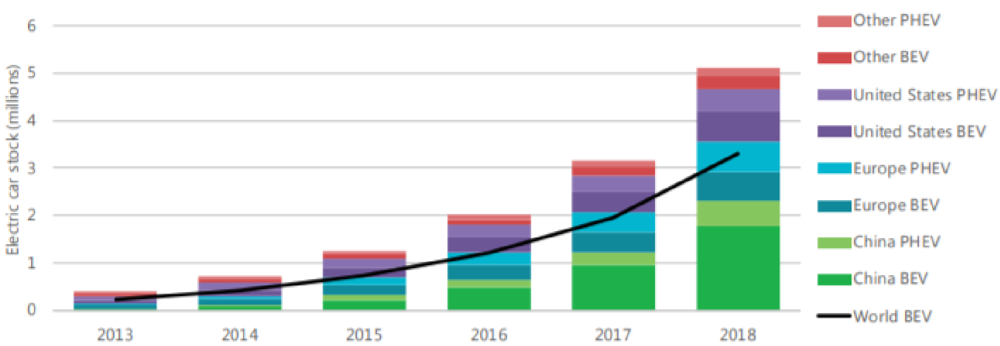



**Figure 5-9. The passenger vehicle stock in the biggest markets**

Source: (Electric Vehicles Initiative et al., 2019)

## 5.4.2 The well-to-wheel emissions

The well-to-wheel[5] (WTW) greenhouse gas emissions from the EV share are defined by the emissions intensity of the power generation and the evolution of the energy used by EVs. In 2018 the amount of GHG emissions emitted on a WTW perspective were around 38 Mt $CO_2$-eq. The equivalent ICE stock would have emitted 78 Mt $CO_2$-eq so consequentially the net savings from the technology replacement from ICE to EV were around 40 Mt $CO_2$-eq. Two are the factors that defined the emission savings: increase of energy efficiency and the decrease in carbon intensity of the electricity generation. In the total net savings China was the biggest contributor with 77 percent, that is equal to 30 Mt $CO_2$-eq, but it is important to underline that this effect comes as a result of the large magnitude of the stock of electric vehicles in China and not as an important advantage in terms of WTW $CO_2$ emissions of EVs over ICE vehicles because the power generation with high carbon intensity. The emission reduction by regions for 2018 is given in the figure 5-10.

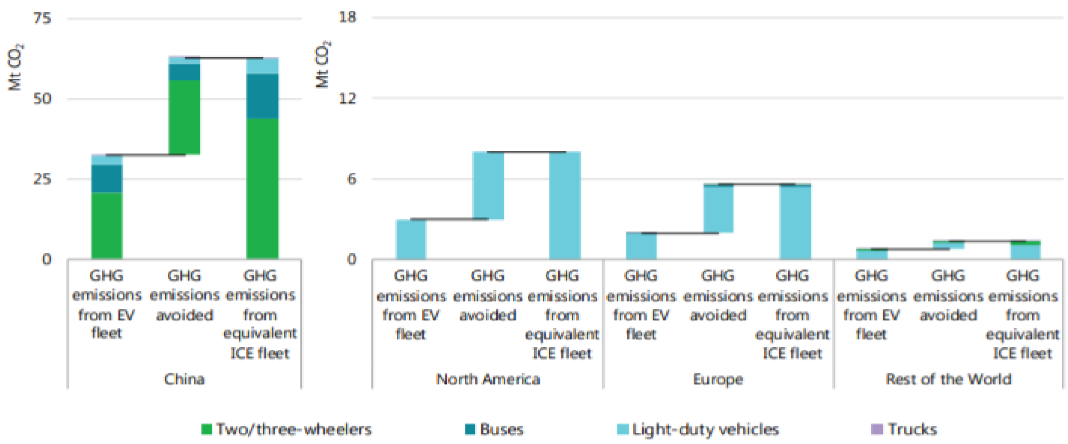



**Figure 5-10. The emissions avoided by the replacement of ICE with EV by mode and region, 2018**

(Electric Vehicles Initiative et al., 2019)

## 5.4.3 Electricity demand

The total global electricity consumption by electric vehicles in 2018 was around 58 TWh. The major contribute, 55 percent was given from the category of two-wheelers, and the 24 percent from LDV that had the biggest increase from the previous year. China covered 83 percent of the total global electricity demand for EVs followed by Europe with 9 percent. So, the highest electricity demand was in China with 47 TWh, followed by Europe with over 5 TWh and the United States with 4 TWh and the remaining 2TWh is covered from the rest of the world. (Electric Vehicles Initiative et al., 2019)

The consumption of electricity by EVs at a global level covers less than 0.5 percent of the total final electricity consumption. The electricity demand inclined with 17 percent that is slower than the growth of two previous years. The electricity consumption by EVs covers less than one percent of the total electricity consumption even in the countries with the highest market share of EVs. The usage of electricity is displacing the oil consumption and in 2018 the consumption of 58 TWh electricity avoid the consumption of 21 Mtoe

[5]Well-to-wheel is the term used to describe the entire process of energy flow, from mining of the energy source to a vehicle being driven by this energy.

that is equal with 0.43 million barrels of oil per day. The demand for electricity from EVs by type of technology and the most important regions are given in the figure 5-11. (Electric Vehicles Initiative et al., 2019)

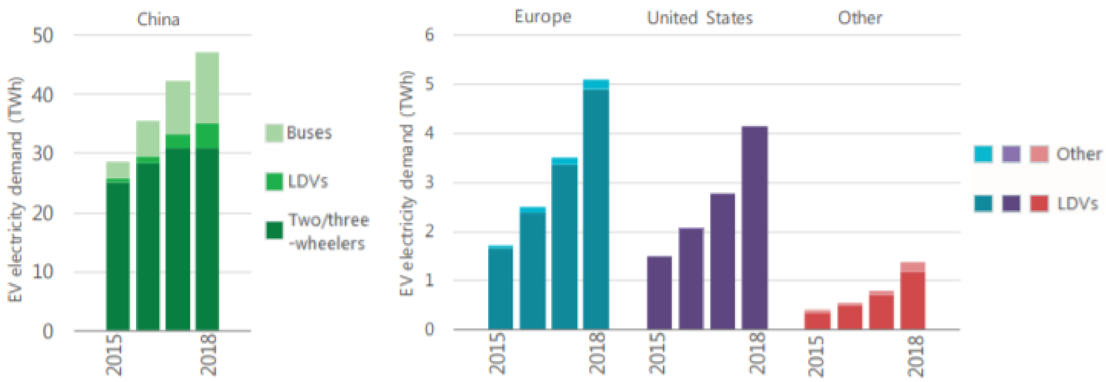



**Figure 5-11. The demand of electricity from EVS by type of technology and region (2015-2018)**

Source: (Electric Vehicles Initiative et al., 2019)

# 6 Methodology

The methodology is defined as a continuously theoretical analyze of different methods applied in a field of study. The difference between methodology and method is that methodology doesn't provide a solution for the problem it gives a theoretical knowledge that provides sufficient information on choosing the right method that can be applied to a specific case. (Igwenagu, 2016)

## 6.1 Research strategy and process

In order to give an answer to the main and sub-questions chose for this thesis, it is decided to be used a certain research strategy. The chosen research strategy includes research methods for a mathematical (simulation) model. With the technological development modeling and simulations are spreading widely and are being considered as a third scientific research methodology next to two traditional research methodologies (deductive[6] and inductive[7]). (Yin and McKay, 2018)

A model aims to inspect in detail in order to obtain useful data by simplifying an event. Models provide a relationship between different variables so that with different manipulation of certain variables the user will obtain data that show the effect of the manipulations. In this way, the purpose of a model is to test or explore different hypothesis done by the user. The models are divided into three main basic types that are: diagrammatic, physical, and mathematical (or simulation) models. In a mathematical model by giving different inputs the system will generate the predicted outcome with the given characteristics of the phenomenon. Without doubts, mathematical models are quantitative models, and they have two major categories that are: deterministic[8] and stochastic[9] models. (Gilbert and Troitzsch, 2005)

When using a simulation method, the first step taken is the development of a simplified model that gives the presumed process that is going to be analyzed. This is called a reference model and it is in the form of a computer program. The model designed is used to generate data that are going to be simulated. The simulation models can be used for two main proposes: explanation and prediction. In the figure below is illustrated the logic of a simulation research method. This type of method has four main components that are: a target, a model, collected data, and simulated data as illustrated in figure 6-1. Target and model are connected with values that have a certain level of precision and in this case, the values are concrete because the variables are measurable. Once the target has preceded the process of data gathering starts, and as a result, a database with collected data is created. On the other hand, after running the model created another database it set with the simulated data. The reference model is created to simulate data for a past event of which we already have the measured effects. This is a way to test if the model is generating data that are similar to the actual data of the process in the real world. (Gilbert and Troitzsch, 2005)

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[6] Deductive approach is a top-down approach
[7] Inductive approach is a bottom up approach
[8] the output is fully determined by the parameter values of the input.
[9] A tool that estimates probably output when the input variables change randomly.

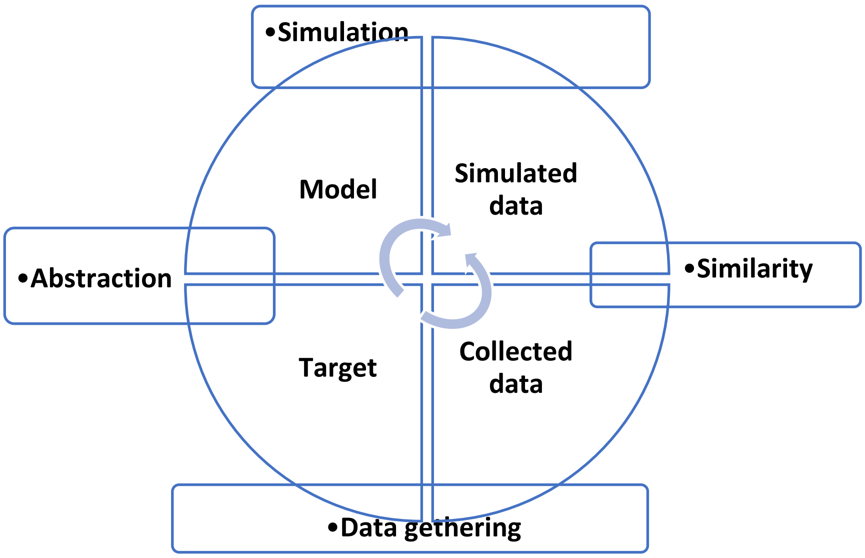


**Figure 6-1. The logic of simulation as a research method**

Source: (Gilbert and Troitzsch, 2005)

## 6.2 Choosing the modeling tool

As mentioned in the section above the research method used for this study was that of a simulation model. Since the study is about the analyze of the Norwegian National Energy System with a focus on transport sector the simulation modeling tool that is going to be used in this study is an energy tool. After clarifying this let list the elements that different energy modeling tool includes according to Lund:

1. A simulation tool that will simulate the operation of a given energy system (a national system in our case);
2. A scenario tool that combines a series of yearly results into a long-term scenario;
3. An equilibrium tool that tempts to explain the behavior of the different elements such as: energy supply, energy demand, and the prices;
4. A top-down tool that uses macroeconomic data to explain the fluctuations of the prices;
5. A bottom-up tool for analyzation and the identification of different energy technologies by identifying alternatives and option for investments;
6. Operation optimizing tools that can be also a simulation tool with optimizing features for a given system;
7. Investment optimization tools that can be scenario tools with investment optimizing features for new technologies or energy stations; (Lund, 2014)

According to Lund, the main purpose of a modeling tool can include some of the characteristics mentioned above or all. When choosing an energy modeling tool it is important to choose the one that includes all the necessary elements to meet the objectives of the study, not to choose the energy tool that includes most the elements because it is rather more important to have the right information that to have a large amount of information but missing the ones that are necessary for the fulfillment of the study objectives.

From what said above the selection of the right modeling tool is a very critical decision that has to be taken when doing simulation research works. With the development of technology and computer science the amount of elections is increasing and in the same time is being more difficult to make a decision for the modeling tool that fulfills the aims and objectives of the research. While evaluating different modeling tools that can be used it is important to take into consideration some important aspect such as: the time needed to learn using the tool, the availability of the training materials, the cost of the software, the availability of the input.

The first step I took in order to create a better idea for the modeling tool that was going to suit best for my work was defining the aim of my thesis that was:

*"To design a possible model of the Norwegian energy system in 2050 based on the replacement of the conventional passenger vehicles with electric vehicles and the integration of a higher scale of wind power in the generation supply"*

After identifying the aim of the study, I started to consider different energy modeling tools available that could fulfill best the aim of my work. Therefore, the modeling approach energyPLAN was chosen and the reasons that led in this decision are listed in the sections above. By using EnergyPLAN as a modeling tool the national energy system can be modeled in a simplified way by making it easy to compare different regulation strategies that could change the Norwegian transport sector, as well as analyzing the ability to integrate RES (e.g. wind power). When doing an energy system analysis, the aim is to explore and estimate different factors or technological improvements that could improve a part of the analyzed energy system, which will simulate changes across the system. The impact of the increasing number of BEV, for instance, will not affect only the transport sector but the power sector, industry sector, and building sector and these effects have to be analyzed from an integrated energy system approach.

### 6.2.1 About EnergyPLAN

EnergyPLAN is an energy modeling tool developed by the Sustainable Energy Planning Research Group of Aalborg University in 1999 in Denmark. Since then it has been updated continuously and the last version EnergyPLAN Version 14.2 was released on February 2019. The purpose of this modeling tool is to analyze the environmental, energy and economic impacts of different energy strategies. This model is not an optimization tool it gives an optimum solution that is based on the defined conditions, and it gives to the users the opportunity to compare different solutions rather than optimizing a single solution. EnergyPLAN is classified as a deterministic model that has as a key objective the optimization of the operation in a given energy system based on inputs that can be demands, costs, imports, RES or excess electricity production, and outputs such as fuel consumption, production of energy, energy balances, total costs. (Lund, 2014)

The focus of the model is the endpoint of the energy system and how the system will operate in the future. What makes the model even more interesting and different from the other energy models it an hour-distribution. So, the simulation results of the energy production of the energy system are generated with all the varieties of seasons, peak loads of energy use for a year hourly. The development of scenarios that are longer than one year is possible by accumulating various one-year-long scenarios into one scenario. The aim of the model is to model the future situation of an energy system, so it has detailed data about future energy technologies that nowadays are under development.

The model has various distribution files but for more accurate results it is possible to put the hour-distribution file of electricity production in the energy system that is going to be studied. (Alaraudanjoki et al., 2016)

According to Lund some of the most important characteristics of EnergyPLAN tool are:

- Is a deterministic model that gives the same result for the same input;
- Has an hour-distribution simulation that allows the analysis of the fluctuations influenced by RES;
- Its systems are aggregated in groups;
- Is focused on the optimization of the operation of a given system;
- Provides a choice between different strategies of regulation given for a certain system;
- Analyses the system for a one-year period in one-hour steps that can be combined to develop an analysis for longer periods;
- Is a model based on analytical programming with direct calculations and very fast in performing;
- This model includes the hourly analysis for the complete system not only one part of it. (Lund, 2014)

The model has been constantly updated since 1999 when it was created, and the last version of the model was launched in January 2019. This is the Version 14.2 of this Energy System Analysis Tool and it replaced the previews Version 14.0 that was launched in November 2018. In total, the model has had twenty-eight updates since its creation in 1999. The front page of the last version of the model that illustrates the chart flow of the system is given in the figure below. This is the model that is going to be used for the simulation of this research.

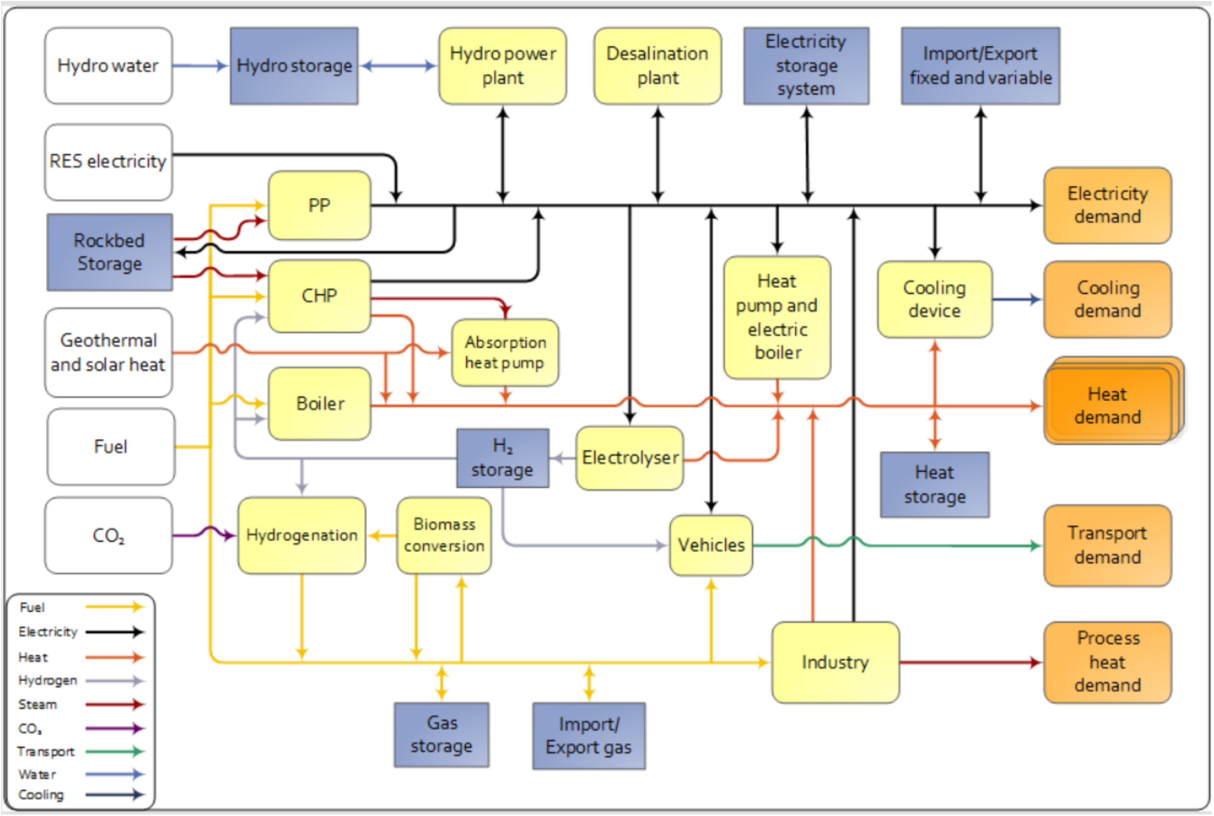


**Figure 6-2. Energy System Analysis tool EnergyPLAN, Version 14.2**

Source:(Lund, 2014)

### 6.2.2 Why EnergyPLAN?

Due to the wide range of available energy modeling tool, it was difficult deciding which would be the appropriate tool that would fulfill the objectives of my thesis. Among others, there were some limits such as training period, cost, and data availability. The availability of data was one of the most important reasons why I choose to use this modeling tool. Information about how to find and input the data into EnergyPLAN is available in The FIDE Guide by David Connolly.

Some of the reasons why I chose to use this modeling tool are:

- EnergyPLAN is a user-friendly modeling tool and requires a relatively short training period that goes up to a month.
- The software was free of charge and has free online training and guides.
- Generates detailed analyses of a complete energy system on an hour basis for a year.
- Gives the opportunity to make analysis for longer periods by accumulating results for various years into a single scenario.
- Is been used to simulate energy systems for a long list of countries.
- The studies done with EnergyPLAN have been published in scientific journals and the quality papers are high.
- This modeling tool considers three main sectors of a national energy system that are: electricity, heat and transport sector. EnergyPLAN has detailed data about future energy technologies that combined with renewable sources can contribute to a more flexible energy system in the future. E.g. the combination

of wind power that is a fluctuating renewable energy source with electric vehicles. (Østergaard, 2015)

Besides the reasons mentioned it was very important for the progress of the work to have the right guide to find and input the required data that was available for this model.

### 6.2.3 How to apply the modeling tool EnergyPLAN

Since the intention of this work is to compare alternative future energy system with different level of EV share and different RES share on the electricity production the modeling tool EnergyPLAN was found suitable to accomplish the main objective of the thesis. This tool not only allows the comparison between different scenarios with increased renewable energy integration but due to the use of an hour-by-hour file distribution the model  is made possible the analysis of the fluctuations that can arise from the technologies that are used in order to increase the renewable energy. (Lund, 2014)

There are several ways to operate the model depending on the purpose of the study, but in general terms, the operation of EnergyPLAN is given in the paragraph below.

EnergyPLAN modeling tool distinguishes two different regulation that is: technical and market-economic. The fists operating mode that were technical regulation the model seeks to keep the import/export to a minimum and identify the solution with least fuel consumption. The second operating mode seeks to identify the consequences of using different technologies on the power market by aiming the optimization of the economic profit. Regardless of the usage of the technical or economic-market mode, the majority of the technologies is involved in the regulation and the total cost of the system is possible to be calculated. (Lund, 2014)

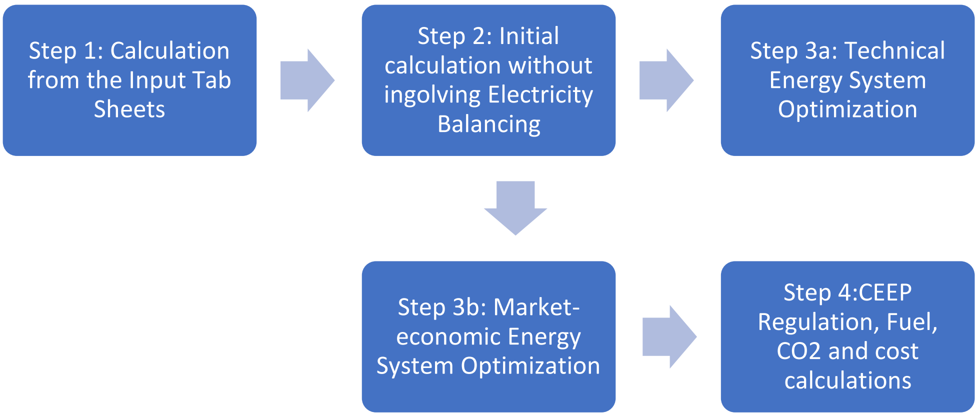


**Figure 6-3. The procedure of energy system analysis with EnergyPLAN**

Source: (Lund, 2014)

As it is illustrated in figure 6-3, the modeling tool EnergyPLAN can be used for different analysis types of energy systems. Depending on the type of analyze that is going to be done, we prioritize the inputs of the model. The strategy chosen for this study is: technical regulation with heat and electricity demand balance and CEEP (Figure 6-4).

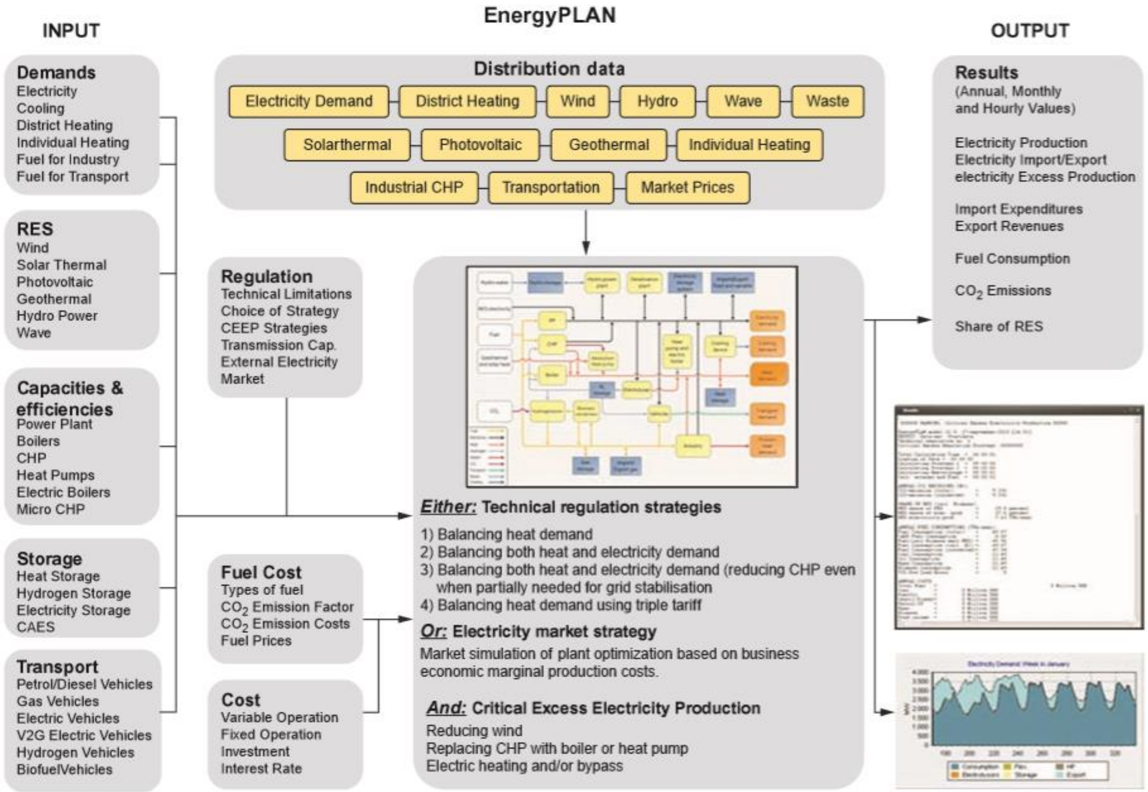


**Figure 6-4.The input-output structure of EnergyPLAN**

Source: (Lund, 2014)

### 6.2.4 Data collection

The collection of the data required to build the model with EnergyPLAN tool was easy with the help of FEIDE Guide. The data required by the software are divided into two main categories: technical and economic data. The reference model requires only the technical data since it is created to ensure the level of accuracy of the simulation. Modeling an energy system with EnergyPLAN requires two of the technical parameters listed below:

1. Total annual energy demand/production (TWh/year)
2. The capacity of the installed units (MW)
3. The total annual production/demand on hourly distribution. (Connolly, 2015)

The data collected for this research work can be categorized by the source in: primary and secondary. Both sources are used for the collection of data for this work. The primary sources are online databases from which two most important are: iea statistics and SSB. The secondary sources are different annual reports of: European Commission, International Environment Agency, IRENA, Norwegian Environment Agency, World Economic Forum, etc. and different scientific papers.

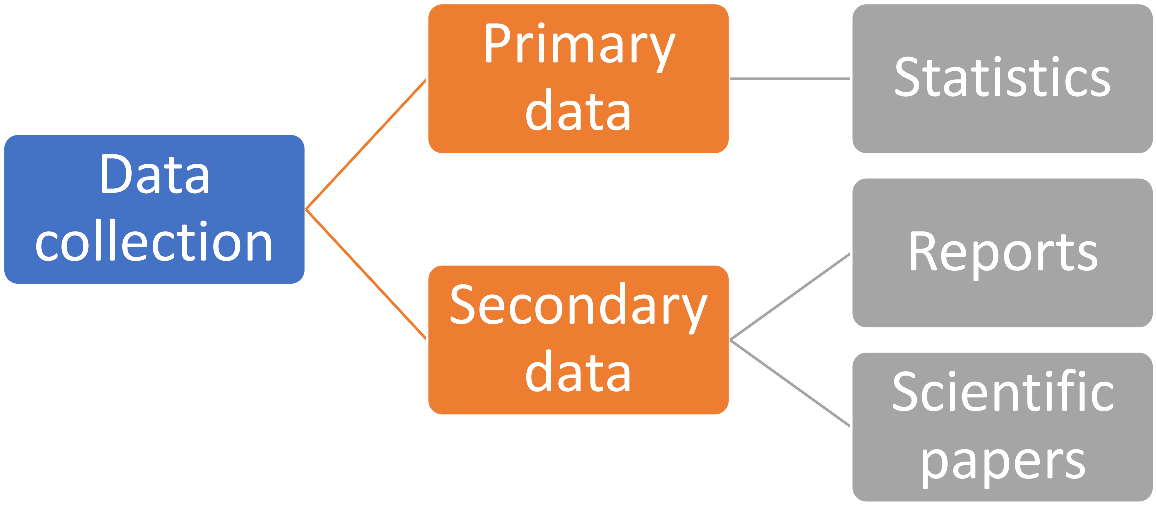


**Figure 6-5. Data collection process**

# 7 Scenarios

The purpose of this chapter is to describe the reference and future scenarios that are built in the modeling tool EnergyPLAN. The chapter is divided in two main sections that are: The reference scenario and the future scenarios. The reference scenario is built based on the Norwegian energy system in 2018. The section of future scenarios contains four different scenarios based on assumptions that consider historical trend, actual incentives and future targets.

## 7.1 The Reference Scenario

The reference scenario is built based in the Norwegian energy system of 2018 that is the year before the actual year when this study is conducted. Norway is one of the countries that actually have an existing model with energyPLAN based on the Norwegian energy system in 2015. Therefore, when creating the reference scenario, I have used the existing model and updated the input data with the latest data that belong to 2018. Besides that, this model had several mistakes in choosing the distribution files and the more important some wrong input that could lead in wrong conclusions.

### 7.1.1 Inputing the data for the Reference scenario

As mentioned in the sections above the modeling tool EnergyPLAN requires a lot of data. Some of the inputs are updated with more recent data and some are left same as in the existing model Norway 2015. The data taken by the existing model will not be explained in this chapter, but it will be available in the section of Appendices

Electricity demand is one of the most important data that the modeling approach energyPLAN requires. According to SSB, the total electricity demand for Norway in 2018 was 136.7 TWh (SSB, 2019), and is calculated as the sum of the electricity demand of every month because the yearly report for 2018 was not available yet. The electricity demand by heating and cooling is taken from the existing model of 2015 because since than only three years have passed and during this period of time there are no changes in the structure of the residential sector regarding to the demand for heating and cooling. The values for heating and cooling are respectively 31.1 TWh/ year and 1 TWh/year (Askeland and Bozhkova, 2017). The file distribution selected for the electricity demand is “el_cons_no_mwh_2015.txt” that was created with historical data from Nordpool by (Askeland and Bozhkova, 2017). All the inputs of the electricity demand are summarized in table 7-1.

**Table 7-1. The inputs of the electricity demand in the EnergyPLAN model**

| *Electricity demand* | *TWh/year* |
|---:|---|
| *Fixed demand* | 136.696 |
| *Heating* | 31.1 |
| *Cooling* | 1 |
| *Transport* | 0.489 |

The data for heating, cooling, and industry and Fuel demand we assume that have the same amounts as in 2015. Hence, the values in our Reference model scenario based on the Norwegian Energy System of 2018 are the same as in the model of 2015.

The focus of this thesis research is the transport sector. That is why finding the correct information about the demand for transport was very important. The input data for the energy demand by transport sector is taken at Statistics Norway, while the electricity consumption from electric vehicles is calculated with the following equation (1):

$$Electricity\ consumption = \frac{Yearly\ road\ traffic\ volume\ by\ electricity}{Avarage\ driven\ km\ per\ kWh}\ (1)$$

In 2018:

- Road traffic volume by electricity – 2449.8 million km (SSB, 2019)
- Average driven km per kWh – 5 km/kWh (Statnett, 2019a)

When replacing the data listed above in the formula (1) by the calculation results that the electricity consumption by EV in Norway for 2018 was 0.489 TWh. The file distribution selected is "Hour_US2001_transportation_BEV_H2.txt". The consumption the oil and oil products were not available divided into categories for 2018. Therefore, in order to make the share of it into the input required by energyPLAN it is assumed that the consumption of jet fuel remains same as in 2015, because there are no important changes in the aviation transport these last three years. When dividing the diesel and petrol the historical tendency taken in consideration. All the inputs for the transport demand are summarized in the table below.

**Table 7-2. The input data in EnergyPLAN for transport fuel in the demand tab**

| *Fuel* | *Fossil (TWh/year)* | *Biofuel (TWh/year)* | *Total (TWh/year)* |
|---|---|---|---|
| *Jet Fuel* | 10.731 | | 10.731 |
| *Diesel* | 26.477 | 4.471 | 30.948 |
| *Petrol* | 10 | | 10 |
| *Natural gas* | 1.189 | | 1.189 |
| *LPG* | 0.02556 | | 0.255 |
| *Electricity dump charge* | | | 0.489 |
| | | | ∑53.612 |

The quantity for all the fuel types consumed by industry sector is taken from Statistics Norway. The input Various as described in FIDE Guide is used when the fuel consumption cannot be distributed anywhere or when it needs to be analyzed separately from the other inputs (Connolly, 2015). The loses are also included under "Various". The table below gives the full picture of the inputs of the Industry and Fuel demand of the reference scenario in EnergyPLAN model.

**Figure 7-1. The input data for Industry and fuel demand**

| *TWh/year* | *Industry* | *Various* |
|---|---|---|
| *Coal* | 7.4 | 1.29 |
| *Oil* | 10.5 | 31.51 |
| *Natural gas* | 3.2 | 52.11 |
| *Biomass* | 4.2 | 9.67 |

Power production in the modeling tool energyPLAN is divided in central production and variable production. Electricity production in Norway is mainly produced by hydropower. For 2018 the total installed capacity of hydropower plans was 32256 MW (International Hyndropower Association, 2019). In the supply section it is required the capacity of Dammed hydropower plant that is calculated with the following equation:

$Dammed\ hydro\ power\ installed\ capacity =\ Tot\ installed\ hydro\ power\ capacity -$
$Pumped\ Storage\ installed\ Capacity - Run\ of\ river\ Installed\ capapcity$ (2)

The values of the variables needed to calculate the installed capacity of Dammed Hydro Powerplants for 2018 are:

- Total installed capacity= 32256 MW (International Hyndropower Association, 2019)
- Pumped storage installed capacity= 1392 MW(International Hyndropower Association, 2019)
- Run of river installed capacity= 1328 MW (ENTSO-E, 2019)

After the substitution of the values listed above in the formula (2) the result of the calculation for 2018 is:

$$Dammed\ Hydropower\ capacity = 31174\ MW - e$$

The storage for Dammed Hydro is 86500 GWh according to (NVE, 2019), and Dammed hydro water supply is 148.41 TWh/year and pump efficiency for the Pump Back Hydro Powerplants is 0.9 according to (Askeland and Bozhkova, 2017).

The inputs for the electricity supply are summarized in table 7-3.

**Table 7-3. Inputs for Central Power Plants supply EnergyPLAN model**

| ***Central Power Plant*** | **Capacity (MW-e)** | **Efficiency** | **Annual Production (TWh/year)** |
|---|---|---|---|
| *Dammed hydro water supply* | | | 148.41 |
| *Dammed hydro power* | 31 174 | 90 | 133.57 |
| *Dammed hydro power storage* | *Storage capacity (GWh)* | *Pump back capacity (MW-e)* | *Pump back efficiency (%)* |
| | 86500 | 1392 | 90 |

The various electricity production is done by wind turbines, run-of-river hydropower plans, and PV panels.

The installed capacity of Wind Turbines in 2018 was 1675 MW (Wind Europe, 2018) from which 1673 MW onshore and 2MW offshore (IRENA, 2019b). The electricity production from wind turbines in 2018 was 3.876 TWh (SSB, 2019) from both onshore and offshore turbines. The file distribution for Norway doesn't exist so the chosen distribution file is wind_DK1_2015 that is the hourly production distribution profile that is based on the wind electricity production of the western Denmark that has similar climate conditions with Norwegian west coast. To regulate the production of electricity from wind turbines, I have used the correction factor minus 0.69 in order to achieve the correct electricity production, and this results in a capacity factor estimated 0.26.

The installed capacity of Photo Voltaic for 2018 according to (IRENA, 2019b) was 68 MW. The hourly distribution file used was "Hour_solar_prod1" that was available from the distribution file folder of EnergyPLAN. The estimated electricity production from Photo Voltaic power plants was 0.05 TWh and I haven't added any correction factor because the information for the total production form Photo Voltaic powerplants is missing. The capacity factor estimated is 0.08.

As mentioned in the sections above the installed capacity of Run of river hydropower plants in Norway for 2018 was 1328 MW (ENTSO-E, 2019). The file distribution for the run of river type is "River_hydro_flow" that can be found in the folder of file distribution of the model Norway 2015 and was build supported by the data measured the water flow of Nidelva river in Rathe (Askeland and Bozhkova, 2017). The estimated electricity production without correction factor, because the information of the actual Run of river powerplants was not available, was 4.8 TWh per year. This indicates a capacity factor equal to 0.41.

**Table 7-4. Variable renewable electricity supply for electricity in EnergyPLAN**

| *Technology* | *Capacity (MW)* | *Estimated production (TWh/year)* | *Correction factor* | *Production after correction (TWh/year)* | *Estimated CF* |
|---|---|---|---|---|---|
| *Wind* | 1675 | 5.08 | -0.69 | 3.88 | 0.26 |
| *PV* | 68 | 0.05 | | 0.05 | 0.08 |
| *River hydro* | 1328 | 4.8 | | 4.8 | 0.41 |

### 7.1.2 The verification of the Reference Model

After finishing with the process of inputting data into EnergyPLAN, the finalization of this important step that will affect all the progress of the work after is the verification of the model. Before starting to build the new scenarios, it is very important to ensure that the model created in EnergyPLAN operates the same as the energy system that we are trying to simulate. The verification is done mainly by the explanation given in the FIDE Guide and by adding some components that I found important for the verification of the reference model. The verification is done as listed in figure 7-2.

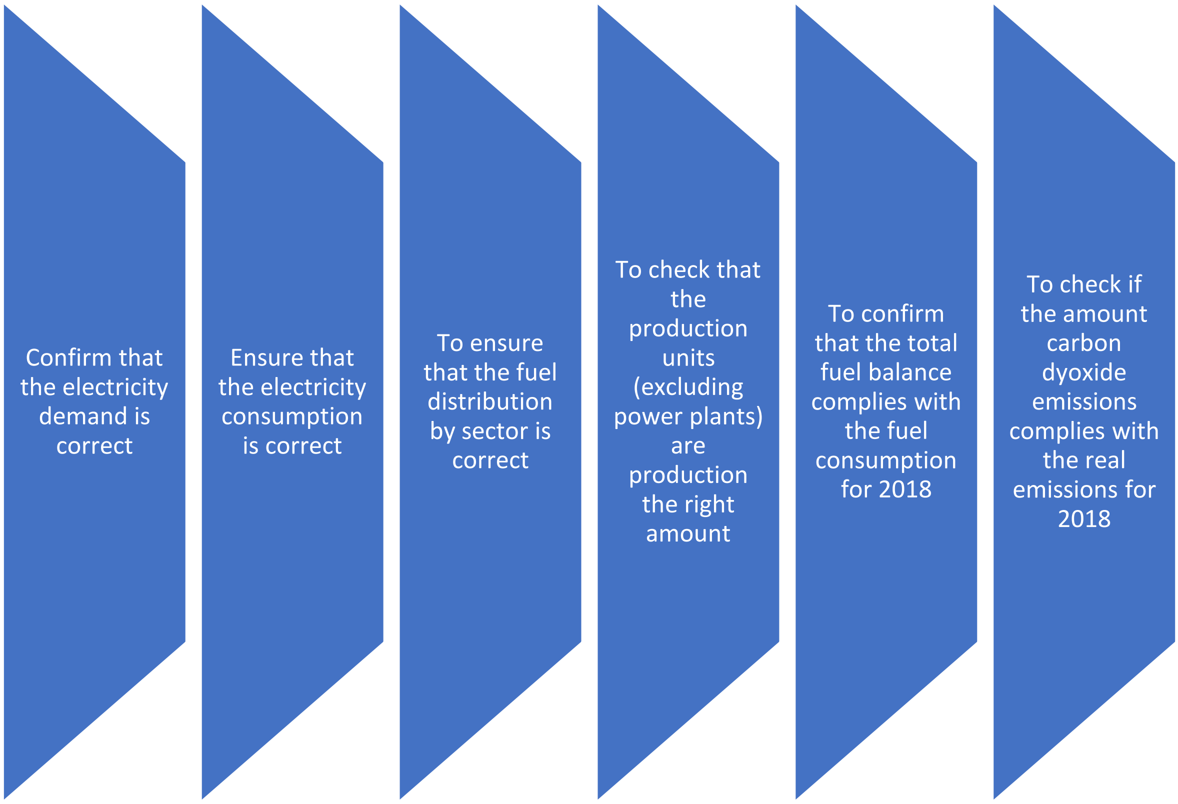


**Figure 7-2. Six steps for the verification of the reference model**

The output of the model complies with the real data for 2018 that are taken from statistics. There are some small differences in values that come as a result of the way the model operates and statistical error. During the period when I was collecting the inputs the same variables for the same year, I have found that there are small changes in values in different official statistical sites or reports. Taken that there is this type of changes in values across official statistical data, the small changes from the results generated from the simulation will EnergyPLAN are acceptable.

In the figure below can be observed the input and output data from the simulation of the reference scenario with EnergyPLAN. All the components mentioned above, that are checked in order to verify that the model simulated with EnergyPLAN works the same as the National Norwegian Energy System in 2018 are underlined with a circle.

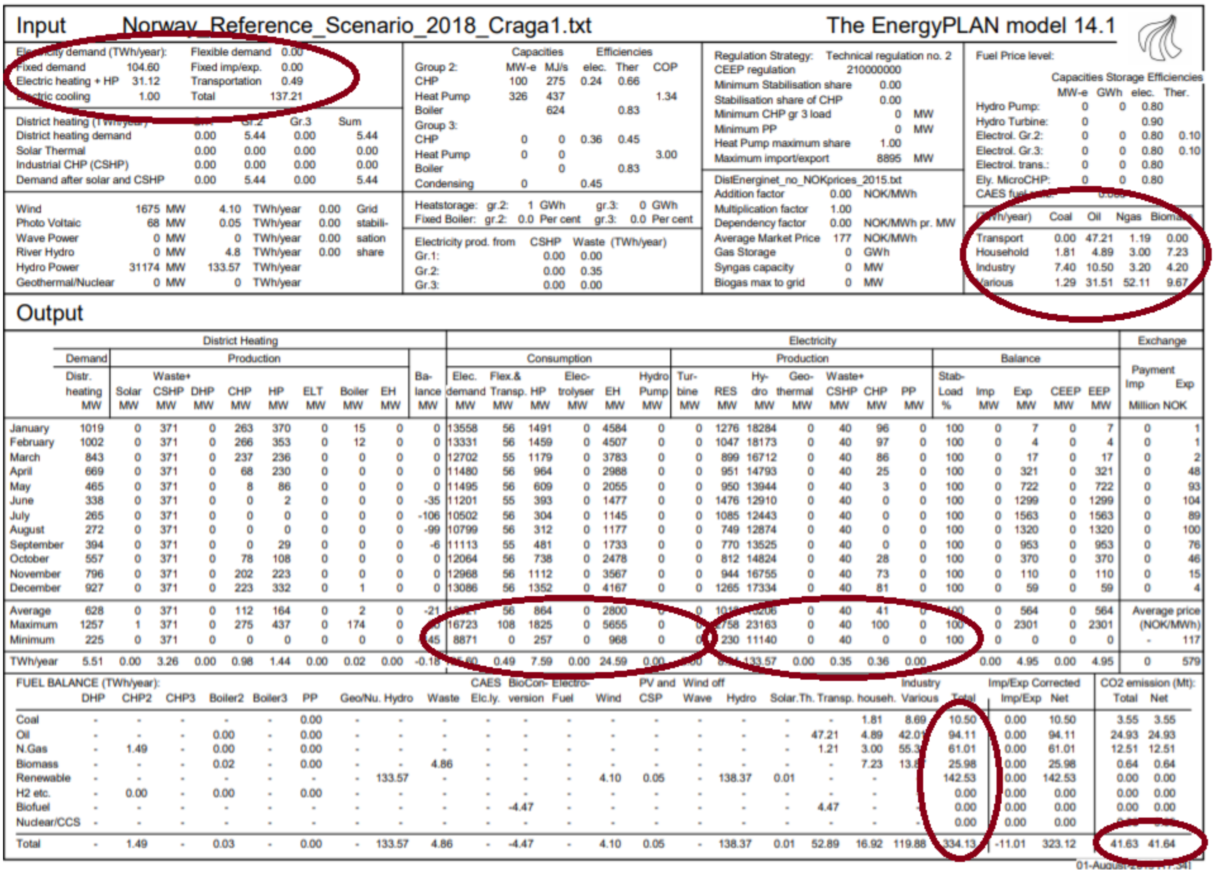


**Figure 7-3. The verification of the Reference Scenario Norway 2018**

The results taken from the simulation of an energy system with EnergyPLAN are in:

- Annual values
- Monthly values
- Hourly values

In this section can be observed the results for electricity demand and production with an hourly basis generated from EnergyPLAN with the input given for the Reference Scenario 2018, and it will be compared with real data for production and consumption that was available at (Statnett, 2019b).

As it can be seen in figure 7-4 (real data left, and data generated with energyPLAN) the line that gives the electricity production in both graphs has the same shape. This indicates that the results generated with energyPLAN are accurate. Due to the climate conditions of Norway, the profile of production and consumption is maximized during the cold winter months when the demand for electricity is higher. The production line follows the demand line in order to fulfill the required demand and minimizing the import of electricity. Norway is self-sufficient regarding electricity and at the same time, it is a net exporter of electricity in the Noord Pool power market. During springtime, the electricity demand declines while the water flow incline, due to a high amount of water from rain and snow melting in the mountains, in order to follow the domestic and external demand and to fill the dams. The demand and production reach the lowest levels during the month of July and August as it can be observed in the following pictures.

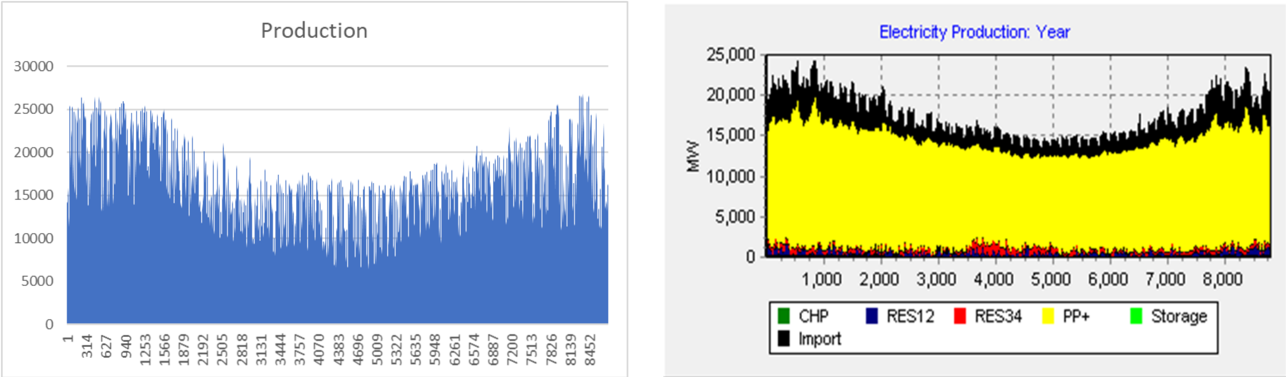


**Figure 7-4. Real electricity production (left) and electricity production according to the Reference model in EnergyPLAN (right) for 2018**

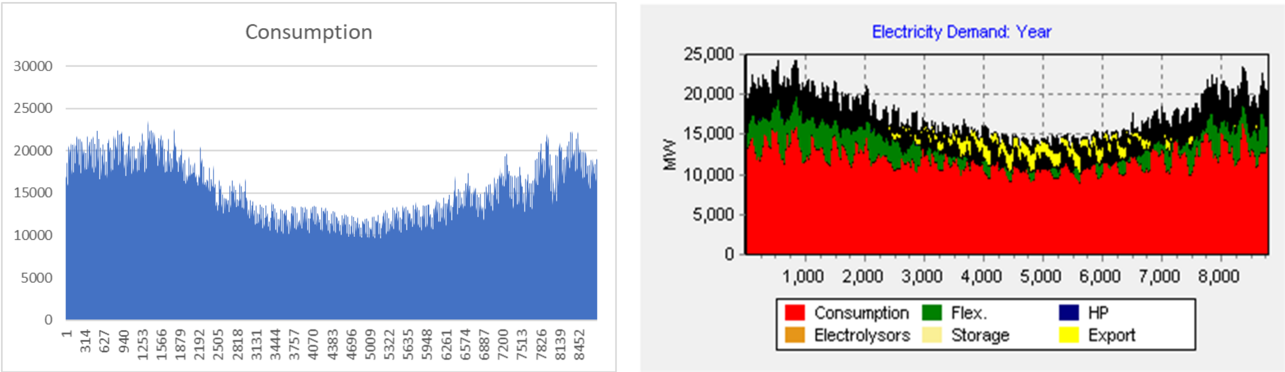


**Figure 7-5. The real electricity consumption (left) and electricity demand according to reference model in EnergyPLAN (right), 2018**

## 7.2 Future scenarios

The purpose of this section is to describe the future trends of passenger transport and build scenarios that are going to be studied with the energy model EnergyPLAN. The scenarios include the electrification of the transport sector in different level, taking into account the increase of the number of passenger electric vehicles and high penetration of wind power in the power system in order to fulfill the increase of electricity demand. In order to build the future scenarios, the analyze of the activity and the future projections have to be studied.

### 7.2.1 The analyses of the transport activity and future projections on passenger transport.

The Norwegian transport sector has radically changed since 1973. The process of economic and population growth has both resulted in a rapid increase in the number of vehicles and transport volumes, consequently, the energy consumption from this sector has increased with exponential growth. For a period of time equal with 42 years between 1973-2015 the energy consumption has increased with 63% and reached the level of 55.5 TWh. The major consumption was covered by road transport that consumed 69% of the total energy consumption by this sector. Only passenger transport covered 36% or 19.98 TWh and road freight 33% or 18.315 TWh (ODYSSEE-MURE, 2019). The remaining 31% or 17.205 TWh is the consumption of air and water transport. (SSB, 2019)

In 2018 the energy consumption by the transport sector was 53.68 TWh that is equal to around 22 percent of the total energy consumption in Norway. The energy consumption for 2018 has a slight decrease with 0.8 percent from the previous year. Oil and oil products are the dominant fuel in the transport sector and represent 47.2 TWh or 88.22 percent of the total consumption. In recent years, the usage of biofuel and natural gas in the transport sector has been increasing in significant amounts. In 2018 the consumption of natural gas and biofuels by transport sector was 1189 GWh equivalent with 2.22% of the total consumption by transport, and 4471 GWh, equivalent with 8.36% of the total consumption by transport. The process of electrification in the transport sector in Norway has started in early 1990 but the progress hasn't been very satisfactory so far. In 2018 the electricity consumption from transport sector was around 632 GWh or 1.2 percent of the total consumption. (SSB, 2019)

The share of RES in the total energy consumption in the transport sector is a very important indicator that shows the actual situation and indicates the future trend. The share of RES in the transport sector rose with 548% in eleven years, from 3.1 percent in 2005 in 17 percent in 2016. In 2013 the share of RES started to quicken, in only one year it doubled from 3.3 percent in 6.6 and continued at 8.8 percent in 2015 and reached the record level of 17 percent in 2016. The increase of RES in the transport sector is related to the increase in the number of electric vehicles in recent years, due to the generation of electricity almost totally with RES. (European Union, 2018)

The increase in transport volume over the years is clearly reflected in the domestic emission release. The transport sector is not only one of the bigger consumers of energy in Norway but at the same time one of the biggest polluters. Energy-related emissions represent the biggest part of the total emission released in the Norwegian territory, 2015 the emissions emitted by transport sector were 33.4% of the total energy-related emission. Emissions from the transport sector have increased with around 28% from 1990 to 2015 and their share grows with 4.7%, from 19.8% to 24.5% of the total energy emissions. Road transport gives the outweigh amount of emissions emitted by the transport sector. In 2015 road transport contributed with 77.8 percent of the total emissions by the transport sector, that is equal with 19.1 percent of the total emissions released in the Norwegian territory. Between 2007 and 2010 the amount of emissions by road transport has slightly downward due to the switch from petrol to diesel driven by the implementation of a new $CO_2$ tax in 2007. (Norwegian Environment Agency et al., 2017)

Since 2005 the $CO_2$ emissions from diesel and petrol passenger cars have decreased with one percent while the total road traffic volumes by the same type of passenger cars have increased with around 17 percent (Norwegian Environment Agency et al., 2017). The different trends on traffic volume and $CO_2$ emissions are driven by the use of more fuel-efficient passenger cars, by the increase of the number of diesel passenger cars and the decrease of the number of petrol passenger cars. The road traffic volume of petrol passenger cars during the period 2005-2015 decreased with around 46% meanwhile the road traffic volume of diesel passenger cars rose with more than three times the amount of 2005 (SSB, 2019).

From what mentioned above it is clear that the shift from the traditional conventional transport system in an electrified transport system is going to lead Norway in the path of the fulfillment of the Paris Agreement in climate changes. In Norway, the process of electrification has started very early but only in the recent years with the increased attention on climate change and sustainable development, a very aggressive campaign of incentives for the promotion of electric cars has started to give its benefits. In figure 6-7, can be observed the tendency of the passenger vehicles in the last ten years.

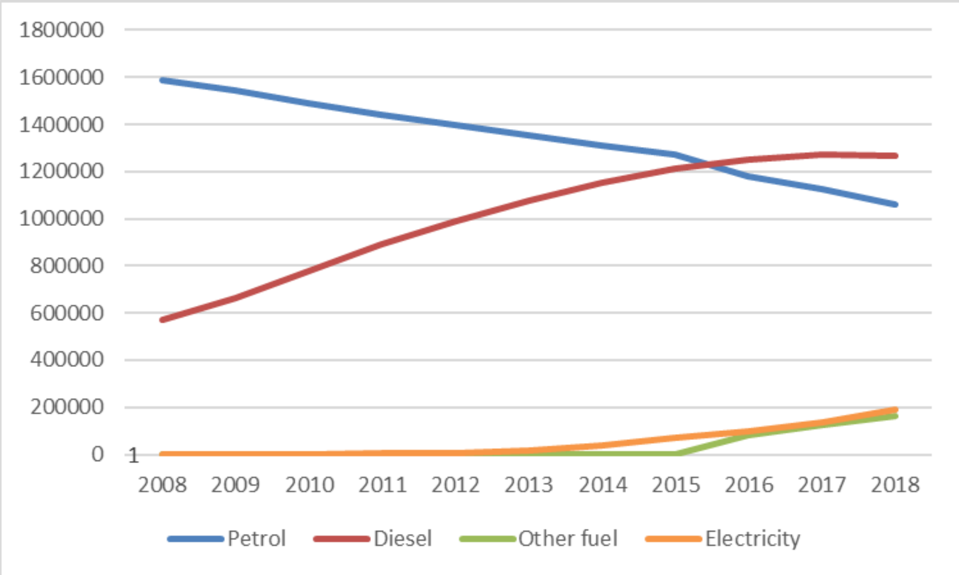


**Figure 7-6. The number of passenger cars 2008-2018 by sources**

In 2017 around 10 percent of the total passenger cars road traffic volume was covered by BEV and PHEV, by increasing with 40 percent from the previous year. EV covered 4 percent of the total road traffic volume in 2017 from 3 percent that the driven distance by EV constituted in 2016. The growing number of kilometers driven by EV and other fuels power cars are causing a decrease of the driven kilometers by diesel- and petrol-powered cars. The decrease in the driving kilometers only by passenger cars was respectively 0.4 and 6 percent for both categories.  (Statistics Norway, 2018b)

According to Statistics Norway, the number of registered passengers EV at the beginning of 2019 was 195351 and it is 40.6 percent higher than the previous year. Since 2013 the number of EV increased with 999.3 percent. (SSB, 2019) Oslo is the city with the highest number of passengers EV in Norway. In 2017 the number of registered passengers EV in Oslo was around 50 percent higher than in the previous year and for every 1 000 inhabitants, there were 37 electric cars in Oslo. The stock of passenger EV in the biggest cities in Norway was led by Oslo like mentioned above with 24 808 followed by Bergen with 12 782 and Bærum with 10 950 cars. In March 2018, 37% of the total new vehicles in Norway were EV. (Statistics Norway, 2018a)

In 2018, the year of our reference scenario, the total number of passenger vehicles was 2684797, from which 1268978 or 47% were diesel cars and 1060783 or 40% were petrol cars. The third more expanded type of passenger vehicles in 2018 was electric vehicles with 190648 cars. In the figure below is given the total share of passenger vehicles in 2018, according to the fuel. From the picture, it can clearly be noticed the high share of vehicles that use electricity on the total number of passenger vehicles. The percentage of passenger cars that run on electricity for this year was 190648 equals to 7 percent of the total number of passenger cars.

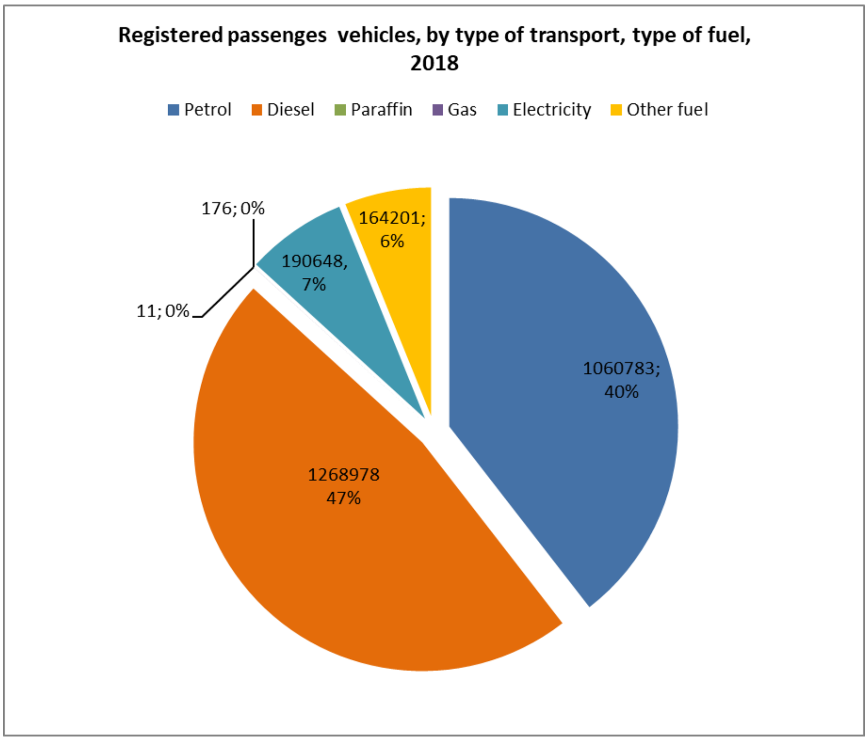


**Figure 7-7. The share of registered passenger vehicles by type of fuel, 2018**

The number of passenger cars will continue growing in the upcoming years due to the increase in population. What is expected to be different is the consummator behavior driven by incentives that support the electrification of the transport sector, will be mainly oriented on electric cars. The aim of the Norwegian government, in order to meet the climate targets for 2030 and 2050, is to replace all the existing diesel and petrol cars and all new cars with new environmentally-friendly vehicles. In the figure 7-8 is illustrated a possible shift traditional conventional passenger car that runs on diesel and petrol, towards electricity.

The increase of the number of electric cars is quicker in the first seven years, from 2018 till 2025 when the number is predicted to be 1778428 electric vehicles in order to achieve the target set to have more than 1.5 million electric vehicles by 2025. According to statistics, the number of sales is increasing very rapidly during 2019, an example is the number of new electric vehicles in March 2019 a total of 11518 vehicles that is almost twice the number registered in the same month in the previous year. Taken into account the information of the statistic for the number of sales in 2019, we assume that the number of electric vehicles at the end of 2019 will be 90 percent higher than in 2018. The trend of other fuel (that includes HEV, FCEV, V2G concept, etc.) will have a more radical increase and at the end of 2019, it will be 2,2 times higher than in 2018.

For 7 years from 2018 till 2025 the number of electric vehicles is predicted to grow with around 9.328 times from 2018 levels. After 2025 for a period of twenty-five years the increase based on the predicted number of 2025 will be around 56 percent, taken that the number of diesel and petrol vehicles is very low, and the total shift from the old traditional conventional vehicles in more environmentally friendly technology happens in 2050 when the number of petrol and diesel cars reaches the value of zero vehicles. But yet, due to the increasing number of population, the increase in the number of passenger vehicles will grow continuously since the targets for the future indicate that all the new light duty vehicles will be electric in order to achieve the long term goal of becoming a low emissions society by 2050, that requires a decrease with 80-95% of the total amount of GHG emission released in national level compared with the levels of 1990.

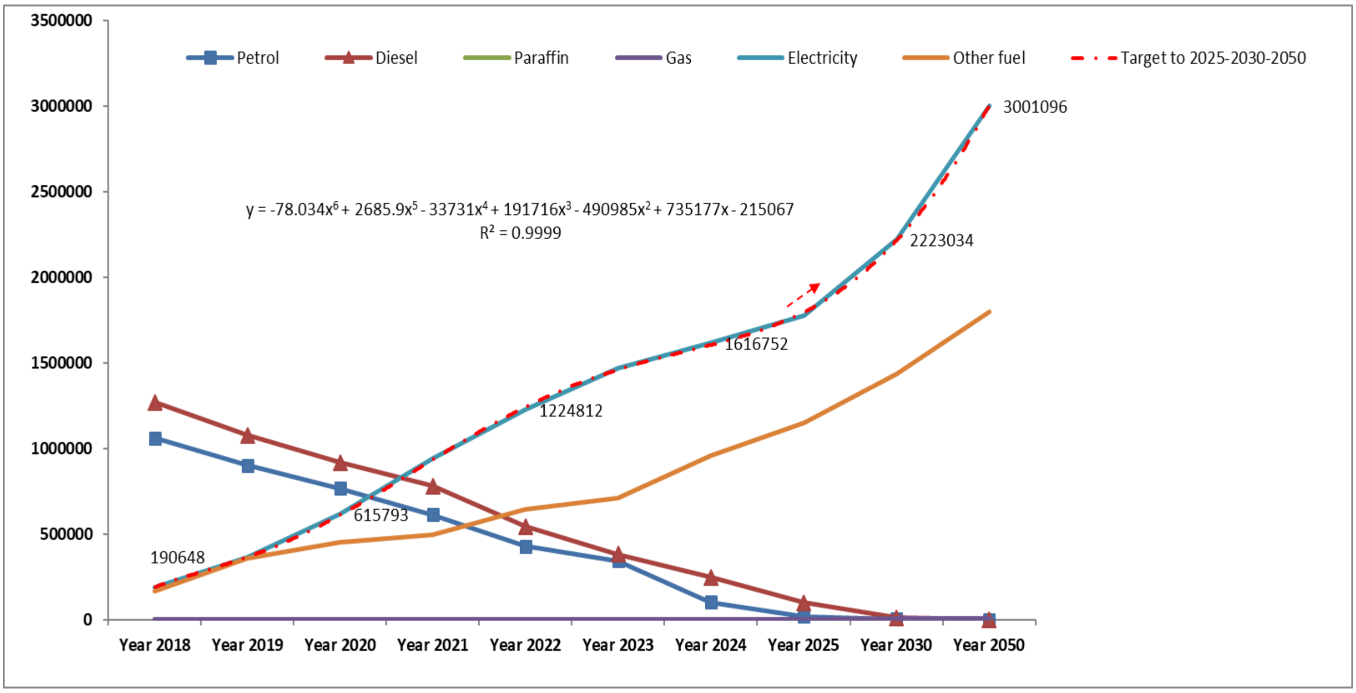


**Figure 7-8. The projections for the number of passenger vehicles by fuel in the future, 2018-2050**

In figure 7-9, can be observed the changes in the number of passenger vehicles by fuel from 2018 till 2050. The share of electric vehicles will have an enormous growth from 7 percent in 2018 it is predicted to reach 58% of the total number of passenger vehicles in 2025 and furthermore around 62.5 percent in 2050. In 2050 the number of petrol and diesel vehicles is predicted to be zero and the market share is divided between electricity and other fuels with 62.5 percent or 3001096 and 37.5 or 1797928 vehicles each.

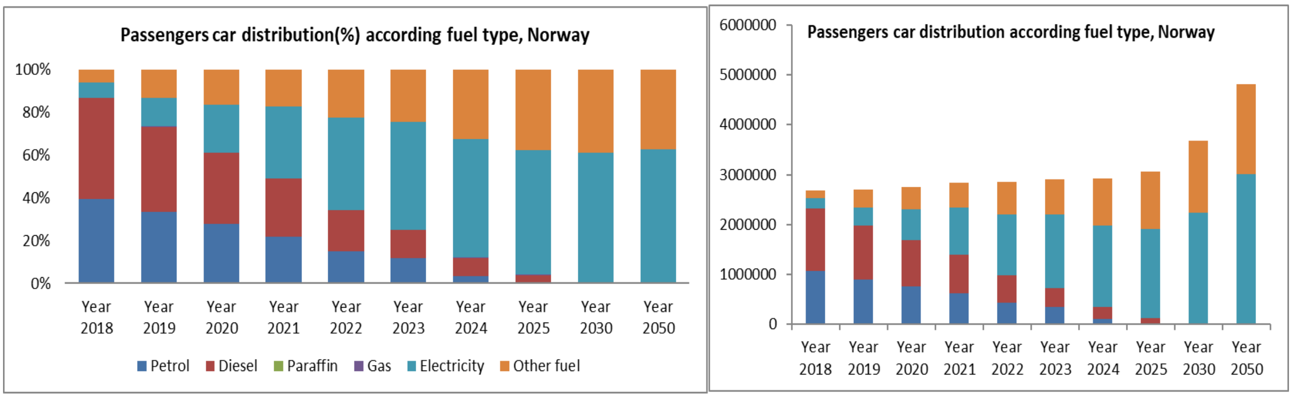


**Figure 7-9. The distribution of passenger vehicles in number and percentage by fuel, 2018-2050**

The changes in the structure of passenger vehicles will be reflected in the energy demand, in amount and type of energy required. The passenger transport in the future will be released form the historical dependence on fossil fuels and will be connected in the clean Norwegian power supply. From 0.49 TWh that was the electricity demand from passenger cars in 2018 the electricity demand from transport sector, in 2025 is calculated to be around 4.384 TWh and will continue increasing to reach 5.398 TWh in

2030 and furthermore 7.287 TWh in 2050. The increased demand for electricity on the other side brings the rapid decrease for diesel and petrol that in 2025 are respectively around 71 GWh and 342.8 GWh and reach the level of zero in 2050 as a consequence of the full replacement of petrol and diesel cars that run on electricity or other fuels (other than petrol or diesel).

To calculate the electricity demand for electric vehicles in the future is assumed that the annual average of driven kilometers per vehicle in Norway in the future will be 12141. As mentioned previously the average efficiency of electric vehicles is 5 km/kWh or 2kWh/km (Statnett, 2019a). The yearly electricity consumption from electric vehicles is calculated with equation (3):

$$Yearly\ electricity\ consumpetion\ by\ EV = Avarage\ driven(\frac{km}{vehicle}) * 0.2(\frac{kWh}{km}) *\ number\ of\ vehicles$$
(3)

The electrification of the transport sector contributes to the increase in the share of renewable energy in this sector since the electricity production in Norway is based on hydropower. The increase in electricity demand, by the other hand, will require new generating sources of electricity in order to fulfill the demand. Taking that the power system in Norway is mainly based in only one generating source the new investment should be in RES, other than hydro by diversifying the electricity generation and increasing, even more, the energy security of the Norwegian energy system and the power system in particular.

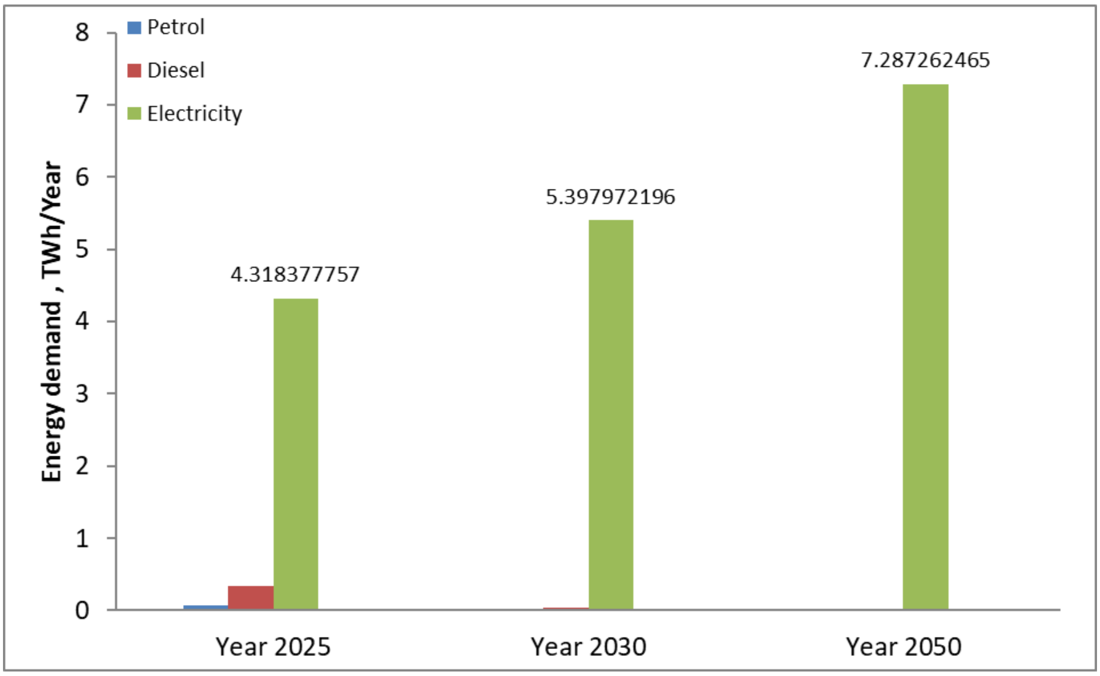


**Figure 7-10. The energy demand by passenger vehicles in the future**

During the calculation done in this section are supported in the following characteristics:

- According to Statistics Norway in 2018 the total number of passenger cars in Norway was around 2751948 (including diesel, petrol, EV and other) (SSB, 2019);
- The travel distance from the road, railway and water transport for 2018 was estimated to be around 46000 million km, from which 78.2% of the total amount or 35989.1 million km was the contribution of the passenger vehicles (SSB, 2019);
- Surveys have found that the current stock of cars in Norway has a fuel economy of about 3.9 l/100km; (Malka, 2016)
- The increasing rate of passenger cars in the period 2017-2018 was around 1.6%;
- The average number of cars for capita is around 525 cars/ 1000 inhabitant (SSB, 2019);

### 7.2.2 Building future scenarios

The reference scenario that was built for the Norwegian energy system 2018 is the start point for building future scenarios. The reference scenario will be extrapolated in 2025, 2030, 2050 that is the timeframe of this project. All the future scenarios are built based on the analysis of the future trend of transport sector done in the section above and some general assumptions, that are listed below:

- The total number of vehicles will continue increasing by following the trends of population growth;
- In 2050 the number of petrol and diesel cars will become zero;
- The increasing electricity demand will be covered with new wind generating units;
- The energy demand by passenger cars will decrease by around 30% till 2050 due to efficiency improvement;
- All the scenarios are frozen, due to study limitations the scenarios keep variables from some energy sectors unchangeable over the years;

The scenarios built in this study consider only the increase of the number of passenger electric vehicles in Norway, that contribute in the increase of electricity demand that will affect the security of self-sufficiency of the Norwegian power system in the future. In order to maintain the self-sufficiency and energy security of the power system the installation of new wind turbines, due to good wind sources in the Norwegian coast, is chosen as the solution given to the increase of electricity demand. With the purpose of answering the main research question of this study I have built:

- A short-term scenario for 2025
- A mid-term scenario for 2030
- Two long-term scenarios for 2050
    - Long-term scenario with the existing power supply
    - Long-term scenario with optimum wind penetration

#### 7.2.2.1 EV 2025 – a short term scenario

The scenario EV 2025 is the first scenario built and is a prediction for the future energy system of Norway in 2025. This scenario considers only changes in the transport sector and assumes that in the other sectors all the values will remain the same as in the Reference Scenario. The power supply is also assumed to be the existing power supply, and no new powerplants are added or old powerplants are closed. The simulation will be done on an hourly basis with a technical solution that balances heat and electricity. The values chosen for the number of electric vehicles are explained in section 7.2.1 and the increase in electricity demand is calculated according to the equation (3) part of the same section.

It is very important to clarify that in this scenario the annual investment costs and fixed operating costs are kept the same as in the reference scenario since there are no changes in the system supply. What changes from the reference scenario is the total variable cost, influenced by the replacement of a certain amount of fossil fuels with electricity and the reduction of $CO_2$ emissions.

In table 7-1, are given the values for the short-term scenario EV 2025. It is important to underline that all the values given for the variables that are part of this table are predicted values taken by a detailed analysis that considers different assumption and targets that the Norwegian Government has set for the transport sector. Therefore, the increase in the number of electric cars is very high in this first period because of the target of having more than 1.5 million electric vehicles by 2050.

**Table 7-5. The short-term scenario EV 2025**

| Number of EV | Electricity demand by EV (Twh/year) | Total energy demand (TWh/year) |
|---|---|---|
| **1778428** | 4.318 | 141.03 |

#### 7.2.2.2 EV 2030 – a mid-term scenario

The second scenario built for this study was a mid-term scenario for the predicted energy system in Norway in 2030. This scenario takes into consideration all the assumptions done in the scenario for 2025 and uses the same simulation with an hourly basis and a technical solution that balances heat and electricity. The values chosen for the number of electric vehicles are explained in section 7.2.1 and the increase in electricity demand is calculated according to the equation (3) part of the same section.

In 2030 the power supply is kept the same as the existing power supply. This because the growth of electricity demand by the transport sector as a result of the process replacing diesel and petrol cars with electric and other fuel cars, does not exceed the export of electricity. Therefore, a part of the electricity that before was exported outside of Norway now is used to cover the increased electricity demand. The electricity demand by electric vehicles, the total electricity demand, and the number of electric vehicles is given in table 7-6. It is important to underline that all the values for the variables mentioned above are predicted values based on assumptions and analysis.

**Table 7-6. EV 2030 - a mid-term scenario**

| Number of EV | Electricity demand by EV (Twh/year) | The total electricity demand (TWh/year) |
|---|---|---|
| **2223034** | 5.318 | 142.11 |

### 7.2.2.3 EV 2050 Existing and EV 2050 Wind Optimum – two long term scenarios

The timeframe of this study was 2050. It is assumed that in 2050 the replacement of the conventional passenger vehicles with new electric and other fuel vehicles is finished. Therefore, the total number of passenger vehicles in 2050 is divided between electric vehicles and other fuel vehicles. Two different scenarios are built for 2050.

For the first scenario that is named EV 2050 Existing takes into consideration all the assumptions done in the scenario for the two first scenarios (EV 2025 and EV 2030) and uses the same simulation with an hourly basis and a technical solution that balances heat and electricity. The values chosen for the number of electric vehicles are explained in section 7.2.1 and the increase in electricity demand is calculated according to the equation (3) part of the same section.

**Table 7-7. EV 2050 Existing and Wind - the long-term scenarios**

| ***Scenario*** | **Number of EV passenger vehicles** | **Electricity demand by EV** | **Total electricity demand (TWh/year)** | **The installed capacity of wind power** |
|---|---|---|---|---|
| *EV 2050 Existing* | 3001096 | 7.287 | 144.0 | 1650 |
| *EV 2050 Wind* | 3001096 | 7.287 | 153.84 | 8000 |

Due to the increasing trend of electricity demand by transport sector, the electricity demand in 2050 is expected to overcome the production by rising the need for installing new generating units in order to save the self-sufficiency and energy security of the Norwegian power system, as a very important element of the national power system, part of the Energy Trilemma. Taken that Norway has abundant unexplored wind sources with good potential, in this study based on today's trends and under construction projects for electricity generation, we assume that the electricity demand will be met by installing new wind generating units.

The long-term scenario of 2050 has an extra scenario with new installed wind capacity named EV 2050 Wind Scenario.  In order to create the EV 2050 Wind Optimum scenario, an optimization analyze is done for finding the optimum of the new wind capacity in order to make the investment feasible in terms of cost. For both, Wind Optimum and High Wind Penetration scenario, the values are chosen for the number of electric vehicles are explained in section **Error! Reference source not found.** and increase of electricity demand is calculated according to the equation (3) part of the same section. An important difference that

As mentioned above in 2050 driven by the increase in electricity demand by the transport sector is it expected that the electricity demand will overcome domestic electricity production. In this way, Norway will lose the self-sufficiency on the power sector and at the same time the importance on the European power market as one of the bigger exporters of green electricity. Taken that Norway is abundant on natural sources and electricity is generated mainly only by hydropower plants the increase of the domestic demand will increase the interest in building new generating units.

The extra electricity demand will be covered by installing new wind turbines. While the wind power potential is high, it is very important to find an optimum that makes the investment of wind turbines feasible. An optimization analysis is done in order to find the optimum installed wind capacity. This analysis considers some important findings of a study done by CenSES, that underlines that in 2050 the population will grow with 38% form 2015 by adding an electricity demand by residential sector with around 25% (Rosenberg et al., 2015). The population growth and the demand growth are not in the same levels due to the increase of energy efficiency in all sector, including the residential sector.

In the EV 2050 Wind optimum scenario is it assumed an increase of the energy demand of the residential sector with 9.84 TWh based on the findings of (Rosenberg et al., 2015), and electricity demand by transport sector is assumed to be 7.29 TWh, the calculations are explained in the sections above.

To sum up, the optimum installed wind power capacity will not only cover the added electricity demand by transport sector in 2050, but in the same time the added electricity demand by residential sector and furthermore it should ensure a certain amount of electricity for export, by saving the importance that Norway has in the European Power market as an exporter of green electricity. In the figure below is illustrated the optimum wind penetration for the Norwegian energy system in 2050, that considers all the elements mentioned above.

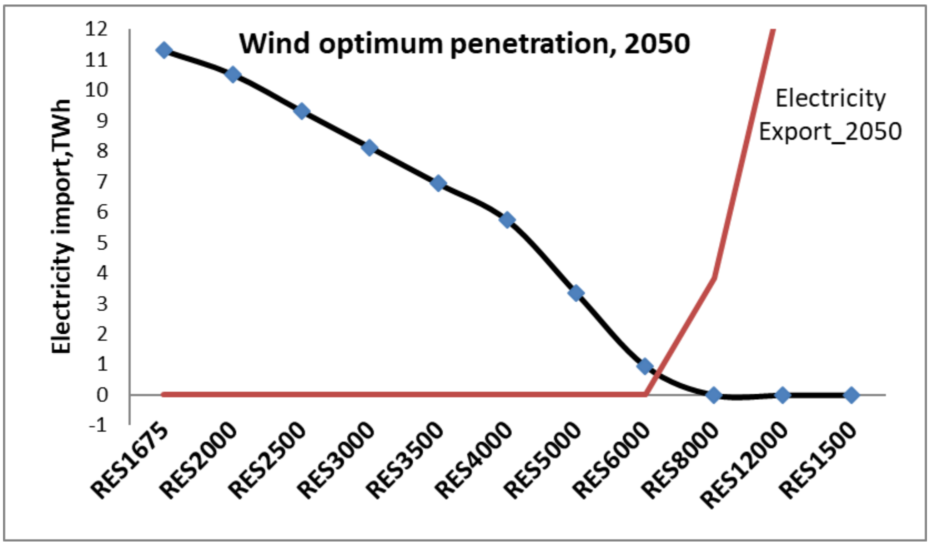


**Figure 7-11. The optimization of wind penetration in the Norwegian energy system of 2050**

As it is illustrated in figure 7-11 in 2050 with the added electricity demand by passenger cars and residential sector the electricity generation will not cover the domestic electricity demand. From a net exporter of electricity, Norway will automatically become a net importer. The optimization of the system firstly requires achieving the self-sufficiency of the power system by making the import of electricity zero. Secondly, since fluctuation on the electricity demand can appear any time and it is in the interest of the country to keep the place like a net exporter of green electricity in the European electricity market it is of high interest that the production of electricity to be higher than the predicted electricity demand. In this way, if fluctuation appears any time, the country will still be able to cover its electricity demand and if not the amount of electricity that remains after the domestic demand is covered can be exported by bringing revenue.

The Norwegian Energy System in 2050, according to this scenario with the assumptions mentioned above has an optimum wind penetration when the installed wind power capacity is 8000 MW. As it can be observed in the graph in the figure above in the optimum wind penetration the import of electricity is zero and the export reaches the level of 3.82 TWh/year.

An important difference between the Wind Optimum and the other scenarios is the change of the annual investment cost caused by the increase of the installed capacity of wind turbines. Therefore, the total annual cost will be increased not only by total variable cost but also by the added investment cost for the new wind power capacity.

# 8 Results

The purpose of this chapter is to present the results of the simulation with EnergyPLAN for all the future scenarios built for the Norwegian energy system in 2025, 2030, and 2050. All the results are summarized in a table where only the main elements that help to answer the research questions will be emphasized.

The focus of this study was to analyze how a possible electrification of the transport sector would affect the total amount of CO2 emissions emitted in the Norwegian energy system, and the increase the installed wind capacity in order to avoid compromising the energy security of the future Norwegian energy system.

In the table 8-1 are summarized the results for fours future scenarios (EV 2025, EV 2030, EV 2050 Existing, and EV 2050 Wind) and the Reference scenario for 2018.

**Table 8-1. The results of the simulation with EnergyPLAN**

| | **Reference** | **EV 2025** | **EV 2030** | **EV 2050** | |
|---|---|---|---|---|---|
| | | | | EV 2050 existing | EV 2050 Wind optimum |
| **CO2 emissions (Mt)** | 41.64 | 38.68 | 36.69 | 35.9 | 35.85 |
| **RES share of PES (%)** | 50.4 | 52.2 | 53.4 | 53.9 | 56.1 |
| **RES share on electricity demand** | 134.6 | 130 | 128.7 | 126.6 | 107.5 |
| **Fuel consumption (TWh)** | 323.12 | 320.24 | 315.06 | 316.38 | 319.47 |
| **Electricity demand (TWH)** | 137.21 | 141.03 | 142.11 | 144.0 | 153.84 |
| **Electricity Import (TWh)** | 0 | 0 | 0 | 1.66 | 0 |
| **Electricity Export (TWh)** | 4.95 | 1.24 | 0.19 | 0 | 3.82 |
| **Total cost (mln NOK)** | 97159 | 89949 | 84916 | 83281 | 87639 |

In table 8-1, is represented the electricity demand for all the scenarios built in this study, including the reference scenario that was built based on the Norwegian Energy System in 2018. From 2018 till 2050 the electricity demand grows in two paths. In the first path, the electricity demand is increased only with the increase of the electricity demand by the transport sector, that comes from the replacement of the conventional vehicles with electric vehicles and from 137.21 TWh the electricity demand reaches 144 TWh in 2050. In the second path, an increase with 9.82 TWh in the residential sector is predicted due to the increase in the number of population and consequently the energy demand that is assumed to be covered with electricity. The second path leads to the scenario EV 2050 Wind where the total electricity demand is 153.84 TWh.

While the electricity consumption has a growing tendency, the total fuel consumption decreases until 2030 regardless of the increase in the total number of passenger vehicles. This thanks to the increase of the efficiency, because the electric motor of new electric cars that have replaced the old conventional cars with ICE motor have an efficiency that is three to four times higher. Only in EV 2050 Wind scenario that takes into consideration the increase of energy demand in the residential sector due to the population growth the total fuel consumption increases. The fluctuations in energy demand affect the total annual cost of the system. As a result of the decreased energy demand, the total annual cost decreases in the future, regardless that the income from the export of electricity decreases and in 2050 becomes negative because Norway from a net exporter of electricity becomes a net importer.

In figure 8-1, is illustrated the change in electricity demand, fuel demand and cost of the total system for all the scenarios.

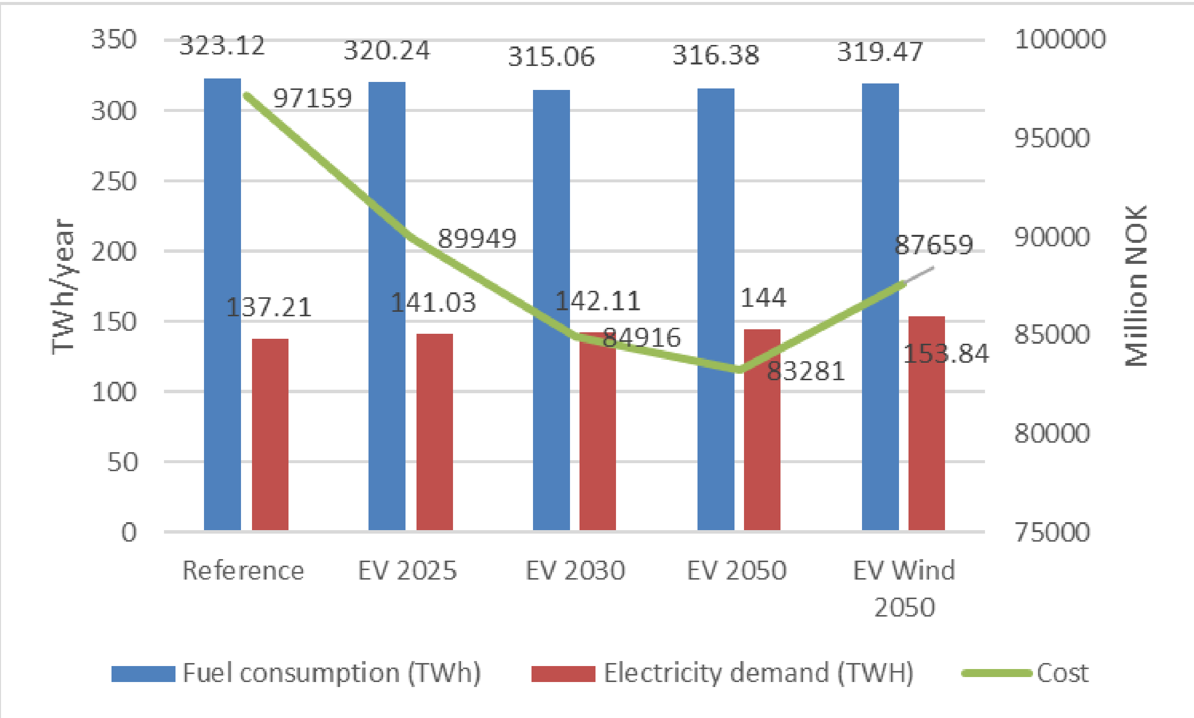


**Figure 8-1.The effects of the changes in the fuel and electricity demand on the total annual cost of the system**

As it can be seen from figure 8-1 in the last scenario, EV 2050 Wind all the indicators are increased because different from the other this is a half-frozen scenario and takes into consideration the increase of the energy demand in the residential sector due to the population growth. The other scenarios are frozen scenarios and consider only the changes on the number of passenger vehicles, both increase of the total number of passenger cars and the replacement of the diesel and petrol vehicles with electric vehicles or other fuels that are more efficient and environmentally friendly.

As mentioned at the beginning of this section the focus of this study is to analyze the tendency of $CO_2$ emissions with the increase of the scale of electrification in the transport sector, in this case, the replacement of the diesel and petrol passenger vehicles with electric or other fuel vehicles. As it was expected in the general assumptions of the study the switch of the conventional vehicles with new more efficient electric or other fuel vehicles results in significant emission reduction. In a period of 32 years between 2018 and 2050, regardless the increase of the traffic volume and number of vehicles as a result of the replacement of fossil fuel with electricity and efficiency improvements the $CO_2$ emissions will decrease with 5.74 Mt $CO_2$. When compared with the EV 2050 Wind scenario that considers an increase in energy demand by transport sector with 9.82 TWh the $CO_2$ emissions have a further decrease with 0.05 Mt $CO_2$ per year.

In figure 8-2, is illustrated how the increase in electricity demand by transport sector (in the last scenario is the increase of electricity by the transport and residential sector), affects the emission reduction.

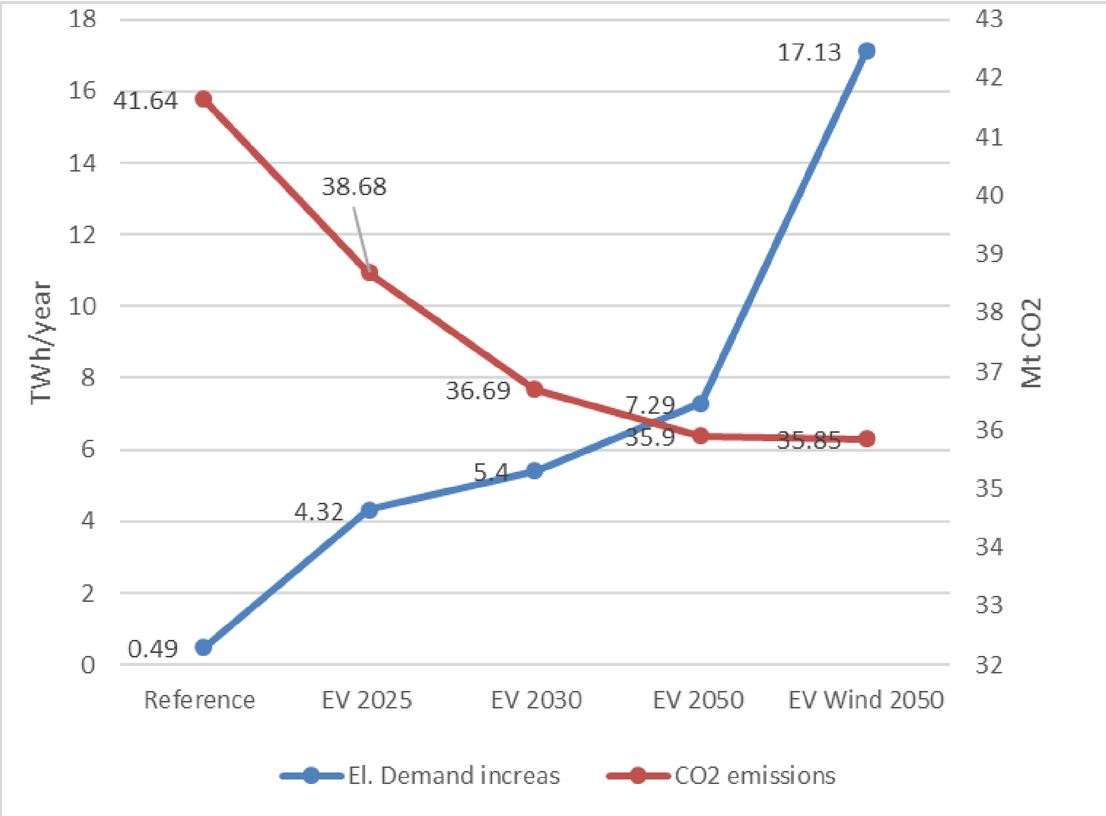


**Figure 8-2.The reduction of $CO_2$ emission with the increase in electricity demand**

Due to the electricity generation based on RES, the replacement of fossil fuels with electricity increases the share of RES on the primary energy supply of the total energy system. From 50.4 percent that is the share of RES of PES in the reference scenario of 2018 in 2050, it reaches the values of 53.9 percent in the EV 2050 Scenario and 56.1 percent in the EV 2050 Wind Scenario.

In figure 8-3, is given the change of the RES share on the total primary energy supply for the future scenarios of the Norwegian energy system.

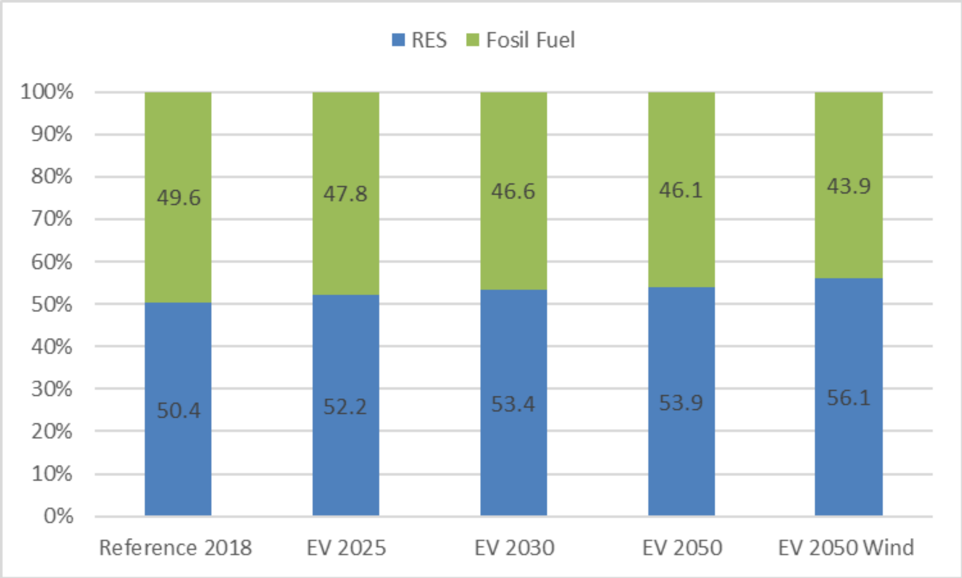


**Figure 8-3. The progress on RES share in the primary energy supply of the Norwegian energy system**

# 9 Conclusions

The findings of this study suggest adding an optimum wind power capacity in 2050 because it would result in the increase of RES share in the PES of the country from 50.4% to 56.1%, and it would reduce the CO2 emissions with 13.9% compared with the levels of the reference scenario. Furthermore, it would increase the energy security of the Norwegian energy system and would generate more electricity than the domestic demand by keeping the role of Norway as a net exporter of green electricity in the European power market. The reduction of $CO_2$ emission compared with the level in 1990 is negative. From 35.85 Mt $CO_2$ (SSB, 2019) the amount of emissions emitted in 2050 according to the results taken by the simulation with energyPLAN was 35.85 Mt$CO_2$.

In conclusion, based on the number of all analysis done for this study that take in consideration technical as well as socio-economic effects of a possible switch from conventional passenger vehicles to electric passenger vehicles, it is obvious that the interaction between the transport sector and the proposed RES based energy system is crucial for the integration of large scale of wind power in the future energy system of Norway.

Moreover, it can be conducted that all the forms of energy storage technologies (ST), as well as electric vehicles, would have a central role in the future Norwegian energy system. Especially a great interest stands in integrating and converting the EV technology into a V2G technology. Due to low electricity demand during the night time, the electricity produced by wind farms could be conserved by using ST. In this case, EV serves as a solution with good potential and low cost for energy storage. Furthermore, it may serve as a potential grid stabilization technology for the future energy system of Norway.

Some suggestions for further work to expand the analysis conducted in this master thesis are:

- It would be of great interest to analyze the techno-economic effects that the integration of different fuels within the transport sector (e.g. the introduction of hydrogen fuel cell vehicles). Therefore, the effects of such technologies that utilize hydrogen as the energy carrier could be investigated in the future.
- Another interesting future work would be analyzing the effects of technical means of wind integration. In this way more synergy effects could possibly be created both in the heat storage by introducing into the model Heat Pump for heat storage and in the transport sector, using the effects of synergy. This would, of course, bring the need for increasing the ability of the energy system to integrate large volumes of wind power in the future.

Lastly, this study can be expanded by analyzing the effects of various technical means of wind integration by applying a Technical Optimization strategy in the modeling tool EnergyPLAN. Hence, it would be of high interest to know how different potential options and solutions that use optimization strategies can affect the fuel consumption, CO2 emissions, CEEP and the social-economic cost of the future energy system in Norway.

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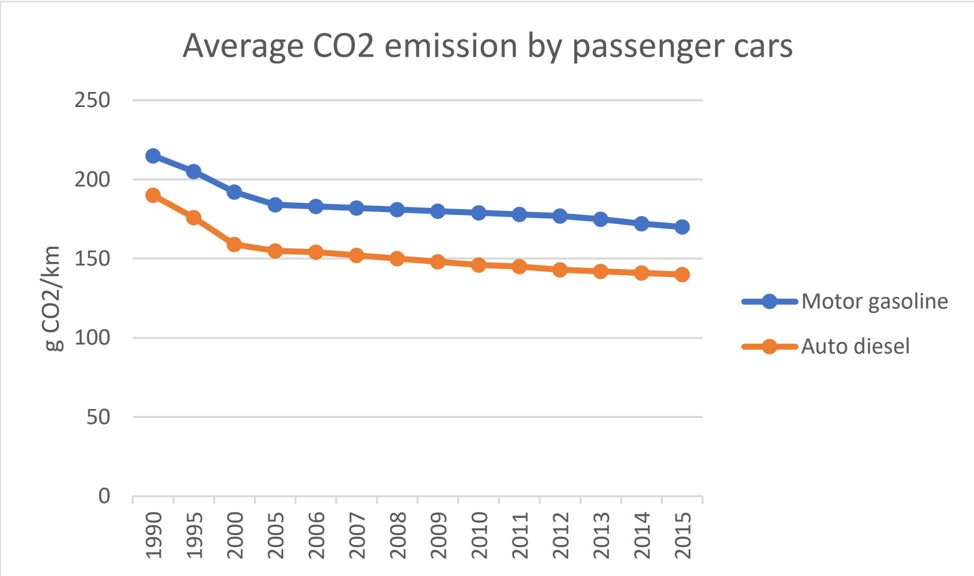
# Appendices

## Appendix 1

The graph below gives the average $CO_2$ emissions for passenger cars, motor gasoline and auto diesel, calculated with the usage of Handbook of Emission Factors. The calculation includes the cold start emissions and evaporation.



## Appendix 2

This section contains all the input data for the Reference scenario in EnergyPLAN model. All the tables in this section are taken by the document," The Norwegian Energy System 2015. Reference scenario model description" from (Askeland and Bozhkova, 2017).

***Demand Tab***

**Individual heating**

| Indv. heating | Fuel input [TWh/year] | Efficiency [%] | Heat demand [TWh/year] | Electric efficiency [%] | Capacity limit [-] |
|---|---|---|---|---|---|
| Coal | 1.81 | 80 | 1.45 | - | - |
| Oil | 4.89 | 92 | 4.50 | - | - |
| Ngas | 3 | 100 | 3 | - | - |
| Biomass | 7.23 | 83 | 6.00 | - | - |
| Heat pump | - | - | 15 | 2.3 (COP) | 1 |
| El. heating | - | - | 24.6 | - | 1 |

**District heating**

| DH group | Production [TWh/year] | Network losses [%] | Heat demand [TWh/year] |
|---|---|---|---|
| Group 1 | 0 | 0 | 0 |
| Group 2 | 5.444 | 11 | 4.83 |
| Group 3 | 0 | 0 | 0 |

**Cooling**

| Cooling | Electricity consumption [TWh/year] | Heat consumption [TWh/year] | COP [-] | Cooling demand [TWh/year] |
|---|---|---|---|---|
| Electric | 1 | - | 1 | 1.0 |
| Group 1 | - | 0 | - | 0 |
| Group 2 | - | 0.07 | 2.4 | 0.17 |
| Group 3 | - | 0 | - | 0 |

***Supply Tab***

**Fuel distribution (Heat and electricity)**

| CHP | Group 2 | Group 3 |
|---|---|---|
| **CHP condensing mode operation** | | |
| Electric capacity (PP1) [MW-e] | - | - |
| Electric efficiency [%] | - | - |
| **CHP back pressure mode operation** | | |
| Electric capacity [MW-e] | 100 | 0 |
| Thermal capacity [MJ/s] | 275 | 0 |
| Electric efficiency [%] | 24 | 0 |
| Thermal efficiency [%] | 66 | 0 |

**The production and capacity of the boilers**

| Boiler type | Fuel input [GWh] | Efficiency [%] | Production [GWh] | Full load hours [h] | Capacity [MW] |
|---|---|---|---|---|---|
| **Oil** | 87.1 | 92 | 80.132 | 2 500 | 32.05 |
| **Ngas** | 205.8 | 92 | 189.336 | 2500 | 75.7 |
| **Biomass** | 1 914.8 | 87 | 1 665.9 | 3 225 | 516.6 |
| **Electric** | - | 98 | 784 | 2500 | 313.6 |

**Heat only**

| Heat only | Group 1 | Group 2 | Group 3 | Unit |
|---|---|---|---|---|
| **Solar Thermal** | | | | |
| Production | 0 | 0.004 | 0 | [TWh/year] |
| Storage | 0 | 0.07 | 0 | [GWh] |
| Loss | 0 | 0.05 | 0 | [% share] |
| Share | 0 | 0.0007 | 0 | [% share] |
| Result | 0 | 0 | 0 | [TWh/year] |
| **Compression Heat Pump** | | | | |
| Electric capacity | - | 325.78 | 0 | [MW-e] |
| COP | - | 1.34 | 0 | [-] |
| Thermal capacity | - | 437 | 0 | [MJ/s] |
| **Geothermal from Absorption HP** | 0 | 0 | 0 | [TWh/year] |
| **Industrial Excess Heat** | 0 | 0.181 | 0 | [TWh/year] |

**Fuel distribution**

| Fuel | Coal [TWh/year] | Oil [TWh/year] | Ngas [TWh/year] | Biomass [TWh/year] |
|---|---|---|---|---|
| DHP | 0 | 0 | 0 | 0 |
| CHP2 | 0 | 0 | 7.62 | 0 |
| CHP3 | 0 | 0 | 0 | 0 |
| Boiler2 | 0 | 0.0871 | 0.2058 | 1.9148 |
| Boiler3 | 0 | 0 | 0 | 0 |
| PP1 | 0 | 0 | 0 | 0 |
| PP2 | 0 | 0 | 0 | 0 |

**Waste incineration**

| Unit | Waste input [TWh/year] | DH efficiency [%] | DH prod. [TWh/year] | Electric efficiency [%] | Electricity prod. [TWh/year] |
|---|---|---|---|---|---|
| Group 1 | 0 | 0.8 | 0 | 0 | 0 |
| Group 2 | 4.8568 | 0.633 | 3.07 | 0.073 | 0.35 |
| Group 3 | 0 | 0 | 0 | 0 | 0 |
| Total | 4.86 | - | 3.07 | - | 0.35 |

**$CO_2$ for different fuel type**

| Fuel type | $CO_2$ content | 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] |

***Cost***

The price of $CO_2$ =60 NOK/ $tCO_2$

The interest rate = 4%

**Investment and O&M fixed costs**

| Technology | Unit | Investment [MNOK/Unit] | Period [Years] | O&M [% of inv.] |
|---|---|---|---|---|
| **Heat & Electricity** | | | | |
| Small CHP units | [MW-e] | 10 | 25 | 2.6 |
| Heat storage CHP | [GWh] | 61.1 | 20 | 0 |
| Waste CHP | [TWh/year] | 4 689 | 20 | 2.8 |
| Heat pump gr 2 | [MW-e] | 1.14 | 20 | 0.3 |
| Boilers gr 2+3 | [MW-th] | 5.7 | 20 | 8.9 |
| **Renewable energy** | | | | |
| Wind | [MW-e] | 10.25 | 20 | 0.77 |
| Photo voltaic | [MW-e] | 15 | 25 | 2 |
| River of hydro | [MW-e] | 8.8 | 40 | 1.5 |
| Hydro power | [MW-e] | 8.8 | 40 | 1.5 |
| Hydro pump | [MW-e] | 1.31 | 40 | 1.5 |
| Industrial excess heat | [TWh/year] | 30 | - | - |
| **Heat infrastructure** | | | | |
| Indv. boilers | [1000-Units] | 0.063 | 20 | 13.9 |
| Indv. HP | [1000-Units] | 0.063 | 15 | 0.2 |
| Indv. Electric heat | [1000-Units] | 0.018 | 20 | 13 |
| Indv. Solar thermal | [1000-Units] | 49.9 | 25 | 0 |

**Additional O&M and investment costs**

| Description of investment | Period [Years] | O&M [% of inv.] | Total inv. cost [MNOK] |
|---|---|---|---|
| **DH Network** | 40 | 0.1 | 3906.59 |
| **DH Substation** | 20 | 8.5 | 265.44 |

**Fuel prices**

| | Coal | Fuel oil | Diesel /Gasoil | Petrol /JP | Ngas | Biomass |
|---|---|---|---|---|---|---|
| **Fuel price** | 28.48 | 85.74 | 151.83 | 160.76 | 72.88 | 62.6 |
| **Fuel handling costs** | | | | | | |
| Central CHP and power stations | 0.6 | 2.04 | - | - | 3.83 | 10.39 |
| Dec. CHP, DH and industry | - | 17.14 | - | - | 10.43 | 10.03 |
| Individual households | - | - | 26.01 | - | 26.37 | 54.78 |
| Transport (road and train) | - | - | 28.29 | 38.12 | - | 102.97 |
| Transport (air) | - | - | - | 6.23 | - | - |
| **Taxes** | | | | | | |
| Individual households | - | - | 132.31 | - | 22.77 | - |
| Industry | - | 77.46 | - | - | 22.77 | - |
| Boilers | - | 77.46 | - | - | 22.77 | - |
| CHP units | - | 77.46 | - | - | 22.77 | - |

**Electricity convention taxes**

| NOK/MWh | DH systems | Individual houses |
|---|---|---|
| Electric heating | 0.0048 | 0.16 |
| Heat Pumps | 0.0048 | 0.16 |
| Electrolysers | 0.0048 | 0.16 |
| Electric cars | - | 0.16 |
| Pump storage | 0.0048 | - |

**Variable O&M costs**

| | Cost | Unit |
|---|---|---|
| **DH and CHP systems** | | |
| Boiler | 11 | NOK/MWh-th |
| CHP | 30 | NOK/MWh-e |
| Heat Pump | 12 | NOK/MWh-e |
| Electric heating | 1 | NOK/MWh-e |
| **Individual** | | |
| Boiler | 15 | NOK/MWh-th |
| CHP | 0 | NOK/MWh-e |
| Heat Pump | 2 | NOK/MWh-e |
| Electric heating | 1 | NOK/MWh-e |

# Input Norway_Reference_Scenario_2018_Craga1.txt The EnergyPLAN model 14.1

| Electricity demand (TWh/year): | | Flexible demand | 0.00 |
|---|---|---|---|
| Fixed demand | 104.60 | Fixed imp/exp. | 0.00 |
| Electric heating + HP | 31.12 | Transportation | 0.49 |
| Electric cooling | 1.00 | Total | 137.21 |

| District heating (TWh/year) | Gr.1 | Gr.2 | Gr.3 | Sum |
|---|---|---|---|---|
| District heating demand | 0.00 | 5.44 | 0.00 | 5.44 |
| 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 | 5.44 | 0.00 | 5.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wind | 1675 | MW | 4.10 | TWh/year | 0.00 | Grid |
| Photo Voltaic | 68 | MW | 0.05 | TWh/year | 0.00 | stabili- |
| Wave Power | 0 | MW | 0 | TWh/year | 0.00 | sation |
| River Hydro | 0 | MW | 4.8 | TWh/year | 0.00 | share |
| Hydro Power | 31174 | MW | 133.57 | 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 | 0 | | 0.45 | | |

Heatstorage: gr.2: 1 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 | 0.35 |
| 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 |

| DistEnerginet_no_NOKprices_2015.txt | | |
|---|---|---|
| Addition factor | 0.00 | NOK/MWh |
| Multiplication factor | 1.00 | |
| Dependency factor | 0.00 | NOK/MWh pr. MW |
| Average Market Price | 177 | NOK/MWh |
| Gas Storage | 0 | GWh |
| Syngas capacity | 0 | MW |
| Biogas max to grid | 0 | MW |

Fuel Price level:

| 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 | 47.21 | 1.19 | 0.00 |
| Household | 1.81 | 4.89 | 3.00 | 7.23 |
| Industry | 7.40 | 10.50 | 3.20 | 4.20 |
| Various | 1.29 | 31.51 | 52.11 | 9.67 |

# 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 | 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 | 1019 | 0 | 371 | 0 | 263 | 370 | 0 | 15 | 0 | 0 | 13558 | 56 | 1491 | 0 | 4584 | 0 | 0 | 1276 | 18284 | 0 | 40 | 96 | 0 | 100 | 0 | 7 | 0 | 7 | 0 | 1 |
| February | 1002 | 0 | 371 | 0 | 266 | 353 | 0 | 12 | 0 | 0 | 13331 | 56 | 1459 | 0 | 4507 | 0 | 0 | 1047 | 18173 | 0 | 40 | 97 | 0 | 100 | 0 | 4 | 0 | 4 | 0 | 1 |
| March | 843 | 0 | 371 | 0 | 237 | 236 | 0 | 0 | 0 | 0 | 12702 | 55 | 1179 | 0 | 3783 | 0 | 0 | 899 | 16712 | 0 | 40 | 86 | 0 | 100 | 0 | 17 | 0 | 17 | 0 | 2 |
| April | 669 | 0 | 371 | 0 | 68 | 230 | 0 | 0 | 0 | 0 | 11480 | 56 | 964 | 0 | 2988 | 0 | 0 | 951 | 14793 | 0 | 40 | 25 | 0 | 100 | 0 | 321 | 0 | 321 | 0 | 48 |
| May | 465 | 0 | 371 | 0 | 8 | 86 | 0 | 0 | 0 | 0 | 11495 | 56 | 609 | 0 | 2055 | 0 | 0 | 950 | 13944 | 0 | 40 | 3 | 0 | 100 | 0 | 722 | 0 | 722 | 0 | 93 |
| June | 338 | 0 | 371 | 0 | 0 | 2 | 0 | 0 | 0 | -35 | 11201 | 55 | 393 | 0 | 1477 | 0 | 0 | 1476 | 12910 | 0 | 40 | 0 | 0 | 100 | 0 | 1299 | 0 | 1299 | 0 | 104 |
| July | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 | 10502 | 56 | 304 | 0 | 1145 | 0 | 0 | 1085 | 12443 | 0 | 40 | 0 | 0 | 100 | 0 | 1563 | 0 | 1563 | 0 | 89 |
| August | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 | 10799 | 56 | 312 | 0 | 1177 | 0 | 0 | 749 | 12874 | 0 | 40 | 0 | 0 | 100 | 0 | 1320 | 0 | 1320 | 0 | 100 |
| September | 394 | 0 | 371 | 0 | 0 | 29 | 0 | 0 | 0 | -6 | 11113 | 55 | 481 | 0 | 1733 | 0 | 0 | 770 | 13525 | 0 | 40 | 0 | 0 | 100 | 0 | 953 | 0 | 953 | 0 | 76 |
| October | 557 | 0 | 371 | 0 | 78 | 108 | 0 | 0 | 0 | 0 | 12064 | 56 | 738 | 0 | 2478 | 0 | 0 | 812 | 14824 | 0 | 40 | 28 | 0 | 100 | 0 | 370 | 0 | 370 | 0 | 46 |
| November | 796 | 0 | 371 | 0 | 202 | 223 | 0 | 0 | 0 | 0 | 12968 | 56 | 1112 | 0 | 3567 | 0 | 0 | 944 | 16755 | 0 | 40 | 73 | 0 | 100 | 0 | 110 | 0 | 110 | 0 | 15 |
| December | 927 | 0 | 371 | 0 | 223 | 332 | 0 | 1 | 0 | 0 | 13086 | 56 | 1352 | 0 | 4167 | 0 | 0 | 1265 | 17334 | 0 | 40 | 81 | 0 | 100 | 0 | 59 | 0 | 59 | 0 | 4 |
| Average | 628 | 0 | 371 | 0 | 112 | 164 | 0 | 2 | 0 | -21 | 12021 | 56 | 864 | 0 | 2800 | 0 | 0 | 1018 | 15206 | 0 | 40 | 41 | 0 | 100 | 0 | 564 | 0 | 564 | Average price | |
| Maximum | 1257 | 1 | 371 | 0 | 275 | 437 | 0 | 174 | 0 | 50 | 16723 | 108 | 1825 | 0 | 5655 | 0 | 0 | 2758 | 23163 | 0 | 40 | 100 | 0 | 100 | 0 | 2301 | 0 | 2301 | (NOK/MWh) | |
| Minimum | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 8871 | 0 | 257 | 0 | 968 | 0 | 0 | 230 | 11140 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | - | 117 |
| TWh/year | 5.51 | 0.00 | 3.26 | 0.00 | 0.98 | 1.44 | 0.00 | 0.02 | 0.00 | -0.18 | 105.60 | 0.49 | 7.59 | 0.00 | 24.59 | 0.00 | 0.00 | 8.94 | 133.57 | 0.00 | 0.35 | 0.36 | 0.00 | | 0.00 | 4.95 | 0.00 | 4.95 | 0 | 579 |

| 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 | Imp/Exp Corrected Net | CO2 emission (Mt): Total | CO2 emission (Mt): Net |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal | - | - | - | - | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | 1.81 | 8.69 | 10.50 | 0.00 | 10.50 | 3.55 | 3.55 |
| Oil | - | - | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 47.21 | 4.89 | 42.01 | 94.11 | 0.00 | 94.11 | 24.93 | 24.93 |
| N.Gas | - | 1.49 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 1.21 | 3.00 | 55.31 | 61.01 | 0.00 | 61.01 | 12.51 | 12.51 |
| Biomass | - | - | - | 0.02 | - | 0.00 | - | - | 4.86 | - | - | - | - | - | - | - | - | - | 7.23 | 13.87 | 25.98 | 0.00 | 25.98 | 0.64 | 0.64 |
| Renewable | - | - | - | - | - | - | - | 133.57 | - | - | - | - | 4.10 | 0.05 | - | 138.37 | 0.01 | - | - | - | 142.53 | 0.00 | 142.53 | 0.00 | 0.00 |
| H2 etc. | - | 0.00 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biofuel | - | - | - | - | - | - | - | - | - | - | -4.47 | - | - | - | - | - | - | 4.47 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nuclear/CCS | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | - | 1.49 | - | 0.03 | - | 0.00 | - | 133.57 | 4.86 | - | -4.47 | - | 4.10 | 0.05 | - | 138.37 | 0.01 | 52.89 | 16.92 | 119.88 | 334.13 | -11.01 | 323.12 | 41.63 | 41.64 |

Output specifications   Norway_Reference_Scenario_2018_Craga1.txt   The EnergyPLAN model 14.1

District Heating Production

| | Gr.1 | | | | Gr.2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| January | 0 | 0 | 0 | 0 | 1019 | 0 | 371 | 263 | 370 | 0 | 15 | 0 | 53 | 0 |
| February | 0 | 0 | 0 | 0 | 1002 | 0 | 371 | 266 | 353 | 0 | 12 | 0 | 33 | 0 |
| March | 0 | 0 | 0 | 0 | 843 | 0 | 371 | 237 | 236 | 0 | 0 | 0 | 168 | 0 |
| April | 0 | 0 | 0 | 0 | 669 | 0 | 371 | 68 | 230 | 0 | 0 | 0 | 212 | 0 |
| May | 0 | 0 | 0 | 0 | 465 | 0 | 371 | 8 | 86 | 0 | 0 | 0 | 214 | 0 |
| June | 0 | 0 | 0 | 0 | 338 | 0 | 371 | 0 | 2 | 0 | 0 | 0 | 214 | -35 |
| July | 0 | 0 | 0 | 0 | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 214 | -106 |
| August | 0 | 0 | 0 | 0 | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 214 | -99 |
| September | 0 | 0 | 0 | 0 | 394 | 0 | 371 | 0 | 29 | 0 | 0 | 0 | 214 | -6 |
| October | 0 | 0 | 0 | 0 | 557 | 0 | 371 | 78 | 108 | 0 | 0 | 0 | 214 | 0 |
| November | 0 | 0 | 0 | 0 | 796 | 0 | 371 | 202 | 223 | 0 | 0 | 0 | 214 | 0 |
| December | 0 | 0 | 0 | 0 | 927 | 0 | 371 | 223 | 332 | 0 | 1 | 0 | 372 | 0 |
| Average | 0 | 0 | 0 | 0 | 628 | 0 | 371 | 112 | 164 | 0 | 2 | 0 | 196 | -21 |
| Maximum | 0 | 0 | 0 | 0 | 1257 | 1 | 371 | 275 | 437 | 0 | 174 | 0 | 1000 | 50 |
| Minimum | 0 | 0 | 0 | 0 | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 |
| Total for the whole year TWh/year | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 3.26 | 0.98 | 1.44 | 0.00 | 0.02 | 0.00 | | -0.18 |

| | Gr.3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | District heating MW | Solar MW | CSHP MW | CHP MW | HP MW | ELT MW | Boiler MW | EH MW | Storage MW | Balance MW |
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 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 |

| | RES specification | | | | |
|---|---|---|---|---|---|
| | RES1 Wind MW | RES2 Photo \ MW | RES3 Wave F MW | RES 4-7 er MW | Total MW |
| January | 645 | 0 | 0 | 631 | 1276 |
| February | 556 | 2 | 0 | 489 | 1047 |
| March | 443 | 3 | 0 | 452 | 899 |
| April | 417 | 8 | 0 | 526 | 951 |
| May | 540 | 9 | 0 | 401 | 950 |
| June | 392 | 12 | 0 | 1071 | 1476 |
| July | 419 | 10 | 0 | 656 | 1085 |
| August | 303 | 9 | 0 | 437 | 749 |
| September | 381 | 6 | 0 | 384 | 770 |
| October | 337 | 3 | 0 | 473 | 812 |
| November | 439 | 1 | 0 | 503 | 944 |
| December | 727 | 1 | 0 | 537 | 1265 |
| Average | 467 | 5 | 0 | 546 | 1018 |
| Maximum | 1675 | 68 | 0 | 1328 | 2758 |
| Minimum | 0 | 0 | 0 | 6 | 230 |
| Total for the whole year TWh/year | 4.10 | 0.05 | 0.00 | 4.80 | 8.94 |

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million NOK)

| | | |
|---|---|---|
| Total Fuel ex Ngas exchange = | | 55103 |
| Uranium = | 0 | |
| Coal = | 1076 | |
| FuelOil = | 13615 | |
| Gasoil/Diesel= | 20754 | |
| Petrol/JP = | 13611 | |
| Gas handling = | 461 | |
| Biomass = | 6338 | |
| Food income = | 0 | |
| Waste = | -753 | |
| Total Ngas Exchange costs = | | 16001 |
| Marginal operation costs = | | 510 |
| Total Electricity exchange = | | -579 |
| Import = | 0 | |
| Export = | -579 | |
| Bottleneck = | 0 | |
| Fixed imp/ex= | 0 | |
| Total CO2 emission costs = | | 2498 |
| Total variable costs = | | 73533 |
| Fixed operation costs = | | 5489 |
| Annual Investment costs = | | 18137 |
| TOTAL ANNUAL COSTS = | | 97159 |

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 | 2 | 398 | 0 | 559 | 135 | 6297 | 7391 | 0 | 0 | 0 | 0 | 0 | 0 | 7391 | 7391 | 0 |
| February | 1 | 403 | 0 | 550 | 135 | 6297 | 7386 | 0 | 0 | 0 | 0 | 0 | 0 | 7386 | 7386 | 0 |
| March | 0 | 359 | 0 | 461 | 135 | 6297 | 7252 | 0 | 0 | 0 | 0 | 0 | 0 | 7252 | 7252 | 0 |
| April | 0 | 104 | 0 | 364 | 135 | 6297 | 6900 | 0 | 0 | 0 | 0 | 0 | 0 | 6900 | 6900 | 0 |
| May | 0 | 12 | 0 | 251 | 135 | 6297 | 6694 | 0 | 0 | 0 | 0 | 0 | 0 | 6694 | 6694 | 0 |
| June | 0 | 0 | 0 | 180 | 135 | 6297 | 6612 | 0 | 0 | 0 | 0 | 0 | 0 | 6612 | 6612 | 0 |
| July | 0 | 0 | 0 | 140 | 135 | 6297 | 6572 | 0 | 0 | 0 | 0 | 0 | 0 | 6572 | 6572 | 0 |
| August | 0 | 0 | 0 | 144 | 135 | 6297 | 6576 | 0 | 0 | 0 | 0 | 0 | 0 | 6576 | 6576 | 0 |
| September | 0 | 1 | 0 | 211 | 135 | 6297 | 6644 | 0 | 0 | 0 | 0 | 0 | 0 | 6644 | 6644 | 0 |
| October | 0 | 118 | 0 | 302 | 135 | 6297 | 6853 | 0 | 0 | 0 | 0 | 0 | 0 | 6853 | 6853 | 0 |
| November | 0 | 306 | 0 | 435 | 135 | 6297 | 7173 | 0 | 0 | 0 | 0 | 0 | 0 | 7173 | 7173 | 0 |
| December | 0 | 338 | 0 | 508 | 135 | 6297 | 7278 | 0 | 0 | 0 | 0 | 0 | 0 | 7278 | 7278 | 0 |
| Average | 0 | 169 | 0 | 341 | 135 | 6297 | 6943 | 0 | 0 | 0 | 0 | 0 | 0 | 6943 | 6943 | 0 |
| Maximum | 20 | 417 | 0 | 690 | 135 | 6297 | 7558 | 0 | 0 | 0 | 0 | 0 | 0 | 7558 | 7558 | 0 |
| Minimum | 0 | 0 | 0 | 118 | 135 | 6297 | 6550 | 0 | 0 | 0 | 0 | 0 | 0 | 6550 | 6550 | 0 |
| Total for the whole year TWh/year | 0.00 | 1.49 | 0.00 | 3.00 | 1.19 | 55.31 | 60.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 60.99 | 60.99 | 0.00 |

RES Share: 50.4 Percent of Primary Energy 134.6 Percent of Electricity 142.9 TWh electricity from RES 01-August-2019 [17:34]

# Input Norway_EV_Scenario_2025_Craga.txt

## The EnergyPLAN model 14.1

| Electricity demand (TWh/year): | | Flexible demand | 0.00 |
|---|---|---|---|
| Fixed demand | 104.59 | Fixed imp/exp. | 0.00 |
| Electric heating + HP | 31.12 | Transportation | 4.32 |
| Electric cooling | 1.00 | Total | 141.03 |

| District heating (TWh/year) | Gr.1 | Gr.2 | Gr.3 | Sum |
|---|---|---|---|---|
| District heating demand | 0.00 | 5.44 | 0.00 | 5.44 |
| 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 | 5.44 | 0.00 | 5.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wind | 1675 | MW | 4.10 | TWh/year | 0.00 | Grid |
| Photo Voltaic | 68 | MW | 0.05 | TWh/year | 0.00 | stabili- |
| Wave Power | 0 | MW | 0 | TWh/year | 0.00 | sation |
| River Hydro | 0 | MW | 4.8 | TWh/year | 0.00 | share |
| Hydro Power | 31174 | MW | 133.57 | 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 | 0 | | 0.45 | | |

Heatstorage: gr.2: 1 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 | 0.35 |
| 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 |

DistEnerginet_no_NOKprices_2015.txt

| | | |
|---|---|---|
| Addition factor | 0.00 | NOK/MWh |
| Multiplication factor | 1.00 | |
| Dependency factor | 0.00 | NOK/MWh pr. MW |
| Average Market Price | 177 | NOK/MWh |
| Gas Storage | 0 | GWh |
| Syngas capacity | 0 | MW |
| Biogas max to grid | 0 | MW |

Fuel Price level:

| | 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 | 35.93 | 1.19 | 0.00 |
| Household | 1.81 | 4.89 | 3.00 | 7.23 |
| Industry | 7.40 | 10.50 | 3.20 | 4.20 |
| Various | 1.29 | 31.51 | 52.11 | 9.67 |

# 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 | 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 |
| January | 1019 | 0 | 371 | 0 | 271 | 363 | 0 | 14 | 0 | 0 | 13556 | 493 | 1486 | 0 | 4584 | 0 | 0 | 1276 | 18705 | 0 | 40 | 99 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 1002 | 0 | 371 | 0 | 274 | 346 | 0 | 12 | 0 | 0 | 13330 | 492 | 1453 | 0 | 4507 | 0 | 0 | 1047 | 18595 | 0 | 40 | 99 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 843 | 0 | 371 | 0 | 264 | 209 | 0 | 0 | 0 | 0 | 12701 | 489 | 1159 | 0 | 3783 | 0 | 0 | 899 | 17098 | 0 | 40 | 96 | 0 | 100 | 0 | 1 | 0 | 1 | 0 | 0 |
| April | 669 | 0 | 371 | 0 | 99 | 200 | 0 | 0 | 0 | 0 | 11479 | 493 | 941 | 0 | 2988 | 0 | 0 | 951 | 14937 | 0 | 40 | 36 | 0 | 100 | 0 | 63 | 0 | 63 | 0 | 9 |
| May | 465 | 0 | 371 | 0 | 12 | 82 | 0 | 0 | 0 | 0 | 11494 | 492 | 606 | 0 | 2055 | 0 | 0 | 950 | 13825 | 0 | 40 | 4 | 0 | 100 | 0 | 172 | 0 | 172 | 0 | 22 |
| June | 338 | 0 | 371 | 0 | 0 | 2 | 0 | 0 | 0 | -35 | 11201 | 490 | 393 | 0 | 1477 | 0 | 0 | 1476 | 12388 | 0 | 40 | 0 | 0 | 100 | 0 | 343 | 0 | 343 | 0 | 27 |
| July | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 | 10501 | 493 | 304 | 0 | 1145 | 0 | 0 | 1085 | 11740 | 0 | 40 | 0 | 0 | 100 | 0 | 422 | 0 | 422 | 0 | 24 |
| August | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 | 10799 | 491 | 312 | 0 | 1177 | 0 | 0 | 749 | 12339 | 0 | 40 | 0 | 0 | 100 | 0 | 349 | 0 | 349 | 0 | 27 |
| September | 394 | 0 | 371 | 0 | 2 | 27 | 0 | 0 | 0 | -6 | 11113 | 490 | 480 | 0 | 1733 | 0 | 0 | 770 | 13244 | 0 | 40 | 1 | 0 | 100 | 0 | 240 | 0 | 240 | 0 | 19 |
| October | 557 | 0 | 371 | 0 | 93 | 93 | 0 | 0 | 0 | 0 | 12063 | 494 | 727 | 0 | 2478 | 0 | 0 | 812 | 14950 | 0 | 40 | 34 | 0 | 100 | 0 | 75 | 0 | 75 | 0 | 9 |
| November | 796 | 0 | 371 | 0 | 223 | 202 | 0 | 0 | 0 | 0 | 12967 | 491 | 1097 | 0 | 3567 | 0 | 0 | 944 | 17073 | 0 | 40 | 81 | 0 | 100 | 0 | 17 | 0 | 17 | 0 | 2 |
| December | 927 | 0 | 371 | 0 | 243 | 312 | 0 | 1 | 0 | 0 | 13085 | 491 | 1337 | 0 | 4167 | 0 | 0 | 1265 | 17693 | 0 | 40 | 89 | 0 | 100 | 0 | 6 | 0 | 6 | 0 | 0 |
| Average | 628 | 0 | 371 | 0 | 123 | 152 | 0 | 2 | 0 | -21 | 12021 | 492 | 856 | 0 | 2800 | 0 | 0 | 1018 | 15206 | 0 | 40 | 45 | 0 | 100 | 0 | 141 | 0 | 141 | Average price | |
| Maximum | 1257 | 1 | 371 | 0 | 275 | 437 | 0 | 174 | 0 | 43 | 16721 | 958 | 1825 | 0 | 5655 | 0 | 0 | 2758 | 23549 | 0 | 40 | 100 | 0 | 100 | 0 | 599 | 0 | 599 | (NOK/MWh) | |
| Minimum | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 8871 | 0 | 257 | 0 | 968 | 0 | 0 | 230 | 10287 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | - | 113 |
| TWh/year | 5.51 | 0.00 | 3.26 | 0.00 | 1.08 | 1.34 | 0.00 | 0.02 | 0.00 | -0.18 | 105.59 | 4.32 | 7.52 | 0.00 | 24.59 | 0.00 | 0.00 | 8.94 | 133.57 | 0.00 | 0.35 | 0.39 | 0.00 | | 0.00 | 1.24 | 0.00 | 1.24 | 0 | 140 |

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 | - | - | - | - | - | - | - | - | - | - | - | - | 1.81 | 8.69 | 10.50 | 0.00 | 10.50 | 3.55 | 3.55 |
| Oil | - | - | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 35.93 | 4.89 | 42.01 | 82.83 | 0.00 | 82.83 | 21.94 | 21.94 |
| N.Gas | - | 1.64 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 1.21 | 3.00 | 55.31 | 61.16 | 0.00 | 61.16 | 12.54 | 12.55 |
| Biomass | - | - | - | 0.02 | - | 0.00 | - | - | 4.86 | - | - | - | - | - | - | - | - | - | 7.23 | 13.87 | 25.98 | 0.00 | 25.98 | 0.64 | 0.64 |
| Renewable | - | - | - | - | - | - | - | 133.57 | - | - | - | - | 4.10 | 0.05 | - | 138.37 | 0.01 | - | - | - | 142.53 | 0.00 | 142.53 | 0.00 | 0.00 |
| H2 etc. | - | 0.00 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biofuel | - | - | - | - | - | - | - | - | - | - | -4.47 | - | - | - | - | - | - | 4.47 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nuclear/CCS | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | - | 1.64 | - | 0.02 | - | 0.00 | - | 133.57 | 4.86 | - | -4.47 | - | 4.10 | 0.05 | - | 138.37 | 0.01 | 41.62 | 16.92 | 119.88 | 323.00 | -2.76 | 320.24 | 38.68 | 38.68 |

04-August-2019 [00:13]

# Output specifications    Norway_EV_Scenario_2025_Craga.txt    The EnergyPLAN model 14.1

District Heating Production

| | Gr.1 | | | | Gr.2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| January | 0 | 0 | 0 | 0 | 1019 | 0 | 371 | 271 | 363 | 0 | 14 | 0 | 19 | 0 |
| February | 0 | 0 | 0 | 0 | 1002 | 0 | 371 | 274 | 346 | 0 | 12 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 843 | 0 | 371 | 264 | 209 | 0 | 0 | 0 | 11 | 0 |
| April | 0 | 0 | 0 | 0 | 669 | 0 | 371 | 99 | 200 | 0 | 0 | 0 | 14 | 0 |
| May | 0 | 0 | 0 | 0 | 465 | 0 | 371 | 12 | 82 | 0 | 0 | 0 | 14 | 0 |
| June | 0 | 0 | 0 | 0 | 338 | 0 | 371 | 0 | 2 | 0 | 0 | 0 | 14 | -35 |
| July | 0 | 0 | 0 | 0 | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 14 | -106 |
| August | 0 | 0 | 0 | 0 | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 14 | -99 |
| September | 0 | 0 | 0 | 0 | 394 | 0 | 371 | 2 | 27 | 0 | 0 | 0 | 14 | -6 |
| October | 0 | 0 | 0 | 0 | 557 | 0 | 371 | 93 | 93 | 0 | 0 | 0 | 14 | 0 |
| November | 0 | 0 | 0 | 0 | 796 | 0 | 371 | 223 | 202 | 0 | 0 | 0 | 14 | 0 |
| December | 0 | 0 | 0 | 0 | 927 | 0 | 371 | 243 | 312 | 0 | 1 | 0 | 318 | 0 |
| Average | 0 | 0 | 0 | 0 | 628 | 0 | 371 | 123 | 152 | 0 | 2 | 0 | 39 | -21 |
| Maximum | 0 | 0 | 0 | 0 | 1257 | 1 | 371 | 275 | 437 | 0 | 174 | 0 | 1000 | 43 |
| Minimum | 0 | 0 | 0 | 0 | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 |
| Total for the whole year TWh/year | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 3.26 | 1.08 | 1.34 | 0.00 | 0.02 | 0.00 | | -0.18 |

| | Gr.3 | | | | | | | | | | RES specification | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 Wave I MW | RES 4-7 er MW | Total MW |
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 645 | 0 | 0 | 631 | 1276 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 556 | 2 | 0 | 489 | 1047 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 443 | 3 | 0 | 452 | 899 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 417 | 8 | 0 | 526 | 951 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 540 | 9 | 0 | 401 | 950 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 392 | 12 | 0 | 1071 | 1476 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 419 | 10 | 0 | 656 | 1085 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 303 | 9 | 0 | 437 | 749 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 381 | 6 | 0 | 384 | 770 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 337 | 3 | 0 | 473 | 812 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 439 | 1 | 0 | 503 | 944 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 727 | 1 | 0 | 537 | 1265 |
| Average | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 467 | 5 | 0 | 546 | 1018 |
| Maximum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1675 | 68 | 0 | 1328 | 2758 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 230 |
| 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 | 4.10 | 0.05 | 0.00 | 4.80 | 8.94 |

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million NOK)

| | | |
|---|---|---|
| Total Fuel ex Ngas exchange = | | 47593 |
| Uranium = | 0 | |
| Coal = | 1076 | |
| FuelOil = | 13615 | |
| Gasoil/Diesel= | 15387 | |
| Petrol/JP = | 11463 | |
| Gas handling = | 466 | |
| Biomass = | 6337 | |
| Food income = | 0 | |
| Waste = | -753 | |
| Total Ngas Exchange costs = | | 16041 |
| Marginal operation costs = | | 510 |
| Total Electricity exchange = | | -140 |
| Import = | 0 | |
| Export = | -140 | |
| Bottleneck = | 0 | |
| Fixed imp/ex= | 0 | |
| Total CO2 emission costs = | | 2321 |
| Total variable costs = | | 66323 |
| Fixed operation costs = | | 5489 |
| Annual Investment costs = | | 18137 |
| TOTAL ANNUAL COSTS = | | 89949 |

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 | 2 | 411 | 0 | 559 | 135 | 6297 | 7404 | 0 | 0 | 0 | 0 | 0 | 0 | 7404 | 7404 | 0 |
| February | 1 | 414 | 0 | 550 | 135 | 6297 | 7398 | 0 | 0 | 0 | 0 | 0 | 0 | 7398 | 7398 | 0 |
| March | 0 | 400 | 0 | 461 | 135 | 6297 | 7293 | 0 | 0 | 0 | 0 | 0 | 0 | 7293 | 7293 | 0 |
| April | 0 | 150 | 0 | 364 | 135 | 6297 | 6946 | 0 | 0 | 0 | 0 | 0 | 0 | 6946 | 6946 | 0 |
| May | 0 | 18 | 0 | 251 | 135 | 6297 | 6701 | 0 | 0 | 0 | 0 | 0 | 0 | 6701 | 6701 | 0 |
| June | 0 | 0 | 0 | 180 | 135 | 6297 | 6612 | 0 | 0 | 0 | 0 | 0 | 0 | 6612 | 6612 | 0 |
| July | 0 | 0 | 0 | 140 | 135 | 6297 | 6572 | 0 | 0 | 0 | 0 | 0 | 0 | 6572 | 6572 | 0 |
| August | 0 | 0 | 0 | 144 | 135 | 6297 | 6576 | 0 | 0 | 0 | 0 | 0 | 0 | 6576 | 6576 | 0 |
| September | 0 | 3 | 0 | 211 | 135 | 6297 | 6646 | 0 | 0 | 0 | 0 | 0 | 0 | 6646 | 6646 | 0 |
| October | 0 | 141 | 0 | 302 | 135 | 6297 | 6875 | 0 | 0 | 0 | 0 | 0 | 0 | 6875 | 6875 | 0 |
| November | 0 | 337 | 0 | 435 | 135 | 6297 | 7204 | 0 | 0 | 0 | 0 | 0 | 0 | 7204 | 7204 | 0 |
| December | 0 | 369 | 0 | 508 | 135 | 6297 | 7309 | 0 | 0 | 0 | 0 | 0 | 0 | 7309 | 7309 | 0 |
| Average | 0 | 186 | 0 | 341 | 135 | 6297 | 6960 | 0 | 0 | 0 | 0 | 0 | 0 | 6960 | 6960 | 0 |
| Maximum | 20 | 417 | 0 | 690 | 135 | 6297 | 7558 | 0 | 0 | 0 | 0 | 0 | 0 | 7558 | 7558 | 0 |
| Minimum | 0 | 0 | 0 | 118 | 135 | 6297 | 6550 | 0 | 0 | 0 | 0 | 0 | 0 | 6550 | 6550 | 0 |
| Total for the whole year TWh/year | 0.00 | 1.64 | 0.00 | 3.00 | 1.19 | 55.31 | 61.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 61.14 | 61.14 | 0.00 |

RES Share: 52.2 Percent of Primary Energy 130.0 Percent of Electricity 142.9 TWh electricity from RES

04-August-2019 [00:13]

# Input Norway_EV_Scenario_2030_Craga.txt The EnergyPLAN model 14.1

| Electricity demand (TWh/year): | | Flexible demand | 0.00 |
|---|---|---|---|
| Fixed demand | 104.59 | Fixed imp/exp. | 0.00 |
| Electric heating + HP | 31.12 | Transportation | 5.40 |
| Electric cooling | 1.00 | Total | 142.11 |

| District heating (TWh/year) | Gr.1 | Gr.2 | Gr.3 | Sum |
|---|---|---|---|---|
| District heating demand | 0.00 | 5.44 | 0.00 | 5.44 |
| 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 | 5.44 | 0.00 | 5.44 |

| | | | | | | Grid stabili-sation share |
|---|---|---|---|---|---|---|
| Wind | 1675 | MW | 4.10 | TWh/year | 0.00 | |
| Photo Voltaic | 68 | MW | 0.05 | TWh/year | 0.00 | |
| Wave Power | 0 | MW | 0 | TWh/year | 0.00 | |
| River Hydro | 0 | MW | 4.8 | TWh/year | 0.00 | |
| Hydro Power | 31174 | MW | 133.57 | 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 | 0 | | 0.45 | | |

Heatstorage: gr.2: 1 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 | 0.35 |
| 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 |

| DistEnerginet_no_NOKprices_2015.txt | | |
|---|---|---|
| Addition factor | 0.00 | NOK/MWh |
| Multiplication factor | 1.00 | |
| Dependency factor | 0.00 | NOK/MWh pr. MW |
| Average Market Price | 177 | 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 | 28.37 | 1.19 | 0.00 |
| Household | 1.81 | 4.89 | 3.00 | 7.23 |
| Industry | 7.40 | 10.50 | 3.20 | 4.20 |
| Various | 1.29 | 31.51 | 52.11 | 9.67 |

# 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 | 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 | 1019 | 0 | 371 | 0 | 273 | 361 | 0 | 14 | 0 | 0 | 13556 | 617 | 1485 | 0 | 4584 | 0 | 0 | 1276 | 18826 | 0 | 40 | 99 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 1002 | 0 | 371 | 0 | 275 | 345 | 0 | 12 | 0 | 0 | 13330 | 615 | 1452 | 0 | 4507 | 0 | 0 | 1047 | 18717 | 0 | 40 | 100 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 843 | 0 | 371 | 0 | 266 | 206 | 0 | 0 | 0 | 0 | 12701 | 612 | 1157 | 0 | 3783 | 0 | 0 | 899 | 17217 | 0 | 40 | 97 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 669 | 0 | 371 | 0 | 107 | 192 | 0 | 0 | 0 | 0 | 11479 | 616 | 935 | 0 | 2988 | 0 | 0 | 951 | 14997 | 0 | 40 | 39 | 0 | 100 | 0 | 9 | 0 | 9 | 0 | 1 |
| May | 465 | 0 | 371 | 0 | 14 | 80 | 0 | 0 | 0 | 0 | 11494 | 615 | 605 | 0 | 2055 | 0 | 0 | 950 | 13800 | 0 | 40 | 5 | 0 | 100 | 0 | 26 | 0 | 26 | 0 | 3 |
| June | 338 | 0 | 371 | 0 | 0 | 2 | 0 | 0 | 0 | -35 | 11201 | 612 | 393 | 0 | 1477 | 0 | 0 | 1476 | 12220 | 0 | 40 | 0 | 0 | 100 | 0 | 53 | 0 | 53 | 0 | 4 |
| July | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 | 10501 | 617 | 304 | 0 | 1145 | 0 | 0 | 1085 | 11506 | 0 | 40 | 0 | 0 | 100 | 0 | 65 | 0 | 65 | 0 | 4 |
| August | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 | 10799 | 614 | 312 | 0 | 1177 | 0 | 0 | 749 | 12166 | 0 | 40 | 0 | 0 | 100 | 0 | 54 | 0 | 54 | 0 | 4 |
| September | 394 | 0 | 371 | 0 | 2 | 27 | 0 | 0 | 0 | -6 | 11113 | 612 | 480 | 0 | 1733 | 0 | 0 | 770 | 13163 | 0 | 40 | 1 | 0 | 100 | 0 | 36 | 0 | 36 | 0 | 3 |
| October | 557 | 0 | 371 | 0 | 99 | 87 | 0 | 0 | 0 | 0 | 12063 | 617 | 722 | 0 | 2478 | 0 | 0 | 812 | 15003 | 0 | 40 | 36 | 0 | 100 | 0 | 10 | 0 | 10 | 0 | 1 |
| November | 796 | 0 | 371 | 0 | 229 | 196 | 0 | 0 | 0 | 0 | 12967 | 613 | 1092 | 0 | 3567 | 0 | 0 | 944 | 17174 | 0 | 40 | 83 | 0 | 100 | 0 | 2 | 0 | 2 | 0 | 0 |
| December | 927 | 0 | 371 | 0 | 249 | 305 | 0 | 2 | 0 | 0 | 13085 | 614 | 1332 | 0 | 4167 | 0 | 0 | 1265 | 17803 | 0 | 40 | 91 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average | 628 | 0 | 371 | 0 | 126 | 150 | 0 | 2 | 0 | -21 | 12021 | 615 | 854 | 0 | 2800 | 0 | 0 | 1018 | 15206 | 0 | 40 | 46 | 0 | 100 | 0 | 21 | 0 | 21 | Average price | |
| Maximum | 1257 | 1 | 371 | 0 | 275 | 437 | 0 | 174 | 0 | 43 | 16721 | 1197 | 1825 | 0 | 5655 | 0 | 0 | 2758 | 23658 | 0 | 40 | 100 | 0 | 100 | 0 | 93 | 0 | 93 | (NOK/MWh) | |
| Minimum | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 8871 | 0 | 257 | 0 | 968 | 0 | 0 | 230 | 9945 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | - | 112 |
| TWh/year | 5.51 | 0.00 | 3.26 | 0.00 | 1.10 | 1.31 | 0.00 | 0.02 | 0.00 | -0.18 | 105.59 | 5.40 | 7.50 | 0.00 | 24.59 | 0.00 | 0.00 | 8.94 | 133.57 | 0.00 | 0.35 | 0.40 | 0.00 | | 0.00 | 0.19 | 0.00 | 0.19 | 0 | 21 |

| 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 | - | - | - | - | - | - | - | - | - | - | - | - | 1.81 | 8.69 | 10.50 | 0.00 | 10.50 | 3.55 | 3.55 |
| Oil | - | - | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 28.37 | 4.89 | 42.01 | 75.27 | 0.00 | 75.27 | 19.94 | 19.94 |
| N.Gas | - | 1.67 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 1.21 | 3.00 | 55.31 | 61.20 | 0.00 | 61.20 | 12.55 | 12.55 |
| Biomass | - | - | - | 0.02 | - | 0.00 | - | - | 4.86 | - | - | - | - | - | - | - | - | - | 7.23 | 13.87 | 25.98 | 0.00 | 25.98 | 0.64 | 0.64 |
| Renewable | - | - | - | - | - | - | - | 133.57 | - | - | - | - | 4.10 | 0.05 | - | 138.37 | 0.01 | - | - | - | 142.53 | 0.00 | 142.53 | 0.00 | 0.00 |
| H2 etc. | - | 0.00 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biofuel | - | - | - | - | - | - | - | - | - | - | -4.47 | - | - | - | - | - | - | 4.47 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nuclear/CCS | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | - | 1.67 | - | 0.02 | - | 0.00 | - | 133.57 | 4.86 | - | -4.47 | - | 4.10 | 0.05 | - | 138.37 | 0.01 | 34.06 | 16.92 | 119.88 | 315.47 | -0.42 | 315.06 | 36.68 | 36.69 |

04-August-2019 [00:16]

# Output specifications Norway_EV_Scenario_2030_Craga.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 Stor-age MW | Gr.2 Ba-lance 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 Stor-age MW | Gr.3 Ba-lance MW | RES specification RES1 Wind MW | RES2 Photo \ MW | RES3 Wave F MW | RES 4-7 er MW | Total MW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0 | 0 | 0 | 0 | 1019 | 0 | 371 | 273 | 361 | 0 | 14 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 645 | 0 | 0 | 631 | 1276 |
| February | 0 | 0 | 0 | 0 | 1002 | 0 | 371 | 275 | 345 | 0 | 12 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 556 | 2 | 0 | 489 | 1047 |
| March | 0 | 0 | 0 | 0 | 843 | 0 | 371 | 266 | 206 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 443 | 3 | 0 | 452 | 899 |
| April | 0 | 0 | 0 | 0 | 669 | 0 | 371 | 107 | 192 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 417 | 8 | 0 | 526 | 951 |
| May | 0 | 0 | 0 | 0 | 465 | 0 | 371 | 14 | 80 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 540 | 9 | 0 | 401 | 950 |
| June | 0 | 0 | 0 | 0 | 338 | 0 | 371 | 0 | 2 | 0 | 0 | 0 | 14 | -35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 392 | 12 | 0 | 1071 | 1476 |
| July | 0 | 0 | 0 | 0 | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 14 | -106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 419 | 10 | 0 | 656 | 1085 |
| August | 0 | 0 | 0 | 0 | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 14 | -99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 303 | 9 | 0 | 437 | 749 |
| September | 0 | 0 | 0 | 0 | 394 | 0 | 371 | 2 | 27 | 0 | 0 | 0 | 14 | -6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 381 | 6 | 0 | 384 | 770 |
| October | 0 | 0 | 0 | 0 | 557 | 0 | 371 | 99 | 87 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 337 | 3 | 0 | 473 | 812 |
| November | 0 | 0 | 0 | 0 | 796 | 0 | 371 | 229 | 196 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 439 | 1 | 0 | 503 | 944 |
| December | 0 | 0 | 0 | 0 | 927 | 0 | 371 | 249 | 305 | 0 | 2 | 0 | 124 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 727 | 1 | 0 | 537 | 1265 |
| Average | 0 | 0 | 0 | 0 | 628 | 0 | 371 | 126 | 150 | 0 | 2 | 0 | 23 | -21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 467 | 5 | 0 | 546 | 1018 |
| Maximum | 0 | 0 | 0 | 0 | 1257 | 1 | 371 | 275 | 437 | 0 | 174 | 0 | 254 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1675 | 68 | 0 | 1328 | 2758 |
| Minimum | 0 | 0 | 0 | 0 | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 230 |
| Total for the whole year TWh/year | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 3.26 | 1.10 | 1.31 | 0.00 | 0.02 | 0.00 | | -0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 4.10 | 0.05 | 0.00 | 4.80 | 8.94 |

Own use of heat from industrial CHP: 0.00 TWh/year

| ANNUAL COSTS (Million NOK) | | |
|---|---|---|
| Total Fuel ex Ngas exchange = | | 42550 |
| Uranium = | 0 | |
| Coal = | 1076 | |
| FuelOil = | 13615 | |
| Gasoil/Diesel= | 11846 | |
| Petrol/JP = | 9960 | |
| Gas handling = | 468 | |
| Biomass = | 6337 | |
| Food income = | 0 | |
| Waste = | -753 | |
| Total Ngas Exchange costs = | | 16050 |
| Marginal operation costs = | | 510 |
| Total Electricity exchange = | | -21 |
| Import = | 0 | |
| Export = | -21 | |
| Bottleneck = | 0 | |
| Fixed imp/ex= | 0 | |
| Total CO2 emission costs = | | 2201 |
| Total variable costs = | | 61290 |
| Fixed operation costs = | | 5489 |
| Annual Investment costs = | | 18137 |
| TOTAL ANNUAL COSTS = | | 84916 |

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 | 2 | 413 | 0 | 559 | 135 | 6297 | 7406 | 0 | 0 | 0 | 0 | 0 | 0 | 7406 | 7406 | 0 |
| February | 1 | 417 | 0 | 550 | 135 | 6297 | 7400 | 0 | 0 | 0 | 0 | 0 | 0 | 7400 | 7400 | 0 |
| March | 0 | 403 | 0 | 461 | 135 | 6297 | 7297 | 0 | 0 | 0 | 0 | 0 | 0 | 7297 | 7297 | 0 |
| April | 0 | 162 | 0 | 364 | 135 | 6297 | 6958 | 0 | 0 | 0 | 0 | 0 | 0 | 6958 | 6958 | 0 |
| May | 0 | 21 | 0 | 251 | 135 | 6297 | 6703 | 0 | 0 | 0 | 0 | 0 | 0 | 6703 | 6703 | 0 |
| June | 0 | 0 | 0 | 180 | 135 | 6297 | 6612 | 0 | 0 | 0 | 0 | 0 | 0 | 6612 | 6612 | 0 |
| July | 0 | 0 | 0 | 140 | 135 | 6297 | 6572 | 0 | 0 | 0 | 0 | 0 | 0 | 6572 | 6572 | 0 |
| August | 0 | 0 | 0 | 144 | 135 | 6297 | 6576 | 0 | 0 | 0 | 0 | 0 | 0 | 6576 | 6576 | 0 |
| September | 0 | 3 | 0 | 211 | 135 | 6297 | 6647 | 0 | 0 | 0 | 0 | 0 | 0 | 6647 | 6647 | 0 |
| October | 0 | 149 | 0 | 302 | 135 | 6297 | 6884 | 0 | 0 | 0 | 0 | 0 | 0 | 6884 | 6884 | 0 |
| November | 0 | 346 | 0 | 435 | 135 | 6297 | 7213 | 0 | 0 | 0 | 0 | 0 | 0 | 7213 | 7213 | 0 |
| December | 0 | 377 | 0 | 508 | 135 | 6297 | 7318 | 0 | 0 | 0 | 0 | 0 | 0 | 7318 | 7318 | 0 |
| Average | 0 | 190 | 0 | 341 | 135 | 6297 | 6964 | 0 | 0 | 0 | 0 | 0 | 0 | 6964 | 6964 | 0 |
| Maximum | 20 | 417 | 0 | 690 | 135 | 6297 | 7558 | 0 | 0 | 0 | 0 | 0 | 0 | 7558 | 7558 | 0 |
| Minimum | 0 | 0 | 0 | 118 | 135 | 6297 | 6550 | 0 | 0 | 0 | 0 | 0 | 0 | 6550 | 6550 | 0 |
| Total for the whole year TWh/year | 0.00 | 1.67 | 0.00 | 3.00 | 1.19 | 55.31 | 61.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 61.17 | 61.17 | 0.00 |

RES Share: 53.4 Percent of Primary Energy 128.7 Percent of Electricity 142.9 TWh electricity from RES 04-August-2019 [00:16]

## Input NORWAY_EV_2050_CRAGA.txt — The EnergyPLAN model 14.1

| Electricity demand (TWh/year): | | Flexible demand | 0.00 |
|---|---|---|---|
| Fixed demand | 104.59 | Fixed imp/exp. | 0.00 |
| Electric heating + HP | 31.12 | Transportation | 7.29 |
| Electric cooling | 1.00 | Total | 144.00 |

| District heating (TWh/year) | Gr.1 | Gr.2 | Gr.3 | Sum |
|---|---|---|---|---|
| District heating demand | 0.00 | 5.44 | 0.00 | 5.44 |
| 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 | 5.44 | 0.00 | 5.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wind | 1800 MW | 4.41 | TWh/year | 0.00 | Grid |
| Photo Voltaic | 68 MW | 0.05 | TWh/year | 0.00 | stabili- |
| Wave Power | 0 MW | 0 | TWh/year | 0.00 | sation |
| River Hydro | 0 MW | 4.8 | TWh/year | 0.00 | share |
| Hydro Power | 31174 MW | 133.57 | 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 | 0 | | 0.45 | | |

Heatstorage: gr.2: 1 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 | 0.35 |
| 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 |

| DistEnerginet_no_NOKprices_2015.txt | | |
|---|---|---|
| Addition factor | 0.00 | NOK/MWh |
| Multiplication factor | 1.00 | |
| Dependency factor | 0.00 | NOK/MWh pr. MW |
| Average Market Price | 177 | 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. | 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 | 24.72 | 2.00 | 0.00 |
| Household | 1.81 | 4.89 | 3.00 | 7.23 |
| Industry | 7.40 | 10.50 | 3.20 | 4.20 |
| Various | 1.29 | 31.51 | 52.11 | 9.67 |

## 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 | 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 | 1019 | 0 | 371 | 0 | 275 | 359 | 0 | 14 | 0 | 0 | 13556 | 833 | 1483 | 0 | 4584 | 0 | 0 | 1324 | 18537 | 0 | 40 | 100 | 0 | 100 | 455 | 0 | 0 | 0 | 90 | 0 |
| February | 1002 | 0 | 371 | 0 | 275 | 345 | 0 | 12 | 0 | 0 | 13330 | 830 | 1452 | 0 | 4507 | 0 | 0 | 1089 | 18448 | 0 | 40 | 100 | 0 | 100 | 443 | 0 | 0 | 0 | 83 | 0 |
| March | 843 | 0 | 371 | 0 | 268 | 204 | 0 | 0 | 0 | 0 | 12701 | 826 | 1156 | 0 | 3783 | 0 | 0 | 932 | 17132 | 0 | 40 | 97 | 0 | 100 | 264 | 0 | 0 | 0 | 45 | 0 |
| April | 669 | 0 | 371 | 0 | 122 | 176 | 0 | 0 | 0 | 0 | 11479 | 832 | 924 | 0 | 2988 | 0 | 0 | 982 | 15113 | 0 | 40 | 44 | 0 | 100 | 43 | 0 | 0 | 0 | 7 | 0 |
| May | 465 | 0 | 371 | 0 | 17 | 77 | 0 | 0 | 0 | 0 | 11494 | 830 | 603 | 0 | 2055 | 0 | 0 | 990 | 13939 | 0 | 40 | 6 | 0 | 100 | 7 | 0 | 0 | 0 | 1 | 0 |
| June | 338 | 0 | 371 | 0 | 0 | 2 | 0 | 0 | 0 | -35 | 11201 | 826 | 393 | 0 | 1477 | 0 | 0 | 1505 | 12353 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 | 10501 | 833 | 304 | 0 | 1145 | 0 | 0 | 1116 | 11626 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 | 10799 | 829 | 312 | 0 | 1177 | 0 | 0 | 772 | 12305 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 394 | 0 | 371 | 0 | 3 | 27 | 0 | 0 | 0 | -6 | 11113 | 827 | 479 | 0 | 1733 | 0 | 0 | 799 | 13310 | 0 | 40 | 1 | 0 | 100 | 2 | 0 | 0 | 0 | 0 | 0 |
| October | 557 | 0 | 371 | 0 | 106 | 80 | 0 | 0 | 0 | 0 | 12063 | 833 | 717 | 0 | 2478 | 0 | 0 | 838 | 15122 | 0 | 40 | 39 | 0 | 100 | 53 | 0 | 0 | 0 | 9 | 0 |
| November | 796 | 0 | 371 | 0 | 237 | 188 | 0 | 0 | 0 | 0 | 12967 | 828 | 1086 | 0 | 3567 | 0 | 0 | 976 | 17079 | 0 | 40 | 86 | 0 | 100 | 266 | 0 | 0 | 0 | 45 | 0 |
| December | 927 | 0 | 371 | 0 | 255 | 298 | 0 | 3 | 0 | 0 | 13085 | 829 | 1327 | 0 | 4167 | 0 | 0 | 1319 | 17622 | 0 | 40 | 93 | 0 | 100 | 334 | 0 | 0 | 0 | 45 | 0 |
| Average | 628 | 0 | 371 | 0 | 129 | 146 | 0 | 2 | 0 | -21 | 12021 | 830 | 851 | 0 | 2800 | 0 | 0 | 1053 | 15206 | 0 | 40 | 47 | 0 | 100 | 155 | 0 | 0 | 0 | Average price | |
| Maximum | 1257 | 1 | 371 | 0 | 275 | 437 | 0 | 174 | 0 | 0 | 16721 | 1616 | 1825 | 0 | 5655 | 0 | 0 | 2866 | 22809 | 0 | 40 | 100 | 0 | 100 | 1039 | 0 | 0 | 0 | (NOK/MWh) | |
| Minimum | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 8871 | 0 | 257 | 0 | 968 | 0 | 0 | 230 | 9914 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 240 | 112 |
| TWh/year | 5.51 | 0.00 | 3.26 | 0.00 | 1.14 | 1.28 | 0.00 | 0.02 | 0.00 | -0.18 | 105.59 | 7.29 | 7.48 | 0.00 | 24.59 | 0.00 | 0.00 | 9.25 | 133.57 | 0.00 | 0.35 | 0.41 | 0.00 | | 1.36 | 0.00 | 0.00 | 0.00 | 326 | 0 |

| 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 | - | - | - | - | - | - | - | - | - | - | - | - | 1.81 | 8.69 | 10.50 | 0.00 | 10.50 | 3.55 | 3.55 |
| Oil | - | - | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 24.72 | 4.89 | 42.01 | 71.62 | 0.00 | 71.62 | 18.97 | 18.97 |
| N.Gas | - | 1.72 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 2.03 | 3.00 | 55.31 | 62.06 | 0.00 | 62.06 | 12.72 | 12.73 |
| Biomass | - | - | - | 0.02 | - | 0.00 | - | - | 4.86 | - | - | - | - | - | - | - | - | - | 7.23 | 13.87 | 25.98 | 0.00 | 25.98 | 0.64 | 0.64 |
| Renewable | - | - | - | - | - | - | - | 133.57 | - | - | - | - | 4.41 | 0.05 | - | 138.37 | 0.01 | - | - | - | 142.83 | 0.00 | 142.83 | 0.00 | 0.00 |
| H2 etc. | - | 0.00 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biofuel | - | - | - | - | - | - | - | - | - | - | -6.47 | - | - | - | - | - | - | 6.47 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nuclear/CCS | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | - | 1.72 | - | 0.03 | - | 0.00 | - | 133.57 | 4.86 | - | -6.47 | - | 4.41 | 0.05 | - | 138.37 | 0.01 | 33.22 | 16.92 | 119.88 | 312.99 | 3.02 | 316.01 | 35.89 | 35.90 |

# Output specifications NORWAY_EV_2050_CRAGA.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 Stor-age MW | Gr.2 Ba-lance MW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0 | 0 | 0 | 0 | 1019 | 0 | 371 | 275 | 359 | 0 | 14 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 1002 | 0 | 371 | 275 | 345 | 0 | 12 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 843 | 0 | 371 | 268 | 204 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 0 | 669 | 0 | 371 | 122 | 176 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 465 | 0 | 371 | 17 | 77 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 338 | 0 | 371 | 0 | 2 | 0 | 0 | 0 | 0 | -35 |
| July | 0 | 0 | 0 | 0 | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 |
| August | 0 | 0 | 0 | 0 | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 |
| September | 0 | 0 | 0 | 0 | 394 | 0 | 371 | 3 | 27 | 0 | 0 | 0 | 0 | -6 |
| October | 0 | 0 | 0 | 0 | 557 | 0 | 371 | 106 | 80 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 796 | 0 | 371 | 237 | 188 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 927 | 0 | 371 | 255 | 298 | 0 | 3 | 0 | 0 | 0 |
| Average | 0 | 0 | 0 | 0 | 628 | 0 | 371 | 129 | 146 | 0 | 2 | 0 | 0 | -21 |
| Maximum | 0 | 0 | 0 | 0 | 1257 | 1 | 371 | 275 | 437 | 0 | 174 | 0 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 |
| Total for the whole year TWh/year | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 3.26 | 1.14 | 1.28 | 0.00 | 0.02 | 0.00 | | -0.18 |

| | 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 Stor-age MW | Gr.3 Ba-lance MW |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 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 |

| RES specification | RES1 Wind MW | RES2 Photo \ MW | RES3 Wave F MW | RES 4-7 er MW | Total MW |
|---|---|---|---|---|---|
| January | 693 | 0 | 0 | 631 | 1324 |
| February | 597 | 2 | 0 | 489 | 1089 |
| March | 476 | 3 | 0 | 452 | 932 |
| April | 448 | 8 | 0 | 526 | 982 |
| May | 580 | 9 | 0 | 401 | 990 |
| June | 422 | 12 | 0 | 1071 | 1505 |
| July | 450 | 10 | 0 | 656 | 1116 |
| August | 325 | 9 | 0 | 437 | 772 |
| September | 409 | 6 | 0 | 384 | 799 |
| October | 362 | 3 | 0 | 473 | 838 |
| November | 472 | 1 | 0 | 503 | 976 |
| December | 781 | 1 | 0 | 537 | 1319 |
| Average | 502 | 5 | 0 | 546 | 1053 |
| Maximum | 1800 | 68 | 0 | 1328 | 2866 |
| Minimum | 0 | 0 | 0 | 6 | 230 |
| Total for the whole year TWh/year | 4.41 | 0.05 | 0.00 | 4.80 | 9.25 |

Own use of heat from industrial CHP: 0.00 TWh/year

| ANNUAL COSTS (Million NOK) | | |
|---|---|---|
| Total Fuel ex Ngas exchange = | | 40316 |
| Uranium = | 0 | |
| Coal = | 1076 | |
| FuelOil = | 13615 | |
| Gasoil/Diesel= | 10398 | |
| Petrol/JP = | 9172 | |
| Gas handling = | 470 | |
| Biomass = | 6338 | |
| Food income = | 0 | |
| Waste = | -753 | |
| Total Ngas Exchange costs = | | 16276 |
| Marginal operation costs = | | 510 |
| Total Electricity exchange = | | 326 |
| Import = | 326 | |
| Export = | 0 | |
| Bottleneck = | 0 | |
| Fixed imp/ex= | 0 | |
| Total CO2 emission costs = | | 2153 |
| Total variable costs = | | 59581 |
| Fixed operation costs = | | 5498 |
| Annual Investment costs = | | 18232 |
| TOTAL ANNUAL COSTS = | | 83311 |

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 | 2 | 416 | 0 | 559 | 228 | 6297 | 7501 | 0 | 0 | 0 | 0 | 0 | 0 | 7501 | 7501 | 0 |
| February | 1 | 417 | 0 | 550 | 228 | 6297 | 7492 | 0 | 0 | 0 | 0 | 0 | 0 | 7492 | 7492 | 0 |
| March | 0 | 406 | 0 | 461 | 228 | 6297 | 7392 | 0 | 0 | 0 | 0 | 0 | 0 | 7392 | 7392 | 0 |
| April | 0 | 185 | 0 | 364 | 228 | 6297 | 7074 | 0 | 0 | 0 | 0 | 0 | 0 | 7074 | 7074 | 0 |
| May | 0 | 25 | 0 | 251 | 228 | 6297 | 6800 | 0 | 0 | 0 | 0 | 0 | 0 | 6800 | 6800 | 0 |
| June | 0 | 0 | 0 | 180 | 228 | 6297 | 6705 | 0 | 0 | 0 | 0 | 0 | 0 | 6705 | 6705 | 0 |
| July | 0 | 0 | 0 | 140 | 228 | 6297 | 6664 | 0 | 0 | 0 | 0 | 0 | 0 | 6664 | 6664 | 0 |
| August | 0 | 0 | 0 | 144 | 228 | 6297 | 6668 | 0 | 0 | 0 | 0 | 0 | 0 | 6668 | 6668 | 0 |
| September | 0 | 4 | 0 | 211 | 228 | 6297 | 6740 | 0 | 0 | 0 | 0 | 0 | 0 | 6740 | 6740 | 0 |
| October | 0 | 160 | 0 | 302 | 228 | 6297 | 6987 | 0 | 0 | 0 | 0 | 0 | 0 | 6987 | 6987 | 0 |
| November | 0 | 359 | 0 | 435 | 228 | 6297 | 7318 | 0 | 0 | 0 | 0 | 0 | 0 | 7318 | 7318 | 0 |
| December | 0 | 387 | 0 | 508 | 228 | 6297 | 7420 | 0 | 0 | 0 | 0 | 0 | 0 | 7420 | 7420 | 0 |
| Average | 0 | 196 | 0 | 341 | 228 | 6297 | 7062 | 0 | 0 | 0 | 0 | 0 | 0 | 7062 | 7062 | 0 |
| Maximum | 20 | 417 | 0 | 690 | 228 | 6297 | 7650 | 0 | 0 | 0 | 0 | 0 | 0 | 7650 | 7650 | 0 |
| Minimum | 0 | 0 | 0 | 118 | 228 | 6297 | 6642 | 0 | 0 | 0 | 0 | 0 | 0 | 6642 | 6642 | 0 |
| Total for the whole year TWh/year | 0.00 | 1.72 | 0.00 | 3.00 | 2.00 | 55.31 | 62.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 62.03 | 62.03 | 0.00 |

RES Share: 53.9 Percent of Primary Energy 126.9 Percent of Electricity 143.2 TWh electricity from RES 07-August-2019 [23:53]

# Input Norway_EV-_WIND8000__2050_OPTIMUM.txt

The EnergyPLAN model 14.1

| Electricity demand (TWh/year): | | Flexible demand | 0.00 |
|---|---|---|---|
| Fixed demand | 104.59 | Fixed imp/exp. | 0.00 |
| Electric heating + HP | 40.96 | Transportation | 7.29 |
| Electric cooling | 1.00 | Total | 153.84 |

| District heating (TWh/year) | Gr.1 | Gr.2 | Gr.3 | Sum |
|---|---|---|---|---|
| District heating demand | 0.00 | 5.44 | 0.00 | 5.44 |
| 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 | 5.44 | 0.00 | 5.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wind | 8000 | MW | 19.58 | TWh/year | 0.00 | Grid |
| Photo Voltaic | 68 | MW | 0.05 | TWh/year | 0.00 | stabili- |
| Wave Power | 0 | MW | 0 | TWh/year | 0.00 | sation |
| River Hydro | 0 | MW | 4.8 | TWh/year | 0.00 | share |
| Hydro Power | 31174 | MW | 133.57 | 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 | 0 | | 0.45 | | |

Heatstorage: gr.2: 1 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 | 0.35 |
| 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 |

| DistEnerginet_no_NOKprices_2015.txt | | |
|---|---|---|
| Addition factor | 0.00 | NOK/MWh |
| Multiplication factor | 1.00 | |
| Dependency factor | 0.00 | NOK/MWh pr. MW |
| Average Market Price | 177 | NOK/MWh |
| Gas Storage | 0 | GWh |
| Syngas capacity | 0 | MW |
| Biogas max to grid | 0 | MW |

Fuel Price level:

| | 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 | 24.72 | 2.00 | 0.00 |
| Household | 1.81 | 4.89 | 3.00 | 7.23 |
| Industry | 7.40 | 10.50 | 3.20 | 4.20 |
| Various | 1.29 | 31.51 | 52.11 | 9.67 |

# 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 | 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 | 1019 | 0 | 371 | 0 | 239 | 382 | 0 | 28 | 0 | 0 | 13556 | 833 | 1500 | 0 | 6418 | 0 | 0 | 3711 | 18522 | 0 | 40 | 87 | 0 | 100 | 0 | 54 | 0 | 54 | 0 | 9 |
| February | 1002 | 0 | 371 | 0 | 239 | 366 | 0 | 26 | 0 | 1 | 13330 | 830 | 1468 | 0 | 6311 | 0 | 0 | 3146 | 18696 | 0 | 40 | 87 | 0 | 100 | 0 | 31 | 0 | 31 | 0 | 5 |
| March | 843 | 0 | 371 | 0 | 227 | 245 | 0 | 0 | 0 | 0 | 12701 | 826 | 1186 | 0 | 5296 | 0 | 0 | 2572 | 17381 | 0 | 40 | 83 | 0 | 100 | 0 | 66 | 0 | 66 | 0 | 10 |
| April | 669 | 0 | 371 | 0 | 123 | 177 | 0 | 0 | 0 | -1 | 11479 | 832 | 924 | 0 | 4184 | 0 | 0 | 2526 | 15050 | 0 | 40 | 45 | 0 | 100 | 0 | 242 | 0 | 242 | 0 | 37 |
| May | 465 | 0 | 371 | 0 | 15 | 79 | 0 | 0 | 0 | 0 | 11494 | 830 | 604 | 0 | 2878 | 0 | 0 | 2988 | 13418 | 0 | 40 | 6 | 0 | 100 | 0 | 646 | 0 | 646 | 0 | 84 |
| June | 338 | 0 | 371 | 0 | 0 | 2 | 0 | 0 | 0 | -35 | 11201 | 826 | 393 | 0 | 2068 | 0 | 0 | 2957 | 12447 | 0 | 40 | 0 | 0 | 100 | 0 | 956 | 0 | 956 | 0 | 77 |
| July | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -106 | 10501 | 833 | 304 | 0 | 1603 | 0 | 0 | 2667 | 11735 | 0 | 40 | 0 | 0 | 100 | 0 | 1201 | 0 | 1201 | 0 | 67 |
| August | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -99 | 10799 | 829 | 312 | 0 | 1649 | 0 | 0 | 1893 | 12569 | 0 | 40 | 0 | 0 | 100 | 0 | 914 | 0 | 914 | 0 | 71 |
| September | 394 | 0 | 371 | 0 | 5 | 25 | 0 | 0 | 0 | -6 | 11113 | 827 | 478 | 0 | 2426 | 0 | 0 | 2209 | 13276 | 0 | 40 | 2 | 0 | 100 | 0 | 682 | 0 | 682 | 0 | 53 |
| October | 557 | 0 | 371 | 0 | 94 | 92 | 0 | 0 | 0 | 0 | 12063 | 833 | 726 | 0 | 3470 | 0 | 0 | 2084 | 15141 | 0 | 40 | 34 | 0 | 100 | 0 | 208 | 0 | 208 | 0 | 25 |
| November | 796 | 0 | 371 | 0 | 213 | 212 | 0 | 0 | 0 | 0 | 12967 | 828 | 1104 | 0 | 4993 | 0 | 0 | 2602 | 17244 | 0 | 40 | 77 | 0 | 100 | 0 | 71 | 0 | 71 | 0 | 9 |
| December | 927 | 0 | 371 | 0 | 186 | 356 | 0 | 13 | 0 | 1 | 13085 | 829 | 1370 | 0 | 5834 | 0 | 0 | 4010 | 17127 | 0 | 40 | 68 | 0 | 100 | 0 | 127 | 0 | 127 | 0 | 10 |
| Average | 628 | 0 | 371 | 0 | 111 | 161 | 0 | 6 | 0 | -21 | 12021 | 830 | 862 | 0 | 3920 | 0 | 0 | 2781 | 15206 | 0 | 40 | 40 | 0 | 100 | 0 | 435 | 0 | 435 | Average price | |
| Maximum | 1257 | 1 | 371 | 0 | 275 | 437 | 0 | 246 | 0 | 138 | 16721 | 1616 | 1825 | 0 | 7917 | 0 | 0 | 8406 | 26044 | 0 | 40 | 100 | 0 | 100 | 0 | 2288 | 0 | 2288 | (NOK/MWh) | |
| Minimum | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 | 8871 | 0 | 257 | 0 | 1355 | 0 | 0 | 233 | 7900 | 0 | 40 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | - | 120 |
| TWh/year | 5.51 | 0.00 | 3.26 | 0.00 | 0.98 | 1.41 | 0.00 | 0.05 | 0.00 | -0.18 | 105.59 | 7.29 | 7.57 | 0.00 | 34.43 | 0.00 | 0.00 | 24.42 | 133.57 | 0.00 | 0.35 | 0.36 | 0.00 | | 0.00 | 3.82 | 0.00 | 3.82 | 0 | 457 |

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 | - | - | - | - | - | - | - | - | - | - | - | - | 1.81 | 8.69 | 10.50 | 0.00 | 10.50 | 3.55 | 3.55 |
| Oil | - | - | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 24.72 | 4.89 | 42.01 | 71.63 | 0.00 | 71.63 | 18.97 | 18.97 |
| N.Gas | - | 1.48 | - | 0.01 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | 2.03 | 3.00 | 55.31 | 61.82 | 0.00 | 61.82 | 12.68 | 12.68 |
| Biomass | - | - | - | 0.05 | - | 0.00 | - | - | 4.86 | - | - | - | - | - | - | - | - | - | 7.23 | 13.87 | 26.01 | 0.00 | 26.01 | 0.64 | 0.64 |
| Renewable | - | - | - | - | - | - | - | 133.57 | - | - | - | - | 19.58 | 0.05 | - | 138.37 | 0.01 | - | - | - | 158.01 | 0.00 | 158.01 | 0.00 | 0.00 |
| H2 etc. | - | 0.00 | - | 0.00 | - | 0.00 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Biofuel | - | - | - | - | - | - | - | - | - | - | -6.47 | - | - | - | - | - | - | 6.47 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nuclear/CCS | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | - | 1.48 | - | 0.06 | - | 0.00 | - | 133.57 | 4.86 | - | -6.47 | - | 19.58 | 0.05 | - | 138.37 | 0.01 | 33.22 | 16.92 | 119.88 | 327.96 | -8.49 | 319.47 | 35.84 | 35.85 |

07-August-2019 [21:51]

# Output specifications     Norway_EV-_WIND8000__2050_OPTIMUM.txt     The EnergyPLAN model 14.1

District Heating Production

| | Gr.1 | | | | Gr.2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| January | 0 | 0 | 0 | 0 | 1019 | 0 | 371 | 239 | 382 | 0 | 28 | 0 | 779 | 0 |
| February | 0 | 0 | 0 | 0 | 1002 | 0 | 371 | 239 | 366 | 0 | 26 | 0 | 741 | 1 |
| March | 0 | 0 | 0 | 0 | 843 | 0 | 371 | 227 | 245 | 0 | 0 | 0 | 659 | 0 |
| April | 0 | 0 | 0 | 0 | 669 | 0 | 371 | 123 | 177 | 0 | 0 | 0 | 882 | -1 |
| May | 0 | 0 | 0 | 0 | 465 | 0 | 371 | 15 | 79 | 0 | 0 | 0 | 1000 | 0 |
| June | 0 | 0 | 0 | 0 | 338 | 0 | 371 | 0 | 2 | 0 | 0 | 0 | 1000 | -35 |
| July | 0 | 0 | 0 | 0 | 265 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 1000 | -106 |
| August | 0 | 0 | 0 | 0 | 272 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 1000 | -99 |
| September | 0 | 0 | 0 | 0 | 394 | 0 | 371 | 5 | 25 | 0 | 0 | 0 | 1000 | -6 |
| October | 0 | 0 | 0 | 0 | 557 | 0 | 371 | 94 | 92 | 0 | 0 | 0 | 1000 | 0 |
| November | 0 | 0 | 0 | 0 | 796 | 0 | 371 | 213 | 212 | 0 | 0 | 0 | 988 | 0 |
| December | 0 | 0 | 0 | 0 | 927 | 0 | 371 | 186 | 356 | 0 | 13 | 0 | 634 | 1 |
| Average | 0 | 0 | 0 | 0 | 628 | 0 | 371 | 111 | 161 | 0 | 6 | 0 | 890 | -21 |
| Maximum | 0 | 0 | 0 | 0 | 1257 | 1 | 371 | 275 | 437 | 0 | 246 | 0 | 1000 | 138 |
| Minimum | 0 | 0 | 0 | 0 | 225 | 0 | 371 | 0 | 0 | 0 | 0 | 0 | 0 | -145 |
| Total for the whole year TWh/year | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 3.26 | 0.98 | 1.41 | 0.00 | 0.05 | 0.00 | | -0.18 |

| | Gr.3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | District heating MW | Solar MW | CSHP MW | CHP MW | HP MW | ELT MW | Boiler MW | EH MW | Storage MW | Balance MW |
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 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 |

| | RES specification | | | | |
|---|---|---|---|---|---|
| | RES1 Wind MW | RES2 Photo \ MW | RES3 Wave F MW | RES 4-7 er MW | Total MW |
| January | 3080 | 0 | 0 | 631 | 3711 |
| February | 2655 | 2 | 0 | 489 | 3146 |
| March | 2116 | 3 | 0 | 452 | 2572 |
| April | 1992 | 8 | 0 | 526 | 2526 |
| May | 2578 | 9 | 0 | 401 | 2988 |
| June | 1874 | 12 | 0 | 1071 | 2957 |
| July | 2000 | 10 | 0 | 656 | 2667 |
| August | 1447 | 9 | 0 | 437 | 1893 |
| September | 1819 | 6 | 0 | 384 | 2209 |
| October | 1609 | 3 | 0 | 473 | 2084 |
| November | 2098 | 1 | 0 | 503 | 2602 |
| December | 3472 | 1 | 0 | 537 | 4010 |
| Average | 2229 | 5 | 0 | 546 | 2781 |
| Maximum | 8000 | 68 | 0 | 1328 | 8406 |
| Minimum | 0 | 0 | 0 | 6 | 233 |
| Total for the whole year TWh/year | 19.58 | 0.05 | 0.00 | 4.80 | 24.42 |

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million NOK)

Total Fuel ex Ngas exchange = 40315
Uranium = 0
Coal = 1076
FuelOil = 13616
Gasoil/Diesel= 10398
Petrol/JP = 9172
Gas handling = 461
Biomass = 6345
Food income = 0
Waste = -753

Total Ngas Exchange costs = 16213

Marginal operation costs = 520

Total Electricity exchange = -457
Import = 0
Export = -457
Bottleneck = 0
Fixed imp/ex= 0

Total CO2 emission costs = 2151

Total variable costs = 58742
Fixed operation costs = 5989

Annual Investment costs = 22908

TOTAL ANNUAL COSTS = 87639

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 | 3 | 361 | 0 | 559 | 228 | 6297 | 7448 | 0 | 0 | 0 | 0 | 0 | 0 | 7448 | 7448 | 0 |
| February | 3 | 362 | 0 | 550 | 228 | 6297 | 7439 | 0 | 0 | 0 | 0 | 0 | 0 | 7439 | 7439 | 0 |
| March | 0 | 344 | 0 | 461 | 228 | 6297 | 7330 | 0 | 0 | 0 | 0 | 0 | 0 | 7330 | 7330 | 0 |
| April | 0 | 186 | 0 | 364 | 228 | 6297 | 7075 | 0 | 0 | 0 | 0 | 0 | 0 | 7075 | 7075 | 0 |
| May | 0 | 23 | 0 | 251 | 228 | 6297 | 6798 | 0 | 0 | 0 | 0 | 0 | 0 | 6798 | 6798 | 0 |
| June | 0 | 0 | 0 | 180 | 228 | 6297 | 6705 | 0 | 0 | 0 | 0 | 0 | 0 | 6705 | 6705 | 0 |
| July | 0 | 0 | 0 | 140 | 228 | 6297 | 6664 | 0 | 0 | 0 | 0 | 0 | 0 | 6664 | 6664 | 0 |
| August | 0 | 0 | 0 | 144 | 228 | 6297 | 6668 | 0 | 0 | 0 | 0 | 0 | 0 | 6668 | 6668 | 0 |
| September | 0 | 7 | 0 | 211 | 228 | 6297 | 6743 | 0 | 0 | 0 | 0 | 0 | 0 | 6743 | 6743 | 0 |
| October | 0 | 142 | 0 | 302 | 228 | 6297 | 6969 | 0 | 0 | 0 | 0 | 0 | 0 | 6969 | 6969 | 0 |
| November | 0 | 322 | 0 | 435 | 228 | 6297 | 7282 | 0 | 0 | 0 | 0 | 0 | 0 | 7282 | 7282 | 0 |
| December | 1 | 282 | 0 | 508 | 228 | 6297 | 7316 | 0 | 0 | 0 | 0 | 0 | 0 | 7316 | 7316 | 0 |
| Average | 1 | 169 | 0 | 341 | 228 | 6297 | 7035 | 0 | 0 | 0 | 0 | 0 | 0 | 7035 | 7035 | 0 |
| Maximum | 28 | 417 | 0 | 690 | 228 | 6297 | 7650 | 0 | 0 | 0 | 0 | 0 | 0 | 7650 | 7650 | 0 |
| Minimum | 0 | 0 | 0 | 118 | 228 | 6297 | 6642 | 0 | 0 | 0 | 0 | 0 | 0 | 6642 | 6642 | 0 |
| Total for the whole year TWh/year | 0.01 | 1.48 | 0.00 | 3.00 | 2.00 | 55.31 | 61.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 61.80 | 61.80 | 0.00 |

RES Share: 56.1 Percent of Primary Energy 140.2 Percent of Electricity 158.3 TWh electricity from RES     07-August-2019 [21:51]