Master's thesis

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Department of Electric Power Engineering

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Renewable Energy in Longyearbyen

Master's thesis in Energy and Environmental Engineering
Supervisor: Karen Byskov Lindberg
June 2020

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Preface

This master's thesis has been written at the Department of Electric Power Engineering at the Norwegian University of Science and Technology (NTNU), under supervision by Karen Byskov Lindberg. The thesis suggests a design for a renewable energy system in the isolated arctic community of Longyearbyen, Svalbard, to replace the current coal power plant. It was written between January and June in 2020, and is a continuation of a specialisation project written about the same topic between August and December 2019.

Abstract

Longyearbyen in Svalbard needs a new energy system to move away from coal power. With climate change becoming an increasingly pressing issue, it is desirable for the new energy to be renewable. Simultaneously, it should be cost-effective and it must supply the remote island community with the security of energy supply it needs to endure the cold and long winters. This master's thesis examines possible energy systems for Longyearbyen, and how to transition towards them.

Based on gathered data, a demand forecast was made for the electricity, heat and transport demand in Longyearbyen in the time period 2021-2050. HOMER (Hybrid Optimization of Multiple Electric Renewables) was used to develop four different cases for an energy system in Longyearbyen that reduce emissions, in addition to a base case (1) that shows the costs and emissions expected from continuing to use coal power in Longyearbyen. The four new cases included a pellets power plant and wind case (2), a coal and wind case (3), a case with only diesel generators and diesel boilers (4), and, lastly a solar and wind power case (5). Additionally, the case results of a 2018 report by Thema and Multiconsult were included, to see how these cases compared to the option of connecting Longyearbyen to mainland Norway with a power cable. The software tool eTransport was used to create an investment plan.

A possible transition towards renewables in Longyearbyen could come in two steps: First, a 21 MW wind park, 5 MWh battery storage and 4 MW electric boiler capacity should be installed. These components provide the best benefits with regards to cost and emission reductions from the system. The second step would be to replace the existing coal power plant. A 7.5 MW pellets plant would be the best solution with regards to costs and emissions, but a 15 MW rooftop PV installation and an additional 10 MWh of battery storage is also a feasible solution, but would make the system more dependent on backup diesel capacity. It is possible to replace the vehicle park with electric vehicles, and case 2 is best suited for this.

Several findings were made about HOMER and eTransport. HOMER was found to be easier to use, and far better suited for a case analysis and sensitivity analyses. eTransport's main benefit is its ability to handle complex investment dynamics, but the software itself cannot handle complex systems with an acceptable runtime. The modelling of energy demand and variable renewables, such as solar and wind power, is also imprecise.

Sammendrag

Longyearbyen på Svalbard trenger et nytt energisystem for å bevege seg bort fra kullkraft. Klimaendringene krever rask handling, og det er derfor ønskelig at et nytt energisystem er basert på fornybar energi. Samtidig må det være kostnads-effektivt og det må tilby det avsidesliggende øysamfunnet den forsyningssikkerheten det trenger for å tåle de lange og kalde vintrene. Denne masteroppgaven undersøker mulige energisystemer for Longyearbyen, og hvordan overgangen til disse bør skje.

Basert på innsamlede data ble det lagd en prognose for energibehovet til kraft, varme og transport i Longyearbyen i tidsperioden 2021-2050. HOMER (Hybrid Optimization of Multiple Electric Renewables) ble brukt til å utvikle fire forskjellige alternativ for energisystem som reduserer utslipp, i tillegg til et nøytralt alternativ (1) som viser kostnadene og utslippene som forventes hvis man fortsetter å bruke kullkraft i Longyearbyen. De fire nye alternativene inkluderer et pellets- og vindkraftalternativ (2), et kull- og vindkraftalternativ (3), et alternativ hvor dieselgeneratorer og dieselkjeler står for all kraft- og varmeproduksjon (4), og, til slutt, et sol- og vindkraftalternativ (5). I tillegg ble analyseresultatene fra en rapport levert av Thema og Multiconsult i 2018 inkludert, for å se hvordan disse alternativene måler seg mot å koble Longyearbyen til fastlands-Norge med en kraftkabel. Programvareverktøyet eTransport ble brukt til å lage en investeringsplan.

En mulig overgang mot fornybar energi i Longyearbyen kan komme i to trinn: Først bør det investeres i en 21 MW vindpark, et batterilagringssystem på 5 MWh og en elektrisk kjele på 4 MW. Disse komponentene gir de største forbedringene med hensyn til kostnads- og utslippsreduksjoner fra systemet, i forhold til investeringskostnaden. Trinn to i overgangen mot et fornybart energisystem er å erstatte det eksisterende kullkraftverket. Et 7,5 MW pelletskraftvarmeverk vil være den beste løsningen med hensyn til kostnader og utslipp, men et 15 MW takmontert solcelleanlegg og ytterligere 10 MWh batterilagring er også en gjennomførbar løsning, men det vil gjøre systemet mer avhengig av diesel som reservekraft. Det er mulig å erstatte bilparken med elektriske kjøretøy, og alternativ 2 (pellets og vind) egner seg best for dette.

Flere erfaringer ble gjort om HOMER og eTransport som analyseverktøy. HOMER er enklere å bruke, og langt bedre egnet for en analyse av ulike alternativ, og sensitivitetsanalyser av alternativene. eTransports viktigste fordel er evnen til å håndtere mer kompleks investeringsdynamikk, men programvaren i seg selv strever med å løse komplekse systemer med en akseptabel kjøretid. Modelleringen av lastbehov, solkraft og vindkraft er også upresis.

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1 | Introduction

1.1 Background

The global average temperature has risen with more than 1 °C since 1880, due to the emissions of greenhouse gases such as CO_2, caused by human activities. The effects of this temperature increase are already visible, especially in the Arctic. In the Norwegian archipelago of Svalbard, located entirely in the Arctic, the temperature has already increased 4 °C since 1970. The effects of this is visible in melting glaciers, crumbling houses due to melting permafrost and increased landslide and avalanche dangers [1].

Under these circumstances it remains ironic at best, that Longyearbyen, the largest settlement in Svalbard, also has the most carbon intensive energy system in Norway. Whereas mainland Norway's electricity is provided by hydro power and wind power, the heat and power demands of Longyearbyen are delivered by a coal power plant and diesel generators. The power plant is old and nearing the end of its lifetime. There is a need to find a new energy system to fulfil the energy demand of the town's 2400 inhabitants. It is necessary to find a system that both reduces the emissions of greenhouse gases from Longyearbyen and also improves the security of energy supply.

This master's thesis is a continuation of my project thesis *Svalbard - 100 % renewable energy system* from the autumn of 2019, where I examined the same topic [2]. It was found that the most likely solutions for a new energy source in Longyearbyen would be a combination of wind and solar power, or the establishing of a new power plant running on wood pellets. The cost of energy storage solutions was found to be a likely barrier to prevent a 100 % renewable fraction. To further examine these findings, it is necessary to do an energy system modelling with a software tool.

There are several challenges in transitioning the Longyearbyen community towards renewables. Among these are the cold climate and harsh winters, the fact that the system is a completely isolated microgrid system 950 km from mainland Norway, and that local resources are scarce.

1.2 Scope and research question

The main research question of this thesis has been to examine *How can the energy system in Longyearbyen be transitioned towards renewables, in a way that is both cost-efficient and ensures security of energy supply?* The main focus of the thesis is on designing an energy system that can cover the electricity and district heat demand. It is also an analysis of how the proposed systems can handle the transition of all fossil fuel land vehicles to electric vehicles. The thesis deals with the energy demand as inflexible, and does not include energy efficiency measures as options in the analysis. The analysis period is 30 years, from 2021-2050. The discount rate is set to 4 %, the norm for investments in Norway [3]. The emission fee for CO_2 is 500 NOK/tonnes [4].

To answer this question, relevant data was gathered on the current energy system in Longyearbyen, the challenges in transitioning remote Arctic communities towards renewables and the prices of energy components.

The HOMER Pro and eTransport energy system modelling tools were used to perform a case analysis, and to lay out an investment plan for the energy system transition. Additionally, HOMER was used to test how the system alternatives handle a move from fossil fuel vehicles to electric vehicles.

It is assumed that Longyearbyen's buildings will continue to be heated by means of the district heating system, and that any new buildings will also be connected to the system. The total energy demand in Longyearbyen is uncertain, both in terms of total energy consumption and peak loads, as parts of it is covered by unmetered diesel-fueled generators and boilers. It is therefore difficult to ascertain the available extra load they can take on. It is assumed that all diesel components are at capacity today, and that the new energy system is designed to cover the part of the load currently delivered by the coal power plant. In other words, the system boundary for the analysis is around the existing coal power plant. The external boilers and generators are assumed to continue operation with their current capacity throughout the model horizon. This might result in the proposed solution being slightly under-dimensioned, and emphasises the advantages of a scalable solution when there are uncertainties in the demand. Furthermore, the thesis only deals with local emissions from combustion of fuels, and does not take into account cradle-to-grave emissions of components in the system.

1.3 Requirements of future energy system

This section describes what should be required of a new energy system. It also explains the criteria of which the different cases in the case study are rated.

One of the key challenges in designing a new energy system in Longyearbyen is the uncertainty of the demand, not only with regards to the future development of the community, but also the current demand, due to lacking measurements and data. Any energy solution should preferably be easily scalable. A modular approach may be beneficial to many components, such as batteries or PV panels, so that more capacity can be included in the future if necessary. This would also help enable a gradual adoption of electric vehicles.

A new energy system should be judged by its net present cost, its CO_2 emissions and improvements in security of energy supply. Electricity prices in Longyearbyen are already considerably higher than mainland Norway, and should ideally not increase. A decrease would obviously be beneficial. Coal is the most carbon intensive common way of generating electricity, and contributes to global warming. One of the requirements of a new system is that it helps reduce the emissions drastically.

The current operational issues with frequent blackouts should also be improved. As Longyearbyen is transitioning to a regular Norwegian municipality, its citizens expect to always have electricity. The system should therefore be reliable and employ mature technology. Additionally, a political goal has been expressed to make Longyearbyen less dependent on imports. Svalbard's cold, harsh winters requires all installations to be resilient to the Arctic climate. This, combined with the permafrost, puts higher technical requirements on all foundations. Maintenance should be easy and predictable, as it can take considerable time to spare parts and special repair technicians to Longyearbyen.

2 | Renewable energy in the Arctic

This chapter presents relevant information about energy systems in remote, arctic settlements, and the difficulties in transitioning them towards renewables. The chapter provides an overview of existing literature on alternative energy systems for Longyearbyen, and also includes a brief study of how Greenland has been moving towards renewables in the last decades.

2.1 The Arctic

While there is no universal definition of what encompasses the Arctic, the term refers to the northernmost parts of the globe [5]. Here, the focus is on the areas that have an Arctic climate and is north of the tree line. This definition includes, amongst other areas, Greenland and the archipelago of Svalbard. The region is characterised by its cold climate and barren landscape [5].

While most of the region is open ocean, there is a permanent ice cover stretching from mainland Russia on the Eurasian side, to mainland Canada on the American side, including Svalbard and Greenland on the Atlantic side. During summer, the ice cover recedes. With no tree growth and snow or ice cover for large parts of the year, Arctic landscapes are barren and rocky. The only vegetation is moss, lichen, grass and shrubs [6]. Permafrost is a defining feature of the Arctic, prevalent everywhere that the average annual temperature is below -2 °C [7]. In Svalbard, permafrost is prevalent everywhere, and the frozen layer of the ground varies between 100-500 m.

Civilisations have been interested in the Arctic region for centuries, mainly in quests to explore new shipping routes and to exploit its natural resources, through activities such as whaling and coal mining [5]. For many of these activities, settlements were established. Arctic settlements are still among the world's most remote and least populated.

2.2 Energy systems in Arctic settlements

Fossil fuels are still the norm in the Arctic regions, and most settlements rely on diesel generators or coal power plants. As the region is sparsely populated, with a challenging climate, reference literature on the subject is scarce. Climate change is a pressing issue, and the Arctic region is one of the areas of the globe that feels the effect of climate change the most. Reducing greenhouse gas emissions by replacing fossil fuel based energy systems with renewable systems is therefore highly relevant.

Transitioning Arctic settlements towards renewables is challenging as the communities are often small and unfit for economies of scale. The remoteness puts requirements on security of energy supply, reliability and ease of maintenance. With cold and long winters, there is a substantial demand for energy for heating. The harsh winter storms and permafrost are two major hurdles to overcome, as they place large technical requirements on the robustness of the construction [2]. The local energy sources available for harnessing is often limited to sun and wind, with solar power often limited to the summer months. The variable production of these requires energy storage, and there has traditionally been financial barriers to these technologies. The costs of PV installations has decreased substantially over the last few decades. A German report found that prices in Germany have dropped 92 % in the period 1990-2020 [8].

2.3 Literature on Svalbard

Started as a coal mining town in the early 20th century, Longyearbyen in Svalbard has grown to be Norway's largest settlement in the Arctic, with roughly 2400 citizens. While originally a mining town, tourism and research are equally important industries now [2]. Several reports have been written on the subject of a new energy system for Longyearbyen.

Alternativer for framtidig energiforsyning på Svalbard from 2018, by Thema and Multiconsult, was written as a commissioned report from the Ministry of Petroleum and Energy [4]. The report includes a case analysis of alternative solutions based on either: 1) CHP generation by either an LNG plant, a pellets plant or a bio coal plant; 2) local renewables, with wind *and* solar power in combination with either battery or hydrogen storage, or alternatively wind *or* solar power in combination with an LNG plant; or 3) a cable connection to mainland Norway. The base case solution of continued coal operation was also considered, with and without carbon capture and storage [4]. Thema and Multiconsult recommended to proceed with more detailed examinations of the three following cases: 1) LNG plant without CCS, 2) Pellets power plant, and 3) solar power and LNG. These were found to be the most attractive, due to costs, emission reduction and little local consequences [4].

In 2019, the report *Feasibility Study for an Energy Storage System for Longyear Energiverk* , was released by Multiconsult, commissioned by Longyearbyen Lokalstyre. The report contained an economical analysis of how the system would be affected by implementing a battery storage, a heat storage, and rooftop PV panels. HOMER was used to model the energy system, and technical plans were laid out for the alternative system components [9]. The report concluded that a 10 MWh/5 MW battery storage and a 30 MWh/3 MW heat storage would save money and contribute to emission reductions in the system. The battery pack would reduce costs by 7 MNOK annually, and the heat storage would save an additional 1.1 MNOK annually. It was also found that adding a PV system on top of this would not save money, but it would reduce emissions [9]

The paper *Transitioning remote Arctic settlements to renewable energy systems – A modelling study of Longyearbyen, Svalbard* was released late 2019 by researchers at the University of Bergen. The paper included a TIMES energy model of Longyearbyen, and it found that transitioning Longyearbyen towards renewables is feasible. Such a solution would rely on wind and solar power, as "the potential of harnessing wind and solar in Arctic locations is significant, and when utilised together they have beneficial complementary properties" [10]. They underlined the importance of energy efficiency measurements, and also concluded that there are significant cost-savings to be made by accepting that a minor part of the energy is provided by fossil fuels, as this can help avoid over-investments. A small amount of fossil fuel capacity also increases the system robustness and reliability.

2.4 Literature on Greenland

Greenland is an autonomous island, formally part of Denmark, located in the northern parts of the Atlantic ocean. The island's climate and geography is largely arctic, with 85 % of the island being permanently covered in ice [11]. The population of 58 000 consist of 90 % native Greenlandic Inuits [12]. Greenland consists of many small communities, and a few towns, spread across the coast line on both the western and eastern side of the island. Traditionally, these communities and settlements got their energy needs covered using imported fuels, mostly diesel and petrol.

A key political goal for Greenland is to become more independent of other countries. In this pursuit, they invested in hydro power plants, with the first out of the current five starting operation in 1993. As of 2017, these five plants covered 60-70 % of the power demand, with imported fossil fuels accounting for the rest [13]. The remoteness of many of the island's smaller communities has been a central challenge in increasing the renewable penetration. As large power cables are too expensive between the communities, there are 70 decentralised energy-systems on the island. These communities still get their energy from the combustion of imported fossil fuels.

As of 2017, the political coalition governing the territory of Greenland planned to increase the hydro power capacity, and provide renewable energy solutions to the smaller communities. Many technologies have or are been explored to find reliable energy solutions for these communities [13].

Since 2015, there has been experiments with geothermal energy. Many communities use waste incineration to provide heating for buildings. Wind power has previously been avoided, due to concerns that the wind turbines would struggle with the harsh weather conditions of the arctic, and that wind conditions would be unfavourable. It is typically not enough wind available to utilise turbines, or too heavy winds for them to safely. However, recent test projects have indicated that modern wind turbines can work favourably in Greenland, providing electricity throughout the year [13].

Solar power by means of PV panels have been frequently used already. While the climate and geography of Greenland is discernibly arctic, most of the territory's population lives south of the Arctic Circle, on latitudes corresponding to the city of Trondheim in Norway. The ground-level solar irradiance is roughly $900kWh/m^2/yr$ [14], which i shigher than in Trondheim. Generally, PV often performs better than expected in Arctic regions, due to frequently clear skies, indirect radiation from snow-covered ground and colder climates allowing the PV panels to work more efficiently.

Igaliku is a small settlement with 23 people. Since 2017, they have been testing a hybrid energy system based on a combination of 100 kW polycrystalline PV panels, 20 kW of very small wind turbines placed on top of the panels that start generating electricity at 2 m/s, two backup diesel generator at 128 kW total capacity, an inverter and a lead-acid battery bank of 190 kWh [15]. The system is estimated to reduce diesel usage by 36,000 L annually. Similar hybrid systems are assumed to be feasible in 57 other small settlements in Greenland [15].

3 | Current energy system and demand

Most of the available data on the energy system in Longyearbyen were reviewed during the project work [2]. This chapter is based on the project thesis, unless otherwise specified.

3.1 Energy generating components

The power plant, its components and expected lifetime

Longyearbyen Energiverk is the only operable power plant in Longyearbyen, and is located near the harbour in Sjøområdet. The plant was built and made operational in 1982-1983 to replace the old one [4]. The plant consists of two turbines, henceforth referred to as T1 and T2, where T1 is used as a combined heat and power turbine (CHP) and T2 is used for electricity only. T1 is a back-pressure turbine, which requires cooling, and the return water from the district heating system is used for this purpose. Therefore, T1 can only generate heat and electricity in combination, and the total production is a function of the current heat consumption [9]. There is also a diesel boiler (DB) in the power plant. The *rated* power output and efficiencies are shown in table 3.1. These are theoretical ratings, and operation have found the maximum heat generation of T1 to be closer to 14 MW [4].

	Electricity generation	**Heat generation**	**Efficiency electricity**	**Efficiency heat**
T1	7.5 MW minus generation at T2	16 MW	19 %	63 %
T2	7.5 MW minus generation at T1		27 %	
DB		5 MW		Unknown

Table 3.1: Overview of turbines [4].

An assessment by OEC Consulting from 2013 provided a maintenance plan that will allow the power plant to continue operation until 2038, provided certain measures, most of which have been fulfilled by Longyearbyen Energiverk [4].

The current location of the power plant gives little room for expansion. It lies next to the previous power plan, which is a cultural heritage site and cannot be demolished. Additionally, it lies next to the main road between Longyearbyen, the airport, and other industry infrastructure. Furthermore, the current location is in a zone marked as potentially threatened by an avalanche. Hotellneset, close to the airport, has been pointed out by Lokalstyret as a potential location for a new power plant (see appendix B) [4].

The steam that runs the turbines come from two coal boilers. After environmental requirements, Longyearbyen Energiverk was obligated to install a gas scrubber that cleans NOx and other exhaust fumes from the coal boilers [4]. The gas scrubber is only connected to one boiler, leaving the other one effectively unused [9].

T1 operates most efficiently when the electricity to heat ratio is 1:3.6, and has a minimum output of 5 MW of heat. When the thermal demand is below 5 MW, excess heat is curtailed in the sea. The same happens when the electricity to heat ratio forces the plant to produce more heat than the demand, in order to meet electricity demand [9].

Backup power

By the crossroad outside UNIS, commonly called UNIS-krysset, there is a backup diesel generator capable of delivering 4.5 MW. Starting the diesel generator takes roughly 10 minutes [9]. This generator is used almost daily to cover peak loads, especially when the mine starts operating in the morning.

In 2017, Longyearbyen Lokalstyre recommended building an extra backup diesel genset of 6 MW and has applied for funding. There is a backup generator in the power plant, but it is out of order and inactive [4]. Consequently, it cannot be relied on for backup power.

To provide backup heat for the district heating system, there are 6 boiler houses, spread along the DH network. They can provide a total of 15.5 MW of heat [4] and are frequently used to cover peak thermal loads, and to compensate for losses in the DH system. Multiconsult and Lokalstyret estimate the peak heat demand to be 18 and 21 MW, respectively [4], but there is no heat load metering, so the actual peak is unknown. In case of a power plant failure, the boiler houses are insufficient to cover peak thermal loads by themselves.

Longyearbyen Energiverk does not have enough diesel generator capacity to provide the necessary power in case of a complete failure of the power plant. Many of the bigger companies and town utilities, such as Kongsberggruppen (SvalSat), Store Norske (Gruve 7), Avinor (the airport) and the town hospital, have their own emergency backup power [4]. This provides Longyearbyen Energiverk some flexibility to cut power loads during an emergency blackout.

Summary of active energy generating units

The following table gives a summary of all active power and heat generating units. Inactive units, such as the backup generator at the power plant, are not included. Privately held units not in connection with the main grid are also not included.

Active electricity and heat generating units	Energy source	Electricity generation [MW]	Heat generation [MW]
Power plant	Coal	7.5	14
Diesel boiler in power plant	Diesel		5
Backup power (UNIS-krysset)	Diesel	4.5	
Boiler houses (6 spread along DH system)	Diesel		15.5
Total		12	34.5

Table 3.2: Overview of electricity and heat generating units

Renewables

There is already some renewable energy installed in Longyearbyen, but none of it is owned or operated by Longyearbyen Energiverk. Longyearbyen Airport, owned by Avinor, have 430 PV panels with power ratings between 265 and 330 W each, for a total of 110-130 kW. They do not feed any electricity into the grid, but the installation helps reduce the power demand in the grid [16]. Avinor also plans expanding their own power production by installing three wind turbines of 6 kW each, which they estimate will deliver a total of

75 MWh annually. Avinor has applied to Lokalstyret for permission to install these turbines [17].

Grid stability and operational issues

There are several issues relating to stability in the energy system, especially with regards to the electric grid. An inherent property of electricity is that it has to be produced at the same time as it is used. If generation and consumption are not synchronised, the frequency will drop or rise, leading to blackouts as protection mechanisms and relays respond to the frequency error. Such blackouts happen frequently in Longyearbyen, according to Rasmus Bøckman, engineer at Longyearbyen Energiverk and energy advisor to Longyearbyen Lokalstyre. Because of considerable delay in a district heating system, short blackouts bear little consequences.

More modern coal power plants crush the coal into a powder. This allows for faster and more controllable combustion. In the coal power plant on Longyearbyen, the coal spends several hours in the cycle through the plant. Due to this, the plant operator has to estimate the power demand in the future, and feed the coal boiler based on that estimate. The coal varies in quality, making it difficult to know its exact heating value. In order to prevent blackouts, they feed the plant with coal according to a low estimate of heating value and a higher estimate of power demand in the near future. Generally, one should avoid starting and stopping turbines frequently, as the extra wear and tear shortens the expected lifetime. It is also not beneficial to run them on low drive, for much the same reasons. Over-generation is easier to deal with than under-generation. All of these factors contribute to make the operation of the coal power plant inefficient and costly.

3.2 Energy distribution

Electrical grid

The current electrical grid suffers from being old, and is expected to require substantial future investments. Parts of the grid is above ground, and not sufficiently protected from harsh weather, leaving the grid prone to blackouts in winter storms. The current electrical grid operates at 22 kV, 11 kV, 230 V IT, 400 V TN and 1000 V [4]. There are no major capacity constraints in the grid, but if a new power plant is established in Hotellneset, it might be necessary with a new power cable to the town [4]. Likewise, if a solar or wind power plant is built on Platåberget or any other plateaus, new cables must be installed.

Due to the relatively short lengths of the electricity grid in Longyearbyen, transmission losses are small. Costs for operating and maintaining the grid is included in the power price instead of a separate grid tariff as on the mainland [18]. The grid operates at 50 Hz, like the rest of Norway.

District heating system

The district heating system provides Longyearbyen's buildings with heat. The DH network dates back to the 50's, with the newest parts being the primary network that was installed in the early 80's along with the new coal power plant. The DH primary network is estimated to last another 15-20 years [4]. The network is structured in a primary network, a secondary network connected through heat exchangers, and for each residential building there is a second heat exchanger connecting the secondary network to the building. There are therefore three separate temperature levels, whereas it is common with only two on mainland Norway. This leads to increased thermal energy losses [4]. The extra diesel boilers are spread evenly along the system. There is currently capacity constraints in the network. Unless the thermal energy demand is lowered, there will be necessary to invest in and upgrade the DH network [4].

The supply temperature is 90 – 120 °C [9], but very often close to $120°C$ according to Rasmus Bøckman. The district heating system operates at constant flow of 115 kg/s, because it is necessary to have a stable return temperature of 80-85 °C for turbine 1, which uses the return water to cool itself down. Most of the district heating consumers are geographically located at a higher altitude than the power plant.

The losses in the DH system are unknown, but both Lokalstyret and Energiverket assume they are substantial [4]. The average for DH systems in mainland Norway is 12.1 % (see appendix). The pipes in Longyearbyen run in parallel with the tap and waste water pipes, to prevent them from freezing. The DH system is also old, and with the cold climate of Longyearbyen, it can be expected that the DH system losses could be somewhere between 16-20 %.

Rasmus Bøckman commented on operational issues stemming from the fact that the customers themselves owns and controls the DH system in their own household, i.e., they can open the valves as much as they want [19]. He also pointed out that with area pricing, there are no incentives for consumers to lower their thermal energy consumption. He knew of cases where consumers had broken radiator valves, and instead of fixing them, they opted for controlling their indoor temperature by opening windows, and wasting energy. The extent of these practices and the associated energy waste is difficult to estimate, but it certainly contributes to an energy demand which is higher than necessary.

3.3 Energy demand

Much of the information regarding the energy demand was communicated during a meeting with Rasmus Bøckman [19]. Time series for electricity and heat production have been provided, with the heat time series extending from January 23rd 2017 and throughout the year, and the electricity production from December 22nd 2016 and till March 22nd 2018. These time series show the output from the power plant, but do *not* include the boiler houses and backup generators. From these components, there are no records of energy generation.

Thermal energy

The thermal energy demand goes to heating buildings and tap water. It is estimated that 70 % of the thermal demand is used for heating buildings, and is dependent on the outside temperature. 30 % goes to tap water, and is fairly constant [4]. Most residential buildings in Longyearbyen do not have thermal load measuring devices. Instead, the consumers pay a fixed price indicated by the area of the residency. Due to this, data is limited on thermal demand from the consumer side and no data exists on losses in the district heating system. Based on his knowledge about the system, Rasmus Bøckman suspects there are considerable losses in it [19].

Many buildings are poorly insulated. Some measurements have been done in a few buildings, and the thermal energy demand in residential buildings in Longyearbyen is considerably higher than in comparable climates in Norway proper. Demands higher than $600kWh/m^2/yr$ have been measured.

The output of the power plant is presented in the figure below.

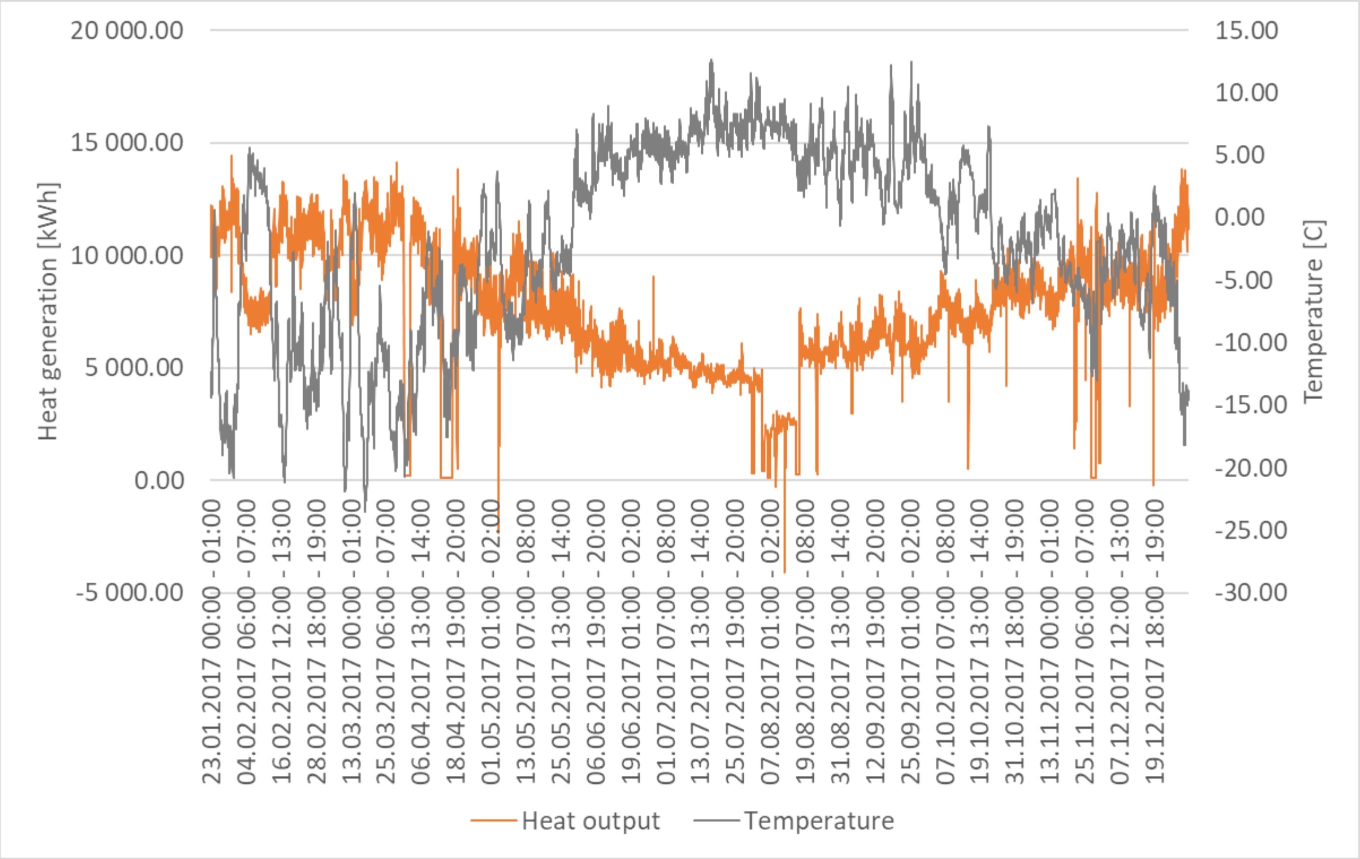


Figure 3.1: Time series of heat output and outdoor temperature from January 23rd 2017 and till December 31st 2017

As seen in figure 3.1, there is an obvious correlation between the heat output and the temperature. This is natural as the need for heating will rise when it is cold outside. The production is steadily high from November and through April, before it declines towards summer. In August, there is almost no heat generation. Peak heat output is almost 15 MW, and occurs when the temperature is around -20 C.

As the diesel boilers of 15.5 MW are not included in this graph, it is likely that the peak demand is even higher. The diesel boilers also account for the period in August with almost no heat generation. Turbine 1 in the power plant cannot output less than 5 MW of heat. When the demand stoops below this, 5 MW generation is maintained and the surplus heat is curtailed. In August, there are periods where the heat demand is so small that the operator prefers to switch to electricity production on turbine 2, and instead opt to use the diesel boilers to deliver the small heat demand.

The time series show that the heat output is occasionally zero. With the Arctic climate, there is a heat demand for residential buildings at all times through the year. It is therefore assumed that most of the short production stops are due to technical difficulties or scheduled maintenance. Because there is considerable delay in a district heating system, short production stops are acceptable.

There are a few negative values for production levels. It is unclear what causes this. One theory could be that because turbine 1 use return water from the district heating system to cool itself down, this is somehow measured right after the turbine starts up and registered as negative values. Technical errors in the measurements could also be the case.

Electrical energy

The following electrical output data was provided by Longyearbyen Energiverk.

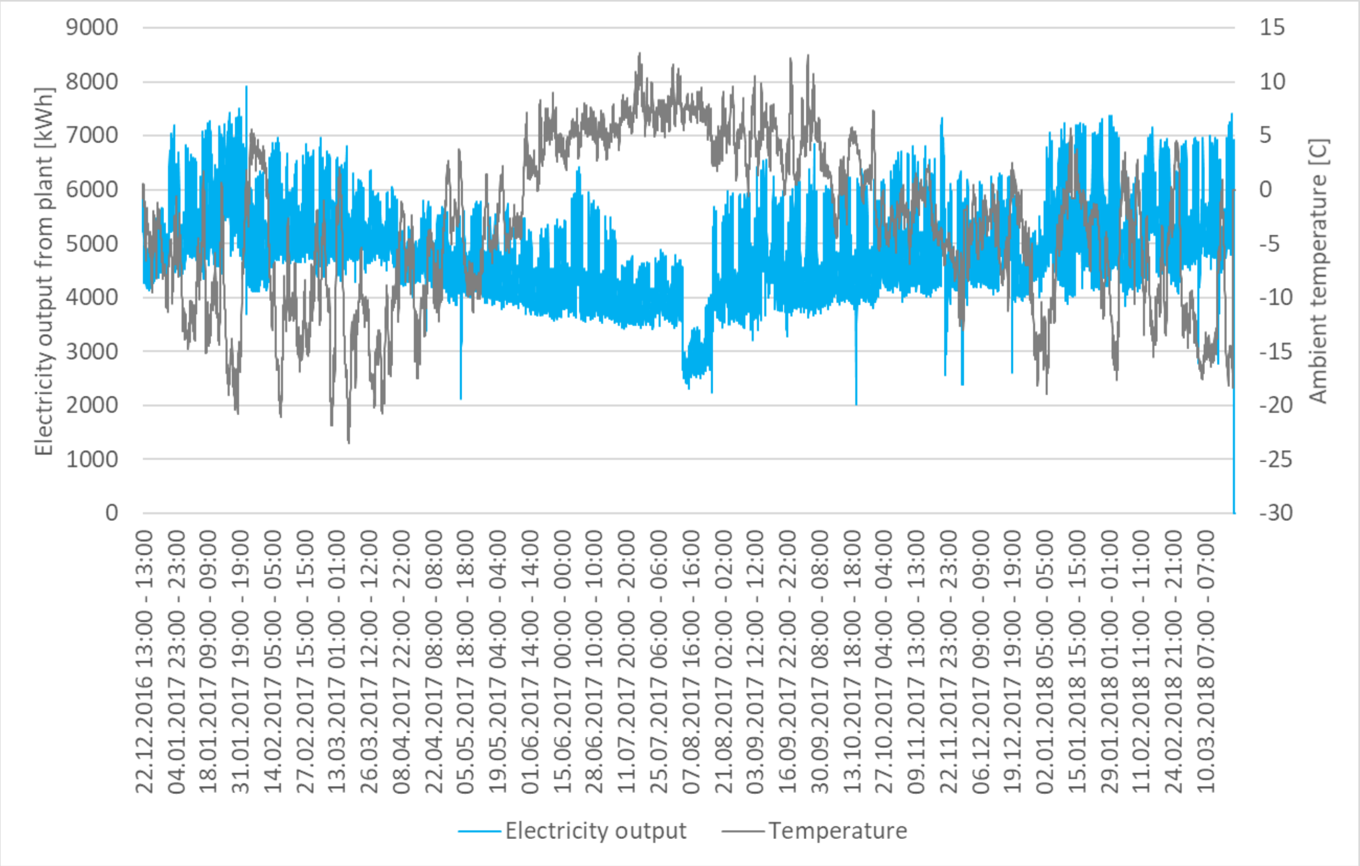


Figure 3.2: Time series of electricity output and temperature from December 22nd 2016 to March 22nd 2018

Figure 3.2 shows that the electricity demand is more seasonally stable than the thermal demand. Electricity in Longyearbyen is used by energy demanding businesses, such as SvalSat and SNSK. Residents use electricity for lights and home appliances. Very little electricity is used for heating.

All electricity consumers in Longyearbyen have load meters installed, and pay based on their exact consumption of electricity. As Longyearbyen is separated from any power grid, and there are no renewables in the system, the power price is completely fixed and decided by Lokalstyret. As of 2019, all electricity consumers pay 1.93 NOK/kWh for the first 10,000 kWh they consume, plus an annual fixed fee of 2,294 NOK. Every kWh consumed over 10,000 kWh costs 2.13 NOK, and every kWh consumed over 50,000 kWh costs 2.33 NOK [18]. This makes electricity considerably more expensive than on the mainland, despite citizens of Svalbard not being subject to the same tax system as mainland Norway.

Peak load

The electricity provided by the backup generator set can be estimated by the difference between delivered electricity paid for by customers and the production at the power plant. 43.0 GWh was billed to consumers in 2017 [4], while the time series show 42.3 GWh provided by the power plant in the same period. Of the 0.6 GWh difference, some energy will go to grid losses, meaning that less than 0.6 GWh or roughly 1.5 % of the electricity demand was delivered by diesel generators. While this additional load may be of high importance when planning for the energy system to be able to meet peak demand, it matters less when it comes to the total energy delivered and the cost of operating the system.

Comparing electricity and heat output of the power plant

Figure 3.3 compares the heat demand to the electricity demand in the time period where there is data available for both, e.g. from January 23rd in 2017 and throughout the rest of 2017.

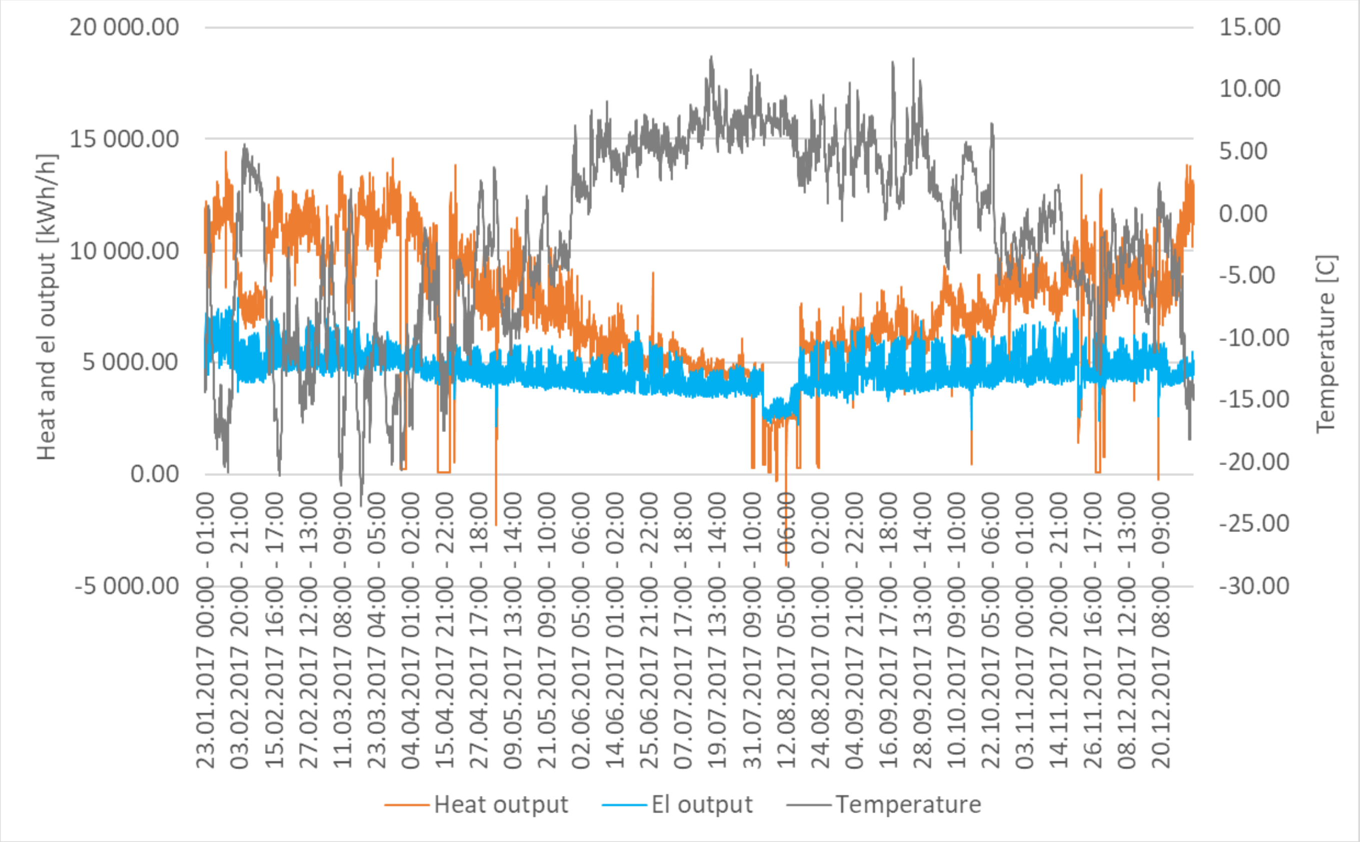


Figure 3.3: Time series of temperature and electricity and heat output from January 23rd 2017 and till December 31st 2017

The heat output is generally higher than the electric power output of the power plant throughout most of the year, aside from in summer around July and August. The graph also illustrates, once again, how the heat demand changes with temperatures and seasons, whereas the electricity demand is fairly constant.

Variations in energy demand through the day

The daily variations in energy demand can be examined by looking at a typical winter's day and a summer's day, such as two Mondays when business operations should be roughly equal.

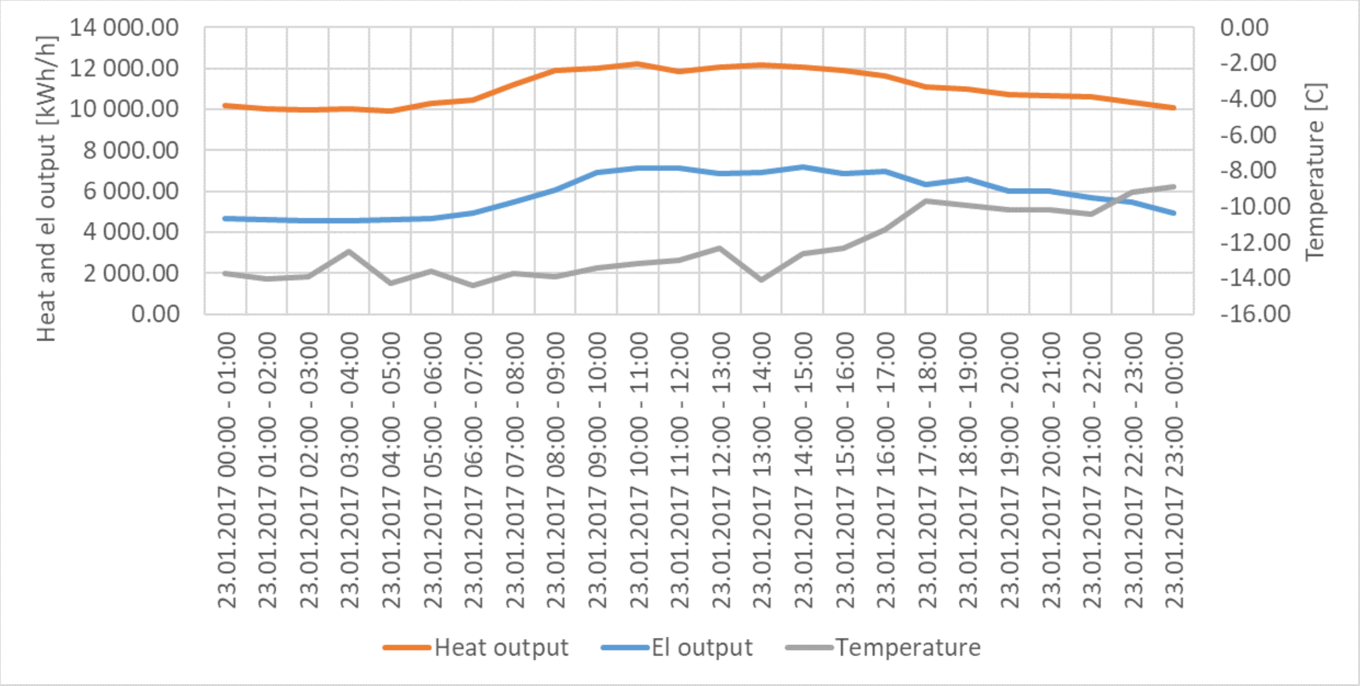


Figure 3.4: Energy demand on January 23rd 2017, a Monday

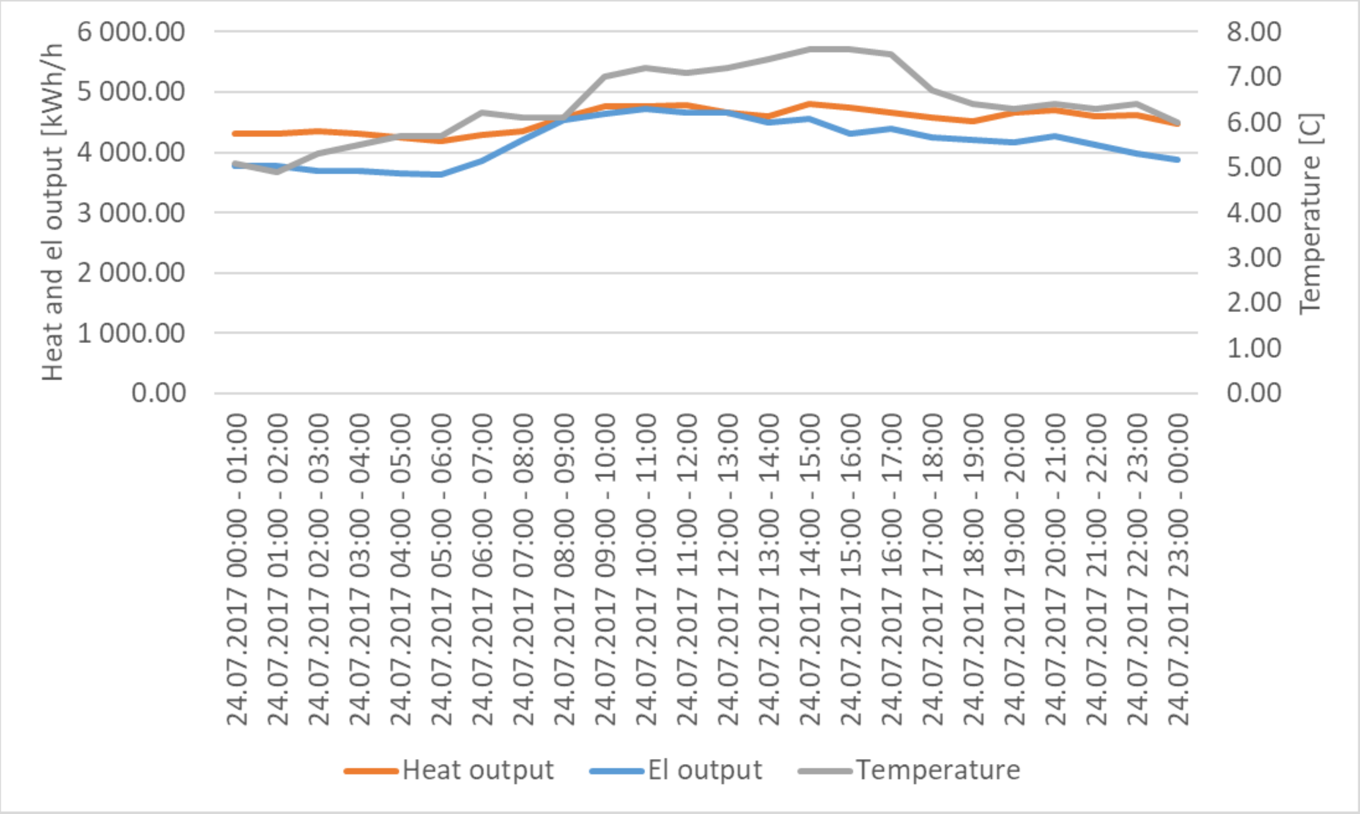


Figure 3.5: Energy demand on July 24th 2017, a Monday

Figure 3.4 and 3.5 show that the curves for both heat and electricity, in both summer and winter, are quite similarly shaped. They are fairly flat from around 22-23 in the evening till around 7 in the morning. Then they gradually rise till a peak value around 9, which is maintained until some time between 16 and 21, before it decreases. This allows the load in a 24 hour period to be modelled similarly in winter and summer, but with a constant multiplier to adjust seasonal variations.

Variations in energy demand through a week

It can also be interesting to look at the typical variations throughout a normal week in Longyearbyen. The following graph shows the heat and electricity demand in a week in February in 2017.

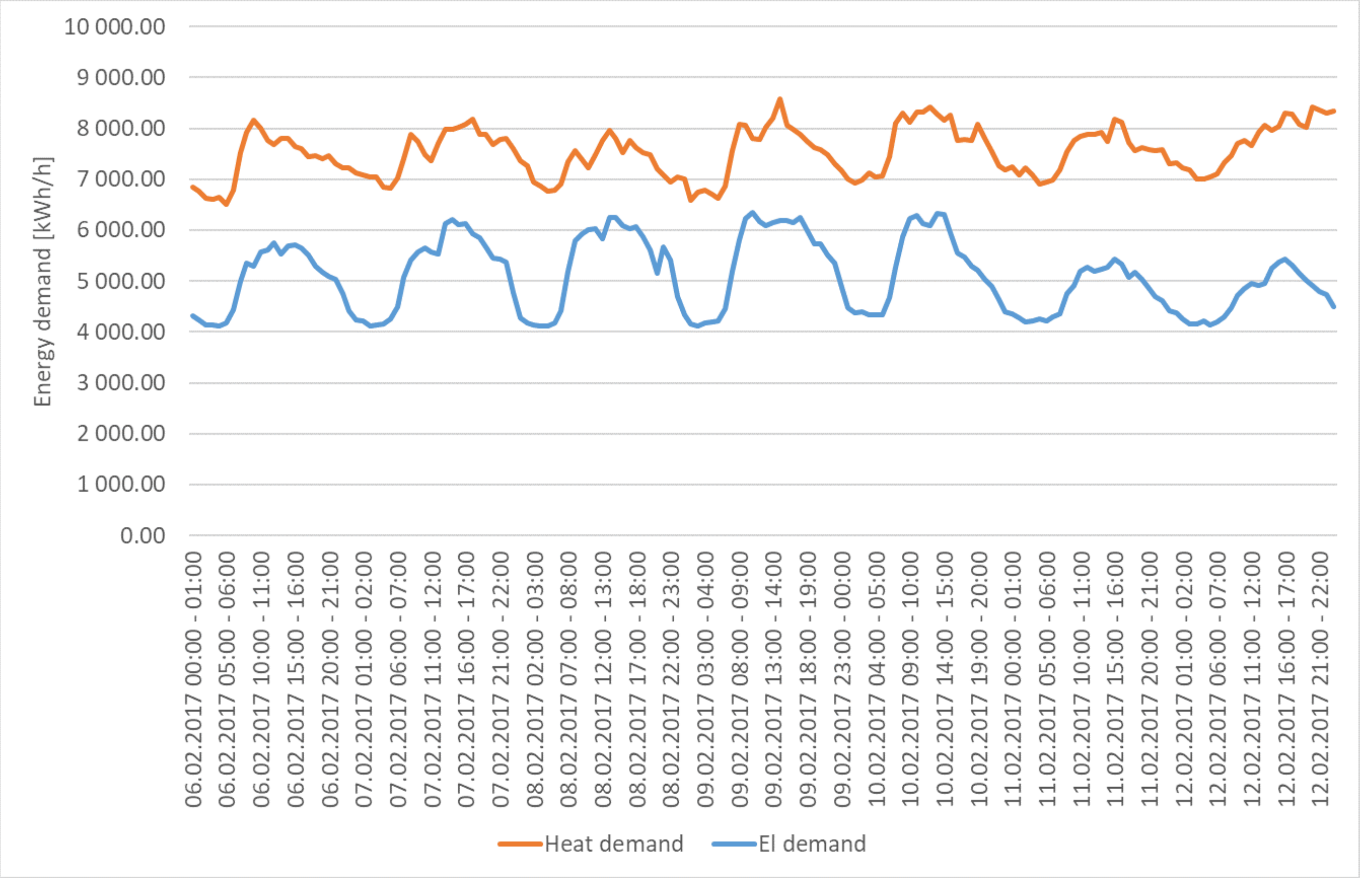


Figure 3.6: Energy demand Monday-Sunday, February 6th-12th, 2017

Figure 3.6 shows the typical variation every day with peaks at midday and lows at night. For the electricity load, it is clear that the night time low is roughly equal all through the week, at about 4000 kWh/h. The daytime peaks hovers around 5800-6200 kWh/h during weekdays, and 5200-5500 kWh/h during weekends. This is likely due to businesses that use electricity being closed on weekends. For the heat demand, there is no difference between weekdays and weekdays this example week.

Electricity demand by consumers

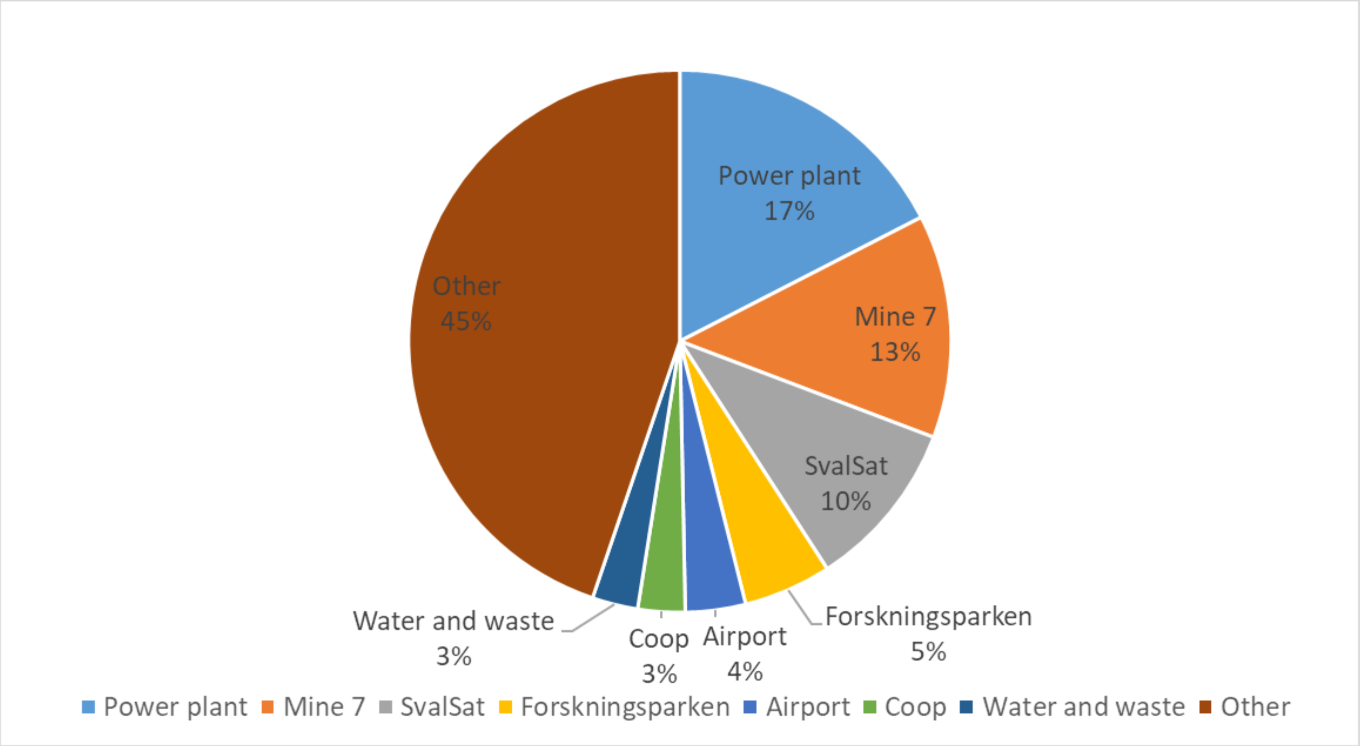


Figure 3.7: Electricity demand by consumers [4].

Figure 3.7 shows all electricity consumers whose demand is above 1000 MWh of electricity annual, with all other consumers being grouped under "other". There is a potential error in the data from the Thema and Multiconsult report, as listed electricity demand for each consumer does not add up to the total. The electricity used by the power plant itself is included in the figure. In case of a transfer to renewables and energy storage, the energy demand of operating the energy system itself will potentially decrease.

Mine 7 and SvalSat - Longyearbyen's two biggest electricity consumers (aside from the power plant) - use a total of 23 % of the town's electricity. This illustrates the effect the development of the business sector of Longyearbyen has on the total energy demand. If the coal mining operation ceases, this will directly cut 13 % of the town's electricity demand. Furthermore, the mining employed 101 people as of 2018 [20], meaning that a close down of coal operations might indirectly lead to many of these workers moving away from Svalbard. SvalSat estimates that their energy demand will, due to planned expansions, increase by roughly 50 % [4].

Thema and Multiconsult assumes in the 2018 report that a shutdown of Mine 7 will not affect the energy demand, as other businesses will appear [4].

Transport

The transport sector in Longyearbyen consists mainly of snowmobiles, cars, snowcats and boats. The vehicles in Longyearbyen are either registered in Longyearbyen specifically, or on Svalbard in general, which mean they can belong to Longyearbyen, Ny-Ålesund or Barentsburg. Assuming that all vehicles registered on Svalbard belong to Longyearbyen makes the total number of vehicles 4053, as of the 31st of December 2019 [21].

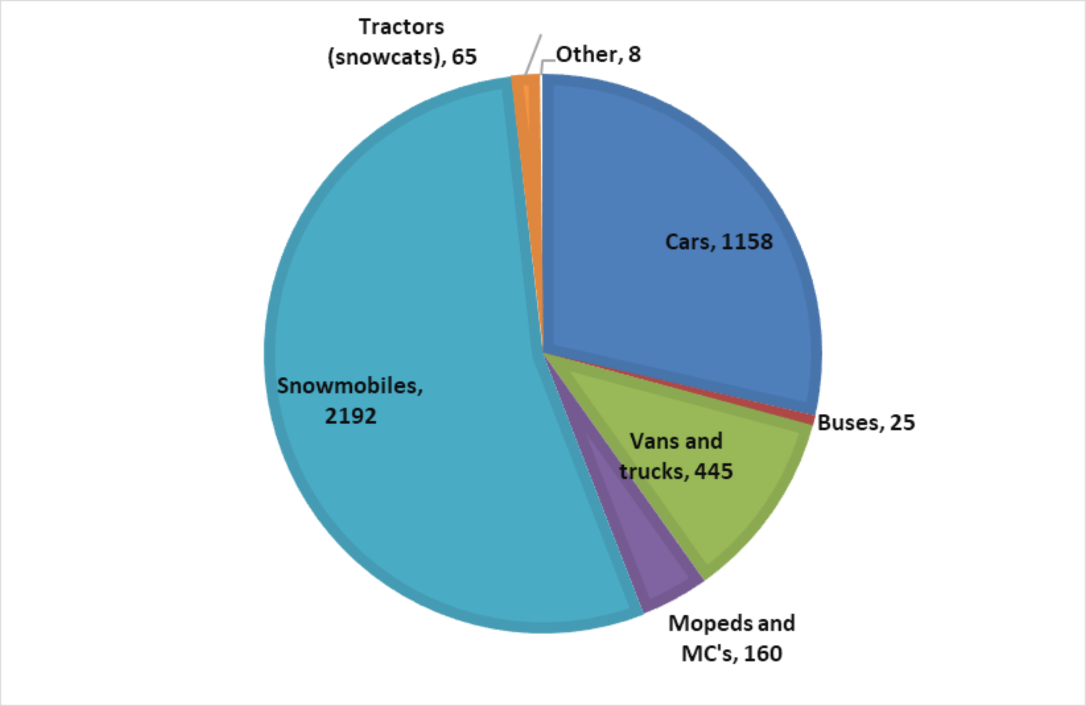


Figure 3.8: Registered vehicles by vehicle type in Svalbard 2019 [21]

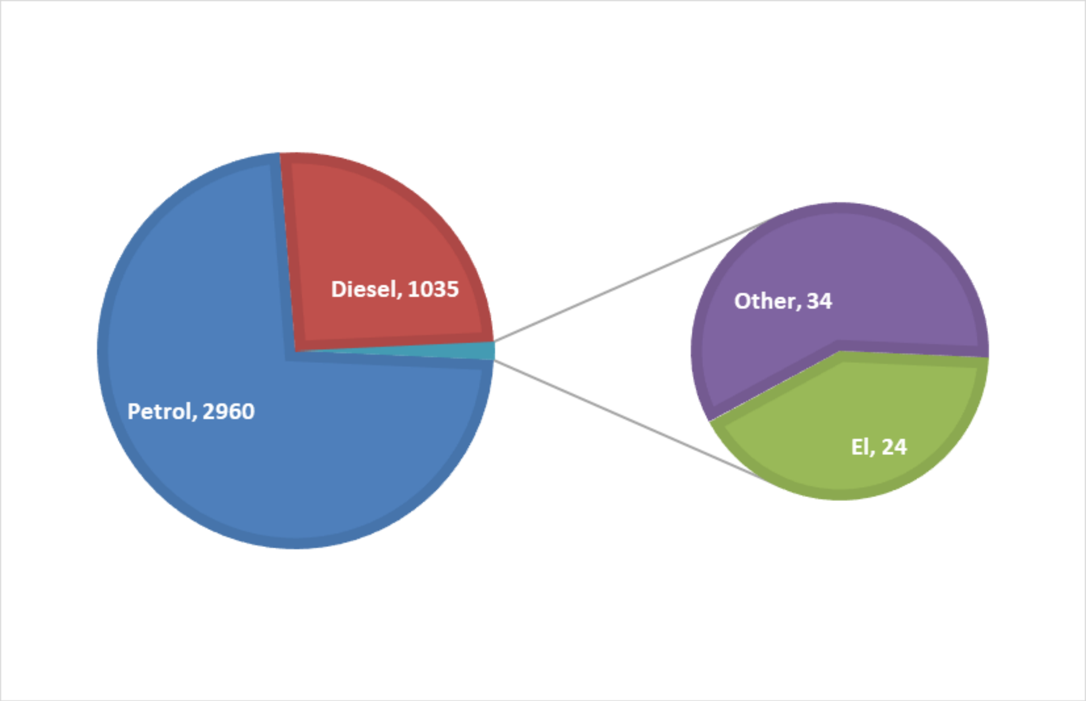


Figure 3.9: Registered vehicles by fuel in Svalbard 2019 [21]

Snowmobiles make out 54 % of the total amount of vehicles, and cars 29 %, as seen in figure 3.8. 47 % of the cars run on diesel. This is due to the popularity of large pickup trucks, that typically run on diesel instead of petrol. There are 24 vehicles running on electricity, and there are 34 vehicles running on "other" fuel types. These are mostly hybrids. The large vehicles, such as trucks or buses, run mostly on diesel. Practically all the snowmobiles run on petrol [21].

Energy demand for transition to electric vehicles

With a limited road network, most vehicle transports are short-distance in and around Longyearbyen. Driving range is therefore not a concern, and Longyearbyen's transport sector on land is well suited for running on electricity. The additional electricity demand necessary if all vehicles were replaced by similar electric vehicles can be estimated to 7.7 GWh. Table 3.3 shows the calculations behind this estimate. This calculation is based on the presumption that all existing vehicles run on petrol, and that the energy demand per km of movement of an electric vehicle is 0.31 that of a similar internal combustion engine vehicle. This is based on the ratio between the Volkswagen e-Golf 100 kW and the Volkswagen Golf Comfortline 1.0 TSI [22].

	Number	Distance per vehicle [km/yr]	Tot. distance per vehicle [km/yr]	Fuel consumption [L/km]	Fuel consump -tion [L/yr]	El. demand if replaced with el vehicles [GWh/yr]
Passenger cars	1,219	9,471	11,545,149	0.1	1,154,514	3.16
Vans and trucks	384	1,1140	4,277,760	0.2	85,552	2.34
Buses, tractors, snowcats, other	98	5,000	490,000	0.3	147,000	0.40
Snowmobiles and MC's	2,352	3,500	8,232,000	0.8	658,560	1.80
Sum	4,053		24,544,909		2,815,627	7.71

Table 3.3: Estimated transport energy demand

Passenger cars in Svalbard drove on average 9471 km/year, and vans drove 11,140 km/yr [23]. It may be noted that the average number of km/year for passenger cars seem too high. Driving from Haugen far up Longyeardalen and down to Sjøområdet - two extremities of the town centre - is roughly 2.2 km. In order to reach 9471 km/yr, one would have to do 6 Haugen-Sjøområdet-Haugen roundtrips per day.

Svalbard Scooterutleie AS answered upon inquiry that all their snowmobiles for rent drove 4-5000 km/yr, and that most private snowmobiles drove 2-3000. The ratio between rental snowmobiles and privately owned snowmobiles is unknown, but assuming it is 50/50, the annual snowmobile driving distance average is 3500 km. Svalbard Snøscooterutleie AS also said their snowmobiles average around 0.8 L/10km.

When visiting Longyearbyen in August 2019, it was noted that the residents favoured large pickup trucks and SUV's, with cars such as the Toyota Rav4 and Toyota Hilux among the most common. With cold winters and many short trips with cold diesel engines, it is expected that the fuel consumption is high. A Hilux from 2009 uses 0.95 L/10km [24]. It is assumed that for all passenger cars, the average is 1 L/10km. For vans and trucks the average is assumed to be 2 L/10km, and similarly for buses, tractors and snowcats 3 L/10km

4 | Demand forecast and requirements of future energy system

This chapter presents the forecasts of thermal and electric energy demand in Longyearbyen towards 2050. There is substantial potential for energy savings in Longyearbyen. The extent of this is hard to map exactly, but based on the findings in the project work, the potential was found to be 25-40 % [2], based on thorough evaluation of buildings owned by Statsbygg and Store Norske Kulkompani AS (see appendix A). For the demand forecast, 30 % is used.

It is assumed that the population in Longyearbyen will remain constant throughout the analysis period, and that any businesses quitting will be replaced by others. Similar assumptions have been made in other reports [4] [9].

4.1 Electricity

The electricity demand is separated by consumers, following the same division as the chapter on existing demand.

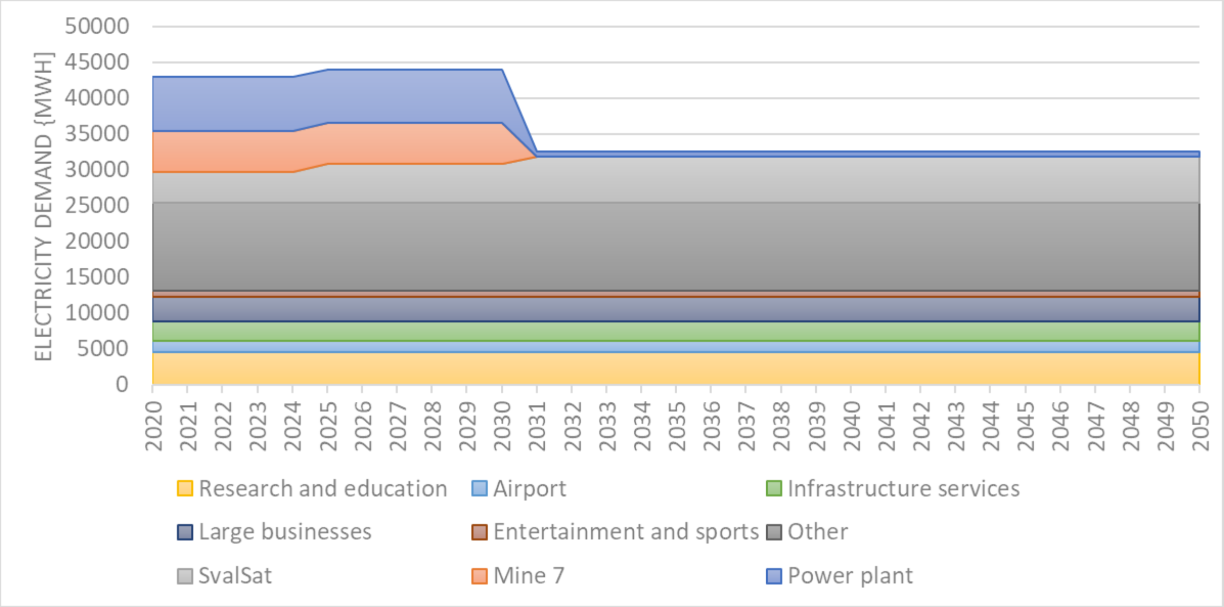


Figure 4.1: Demand forecast for electricity, divided by consumers

As electricity is rarely used for heating, it is assumed that there is limited potential in reducing the demand for residential buildings and for most businesses. The electricity demand is assumed to depend on the population development and a handful of energy intensive industries.

The coal plant itself uses 7.5 GWh of electricity annually. Rasmus Bøckman estimated that 600 MWh of this energy consumption is necessary to power the pumps in the DH system. It is assumed that the coal plant throughout 2030, before it is shut down, and that only the 600 MWh/year part of the load will carry on afterwards. Mine 7 will operate throughout 2030, before it shuts down, reducing its energy demand to 0. Svalsat/KSAT plans to expand its operation and increase its electricity demand by 50 % [4]. It is assumed that it expands by 25 % from 2025, and then by another 25 % (compared to initial value) in 2031. Longyearbyen Folkehøyskole has, as of 2020, recently opened, and it is expected that this will have caused a 10 % increase in the electricity demand since the data on electricity consumption from 2017, as shown in 3.7.

Figure 4.1 shows the expected change in annual electricity demand. It is expected to begin at 42,926 MWh/year, and increase towards 44,011 MWh/yr by 2025. In 2031 it will decrease to 32,478 MWh/year, which will be the demand for the rest of the analysis period.

4.2 Heat

As the population is assumed to be remain constant, the total heated area in Longyearbyen will not change. The buildings are separated into commercial (101,000 m^2) and residential buildings (99,000 m^2), totalling an area of 200 000 m^2.

In *Transitioning remote Arctic settlements to renewable energy systems* it is assumed that the total rate of rebuilt or renovated buildings is 2.3 % [10], based on a reference path estimated by Centre for Sustainable Energy Studies (CenSES). Here, it is assumed that residential buildings will be demolished and rebuilt at a rate of 0.3 % per year, and renovated at a rate of 2 %, for a total rate of 2.3 % annualy. For commercial buildings, it is assumed that the renovation rate will be the same as for residential buildings, but the demolition rate will be slightly higher at 0.5 %.

Rasmus Bøckman estimated the average heat demand in residential buildings to be 340 kWh/m^2. When subtracting this from the total annual heat demand from the power plant output time series, the average heat demand in commercial buildings is estimated to 250 kWh/m^2. Renovation or re-building of buildings is expected to reduce the heat demand by 30 % on average, to 238 kWh/m^2 for residential buildings and 175 for commercial buildings. Figure 4.2 shows how the heat demand will change with these renovation and demolition rates.

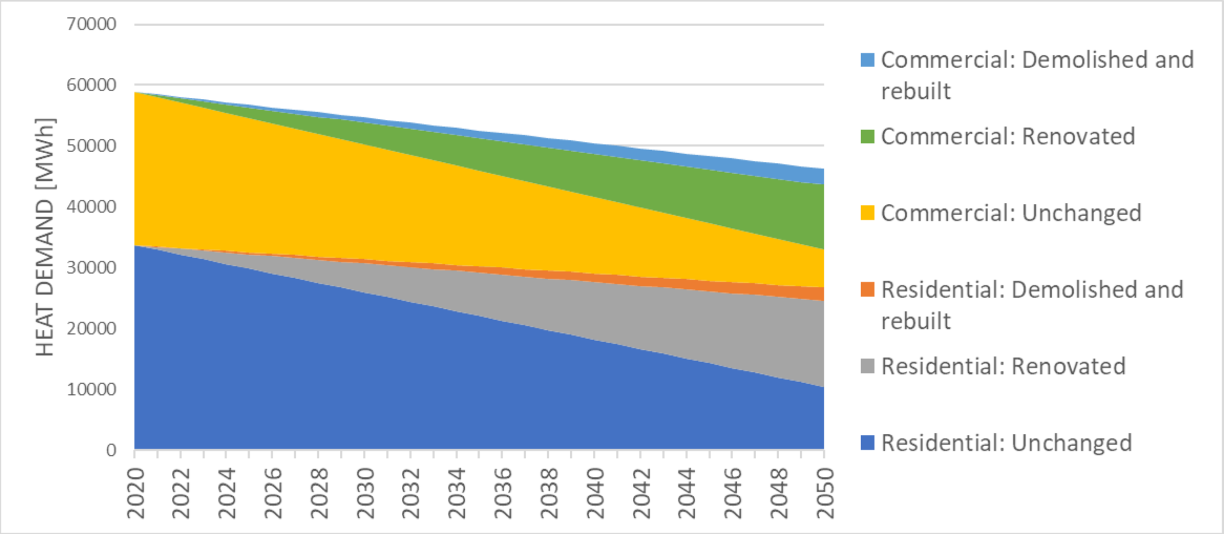


Figure 4.2: Demand forecast for heat, divided between residential and commercial buildings

Beginning at 58.5 GWh/year in 2021, the heat demand will linearly decrease towards 46.2 GWh/year by 2050.

4.3 Transport

It is assumed that there will be no changes in the transport demand in Longyearbyen from 2021-2050. If the transport fuel demand is to be covered by electricity, this will result in an extra 7.7 GWh.

5 | Technologies for energy generation and storage

This chapter presents the techno-economic input parameters of the energy technologies implemented in HOMER and eTransport. Detailed technical information about the technologies can be found in the project thesis [2].

5.1 Steam accumulators

Steam accumulators serve as short-term heat storage. Steam accumulators can, just like batteries in the electrical grid, provide benefits in the form of more efficient operation and load balancing, leading to less fuel consumption, less emissions and lower operational costs [2]. In Longyearbyen, there is significant heat curtailment, which might be better utilised if some heat storage capacity is included in the energy system.

Costs, efficiencies and lifetime

Multiconsult has, in their own 2019 report, suggested a steam accumulator of 30 MWh/3 MW in Longyearbyen. They based their prices on their own internal numbers [9]. This system had an expected lifetime of 40 years, and would cost 29.5 MNOK in investment costs and 147 kNOK in O&M. Assuming these numbers are representative for steam accumulator installations in Longyearbyen, the general costs for installations can be calculated as shown in table 5.1.

Steam accumulators	**2020**
Lifetime (yr)	40
Efficiency (%)	70
Inv. costs (kNOK/MWh)	983
O&M costs (kNOK/MW/yr)	49

Table 5.1: Costs, efficiency and lifetime of steam accumulators [9]

Location

A steam accumulator should be located near the active power plant. If a new power plant is built in Hotellneset, the steam accumulator should be there. If a new energy system is based only on wind and solar power, a potential steam accumulator should be located near the pumps for the DH system.

5.2 Batteries

Potential in Longyearbyen

Batteries give the opportunity for rapid charging and discharging, and are therefore well-suited for short-term energy storage. Batteries can help improve grid stability and enable the use of variable power sources such as wind and sun, by storing excess energy for later consumption. When used with fuel based generators, batteries can contribute to more efficient operation and help reduce fuel consumption [2].

Costs, efficiencies and lifetime

Li-ion batteries have a lifetime of 10 years and a round-trip efficiency of 90 % [10]. Table 5.2 shows the expected costs for batteries now and in the future. With these costs, an 5 MW/10 MWh battery in 2020 would cost:

$$10,000kWh * 3134NOK/kWh + 5MW * 2,550,000NOK/MW = 44,090,000NOK \tag{5.1}$$

and the annual operation and maintenance cost would be

$$43,582NOK/MWh/yr * 10MWh = 435,820NOK/yr \tag{5.2}$$

plus the small variable cost of 23 NOK/MWh stored.

Battery storage (Li-ion)	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inv. cost storage (NOK/kWh)	3,134	2,706	2,352	2,045	2,045	2,045	2,045
Inv. cost charger (kNOK/MW)	2,550	2,018	1,598	1,264	1,000	792	626
O&M cost storage (NOK/MWh/year)	43,582	37,884	32,931	28,625	28,625	28,625	28,625
Var. cost storage (NOK/MWh)	23	23	23	23	23	23	23

Table 5.2: Expected cost development for Li-ion batteries [10]

5.3 Wind power

Potential in Longyearbyen

The areas surrounding Longyearbyen have favourable wind conditions for wind power. This has been confirmed by measurements on Platåberget by Kjeller Vindteknikk, who found the average wind speeds at 40 m above ground to be 5.8 m/s [25].

Costs, efficiencies and lifetime

The predicted cost development of onshore wind power in Longyearbyen is laid out in table 5.3. The lifetime of a wind park is 20 years. It is assumed that wind turbines have a 90 % efficiency.

Onshore Wind	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Lifetime (years)	20	20	20	20	20	20	20
Inv. Cost (kNOK/MW)	11,882	11,123	10,365	9,606	9,606	9,606	9,606
Var. O&M Cost (kNOK/MW/year)	109	102	95	88	88	88	88

Table 5.3: Expected cost development and lifetime for wind power [10]

Locations

Wind speeds around Longyearbyen are higher on the mountain plateaus than in Isfjorden. With lower investment costs and O&M costs, wind turbines is a promising technical solution. Based on wind speed data (see appendix), the areas outlined in figure 5.1 are the most relevant for a wind park. Platåberget - number 2 - is a natural choice, as it is close to the town and there is already road infrastructure up to the plateau to the KSAT/Svalsat facility on the northwest side of it. KSAT has expressed that they do not desire a wind park near their satellite facility [4]. Location 5 is also close to a satellite facility, so if this is to be avoided, location 1, 3 and 4 remain, of which 3 is closest to town. In this analysis, it is assumed that any wind park will be placed on Platåberget.

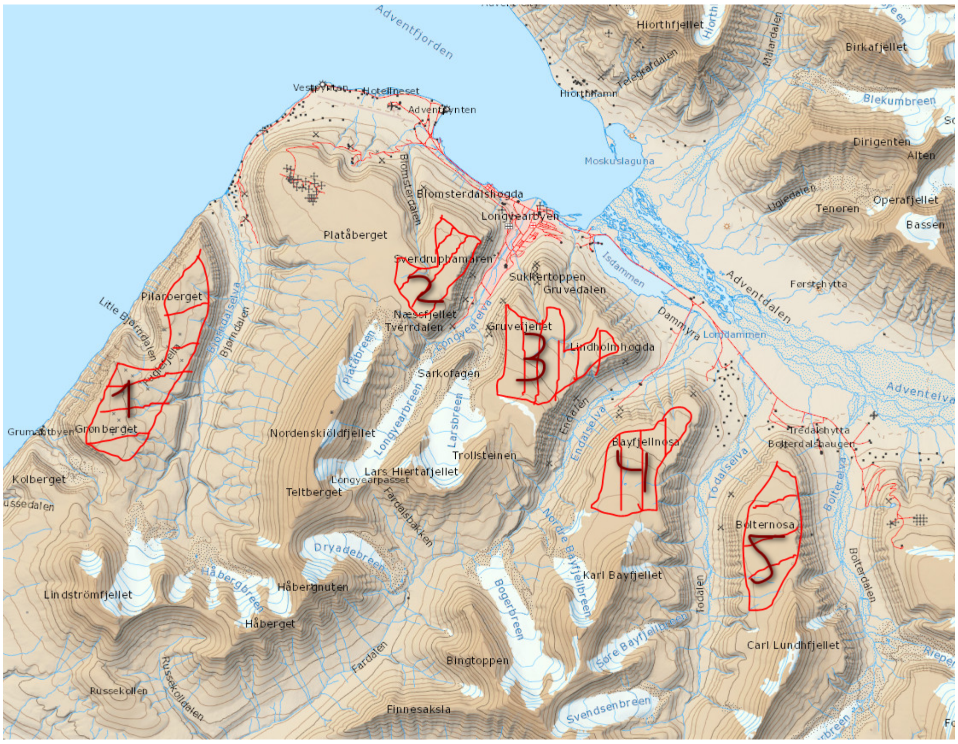


Figure 5.1: Suggested wind park areas around Longyearbyen

Simulating wind power output using Renewables.ninja

The free, online tool Renewables.ninja allows simulation of hourly power output and wind speed from a specified wind turbine, based on a chosen geographical location. The simulation is done using the Virtual Wind Farm model written by Iain Staffell at the Imperial College London. The data source for the simulation tool is NASA's MERRA reanalysis, and CM-SAF's SARAH dataset [26].

Running Ninja Renewables on Platåberget with the Vestas V150-4000 with a hub height of 80 m, gave an annual capacity factor of 32.4 %. The capacity distribution throughout the year is shown in figure 5.2.

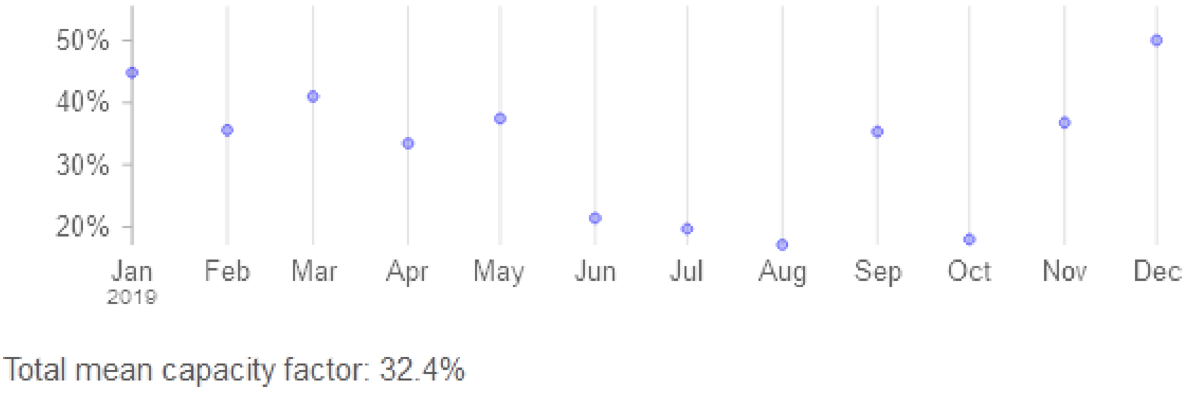


Figure 5.2: Monthly wind capacity factor on Platåberget for Vestas V150-400 turbine [26]

5.4 Solar power

Potential in Longyearbyen

The estimated global solar irradiance in Longyearbyen is 635 $kwh/m^2/yr$, distributed between March and September [2]. PV panels cannot produce any power during winter, but PV panels might be relevant in combination with wind, as there is less wind in summer.

Costs, efficiencies and lifetime

The predicted cost development of PV rooftop installations in Longyearbyen is laid out in table 5.4. The lifetime of PV panels are assumed to be 25 years [10] [9]. It is also assumed that the derating factor is 90 %, meaning that 10 % of the power output is lost due to snow or dust cover, aging, shading or other factors.

PV	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inv. Cost (kNOK/MW)	14,768	12,562	10,355	8,148	8,148	8,148	8,148

Table 5.4: Expected cost development for PV panels [10]

The available cost estimates of PV installations in Longyearbyen vary greatly. Multiconsult operates with 8 NOK/Wp [9], NVE suggest 8.75 NOK/kWp [27] in mainland Norway. According to Multiconsult, investments generally cost 25-35 % more in Longyearbyen [9].

Locations

There are two main alternatives for solar power investments in Longyearbyen. PV panels can be installed on the rooftops of existing buildings, or as a separate ground installation. The latter gives the option of optimising the azimuth of the installation and utilise tracking devices to allow the panels to variate their azimuth as the sun's angle on the sky shifts during the day. Such installations will yield a higher energy output. The downside of such an installation is that it is more costly as roads and power lines must be laid towards the area of installation, and it will occupy a large land area.

In Longyearbyen, the most viable area for a ground installation is on Platåberget, which also happens to be the most viable area for a wind power installation.

A rooftop installation on Longyearbyen's existing buildings would not contribute to any land use, or come at any conflict with regards to tourism, recreation, wind power installations or other competing interests. It would also be cheaper to install.

The total area of Longyearbyen's rooftops is roughly 188 732 m^2 [4]. The potential area for PV rooftop installations will in theory be somewhat higher, due to the pitched roofs. However, not all of this area will be viable for PV panels, due to cultural heritage protection of some buildings, or protruding installations such as ventilation systems. Assuming 80 % of the building area can be used for PV installations, there is capacity for 151 000 m^2 of PV panels in Longyearbyen.

The azimuth of the rooftops, i.e. the direction they are facing, will affect the power output. Based on a rough estimate from maps of Longyearbyen, the rooftop azimuths can be divided as shown in table 5.5.

Table 5.5: Estimates of available rooftop area for PV installation

Type or roof	Percentage of usable area	Area	Tilt	Azimuth
Pitched: Saddle	40 %	60,400 m^2	25 °	-60/120
Pitched: Saddle	40 %	60,400 m^2	25 °	30/150
Flat	20 %	30,200 m^2	0 °	-
Total area	100 %	151,000 m^2		

5.5 Hydrogen as energy storage

To enable an energy system based on wind and/or solar power, energy storage technology suitable for long-term energy storage might be necessary. Hydrogen is a technologically feasible option for this. By means of an electrolysis process, excess electricity can be used to produce hydrogen gas (H_2), which can be stored in specialised tanks and later used to generate electricity and/or heat using hydrogen fuel cells [2]. Other advantages in hydrogen systems is that if Longyearbyen has the necessary infrastructure for hydrogen, it is possible to import more hydrogen if it is found necessary. It is also possible to export hydrogen if the production is higher than the storage capacity allows.

There are two main types of electrolysers: alkaline and PEM. The former use a a potassium hydroxide solution as electrolyte, whereas the latter use a solid polymer membrane. Alkaline electrolysers are a more mature technology, and cheaper than the alternative.

Costs, efficiencies and lifetime

The central challenges in hydrogen for energy storage is its high current costs and the low round-trip efficiency [2]. Hydrogen is a technology that is expected to become more relevant in the future, and subsequently become less expensive and more efficient.

The highest costs are those associated with the electrolyser and the fuel cell, whereas the storage tanks themselves are relatively cheap. A summary of the expected costs, efficiencies and lifetimes for the different electrolysis options, the storage tank and the fuel cell, is presented below in table 5.6. Due to the lower costs of alkaline electrolysers compared to PEM-electrolysers, with roughly equal efficiencies, it seems advisable to focus any analysis on the alkaline option.

Hydrogen	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Liquid storage tank							
Lifetime (yr)	20						
Efficiency (%)	70						
Boil-off rate (%/yr)	40						
Inv. cost (kNOK/GWh)	92,116	74,984	56,655	42,807	42,807	42,807	42,807
O&M cost (kNOK/GWh/year)	2,303	1,874	1,416	1,070	1,070	1,070	1,070
Electrolyser (alkaline)							
Lifetime (yr)	10						
Efficiency (%)	0.64	0.65	0.66	0.67	0.68	0.69	0.70
Inv. cost (kNOK/MW)	11,281	10,923	10,385	9,848	9,848	9,848	9,848
O&M cost (kNOK/MW/year)	282	260	237	237	237	237	237
Electrolyser (PEM)							
Lifetime (yr)	9						
Efficiency (%)	0.68	0.69	0.71	0.71	0.71	0.71	0.71
Inv. cost (kNOK/MW)	17,906	15,578	11,997	11,997	11,997	11,997	11,997
O&M cost (kNOK/MW/year)	379	319	260	260	260	260	260
Fuel cell							
Lifetime (years)	8	8	9	9	9	9	9
Electrical Efficiency (%)	40	43	45	45	45	45	45
Heat to power ratio (-)	1.25	1.11	1.0	1.0	1.0	1.0	1.0
Inv. Cost (kNOK/MW)	20,294	13,642	6,989	6,989	6,989	6,989	6,989
O&M Cost (kNOK/MW/year)	1,015	682	349	349	349	349	349

Table 5.6: Costs, efficiencies and lifetimes of the components in a hydrogen system [10]

Location

The area in Hotellneset designated towards a new power plant would be the likely location for a hydrogen system. Depending on the size of the system, it might be necessary and preferable to go for a modular approach with several smaller units. Regardless of the exact solution, a hydrogen system will be space consuming.

5.6 Pellets power plant

A pellets power plant is a technologically feasible and realistic option if Longyearbyen requires an energy solution similar to the current coal plant, while also reducing CO2 emissions [2]. This includes combining heat and power generation in one facility. The solution would consist of one or more CHP turbines, and one or more boilers that are fed with pellets made out of bio mass. With no tree growth in Svalbard, such pellets would have to be imported.

Costs, efficiencies and lifetime

Costs for pellets power plants were provided by Birgitte Ramm, senior consultant at Multiconsult, in an email correspondence on February the 26th, 2020. Multiconsult's price estimates are summarised in table 5.7.

Pellets power plant	**2020**
Inv. cost (kNOK/MW el)	45,000
O&M cost (kNOK/MW el/year)	400
Var. O&M cost (NOK/MWh el	24.5

Table 5.7: Expected cost of pellets power plant installation in Longyearbyen

The electric efficiency of a pellets power plant can be assumed to be 20 %, and the thermal efficiency 55 %, for a total efficiency of 75 % of the energy in the fuel [4]. A pellets plant can also be assumed to have a lifetime of at least 30 years [4].

Fuel sourcing

The net greenhouse gas emissions of a pellets power plant will depend on how the biomass for the pellets was sourced, including where it was harvested, forestry practices, production and transportation. Pellets can be considered renewable, but only if the forestry practices are sustainable and allow for regrowth [2]. In order to achieve the goal of reducing emissions from the energy system in Longyearbyen, extra care should be given to ensure that the imported pellets come from sustainable practices. There is pellets production in many of Norway's neighbouring countries, such as Sweden, Finland, Germany and Russia [2].

Location

If a new power plant is to be built, Hotellneset close to the airport has been pointed out as the most likely location by Longyearbyen Lokalstyre. The area is already affected by human activities, and a new power plant there is expected to have a small impact on wildlife and tourism [4]. Moving the location for a new power plant is recommended for three reasons: 1) the existing location is in the avalanche danger zone, 2) the existing location gives no room for expansions, and 3) moving to a new location allows the old power plant to be used while a new one is under construction.

5.7 Coal power plant

As there is an existing coal power plant in Longyearbyen, that might be beneficial to keep for some time, some information on coal power should also be covered.

Costs, lifetime and location

Rasmus Bøckman could not provide any estimate of O&M costs for Longyearbyen. It is estimated that the plant can operate for 18 more years [4]. It is fair to assume that if Longyearbyen continues to use coal power after that, an entirely new coal power plant will be built in Hotellneset. The plant would most likely have the same technical solution as the existing plant, and the same efficiencies, but with only one turbine and one boiler. The estimated costs of a new plant and O&M costs are shown in table 5.8. The costs were calculated from estimates by National Renewable Energy Laboratory, using 9.45 NOK/1 USD [28]. The estimated lifetime of a new plant is 30 years.

Coal plant	
Inv. cost (kNOK/MW)	38,140.2
O&M cost (kNOK/MW/year)	311.85

Table 5.8: Costs of coal power [28]

5.8 Electric boilers

Electric boilers allow electricity to be converted to heat. As long as Longyearbyen continues to use a district heating system to warm buildings, electric boilers will be necessary if the energy system is to be based around wind and/or solar power [2].

Costs, efficiencies and lifetime

Electric boilers typically have an efficiency of 98 % and a lifetime of 20 years [10]. The high efficiency is due to the electric boiler not having any exhaust fumes through which heat can escape [2]. Their costs are not expected to change in the next 30 years. A summary of costs is found in table 5.9.

Diesel generator	**2020**
Inv. cost (kNOK/MW)	766
O&M cost (kNOK/MW/year)	4

Table 5.9: Costs of electric boilers 2020-2050 [10]

5.9 Diesel boilers and generators

Diesel boilers and diesel generators are the natural choice for backup power in Longyearbyen, as they are cheap to invest in, reliable and can be acquired in a range of sizes. Boilers and generators allow for quick adjustments of output heat or power. Their main downsides are their high cost of operation, due to high fuel costs, and their high rates of CO_2 emissions [2].

In Longyearbyen, backup power is necessary in case of technical failure to ensure security of energy supply. In case of heavy investments in wind or solar power, or both, they might also be necessary for time periods with little to no wind or sun. Additionally, boilers and generators may be actively used in the day-to-day operation to help meet peak loads.

Costs, efficiencies and lifetime: Diesel generators

Diesel generators have an estimated lifetime of 25 years and an efficiency of 41 % [10]. For installations in Longyearbyen, the costs, are expected to remain unchanged from 2020-2050. Table 5.10 shows the current cost.

Diesel generator	**2020**
Inv. cost (kNOK/MW)	4,218.5
O&M cost (kNOK/MW/year)	462.7
Var. cost ex. fuel (kNOK/MWh)	4.8

Table 5.10: Costs of diesel generators 2020-2050 [10]

Costs, efficiencies and lifetime: Diesel boilers

Diesel boilers are expected to have the same lifetime and costs as diesel generators, but with an 85 % efficiency. The comparably lower efficiency in the generator is because there are significant losses in the form of heat. A diesel boiler is supposed to generate heat, so heat losses are not a problem in the same way.

5.10 Fuel costs

Table 5.11 summarise the expected fuel costs for diesel, coal and pellets. Some notes may be done about the fuel costs.

- Diesel: Costs have historically been stable [4].
- Coal: Coal is currently inexpensive as Longyearbyen Energiverk buys the coal from Store Norske Kulkompani AS that does not meet the required export quality. If Mine 7 close, and coal has to be imported, the price is uncertain. It might increase, as the transport costs money, but it might also decrease in price due to a shrinking coal demand in Europe as countries move away from coal for power generation.
- Pellets: Pellets have to be imported. The price of this is highly uncertain, as the bio mass required pellets production can be sourced in many different ways. Pellets power plants have traditionally not been very common, and the future development of the technology can affect the price of fuels.

	Cost	Certainty
Diesel	7.59 NOK/L [4]	Historically stable
Coal	530 NOK/tonne [4]	Somewhat uncertain
Pellets	1,805 NOK/tonne [4]	Highly uncertain

Table 5.11: Estimated fuel costs

6 | Energy system modelling software

This section provides an overview over the three relevant energy system modelling tools HOMER, TIMES and eTransport.

It should be noted that the previous project thesis also included an overview of these three tools, but it was decided to rewrite this, as experience from the project thesis made it easier to point out the most relevant features of the tools. Especially the section on eTransport has been expanded, as it has been tested in the course of the project thesis.

6.1 HOMER Pro

HOMER (Hybrid Optimization of Multiple Electric Renewables) is a commercial energy investment analysis software tool designed specifically for microgrids [29] [30]. HOMER distinguishes between loads, resources and components. The loads are fed as time profiles for electricity, heat or hydrogen demand, with a 1 minute time step. Resources include solar irradiation, wind, hydro, biomass and available fuels. Components utilise the resources to meet the loads, e.g. by having PV panels convert the solar irradiation into electricity for the electricity demand. Systems can be off-grid or connected to major grids.

When HOMER solves a model, it performs energy balance equations for all time steps in the analysis periods, and finds out how many units of each technology are necessary to meet the loads [29], based on which investment options have been included in the model. HOMER finds the optimal size of each component in the energy system, within the user-specified search-space. The software tool is oriented from a supply-side perspective. Grid and DH system losses are not taken into account, and the demand used as input must therefore include expected transmission losses [30]. Demands can be modelled as fixed or flexible [29].

A wide range of feasible technical solutions are presented in a table, sorted from lowest to highest net present cost. They can also be sorted by other merits, such as emissions or levelised cost of electricity [29]. The analysis is based on the design of new energy systems, and cannot take into account existing components. Whatever system is chosen is kept throughout the analysis period, with no changes aside from replacement of worn out components. HOMER takes into account discount rates, inflation rates, emission fees and fees for unmet load, and considers replacement costs and residual values of the components in the system [29].

HOMER is designed to provide a low-threshold tool for energy system analysis, and it comes with an extensive data library that can be used. This includes pre-defined load profiles, specific real-life models of various components, and it can use geographical coordinates to simulate wind speeds and solar irradiance [30].

Additional functions in the software include easy sensitivity analyses on almost any parameter [30], scheduling of maintenance and energy storage using batteries.

6.2 Times

TIMES (The Integrated MARKAL-EFOM System) is an open-source dynamic energy system model generator [30]. The software requires the use of either ANSWER or VEDA to handle input data and results, in addition to a local GAMS model and a solver such as CPLEX or XPRESS [30].

A TIMES model includes commodities, technologies and scenarios. The commodities include all present energy carriers, services provided, money and emissions. The commodities are tied to technologies, that either creates, converts or uses commodities. TIMES includes the entire energy chain from primary energy sources to end-user technologies, so the technologies (also called processes) range from mining of resources to demand-side technologies such as heating facilities in buildings. Scenarios are designed by applying different constraints, such as maximum emission constraints or minimum renewable fractions [31].

The demand is primarily divided by sector and not energy carriers, and the principal sectors are residential, commercial, agricultural, transport and industry. When the model is solved, all of these sectors are optimised horizontally, and subsequently vertically for all time periods [31], using a dynamic programming algorithm [30]. The resulting solutions for each scenario is the optimal amount of each technology to supply all commodity demands. TIMES is often used for larger, regional energy systems [30]. TIMES has an hourly resolution [30]. The solution optimises for maximum consumer and producer surplus, i.e. intersection between the supply curve and the demand curve in a perfect market [31]. "The model outputs are energy flows, energy commodity prices, GHG emissions, capacities of technologies, energy costs and marginal emissions abatement costs" [31].

6.3 eTransport

eTransport is a non-commercial energy system analysis software developed and used by SINTEF. It is specialised for local energy planning decisions, and analysis energy systems based on energy flows, where it considers a wide range of energy carriers [30]. eTransport uses Microsoft Visio as a graphical interface, with click-and-drag functionality, and it uses CPLEX as an external solver for parts

eTransport consists of two main analysis models: an investment model and an operational model. The latter has an hourly resolution and considers a handful of representative days for the different seasons, as seen in figure 6.1, where it finds the optimal way of operating the system in each window of time. The investment model then finds the optimal investment plan that minimises the net present cost for the analysis period, based on the operation costs from the operatonal model [30]. The flow of eTransport's analysis is shown in figure 6.2. The main output of the eTransport analysis are investment plans, sorted by net present cost, where each investment plan lays out what investments to choose and when to implement them. eTransport can handle changes in the energy system during the course of the analysis period[30].

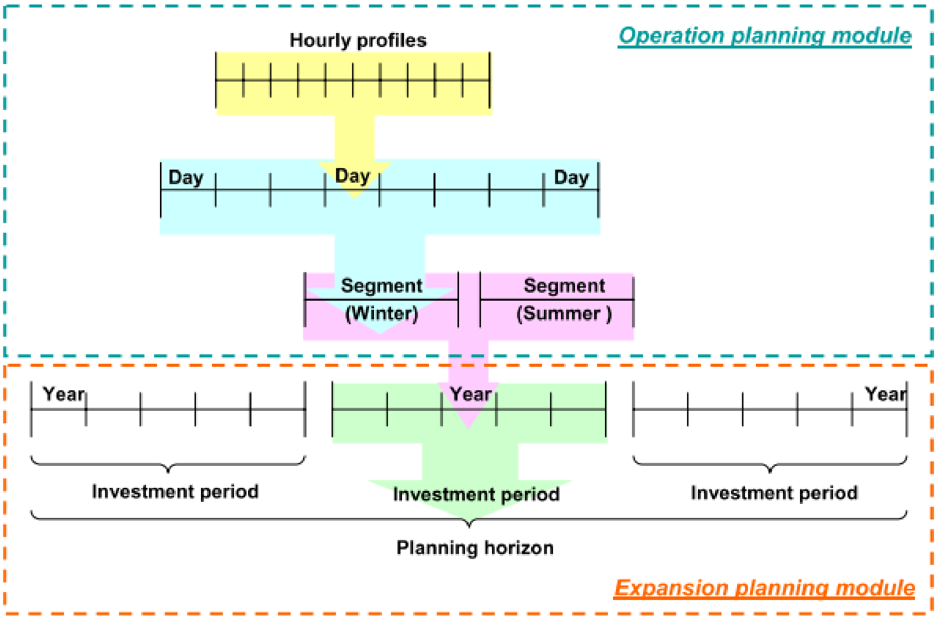


Figure 6.1: Time in eTransport[32]

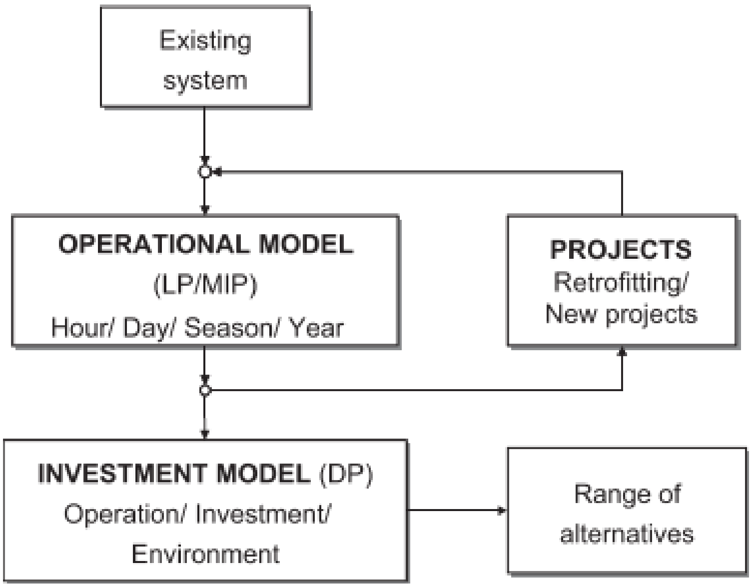


Figure 6.2: Flow of the eTransport model[33]

The operational model

The operational analysis is solved using linear programming and mixed-integer programming. The objective function of the operational analysis [32] is:

$$C = min \sum_{m \in subModels} Objective_m \tag{6.1}$$

where

- C: Minimum operational cost of the system

- *subModels*: A defined set of all modules in eTransport, *subModels* = {El supply, Gas supply, Oil supply, Waste supply, Heat supply, El net, District heating, Gas Pipe, LNG ship, Gas storage, Combined plant, Heat pump, El load, Heat load, Gas load, ...}
- m: Index for different modules
- $Objective_m$: Variable for operational costs

The operational model is written in AMPL (A Mathemathical Programming Language), using CPLEX as a solver.

The investment model

The investment model deals with decisions on which components to keep, which to scrap, what to invest in, and when to do investments. The investment algorithm is based on dynamic programming, and uses C++ [32]. As opposed to HOMER and TIMES, eTransport cannot decide how much capacity of each technology is optimal. Instead, eTransport either accepts or rejects a specific investment opportunity. If different sizes of a component are to be examined, they must be listed separately.

The user inputs different investment opportunities, where each investment opportunity is one or more components grouped together in a package, with an associated investment cost, operating cost, and lifetime. The user has the option to establish logical relationships between investment alternatives, making some alternatives mutually exclusive or dependent on other investments. The window of opportunity for each investment can also be set, making some investments only available in specific investment periods.

Investment and time matrices

eTransport features two matrices that set the rules for available investments. There is an *investment x investment* matrix and a *time x investment* matrix. The user can mark each matrix entry as green, yellow or red. Their meaning is explained in table 6.1, and fig:invMatrix shows an example of investment and time matrices. Here, Wind 2020 can only be invested in if wind 2010 is also invested in. The diesel investment can only be done in the period 2020-2030. The yellow entry in the upper right corner of the time matrix means that wind 2010 has to be invested in in 2020 or earlier.

	Investment matrix	**Time matrix**
Red	Mutually exclusive	Unavailable at this time
Green	Available	Available
Yellow	Dependent If Y-value is yellow, X-value is obligatory	Obligatory investment at this time or before

Table 6.1: Possible entries for investment and time matrices

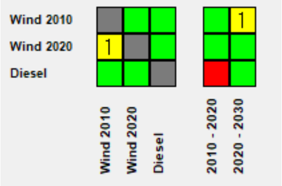


Figure 6.3: Investment matrix and time matrix

Red or yellow entries reduce the feasibility space of the model. The matrices can therefore be used to model real life-constraints, such as investments not being accessible unless other investments are done. The matrices can also be used to improve the runtime of the software, by omitting to analyse solutions that are obviously not feasible or ideal.

6.4 Decision for this thesis work

A key consideration when deciding upon a modelling tool is what size the energy system is. TIMES is considered especially suitable for larger energy systems, whereas eTransport and HOMER are designed with smaller, local energy systems in mind. Despite a large energy demand, Longyearbyen is a small community, and a microgrid oriented modelling tool is better suited for this kind of energy system.

For this case, it was also considered beneficial that the modelling tool should not only answer *what is the optimal energy system?*, but also *what is the optimal way to transition to a new energy system when taking previous investments into account?*. As Longyearbyen already has an energy system, it was deemed necessary to take the remaining lifetime of these components into account. HOMER cannot take into account existing energy infrastructure, or be used to form an investment plan. This pointed towards eTransport as the optimal tool, as it has mechanisms for modelling existing components and different dependency relations between investments.

In the previous project thesis, it was decided to use eTransport to model the Longyearbyen case, for much the same reasons [2]. Significant efforts had been put into setting up a model of the current energy system, of which most was expected to be possible to continue using in this master's thesis. It was therefore initially decided to continue using eTransport as the main modelling tool.

It should be noted here in this chapter that this decision was revised, after substantial issues with using eTransport, and HOMER was adopted as the main software tool for the modelling. This decision is explained in chapter 7, and a comparison of these two modelling tools is provided in chapter 12.2.

7 | Method

7.1 Initial experience using eTransport

The initial idea was to use eTransport to analyse an alternative energy system for Longyearbyen. However, several issues arose when working with eTransport. Most importantly, eTransport was unable to handle a large number of investment opportunities.

eTransport finds the optimal choice of technology and time for an investment, but the size of the investment (in MW for energy sources and MWh for storage components) is given. To use eTransport for sizing components, which was necessary for developing cases, it was necessary to set up many investments for each technology, representing different sizes. The number of analyses performed in eTransport is given by the equation

$$2^n * t \tag{7.1}$$

where n is the number of investment alternatives, and t the number of available investment times. With the required investment alternatives for Longyearbyen, the amount of analyses reached past 50 million, causing frequent software crashes and expected runtimes in the range of several years calculate the model. This made it impossible to obtain the desired results with eTransport.

There were also other issues with eTransport. The experience with the software tool is discussed in detail in chapter 12.2.

7.2 HOMER as an alternative model

It was found necessary to reconsider the choice of analysis tool. Based on the software review, HOMER was reconsidered and adapted as the main software tool to do case simulations.

HOMER works somewhat differently than eTransport. HOMER can find both the optimal technology and the optimal size, but it assumes that no previous energy system exists, and that all investments are done in the first year of the analysis, here 2021. Worn out components are continuously replaced as they exhaust their lifetime, but no other changes are done in the energy system configuration during the analysis period. When the complex investment dynamics of eTransport are omitted, HOMER is able to solve systems considerably faster.

HOMER also has a superior user interface, that is faster and more intuitive to use. It also has better features for pre- and post-processing of data, making it easier to set up demand profiles, power output of wind and solar power, make graphs and tables of results, and do sensitivity analyses.

7.3 Analysis flow

A key benefit in the eTransport software is that eTransport allows the energy system to change during the analysis period. This opens the option of postponing investments that are likely to decrease in cost. It was decided on an analysis flow as shown in figure 7.1.

As eTransport requires the sizing of the components in the investment alternatives to be given, HOMER was used first to design manageable cases for eTransport. The gathered data on energy demand, available resources and techno-economical specifications of energy components were used as input in HOMER, to design a series of feasible cases. Based on different parameters, five of them were compared and analysed further (see chapters 10 and 11. It was found that the most ideal cases were based around different combinations of a small selection of components.

Afterwards, eTransport was used to find the optimal investment time for the best technology alternatives. The components present in the best cases from HOMER were used as specific investment alternatives. A steam accumulator and a hydrogen system, which could not be tested properly in HOMER, were also included.

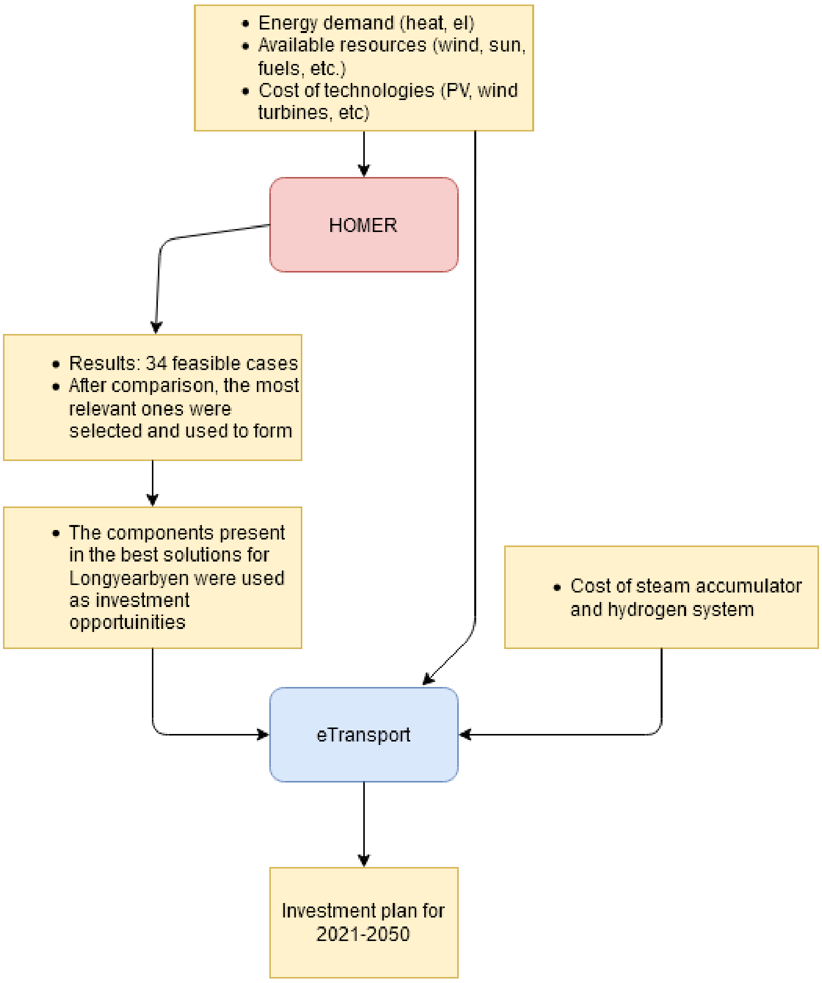


Figure 7.1: Data flow in energy system analysis

8 | HOMER - input and investment alternatives

HOMER was used to design feasible energy systems that could meet the energy demand in Longyearbyen.

8.1 Economics, demand and energy resources

The basic economical settings were set, such as analysis period and discount rate. The maximum annual power shortage was set as 2 %, with a shortage fee equal to the power price of 2.30 NOK/kWh for large consumers. The emission fee was set to 500 NOK/tonne of CO_2.

HOMER requires a location to be set. This is the location where all energy components are placed, so to most accurately model the local geographical conditions for wind, the coordinates 78°13' 15" N 15°25' 54" E, which corresponds to the southern part of Platåberget, was chosen.

To model loads, there is a function to upload .xlsx or .csv file time series for both heat and electricity demand. These functions were used to upload the time series for 2017 provided by Rasmus Bøckman. As the heat production from January 1st to January 22nd were not included in the time series, these values had to be estimated. This was done in the following way:

It was assumed that there was a connection between the heat output and the outdoor temperature. The temperature for the missing period was known from the electricity demand time series. For every hour h in the year, a coefficient C_h was calculated using the following function

$$C_h(T_h) = (Q_h - 5000) * T_h/100000 \tag{8.1}$$

where Q_h is the heat output at hour h in kWh/h and T_h is the temperature outdoors at hour h in Kelvin. 5000 kWh/h is the minimum output of T1. The C_h coefficient expresses how much *extra* heat is generated than the minimum required, as a function of the outdoor temperature T_h. The division by 100000 made the coefficients more manageable. The C values were typically in the 5-20 range.

For the week 4th week in January, as well as the last week in December 2017 (which is assumed to be identical to the last week in December 2016), the average C values were calculated to be 16.79 and 16.29 respectively. The average estimated C in the missing 3-week period was then assumed to be the average of these

$$\overline{C} = (\overline{C_{weekBefore}} + \overline{C_{weekAfter}})/2 = (16.79 + 16.29)/2 = 16.42 \tag{8.2}$$

The heat output for each hour h in the missing 3 weeks was then set to be

$$Q_h = \overline{C} * 100000/T_h + 5000 \tag{8.3}$$

The estimated heat production values in the first 22 days of January 2017 were similar to the end of January that year and to the end of December that year, indicating that the estimate is at least somewhat reasonable.

HOMER has a feature called "multi-year analysis", which enables several parameters to change during the analysis period, such as fuel prices or demand. This feature was used to model the expected future electricity and heat demand, by adding a scaling factor for each of the 30 years, that change the load for any given moment according to the factor. The scale factors were calculated by taking the total measured demand in year 1, as summarised from the coal plant output time series, and dividing it by the forecasted demand that year. No other parameters were expected to change during the analysis period.

HOMER separates between energy resources, such as wind or sun, and the components that utilise them, such as wind turbines and PV panels. Ninja Renewables was used to simulate a time series for the wind speed at 80 m above ground on Platåberget, and this data was uploaded as a time series in HOMER. The global solar irradiance is included in HOMER's own library. This was compared to the irradiance data gathered in the previous project task, and found to be almost identical, making it a natural choice to use HOMER's own data library for solar power modelling. It is possible to choose what fuels are available in the model. The input data on the different fuels are displayed in table 8.1. The fuel prices are expected to remain constant.

It is assumed that the carbon content and heating value of coal is in the lower range of the bituminous coal category, so 70 % carbon content and 24 MJ/kg were chosen for the model [34]. When initially setting up the model, and to test if the model was working, the mass density for bituminous coal was found on the relevant Wikipedia page [35]. The plan was to update this to a more scientific source before the model was run. This was forgotten, and so the results produced were done with the listed Wikipedia value of 1346 kg/m^3. Several sources confirm that this is a good estimate, such as the American Society for Testing and Materials, who has a graph showing how the mass density of bituminous coal changes with the ash content. In this graph, 1346 kg/m^3 corresponds to an ash content of roughly 7 % [36].

	Diesel	**Coal**	**Pellets**
Heating value	43.2 MJ/kg	24 MJ/kg	18.5 MJ/kg
Density	820 kg/m^3	1,346 kg/m^3	1,200 kg/m^3
Carbon content	88 %	70 %	0 (assuming sustainable harvesting)
Cost	7.59 NOK/L [4]	0.530 NOK/kg [4]	1.805 NOK/kg
Source	HOMER library and [4]	[34] [4] [35]	[37] [4]

Table 8.1: Available fuels in Longyearbyen

8.2 Energy components

The different components that could be invested in were designed and the relevant costs were added to them. HOMER can deal with four kinds of cost: Capital Cost, which is the initial investment cost; Replacement Cost, which is the cost of replacing some or all of the component when its reached the end of its lifetime; O&M (operation and maintenance) costs, all variable costs that occur when the component is used, except for fuel; and, lastly, the fuel cost, for the components that require a fuel.

PV panels

The PV panel invest were set up using the HOMER generic flat plate PV system with no tracking. This model assumes an operating temperature of 47°C and an efficiency of 13 %. The derating factor, investment cost and O&M cost was set according to the gathered data. The azimuth was set to 0 °, i.e. south, and the tilt was set to 25 °. While it was found that the expected lifetime of the PV panels is 25 years, this reflects the manufacturer's warranty that power output will not have degraded beyond a certain point, but the panels will likely still function. The lifetime was therefore set to 30 years, as the derating factor accounts for the wear on the panels.

Wind turbines

As scalability was a preferable feature, a small, generic 1.5 MW wind turbine was chosen to be the investment opportunity for wind power, so HOMER was allowed to cheese between a wide range of rated wind power capacities. The hub height was set to 80 m, and the lifetime, costs and efficiencies were set. The power output is automatically simulated according to the wind resource.

Batteries

To model batteries, the HOMER Idealized Battery Model was used. Its features are shown in table 8.2. Additionally, the lifetime and costs were set according to the gathered data. As batteries have a lifetime of 10 years, they will have to be replaced twice, in 2030 and in 2040. HOMER does not account for prices to gradually decrease. Instead, HOMER allows for an investment cost and a replacement cost to be set. The investment cost was set equal to the price of a battery in 2020, and the replacement cost equal to that of a battery in 2030. When the battery is replaced in 2040, however, the price is expected to be even lower, but this is not included in the model. The initial state of charge was set to 50 %, and the minimum state of charge to 20 %.

Idealized battery model	
Nominal voltage	600 V
Nominal capacity	1 MWh
Roundtrip efficiency	90 %
Max. charge current	1,670 A
Max. discharge current	5,000 A

Table 8.2: HOMER's idealized 1 MWh battery

Coal power plant

HOMER has a component called Generic Generator. This was used to model both the pellets power plant and the coal power plant. For the coal plant, the capacity was set to a 7500 kW power output. The efficiency curve, which specifies how high the heat and electricity output is for a given fuel input, was set so that when maximum electricity generation is reached at 7.5 MW, the electricity efficiency is 19 % and the heat efficiency 63 %. The generation ratios are shown in figure 8.1. With these ratings, HOMER gets a maximum theoretical heat output of 24.87 MW, as opposed to the 14 MW found to be the real-life maximum. This has to do with the efficiencies in a CHP plant varying for different outputs, to an extent not possible to accurately model in HOMER. It was therefore decided to omit the 5 MW diesel boiler in the power plant from the HOMER model. This was considered the best solution to avoid too high heat capacity and to accurately model the electricity generation and the losses. Even with this decision, the coal plant has almost 6 MW too much heat capacity, and some of the load covered by the power plant diesel boiler in real life is covered by coal instead, leading to somewhat higher emissions.

HOMER assumes generators are not always run, so their lifetimes are specified in hours of operation, not years of existing. For the coal plant, the lifetime was set to 157,680 hours, which corresponds to 18 years of full load. The capital cost of the coal power plant was set to 0, as it is already existing. The replacement cost and O&M cost were set according to gathered data.

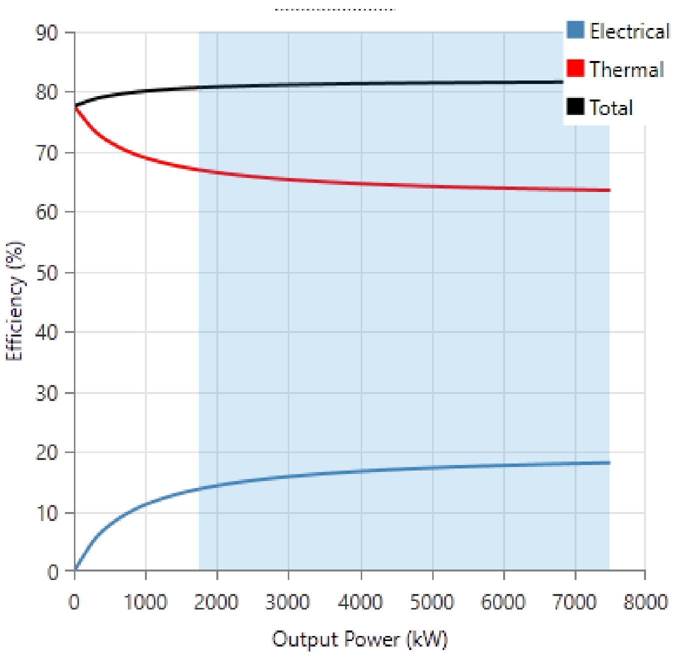


Figure 8.1: Heat and electricity efficiency of coal CHP turbine

Pellets power plant

The pellets plant was modelled similarly to the coal plant, but running on pellets. To allow HOMER to choose between different sizes of the pellets plant, it was decided to set up a module of 2.5 MW electricity generation, allowing for capacities of 2.5, 5, 7.5, 10, etc. The efficiency curve was set up with a total efficiency of 75 %, with a heat ratio of 55 % and an electricity ratio of 20 %. The efficiency curve for a 7.5 MW plant is shown in table 8.2. The capital and O&M costs were set according to gathered data, and the replacement cost was set equal to the capital costs. The plants lifetime was set to 262,800 hours, or 30 years of continuous operation.

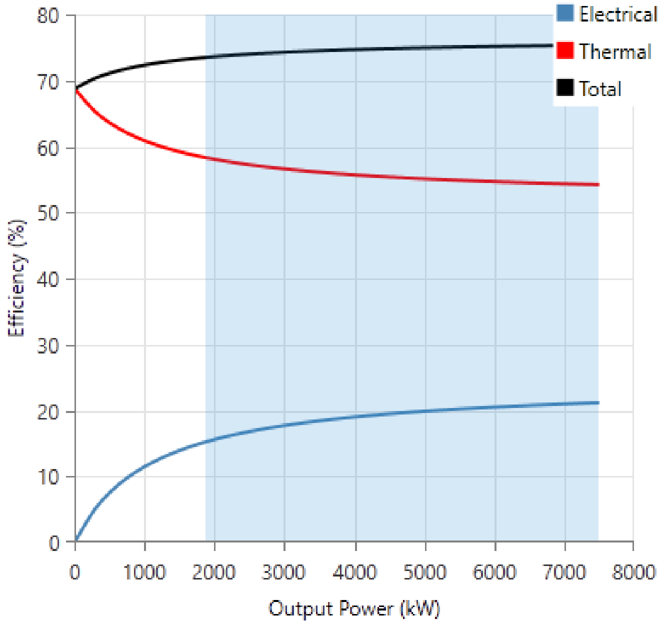


Figure 8.2: Heat and electricity efficiency of pellets CHP turbine for a 7.5 MW power plant

Diesel generator

For the diesel generator, HOMER's Autosize Diesel Generator model was used. This function forces a generator equal to the peak electricity load to be installed in all systems. Under the assumption that the generator would only be used for peak loads or when there is otherwise not enough generation in the system, the lifetime of the generator was set to 10,950 hours, or 1.25 years. The minimum load ratio was set to 25 %, and the maximum generation efficiency of 41 %.

Electric boiler

For systems with a thermal load, HOMER automatically includes a Thermal Load Controller, which is an electric boiler. The prices and lifetime of this component was set according to gathered data.

Diesel boilers

HOMER also includes a boiler, that can run on any desired fuel, has infinite capacity, and is run to make sure the thermal demand is always filled. The boiler has only fuel costs. This was set to run on diesel, and it was given an efficiency of 85 %.

AC/DC converter

An AC/DC converter is included in the HOMER season. This has not been considered in this thesis, and therefore set to have 0 costs and 10 GW capacity, so as not to be accounted for in the costs.

Hydrogen storage system

HOMER has the opportunity to model hydrogen systems, but this was not included. It was considered that a hydrogen investment will be more likely when the coal plant is worn out in 18 years. HOMER cannot handle investments only available in the future, so it was decided to include hydrogen as an alternative in the eTransport analysis.

Steam accumulators

HOMER has no model appropriate for modelling steam accumulators. It was therefore not feasible to make such a model.

8.3 Investment alternatives

HOMER has two main-functions for sizing components. It is possible to use the Optimizer, which freely decides the sizing of all components. It is also possible to define a search-space for each component, which specifies what sizes are allowed. As the optimizer is incompatible with the multi-year analysis that allows for changes in the demand during the analysis, the search-space method was chosen.

The investment options presented to HOMER is summarised in table 8.3. HOMER presented the different results as a list of different system configurations that met the demand, and could be sorted by different properties. Five different systems were chosen to be presented in the case study.

For case 1 it was desired to showcase a base case with continued coal power. Among the cases with only coal, the one with the lowest NPC was chosen. For case 2, the lowest emission system was chosen, which was a pellets and wind hybrid system. For case 3, the lowest net present cost system was chosen, which was a wind and coal hybrid system. For case 4, it was desirable to see how a case running on only diesel with score. Lastly, for case 5, the lowest NPC system without any coal or pellets power plant was picked out, which was a wind and PV hybrid system.

Component	**Search-space**
Pellets plant:	0, 2.5, 5, 7.5, 10, 12.5, 15 [MW]
Coal plant	0, 7.5 [MW]
Wind turbine	0, 4, 6, 8, 10, 12, 14, 16, 18 [number of 1.5 MW turbines]
PV	0, 5, 10, 15, 20, 25, 30, 33.2 [MW]
Battery	0, 5, 10, 15, 20, 25, 30 [MWh]
El. boiler/TLC	0, 4, 8, 12, 16, 20, 24, 28 [MW]
Diesel	Autosize
Boiler	Homer includes infinite capacity

Table 8.3: HOMER analysis search-space

8.4 Sensitivity analyses: Fuel costs and transport

HOMER allows sensitivity analyses to be run on almost any parameter. For this thesis, it was decided to run a sensitivity analysis on a 25 % increase or decrease of the fuel prices of pellets, coal and diesel.

In a 100 % renewable energy system, the transport sector will most probably become electric, which will increase the electricity demand. In order to investigate the impact of electric vehicles, a sensitivity analysis of increased electricity demand of 7.7 GWh was done by adding a second load. The load was distributed equally on every day in the year, according to a daily charging profile estimated by the Norwegian Water Resources and Energy Directorate [38]. This profile is shown in figure 8.3. Note that the profile is scaled up to fit the total 7.7 GWh/yr load. The actual numbers of 30-240 kW have no meaning in themselves. This analysis was run with almost he same search-space as the original, allowing for HOMER to increase generation capacity of the pellets plant, PV and wind installations, as well as the battery storage and electric boiler.

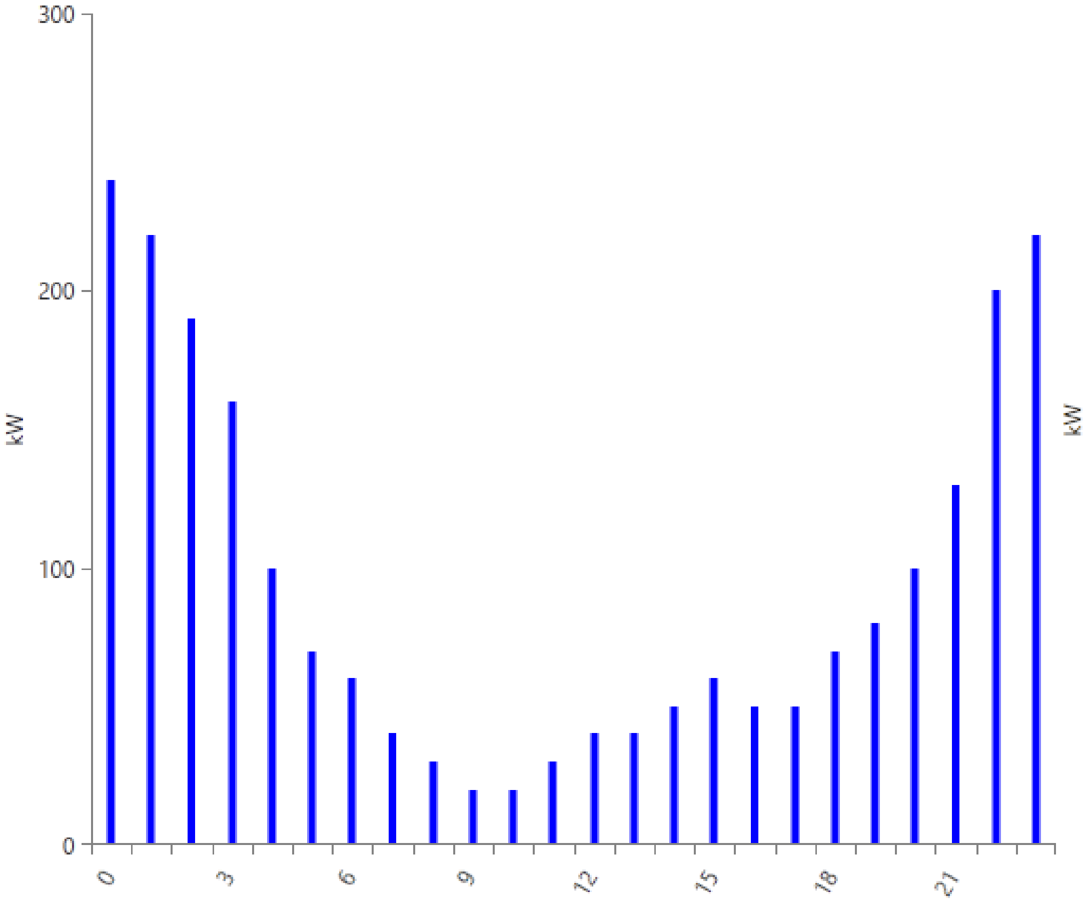


Figure 8.3: EV charging profile through the day

9 | eTransport - input and investment alternatives

This chapter explains how eTransport was used to do a further analysis of the HOMER results.

Based on the results from HOMER (see chapter 11), it was decided to set up eTransport with the following technologies: a wind park, a pellets power plant, a PV installation, as well as batteries and an electric boiler. Additionally, eTransport was used to test if there were any advantages in a hydrogen storage system or a steam accumulator.

9.1 Overview of the system

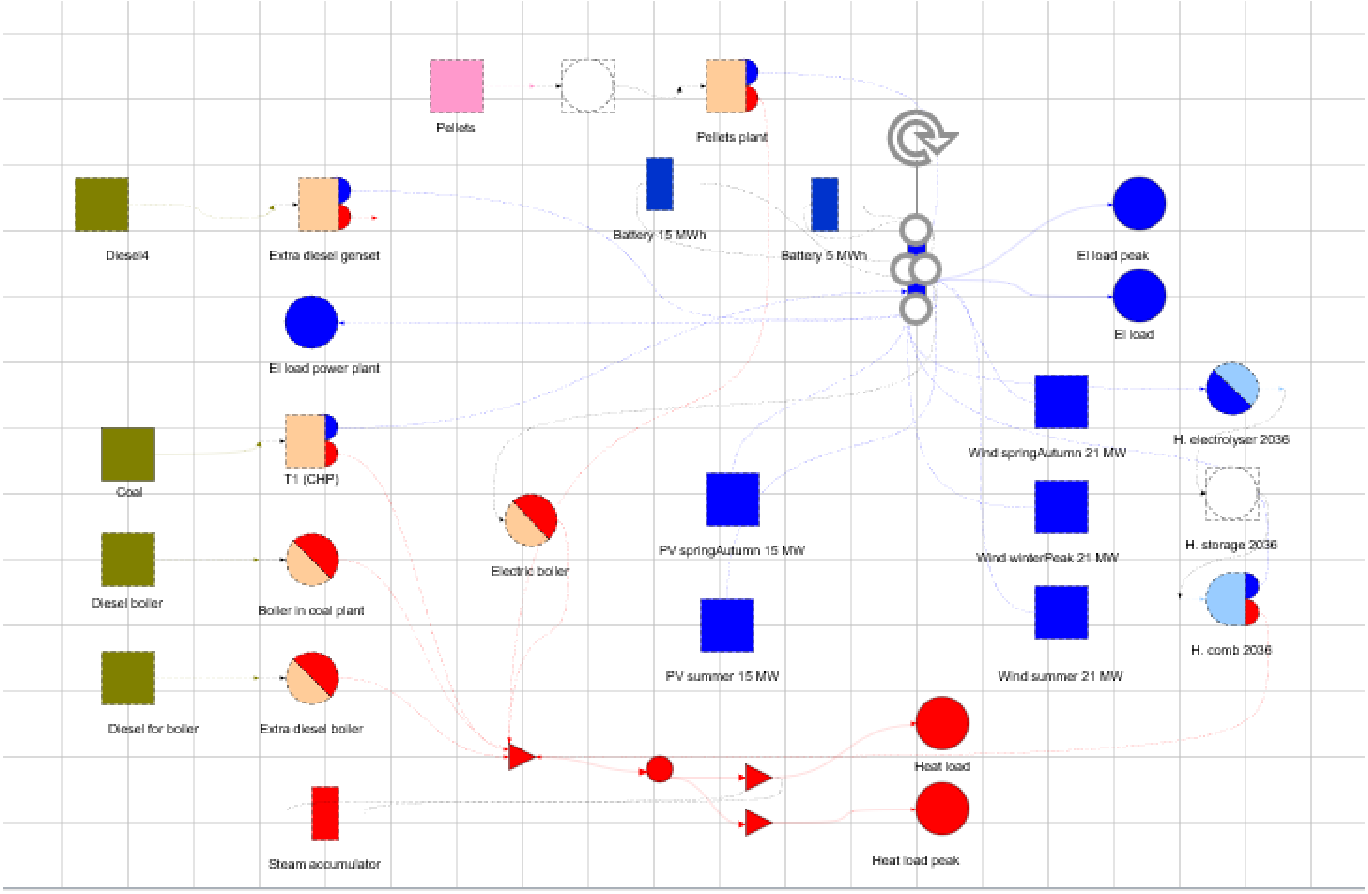


Figure 9.1: The eTransport model

Figure 9.1 shows a graphical overview of all the components and how they are connected in eTransport. All input data is presented in the appendix.

The components in an eTransport model are connected with lines that represent the energy flow. All flows are converted to kWh/h. The principal types of components are energy or fuel sources, energy loads and various conversion components in between. All electricity components are connected to a common bus bar, and all heat components are connected to a DH system consisting of a feed-in-junction, a DH line, a network junction and one load junction for each load.

In eTransport, each year has to be created and listed separately. For this analysis, the years 2021, 2036 and 2050 were included, meaning that the analysis period would go from 2021-2050, with investments available in 2021 and 2036. In HOMER, scale factors were used to adjust heat and electricity demand through the analysis period, in accordance with the demand forecast from chapter 4. The same factors are used here, but instead of 30 periods, there is only two, 2021-2036 and 2036-2050, and the averages of the scaling factors are used in each period.

9.2 Heat and electricity demand input

The components "heat load" and "el load" are used to model the complete electricity and heat demand in Longyearbyen, within the same system boundaries as in HOMER.

eTransport offers two ways of modelling seasonal variations in demand. The user can either design completely different loads for the different seasons, or make a profile for one season, and scale that profile up or down for the other seasons. It is also possible to combine both, which was done here.

All loads, whether heat or electricity, are modelled as 24 hour cycles, with a specified demand for each hour. The year can be split up into any number of segments, consisting of a specified amount of days, as long as the segments total to 365 days. In this model, the year was divided into the segments summer, spring/autumn and winter. The criteria for the division was

Based on the temperature profile through the year, with temperatures between -20 °C and 10 °C, it was deemed suitable to define the summer season as days with average temperature over or equal to 0 °C, autumn and spring as days with average temperatures over or equal to -10 °C and below 0 °C, and lastly winter days as days colder than - 10 °C. The average temperature was calculated for every day and sorted. The segment division resulting from this is shown in table . It must be underlined that these segments do not represent actual seasons, but a division of days based on the outdoor temperature. It is perfectly possible that some days in the winter segment are spring or autumn days, or that very warm autumn days can be included in the summer segment.

Winter days:	65
Spring/autumn days:	142
Summer days:	158
Total:	365

Table 9.1: Division of days in eTransport segments

For each of these segments, it was necessary to find a representative daily profile for heat and power demand. For every hour $h \in [0, 1, 2, ..., 24]$, in every season $s \in [summer, spring/autumn, winter]$, the average demands for heat $Q_{h,s}^{avg}$ and $P_{h,s}^{avg}$ were calculated as

$$Q_{h,s}^{avg} = \sum_{d=1}^{D_s} Q_{h,s}/D_s \tag{9.1}$$

where D_s is the number of days in season s, d is the day, $Q_{h,s}$ is the heat demand in hour h in season s, the hours of the day were examined and heat and electricity production averages calculated.

and

$$P_{h,s}^{avg} = \sum_{d=1}^{D_s} P_{h,s}/D_s \tag{9.2}$$

where $P_{h,s}$ is the power demand in hour h in season s.

This math was done using a simple PowerShell script. Now, having established a representative 24-h demand profile for each of the three seasons, it was desired to streamline these to one profile for electricity and one for heat, that could be scaled up or down with a simple coefficient. For each h in the day, the ratios R^Q and R^P between the corresponding seasonal profiles were calculated as

$$R^Q_{h,spring/autumn-to-summer} = Q^{avg}_{h,spring/autumn}/Q^{avg}_{h,summer} \tag{9.3}$$
$$R^P_{h,spring/autumn-to-summer} = P^{avg}_{h,spring/autumn}/P^{avg}_{h,summer} \tag{9.4}$$

and

$$R^Q_{h,winter-to-summer} = Q^{avg}_{h,winter}/Q^{avg}_{h,summer} \tag{9.5}$$
$$R^P_{h,winter-to-summer} = P^{avg}_{h,winter}/P^{avg}_{h,summer} \tag{9.6}$$

The averages of these ratios were used as scaling factors S:

$$S^Q_{spring/autumn-to-summer} = \frac{1}{24} * \sum R^Q_{h,spring/autumn-to-summer} \tag{9.7}$$
$$S^P_{spring/autumn-to-summer} = \frac{1}{24} * \sum R^P_{h,spring/autumn-to-summer} \tag{9.8}$$
$$S^Q_{winter-to-summer} = \frac{1}{24} * \sum R^Q_{h,winter-to-summer} \tag{9.9}$$
$$S^Q_{winter-to-summer} = \frac{1}{24} * \sum R^P_{h,winter-to-summer} \tag{9.10}$$

The scaling factors between the seasons were then as shown in table 9.2.

Season	**Heat scaling factor**	**Power scaling factor**
Summer	1	1
Spring/autumn	1.433	1.131
Winter	1.603	1.237

Table 9.2: Scaling factors between season

Figure 9.2 and 9.3 shows the different seasonal profiles for the electricity and heat demand, as they were modelled in eTransport.

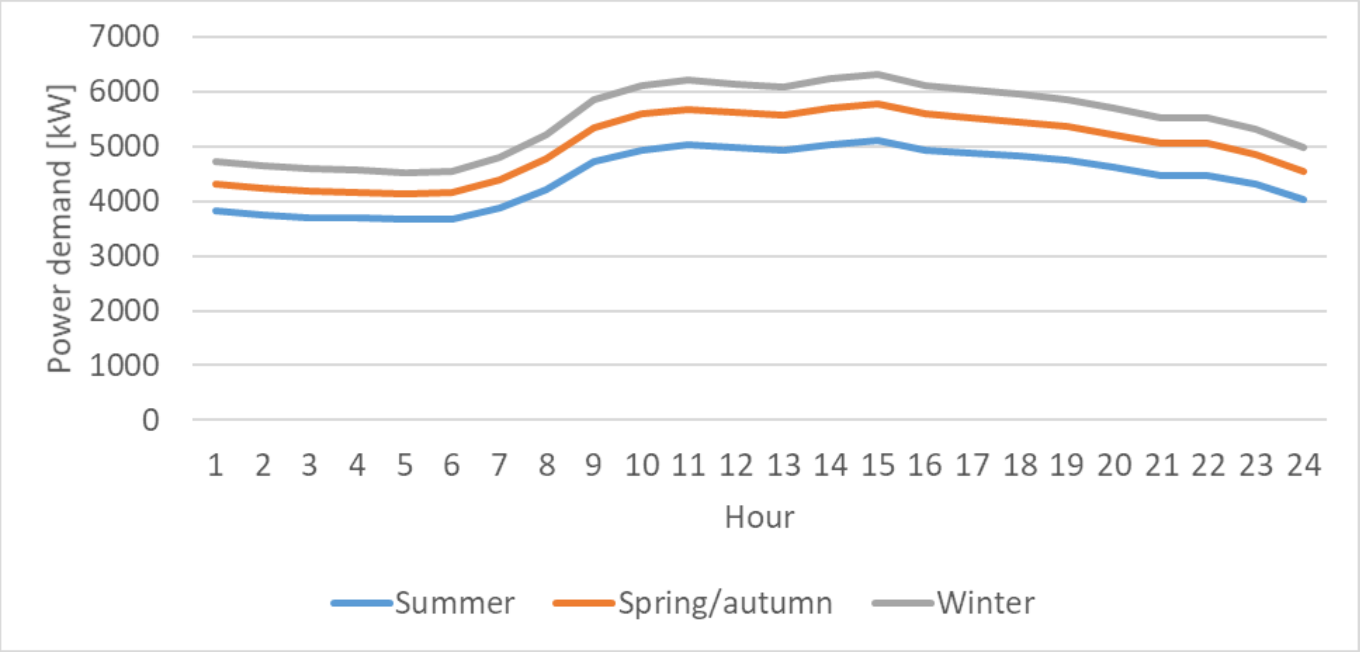


Figure 9.2: Demand curves for electricity as modelled in eTransport

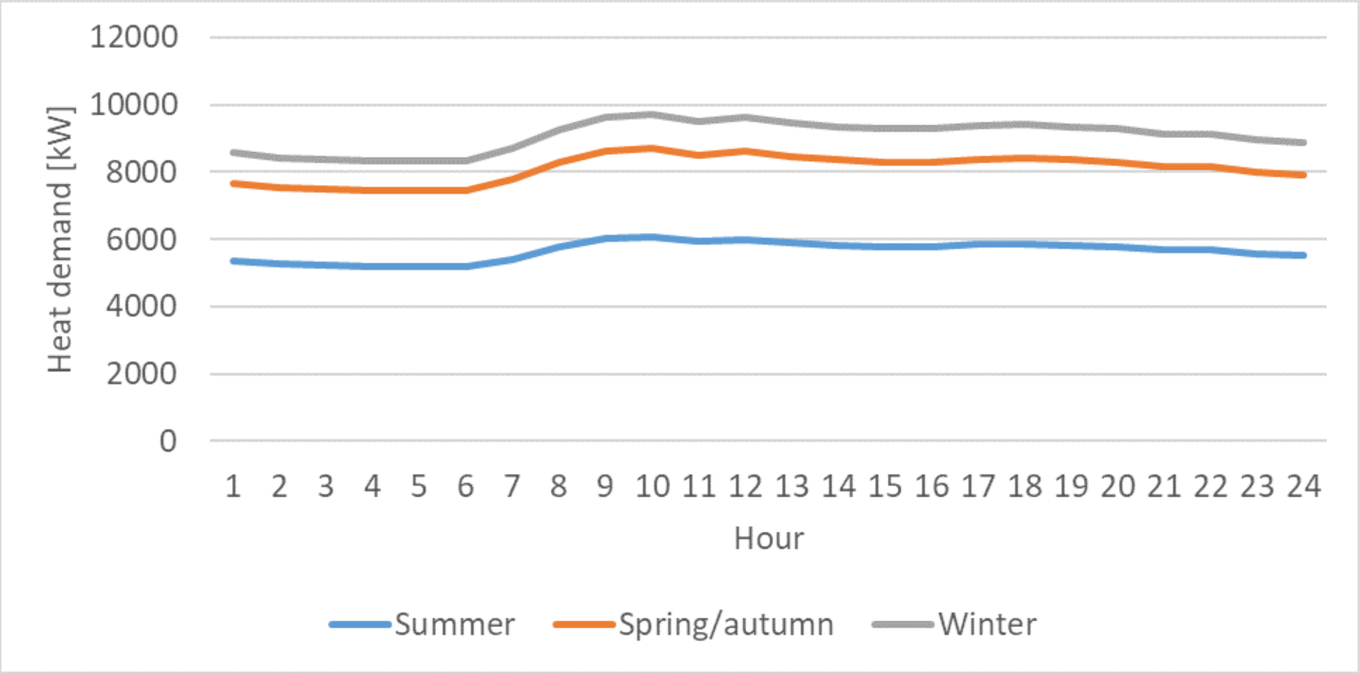


Figure 9.3: Demand curves for heat as modelled in eTransport

To model this in eTransport, one "el load" and one "heat load" was set up with the summer demand profiles. These loads were set to exist in all three segments, and the scaling factors were included in the segment settings

The downside to modelling the segments and demand like this is that the peak demand is omitted. In order to ensure that the system can cover peak demands, one winter day was retracted and replaced with a new segment called "peak" that consisted of just one day. These peak demands were set up by adding an additional el load component and a heat load component. These load components were set to only exist in the peak segment, and their demand profiles were set according to the day of the year with the highest heat load, namely January 30th.

9.3 Energy components

Coal power plant

The coal power plant was modelled using the CHP model in eTransport, and connected to the coal fuel. As mostly T1 is used, and the dynamics around the gas-scrubber and the boiler bottleneck cannot be appropriately modelled in eTransport, T2 was omitted. It was decided to model the diesel boiler in the power plant separately. At full production, T1 can output 7.5 MW of electricity and 14 MW of coal. The CHP model input is "el factor", "heat factor" and "rated capacity". eTransport treats this mathematically as

$$C = F \tag{9.11}$$

$$P = \eta_{el} * C \tag{9.12}$$

$$Q = \eta_{heat} * C \tag{9.13}$$

$$L = (1 - \eta_{el} - \eta_{heat}) * C \tag{9.14}$$

where C is rated capacity, F is fuel input, P is power output, Q is heat output and L is losses. The average electricity efficiency (η_{el}) is 19 %, and the heat efficiency (η_{heat}) 63 %. With a maximum P of 7.5 MW at $\eta_{el} = 0.19$, the rated capacity was set to $C = 7.5MW/0.19 = 39.5MW$. This modelled the power dynamic correctly, but entailed that the maximum heat output $Q = 0.63 * 39.5MW = 24.9MW$, and not 14 MW. To more accurately model the CHP dynamics, some changes were made to the eTransport CHP model's code, in cooperation with Magnus Askeland at SINTEF. The issue was remedied by adding two additional restrictions in the source code that could overrule the P and Q by inserting an "electricity capacity" and a "heat capacity". These were set to 7.5 MW and 14 MW respectively. If the power plant was run at maximum capacity, the heat output was 14 MW, and the remaining 10.9 MW became losses.

The operational mode priority seems to dictate which of the two loads should be prioritised if the ratio between heat and electricity load is unequal to the ratio between heat and electricity production in the coal power plant. As it is more important with regards to grid stability to have a correct power output, and it is also easier to curtail excess heat than electricity, the priority mode is set to "el". The export price of electricity was set to 0, as there is no external market to sell the electricity to.

The CO_2 emission factor was set to 385 kg/MWh, which is the CO_2 emissions from 100 % combustion of 1 MWh of coal, assuming a 70 % carbon content and a lower heating value of 24 MJ/kg. eTransport takes the losses into account later, putting the carbon intensity for delivered energy at a considerable higher level. The emission penalty was set according to gathered data.

Diesel boilers

The diesel boiler in the power plant was modelled using the boiler component in eTransport. This is a simple component, that converts a fuel of choice - here diesel - to heat that is fed to the DH system. The maximum effect was set to 5 MW, with 0.85 efficiency. The emission coefficient was set to 269.0 kg/MWh, corresponding to a carbon content of 88 % and a lower heating value of 43.2 MJ/kg.

Extra diesel boiler capacity was set up in the form of an additional boiler, with the same emissions and efficiency, and 16 MW capacity.

Pellets power plant

The pellets power plant was modelled using the same CHP model. The rated capacity was set to 37.5 MW, the el factor to 0.2 and the heat factor to 0.55. The electricity and heat maximum capacity was set to 7.5 MW and 20.625 WM, respectively, so as not to impose any additional constraints. This gave the pellets plant the same maximum output as in HOMER. The CO_2 emission coefficient was set to 0. No other settings were changed compared to the coal plant. Between the pellets power plant and the pellets source, a "bio mass storage" component was included, which is necessary in eTransport. Its settings were adjusted to not impose any new constraints.

Wind park

A wind park of 21 MW was added to the system. This was done using the eTransport model "El source", which is just an electricity source with a specified maximum outtake and a specified cost. The cost, which would be comparable to a fuel cost, was set to 0. The maximum outtake was set to correspond with the expected wind power output of the installation. To model the seasonal variations in power output, three similar el source components were added in the system: one for summer, which was set to exist only in the summer segment; one for spring/autumn set to exist in that segment; and, lastly, one for winter and the peak day.

The production profiles were set up using the same Ninja Renewables power output time series as in HOMER (except that in HOMER, the wind speed from the time series was used, allowing HOMER to do its own calculations of power). It was necessary to split the time series for the whole year up into representative series for the different segments/seasons. It was assumed that the winter/peak profile consisted of the wind production during Janaury 1st to February 1st, and November 29th to December 31st. Likewise, it was assumed that the spring/autumn profile consisted of the wind production during February 2nd to April 13th, and September 19th to November 28th. The remaining days belonged to summer. For each of these three time series, the average hourly output was calculated using the same math and a modified version of the same script as for when the demand profile was established earlier. The resulting wind profiles for the different seasons are shown in figure 9.4. It should be noted that this modelling gives a good approximation of average wind production through the seasons, but it does not model the day-to-day fluctuations typical for wind turbines.

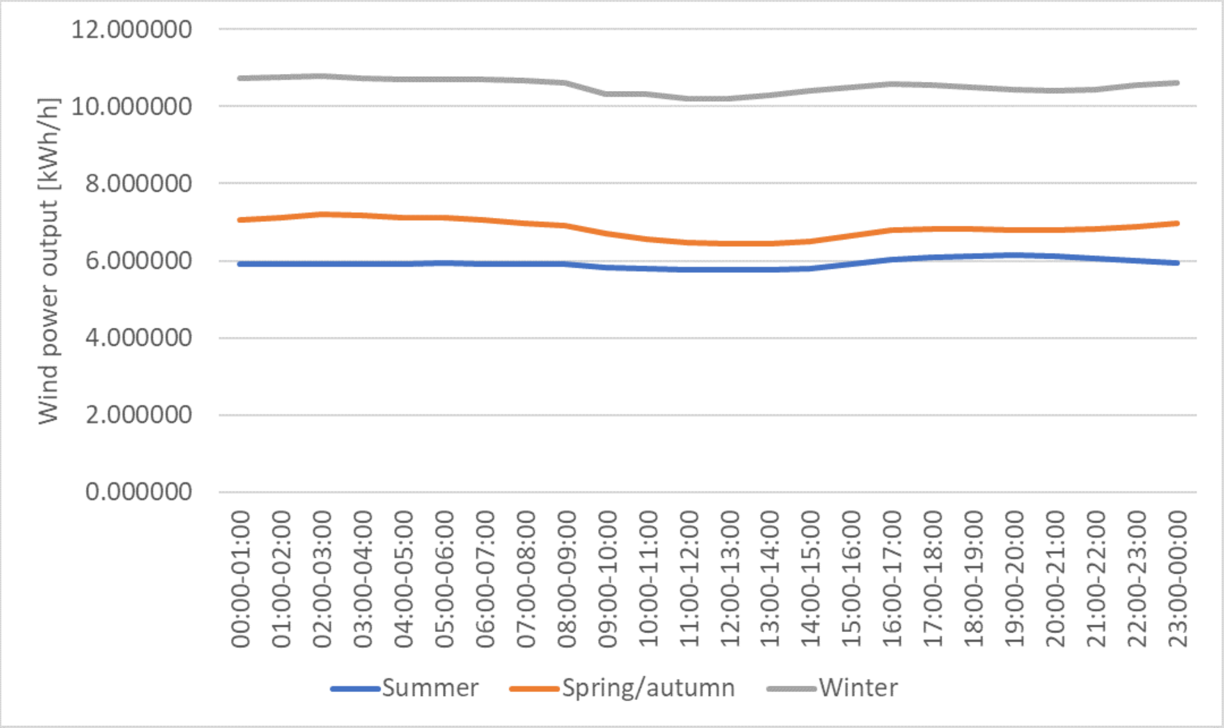


Figure 9.4: Output of a 21 MW wind park

Rooftop PV system

A PV installation of 15 MW was added to the system. This was also modelled with the same el source component as for the wind park. The same script was used to generate seasonal 24 h profiles, based on the different segments. Einar Boman Rinde, an NTNU student who is writing a master's thesis on the same topic, has performed a PVsyst simulation of the power output of rooftop PV installations in Longyearbyen. This data was provided, and used as the basis for the estimated demand profiles, similarly to how the Ninja Renewables wind profile was used to model the power output of the wind park.

Once again, it should be noted that this profile represent averages, but does not take the fluctuating nature of solar power into account. Furthermore, the power output used as a basis for this is based on PV panels being put on all usable rooftop area in Longyearbyen, resulting in 33.2 MW of power. As most of the rooftops are pitched, most roofs have one side that produces more power than the other, due to a more favourable azimuth. With an installation of 15 MW, it might be assumed that all the panels are placed on the most favourable locations, leading to a somewhat higher power output.

Batteries

A 5 MWh and a 15 MWh battery was included. The two batteries were set to exist in all segments. Their efficiencies were set to 0.9 with maximum state of charge set to 100 % and minimum state of charge set to 20 %. For the 5 MWh battery, the charge/discharge rate was set to 1.5 MW and the initial state of charge at 2.5 MWh, or 50 %. For the 15 MWh, the charge/ discharge rate was set to 4.5 MW and the initial state of charge was set to 7.5 MWh.

Steam accumulator

For the steam accumulator, the heat loss was set to 0.001 MWh. The storage capacity was set to 30 MWh and the charge/discharge rate was set to 3 MW. The steam accumulator was set to be active in all segments.

Hydrogen system

To model the hydrogen storage system, it was desirable to include the same hydrogen system as was modelled in the Thema and Multiconsult report from 2018 [4], with a 3.5 GWh storage tank and a 12.000 kg H_2/day. Three components were used: an electrolyser, a storage tank and a fuel cell. All components were set to exist in all segments. The electrolyser is a simple component that converts electric power to hydrogen by applying an efficiency, which was set to 0.67. The maximum production rate was set to 16.67 kWh/h. Here it must be noted that the unit used in eTransport is Sm^3/h. When looking at the source code, however, it is clear that there is no convertion between kWh and Sm^3. This was confirmed by Magnus Askeland at SINTEF [39] . 16.67 kWh/h corresponds to 12,000 kg H_2/day, spread out evenly. For the storage tank, the initial storage was set to 0, the loss factor (which corresponds to $(1-\eta)$) to 0.3, the maximum storage to 3.5 GWh, the minimum storage to 0 and the storage cost was set to 0 NOK. The maximum input and the maximum output were set to 3.5 GWh/h. So as not to be constraint. For the fuel cell, the capacity was set to 16.67 MW. The el factor and the heat factor were set to 0.3 and 0.6, respectively.

Fuel input

The three fuels available in Longyearbyen are diesel, coal and pellets. eTransport has oil, gas, waste and bio mass built in. Both coal and diesel was modelled using the oil source component, with different settings. The bio mass model was used for pellets. Every fuel source can only be connected to one fuel-consuming component, so it was necessary to create several identical fuel sources. For each fuel source component one can set a maximum consumption rate for every hour and a cost for every hour. The maximum consumption was set high enough to never be a constraint. The prices of coal, diesel and pellets were set according to the gathered data. In eTransport, prices are set in NOK/MWh. Using the lower heating value, the prices were calculated as shown in table 9.3.

Fuel	Price [NOK/MWh]
Diesel	771.3
Coal	79.46
Pellets	351.2

Table 9.3: Fuel prices in [NOK/MWh]

Investment alternatives

While HOMER is allowed to choose and size different components and put together several potential energy systems, eTransport has to be presented with specific investment alternatives, that include costs and rated output. Table 9.4 summarise the investment options in eTransport. There is also a time factor to the investment, as investments can be postponed. Investments that were expected to decrease in the future were modelled as two separate investments. Investments in eTransport consist of a specified collection of one or more components, with an investment cost, an annual O&M cost and a lifetime. Therefore, it is expedient to refer to these investments as investment packages. E.g., the three hydrogen components where set as one investment package called "hydrogen", with the price and lifetime being tied to all of the components. eTransport can choose to buy the package or to not buy it. The prices are tied to the investments, and not the components themselves. All components that were expected to decrease in cost during the analysis period, such as the batteries, were modelled as different investments, where the different investments contain the same component, but at different prices. Components that are expected to always be there, such as the load components, are not included in any investments.

Investment	**2021**	**2036**
Coal (keep or scrap)	x	-
Battery 5 MWh	x	x
Battery 15 MWh	x	x
Pellets plant 7.5 MWh	x	x
Steam accumulator 30 MWh/3 MW	x	x
Hydrogen 3.5 GWh storage and 16.67 MW electrolysis	-	x
Wind 21 MW	x	x
PV 15 MW	x	x
Diesel genset 12 MW	o	o
Diesel boiler 16 MW	o	o
Electric boiler 28 MW	o	o

Table 9.4: Investment opportunities in eTransport. "x" = available, "-" = unavailable, "o" = obligatory

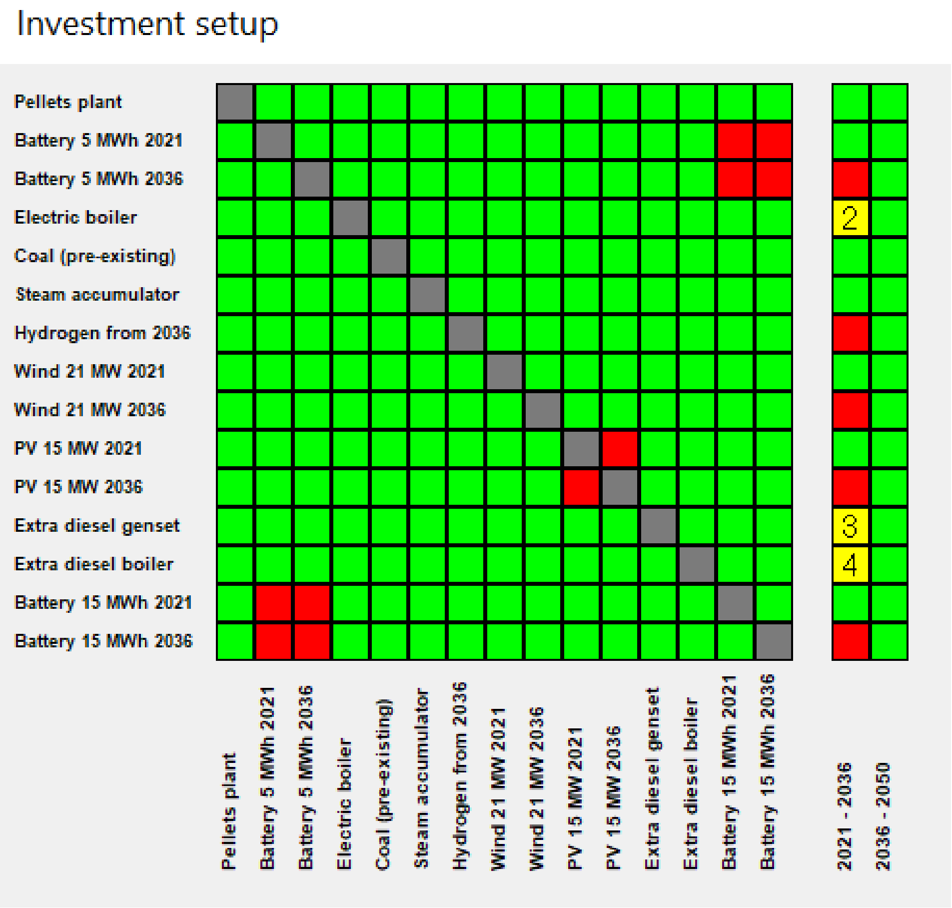
The prices for the different investment packages were set according to the gathered data. For the hydrogen investment package, the lifetime was set to 10 years, despite the individual components having lifetimes varying between 8 and 10.

Investment matrices

Many of the dynamics unique to eTransport can be seen in the model's two investment matrices shown in figure 9.5. The technology matrix is used to determine which investment combinations are allowed (green), mutually exclusive (red) or dependent/required (yellow). The time matrix dictates when investment opportunities are available, and can be used to make an investment illegal until the future. The settings for the Longyearbyen model are shown in figure 9.5. To model different costs for an investment between the periods 2021-2035 and 2036-3050, they have to be presented as two separate investment alternatives, as seen along the Y-axis. The investment dynamics in eTransport are described further in 12.2.

In the technology matrix, all combinations are legal, except for the 5 MWh and the 15 MWh battery, of which the system has to choose maximum one, and the PV installation that has to be installed between 2021-2035 or 2036-2050, but cannot be invested in in both periods. That is because the PV installation has a lifetime of 30 years.

In the time matrix, the investments duplicated to model a future price decrease were set to be unavailable until 2036. The electric boiler, diesel generator and diesel boiler were all set as required investments in 2021.



Investment setup

	Pellets plant	Battery 5 MWh 2021	Battery 5 MWh 2036	Electric boiler	Coal (pre-existing)	Steam accumulator	Hydrogen from 2036	Wind 21 MW 2021	Wind 21 MW 2036	PV 15 MW 2021	PV 15 MW 2036	Extra diesel genset	Extra diesel boiler	Battery 15 MWh 2021	Battery 15 MWh 2036
Pellets plant	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Battery 5 MWh 2021	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥
Battery 5 MWh 2036	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥
Electric boiler	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Coal (pre-existing)	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Steam accumulator	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Hydrogen from 2036	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Wind 21 MW 2021	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Wind 21 MW 2036	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩	🟩	🟩	🟩
PV 15 MW 2021	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟥	🟩	🟩	🟩	🟩
PV 15 MW 2036	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	▨	🟩	🟩	🟩	🟩
Extra diesel genset	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩	🟩
Extra diesel boiler	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩	🟩
Battery 15 MWh 2021	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	🟩
Battery 15 MWh 2036	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨

	2021 - 2036	2036 - 2050
Pellets plant	🟩	🟩
Battery 5 MWh 2021	🟩	🟩
Battery 5 MWh 2036	🟥	🟩
Electric boiler	2	🟩
Coal (pre-existing)	🟩	🟩
Steam accumulator	🟩	🟩
Hydrogen from 2036	🟥	🟩
Wind 21 MW 2021	🟩	🟩
Wind 21 MW 2036	🟥	🟩
PV 15 MW 2021	🟩	🟩
PV 15 MW 2036	🟥	🟩
Extra diesel genset	3	🟩
Extra diesel boiler	4	🟩
Battery 15 MWh 2021	🟩	🟩
Battery 15 MWh 2036	🟥	🟩

Figure 9.5: Investment matrices for the model: Technology matrix to the left and time matrix to the right.

10 | Use cases

Six different cases are compared in this thesis, with the purpose of identifying feasible and beneficial solutions. Five of them have been established using HOMER. The HOMER model generated 34 feasible cases, of which a selection had to be made. The cases were picked after certain merits, to showcase different combinations of technologies, and to see how they perform with regards to costs and emissions.

Case 1: Coal (baseline)

Case 1 is a baseline case, to establish what costs and emissions would be like if Longyearbyen was continued to be run with a coal power plant. For this case, it is assumed that the coal plant is renewed when worn out.

Case 2: Pellets and wind

Case 2 consists of a combination of a pellets power plant and a wind park. It was picked because it is the solution that offers the lowest annual emission rate of CO_2. The combination of a pellets power plant and a wind park seemed promising in the project thesis [2].

Case 3: Coal + wind

Case 3 consist of the existing coal power plant with the addition of a wind park. It is the system with the lowest net present cost in the HOMER analysis, and it shows the benefits of a partial transition towards renewables in Longyearbyen.

Case 4: Diesel

As seen in chapter 2, it is not uncommon for isolated Arctic energy systems to be run using only diesel generators and diesel boilers only. In the event of a complete failure of the coal power plant, this would be the likely temporary solution in Longyearbyen until a new energy system is in place. Such a system would not realistically be operated for 30 years, but it was decided to include it as a case to illustrate the cost differences between the ideal cases compared to a more traditional Arctic microgrid system.

Case 5: Wind + PV

Case 5 was picked to show the lowest obtainable net present cost achievable if the energy system is to be based on local renewables as opposed to a coal power plant or a new power plant based on imported fuels, such as pellets. This case includes a combination of a wind park and a rooftop PV system, with a large battery system for energy storage. It should be noted that the case still includes some import of diesel for generators and boilers, to ensure security of energy supply.

Case 6: Power cable from Finnmark

The 6th case is the alternative of running a power cable from Finnmark on mainland Norway to Longyearbyen. This alternative has previously been modelled by ABB, and was part of the Thema and Multiconsult report [4]. The cable alternative has been included as a case to be able to compare it to the other alternatives.

11 | Results and analysis

This section presents the findings from using the HOMER Energy model tool to suggest new potential energy systems in Longyearbyen for 2021-2050.

11.1 HOMER results

The capacity of the technologies for the different cases are shown in figure 11.1 and 11.2, for electric and heat capacity, respectively. Case 1-5 feature an electric boiler to convert excess electricity to heat. This electric boiler is counted as heat capacity and included in 11.2. It may also be noted that the total capacity is higher for the alternatives with wind and/or solar power. This is necessary as these components will not always produce at maximum capacity.

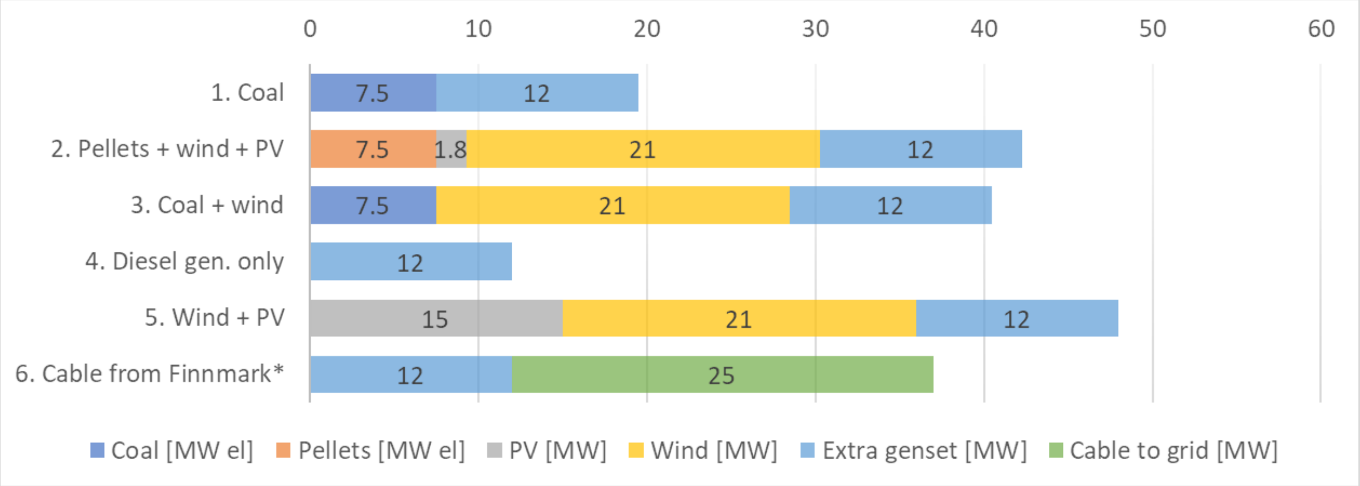


Figure 11.1: Installed electricity capacity for the different cases. *[4]

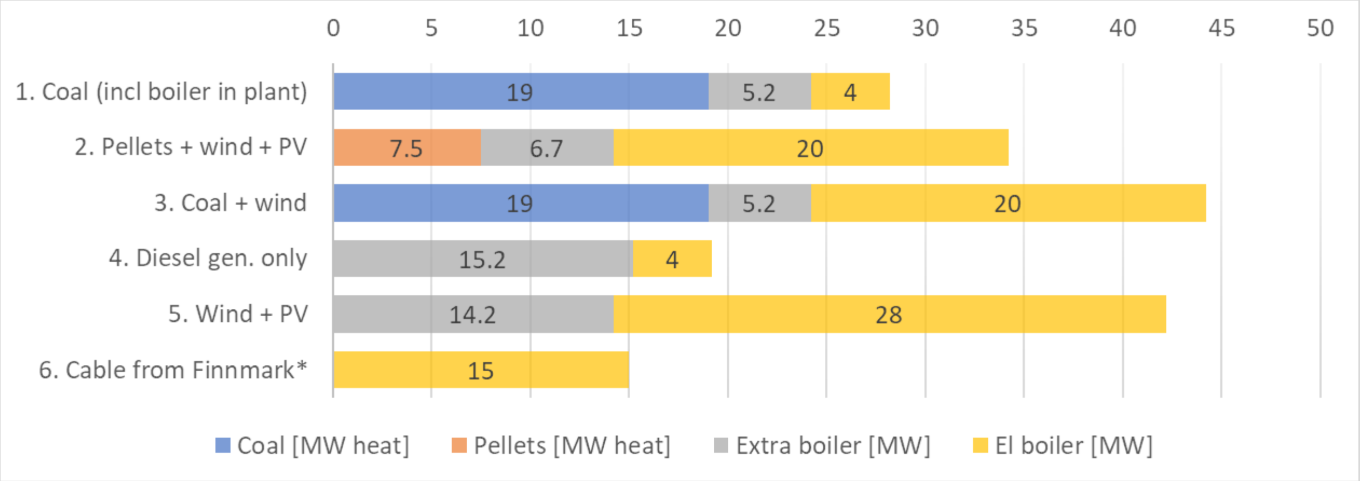


Figure 11.2: Installed heat capacity for the different cases. *[4]

Figure 11.3 shows the net present cost and annual CO_2 emissions of the different cases.

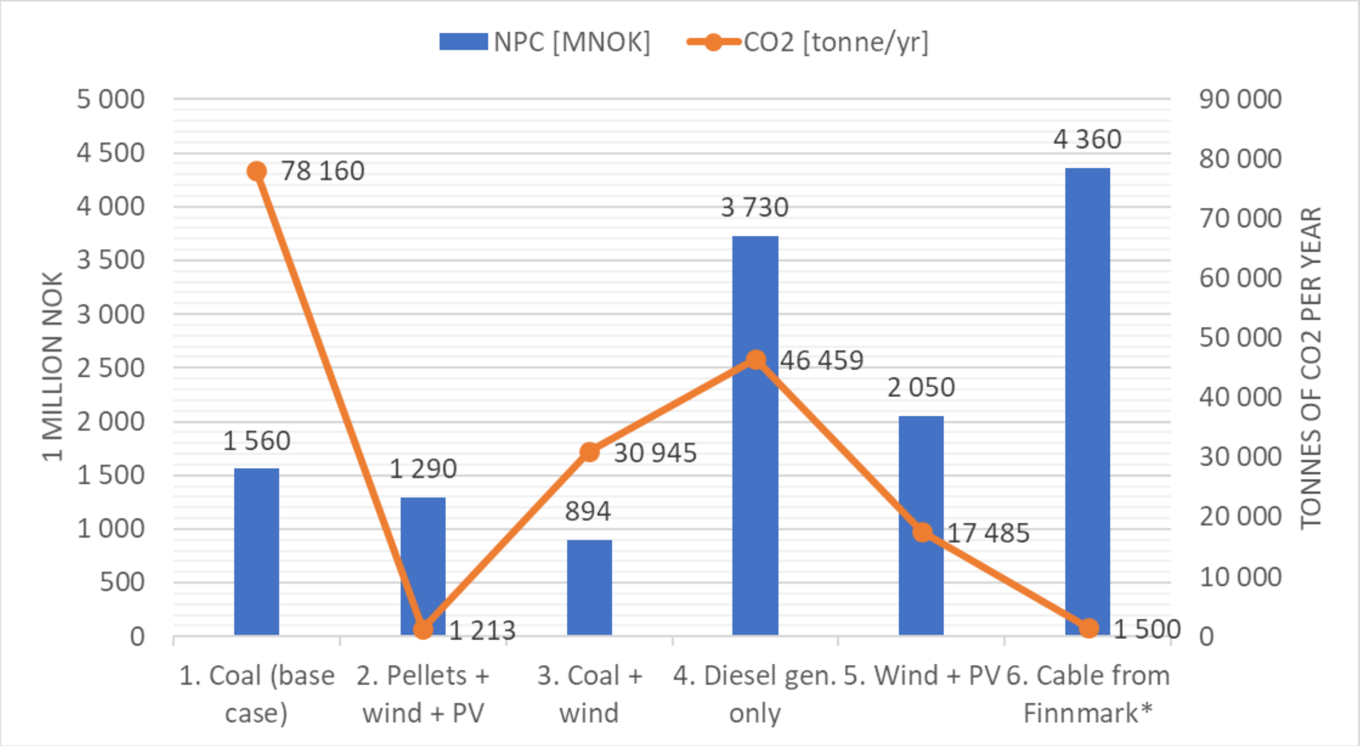


Figure 11.3: NPC and CO_2 of the cases. *[4]

The net present cost of continuing using a coal power plant in Longyearbyen is 1,280 MNOK. This is also the solution with the highest emissions of CO_2, with an average of 83 125 tonnes annually. All the other cases will reduce CO_2 emissions.

Replacing the coal power plant with a similarly sized pellets power plant, in combination with a wind park of 21 MW, will reduce the emissions to 1,342 tonnes of CO_2 annually, and reduce the NPC by 20 MNOK. This is the least carbon intensive solution.

Installing the wind park, but continuing to use coal power to cover part of the load, will be the least expensive solution at 877 MNOK. This solution causes 29,444 tonnes of CO_2 emissions annually, which is a reduction by 65 % compared to the base case.

Running Longyearbyen on diesel generators and diesel boilers exclusively is, as expected, considerably more expensive than case 1-3. The NPC of this solution is 3,370 MNOK, which is 2.6 times higher than the base case. Due to the lower carbon intensity of diesel compared to coal, this solution will, however, reduce /chCO2 emissions by 44 % down to 46,916 tonnes/year.

Opting for the wind park, but with a PV rooftop installation of 15 MW (which will cover roughly 1/3 of the rooftop area in Longyearbyen) instead of a coal or pellets power plant, will increase the NPC by 320 MNOK compared to the base case. A PV + wind system will have an NPC of 1,600 MNOK. It will reduce CO_2 emissions from 83125 tonnes/year to 13,975, an 83 % decrease.

The cable to Finnmark case is by far the most expensive one, at 4,360 MNOK. Due to the low carbon intensity of the mainland Norway electrical grid, this solution is one of the best with regards to emissions, at 1,500 tonnes of CO_2 annually, close to the pellets and wind case.

Case 1: Coal power plant

Technical description

This case is based on the continued use of coal power in Longyearbyen. This includes replacing the existing power plant when its lifetime has been exhausted in about 18 years. It is assumed that only T1 will deliver energy, and that the new replacement coal power plant will consist of a new 7.5 MW electricity turbine, that can generate 19 MW of heat. This will be almost equal to the current turbine and diesel boiler in the power plant. The new power plant would be placed in Hotellneset, and built while the existing one is still in operation.

For this system, extra diesel boiler capacity of 5.2 MW and extra diesel generator capacity of 12 MW would be installed. An electric boiler of 4 MW would enable the transfer of excess electricity to thermal energy for the district heating system. A battery of 5 MWh would also be installed, to help take away some of the highest peaks in winter.

Case 1: Coal power plant		
	Electricity	**Heat**
Installed capacity: Coal plant	CHP turbine: 7.5 MW	CHP turbine: 19 MW
Installed capacity: Diesel	Genset: 12 MW	Boiler: 5.2 MW
Electric boiler		4 MW
Battery	5 MWh	
	Electricity	**Heat**
Annual production: Coal	36.179 GWh	139.429 GWh
Annual production: Diesel		7.077 MWh
Annual consumption: Coal	32,385 tonnes	
Annual consumption: Diesel	846 L	
Annual CO2 emissions	83,125 tonnes	

Table 11.1: Summary of generation capacities, expected production, fuel consumption and CO_2 emissions

As table 11.1 also shows, this system uses on average 32,385 tonnes of coal annually, resulting in emissions of 83,125 tonnes of CO_2.

Cost summary and nominal cash flow

Case 1: Coal power plant	Cost
Capital cost	73,181,000 NOK
Replacement cost	158,560,000 NOK
O&M cost	786,943,000 NOK
Fuel cost	307,100,000 NOK
Salvage revenue	-45,156,000 NOK
NPC	1,280,629,000 NOK

Table 11.2: Cost summary of case 1

Table 11.2 summarises the various costs of this case. These costs cover necessary operational costs, fuel costs and emission fees. With regards to investment costs, they do not cover any grid upgrades that might be necessary when moving production to Hotellneset, or the cost of the extra diesel boiler. For this case, the O&M costs are the highest, as the fuel itself is acquired inexpensively from Store Norske. There is a considerable replacement cost for the power plant in year 19, as seen in figure 11.4 and 11.5 but some of this is returned as salvage value by the end of the analysis period. It may be noted that the replacement cost occurs in year 19, which, in the 2021-2050 period would mean the year 2040. The plant is estimated to last until 2038, but HOMER operates with lifetimes in hours and not years. Because the plant is not always used, this replacement cost is somewhat postponed.

The only investment costs in this case is the electric boiler, the battery and the extra diesel generator and boiler capacity. These costs incur in year 0, but the battery is replaced twice during the analysis period, and leaves no salvage value.

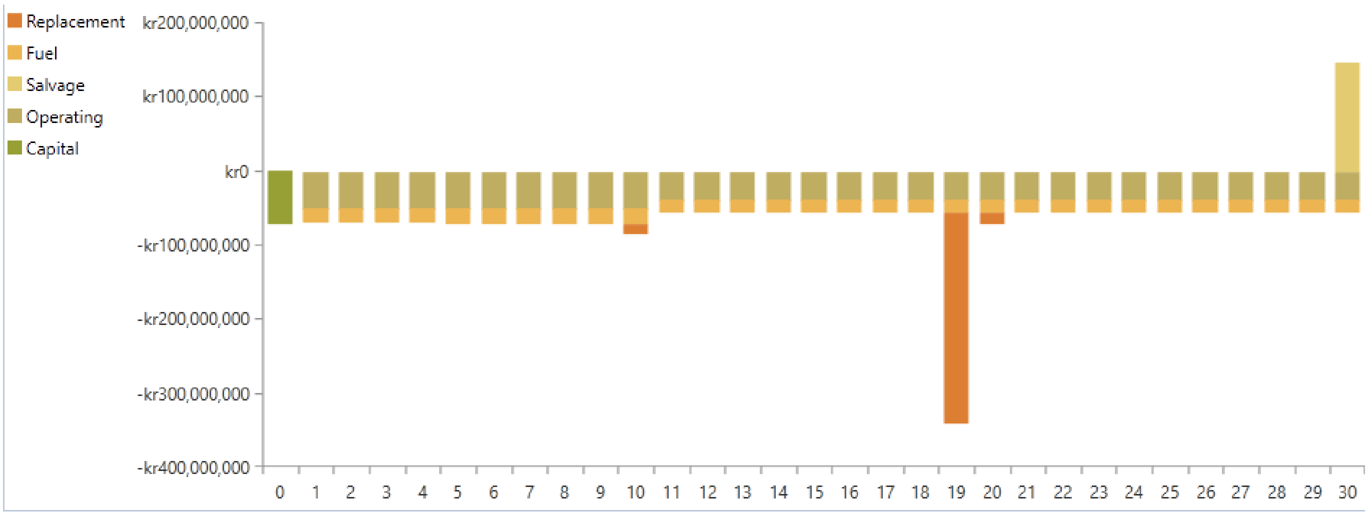


Figure 11.4: Nominal cash flow by cost type

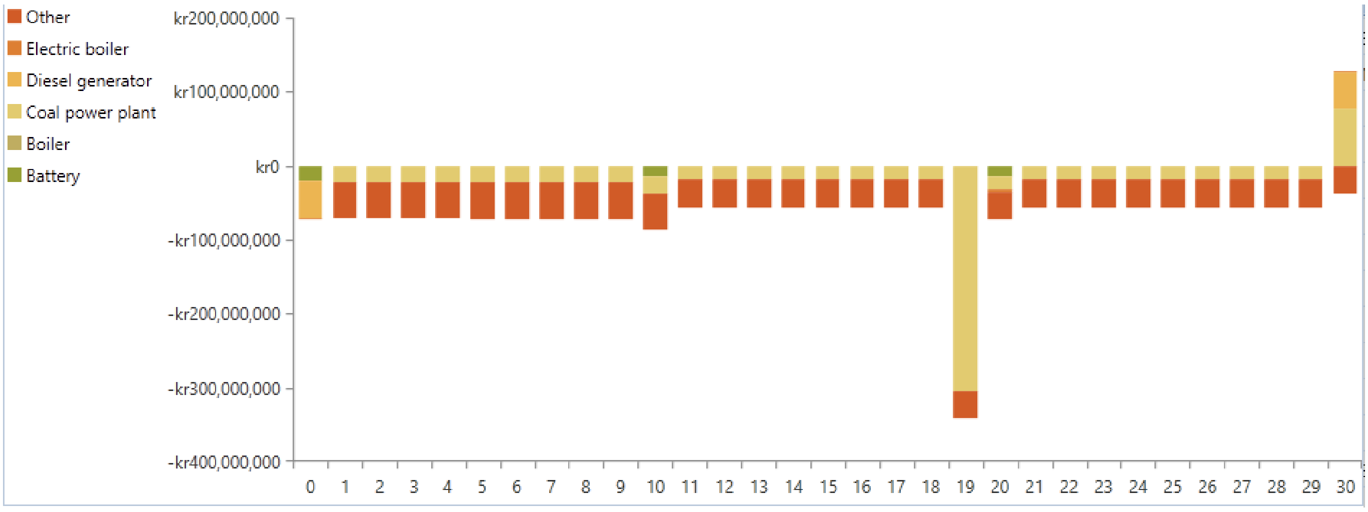


Figure 11.5: Nominal cash flow by component type

Monthly production profiles

As can be seen from figure 11.6 and 11.7, almost the entire heat and electricity load is covered by the coal power plant. The production follows the electricity load closely, leading to considerable over-production and subsequent curtailment of heat production.

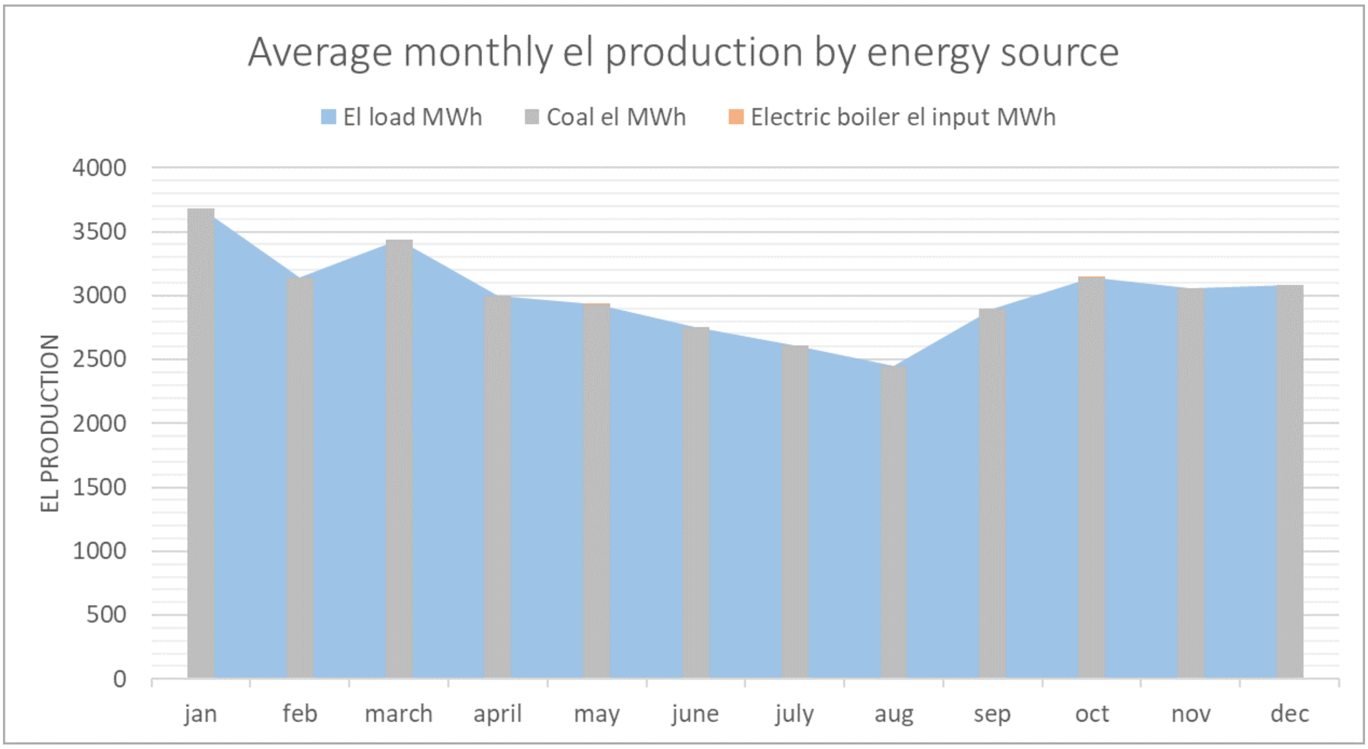


Figure 11.6: Average monthly electricity production by component

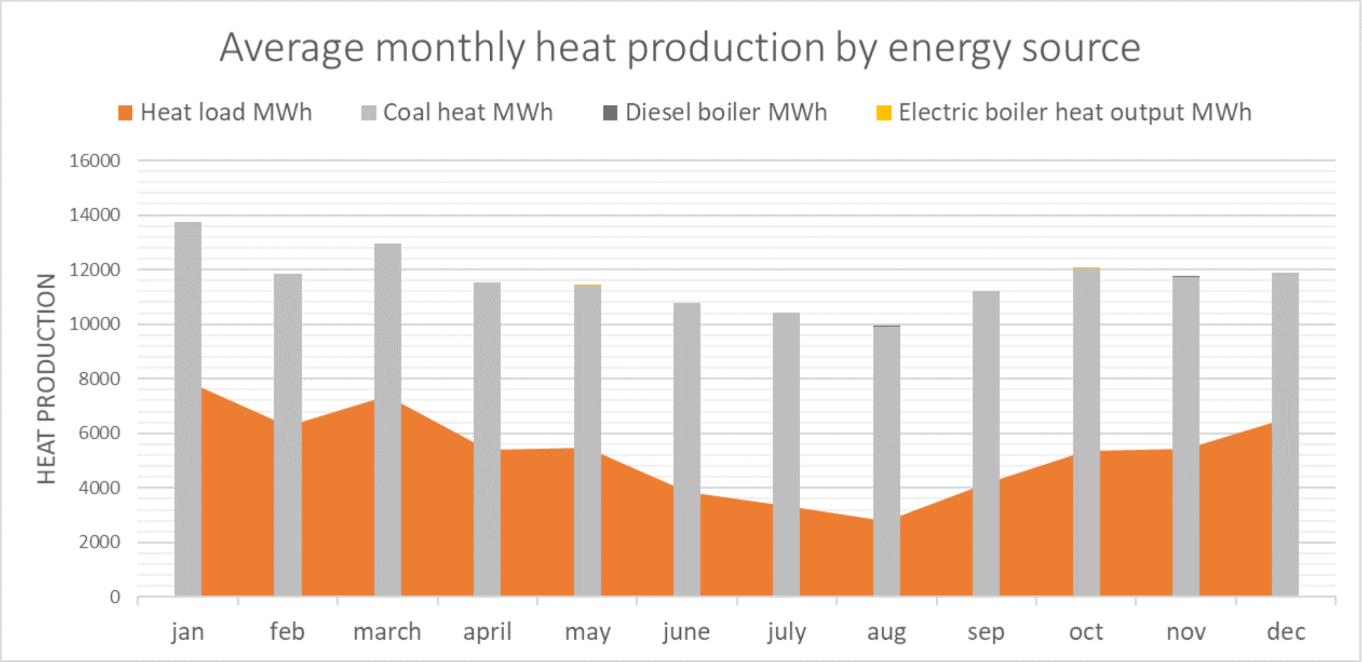


Figure 11.7: Average monthly heat production by component

Example day

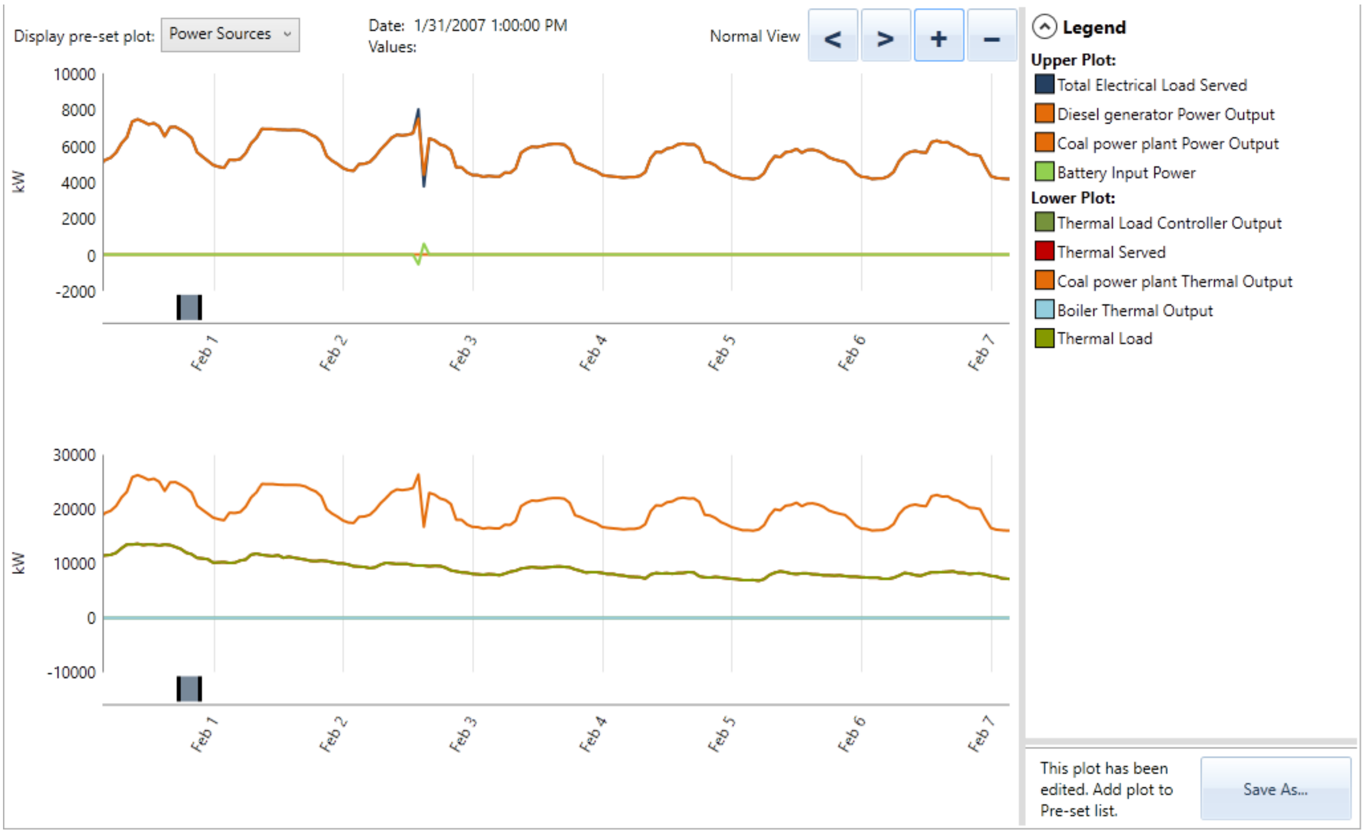


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Figure 11.8: Time series of energy system operation in early February 2021

As can be seen from figure 11.8, the coal power output lines up almost exactly with the electricity demand. There is a constant overproduction of thermal energy, due to HOMER's fixed electricity-to-heat-ratio (the ratio may vary for different power output, but for any given power output, the ratio is fixed). Excess thermal energy is curtailed.

In this case, the battery is rarely used. When it is used, such as on February 2nd, it is due to a sudden high spike in electricity demand. This is covered by the battery, which is recharged right afterwards. Note that the battery graph is for battery input, so when it is above 0 it is charged, and when it is below 0 it is discharged.

Environmental concerns

Continued use of coal power in Longyearbyen is the case that will contribute to the highest amount of greenhouse gas emissions. The emission estimates is based on coal sourced from Svalbard. In the case of a shutdown of the mining operations, and Longyearbyen having to import coal from mainland Europe, the coal would more likely be lignite, with a higher carbon intensity, as well as associated transport emissions.

Due to the gas scrubber, there are practically no emissions of local pollutants such as NOx and SOx. Hotellneset is an area heavily affected by human activities already, and would likely be of little concerns. Longyearbyen Lokalstyre has designated the area for industry or a new power plant [4]. The construction of a new plant would certainly cause local emissions.

Discussion

With regards to the overproduction of thermal energy, three things may be noted. Firstly, not all of this would go to waste, as the actual thermal demand in Longyearbyen is higher than what the HOMER analysis is based on. The HOMER analysis only covers the part of the load previously covered by the coal system. Due to this, some of this thermal energy can replace energy from the diesel fuelled boiler houses. Secondly, the thermal energy waste is likely not as high as portrayed here. Modelling CHP turbines is complicated, due to the flexibility and dynamics of the heat-to-electricity ratio. In real life, it is possible to vary the heat-to-electricity ratio during operation within a certain range. This would have allowed for less curtailment of thermal energy. As the production follows the electrical load, a lower heat-to-electricity ratio would have resulted in less curtailment of thermal energy, but it would not have reduced the costs or emissions from serving the load, as the heat is a by-product of the electricity, and the same amount of coal would still be burnt. Lastly, this indicates that closer research should be done to see whether a steam accumulator or other thermal storage would be a worthy investment.

In real life, it is preferable to keep the output of a coal power plant as stable as possible. There is considerable delay in increasing or decreasing the output of the turbines, and rapidly changing the power output also increases wear and tear. Due to the slow feed-time of the coal to the boiler, the delay is considerable in Longyearbyen, indicating that the battery would likely be used considerably more in real life. Furthermore, the battery could help serve the unknown peak loads served by the diesel generators today, which were not included in the analysis.

The analysis of this case has also omitted the other turbine, T2, which cannot be used unless a gas scrubber is installed at the second boiler.

Case 2: Pellets plant + wind

Technical description

In this case, a 7.5 MW (electricity output) pellets power plant replaces the current coal power plant, and a wind park of 21 MW is established. 5 MWh battery capacity is installed to help even out demand peaks, and a 20 MW electric boiler is installed to enable the conversion of electricity to heat.

For the wind turbines, it is assumed that the 21 MW installation will consist of 14 1.5 MW turbines with a hub height of 80 m. The location is assumed to be on the southernmost parts of Platåberget, close to Longyearbyen and as far away from the KSAT facility as possible. It is assumed the turbines will start production at 4 m/s, reach maximum production at 14 m/s, and then cut off at 25 m/s.

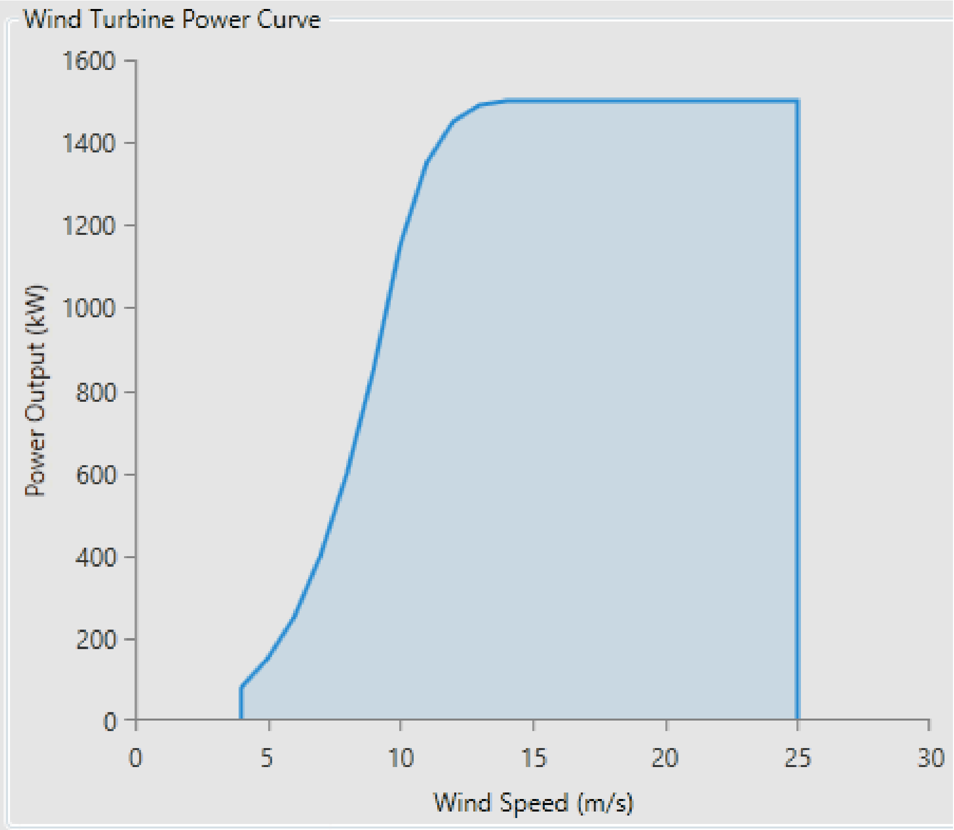

Figure 11.9: Wind power output

The pellets plant will provide heat and electricity when there is not sufficient wind. In design, it will be similar to the coal power plant, with one 7.5 MW CHP turbine that has a 19 MW heat output. The difference will be the boiler, which utilises wood pellets instead of coal.

For this alternative, the optimal size for the electric boiler was found to be 20 MW, instead of 4 MW as for case 1. This is likely because the fuel cost of pellets is higher than coal, increasing the difference in marginal cost between wind and fuel based energy, and subsequently the benefit of being able to convert electricity to heat.

The battery will be the same as in the case 1. Table 11.3 summaries all generation capabilities, and includes fuel usage and CO_2 emissions.

Case 2: Pellets plant + wind		
	Electricity	**Heat**
Installed capacity: Pellets plant	CHP turbine: 7.5 MW	CHP turbine: 19 MW
Installed capacity: Wind	14 x 1.5 MW turbines: 21 MW	
Installed capacity: Diesel	Genset: 12 MW	Boiler: 6.8 MW
Electric boiler		20 MW
Battery	5 MWh	
	Electricity	**Heat**
Annual production: Pellets	11.454 GWh	37.080 GWh
Annual production: Wind	75.864 GWh	
Annual production: Diesel	2.217 MWh	5.150 MWh
Annual consumption: Pellets	12,724 tonnes	
Annual consumption: Diesel	616,359 L	
Annual CO2 emissions	1,342 tonnes	

Table 11.3: Summary of generation capacities, expected production, fuel consumption and CO_2 emissions

Cost summary and nominal cash flow

Case 2: Pellets power plant + wind park	Cost
Capital cost	672,459,000 NOK
Replacement cost	115,721,000 NOK
O&M cost	79,478,000 NOK
Fuel cost	497,287,000 NOK
Salvage revenue	-106,009,000 NOK
NPC	1,258,935,000 NOK

Table 11.4: Cost summary of case 2

Table 11.4 summarise the costs for case 2. The investment costs for this system is 672 MNOK, which includes a wind park, a pellets power plant, battery storage, an electric boiler and extra diesel boiler and generator capacity. The fuel costs, which are mostly for pellets import, are at 497 NOK, and make up a considerable part of the total net present cost (NPC). There is 116 MNOK in replacement cost, which mostly occur in year 20, as seen in fig 11.10, and covers renewal of the wind park. The salvage value on remaining lifetime of components in year 30 is 106 MNOK, and includes residual value on both the diesel generator, pellets plant and the wind park, as seen in 11.11. The annual operating costs are at 79 MNOK. Similarly to case 1, grid investments related to moving energy production to Hotellneset is not included. Likewise, installing a wind park in Platåberget would also require grid investments not included here.

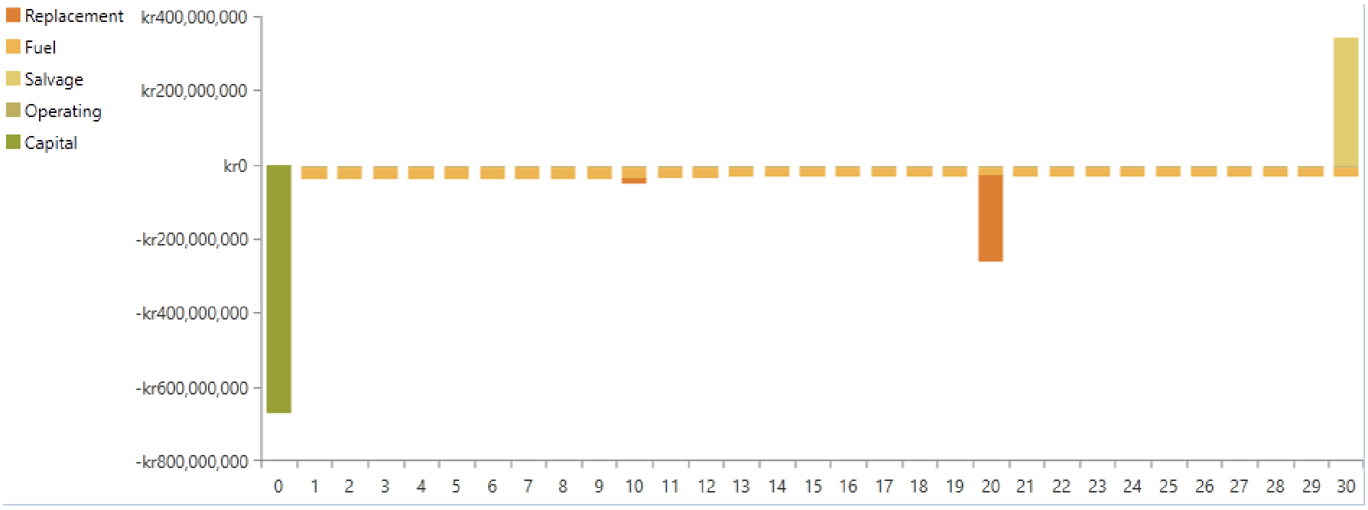

Figure 11.10: Nominal cash flow by cost type

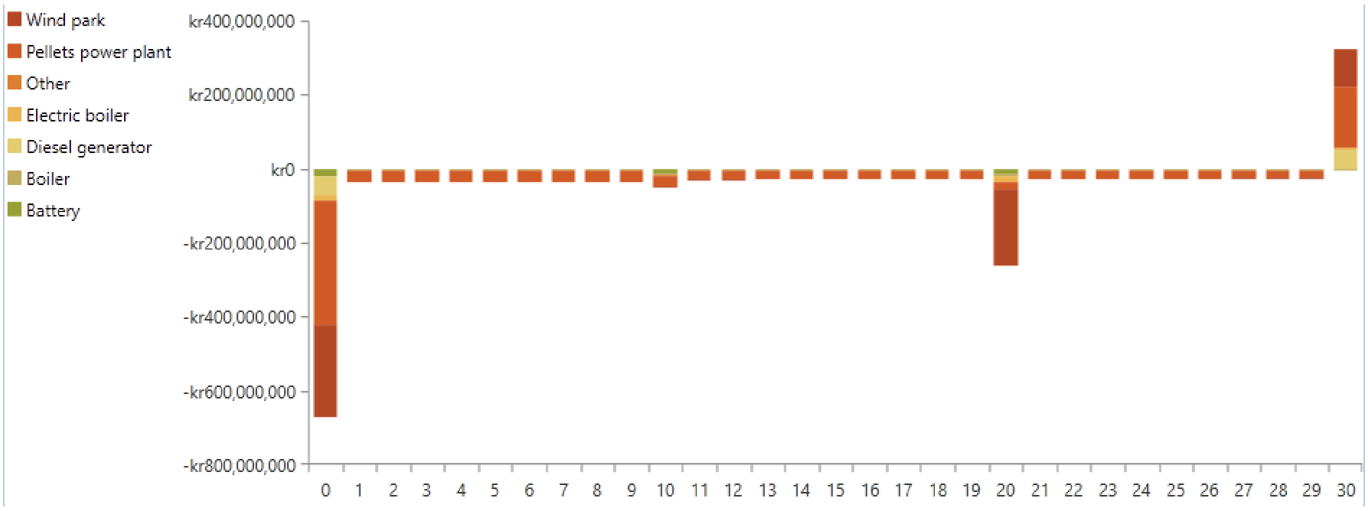

Figure 11.11: Nominal cash flow by component type

Monthly production profiles

Figure 11.12 and 11.13 show which components are used to meet the load in the different months of the year. The diagrams are based on averages throughout the analysis period.

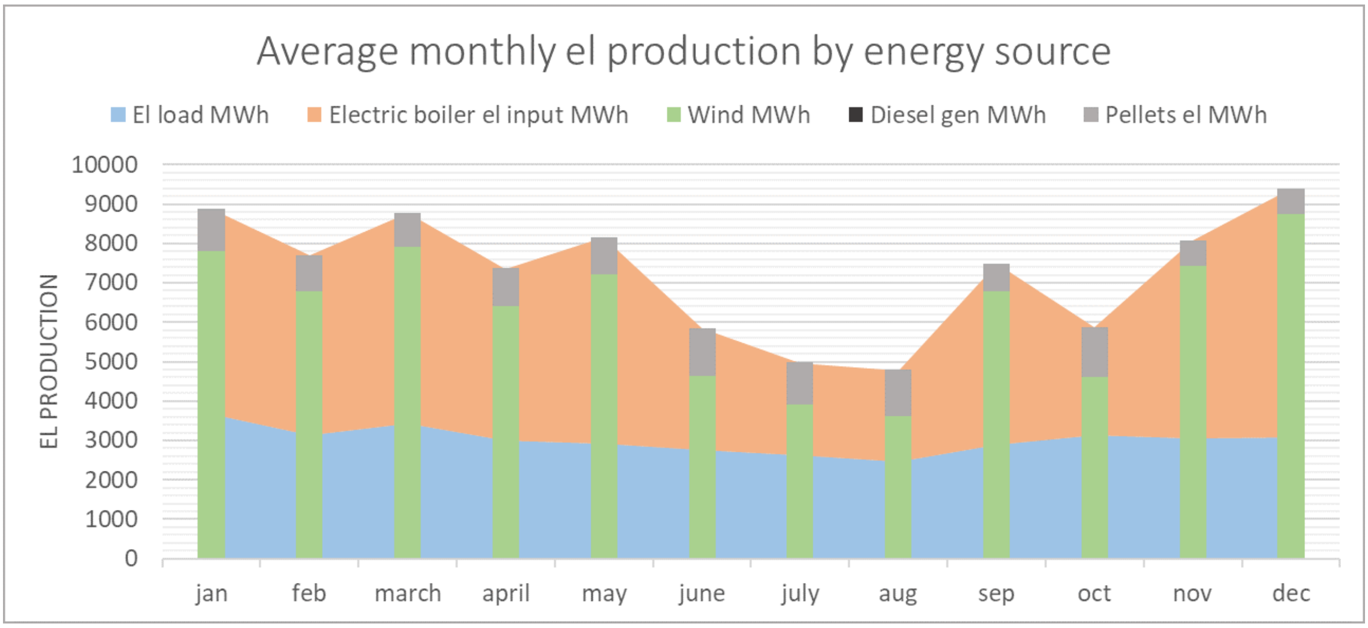

Figure 11.12: Average monthly electricity production by component

With the wind park having the lowest marginal costs for production of electricity, the wind park is the preferred option to cover the electrical load. The wind park produces on average more electricity than necessary to cover the load each month, but this electricity is not evenly distributed. The installed battery can help with storing energy for times with less wind, but as figure 11.12 shows, it is necessary to use the pellets power plant each month to cover electricity loads. All excess electricity is always converted to heat using the electric boiler.

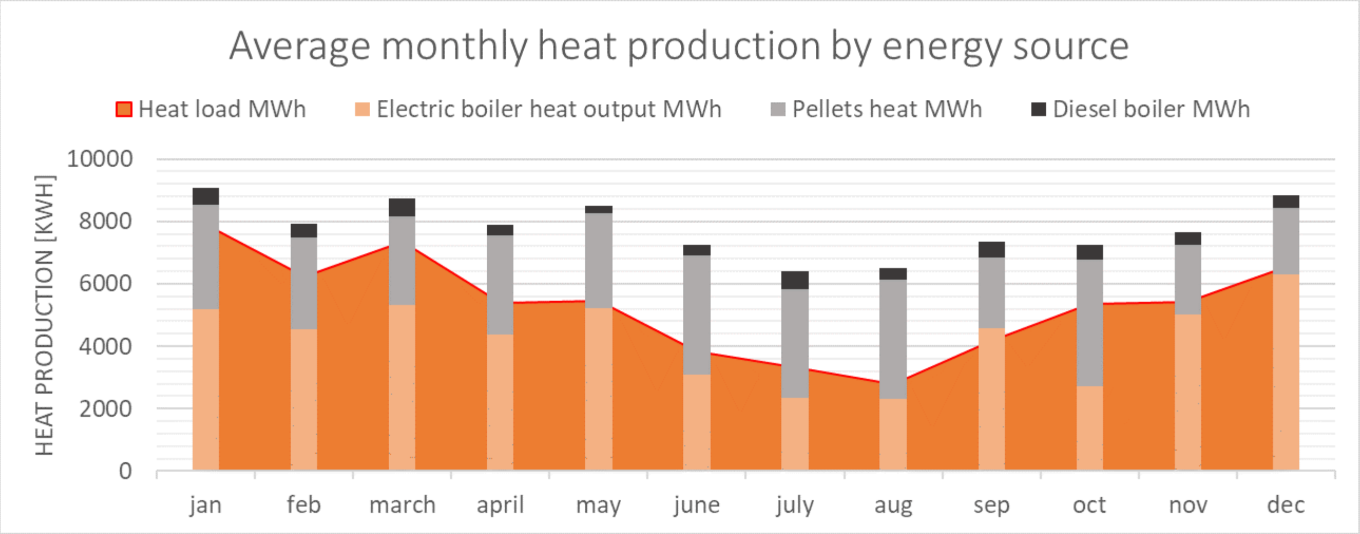

Figure 11.13: Installed heat capacity for the different cases

On average, the electric boiler delivers enough energy to cover the majority of the thermal load. In all months, however, the pellets power plant, which delivers both heat and electricity, is used to cover part of the thermal load. The pellets plant follow the electricity demand. As there is no heat storage, and heat is not always supplied when it is necessary, some of it is curtailed, and diesel boilers have to provide some heat.

Example days

It is possible to gain further insight into how the different components of the energy system work together by examining some sections of the time series.

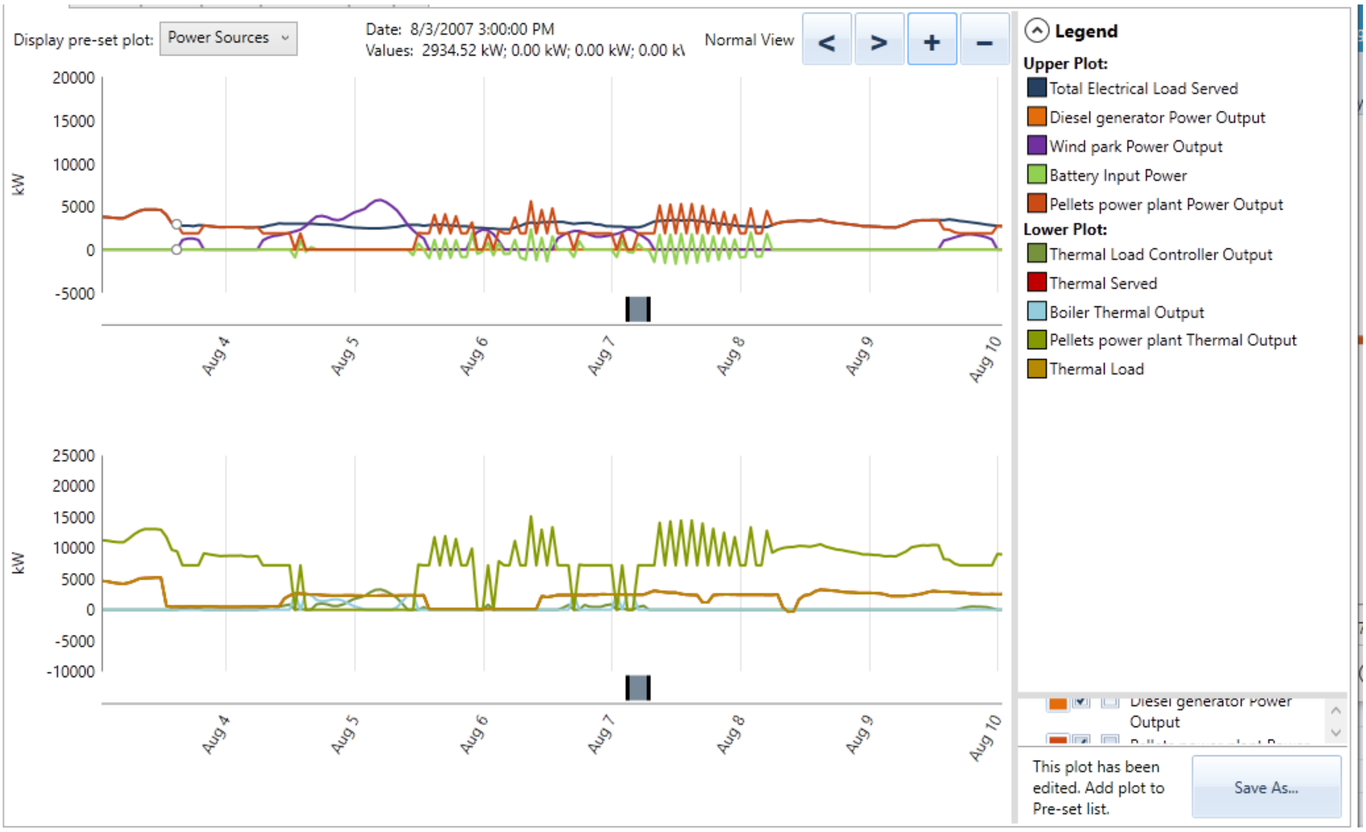

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Figure 11.14: Time series of energy system operation in early August 2021

Figure 11.14 show how the energy system would operate in early August 2021. Throughout this period, the electricity load is fairly stable and constant, whereas the heat load hovers bin the range of 0-5 MW. On August 5th, the wind power output exceeds the electricity load. The electric boiler ("Thermal Load Controller" in the figure) is then used to cover the thermal load with the excess electricity, with the help of the diesel boiler. When the wind speed subsides, and the wind power output is insufficient, the pellets power plant is switched on. The battery is actively used to even out the electricity output and balance it around the load. Due to the fixed heat-to-electricity ratio of the CHP turbine, there is overproduction of heat in this period, which is curtailed.

In winter, the wind speeds in Longyearbyen are on average higher and more stable. From figure 11.15, one sees that in late January and early February in 2021, the wind park consistently puts out enough power to meet the electricity demand, producing an excess of roughly 10 MW. This is almost enough to cover the thermal load with the electric boiler. To cover the last parts of the thermal load, it is cheaper to utilise the diesel boiler, than start up the pellets power plant, which would have to produce both electricity and heat, and has a higher minimum output than the boiler.

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Figure 11.15: Time series of energy system operation in late January and early February 2021

Environmental concerns

As this case has the lowest CO_2 emissions of all, some notes should be made about the carbon intensity of pellets. In this analysis, it was set to 0. Combustion of pellets do result in local CO_2 emissions, but if the rate at which the source of the fuel is allowed to regrow is equal to or exceeds the pellets harvesting, the net CO_2 emissions can be considered 0. This puts requirements for sustainability on the pellets producer, and in the case of a pellets plant solution, Longyearbyen should ensure the pellets come from sustainable forestry businesses. Ideally, the pellets should be sourced from sawdust, chips and other otherwise unusable materials from sustainable forest growth. Forestry can harm local ecosystems [40].

Combustion of pellets in Longyearbyen can cause local pollutants. This could be remedied by installing a gas scrubber, as has been done for the existing coal power plant. The construction of the new power plant in Hotellneset would also cause local emissions, but would cause little damage to local flora and fauna, as Hotellneset is already heavily affected by human activities.

The area designated for the wind park in Platåberget is used by some locals for everyday hikes, but is not a popular tourist destination. The area is already affected by industry, located directly south of the KSAT facility. It is also of little importance for most local wildlife, which typically stays close to the shore, and only occasionally crosses Platåberget when moving from one area to another. The animals that live close to Longyearbyen are also accustomed with humans and human infrastructure, so wind turbines will likely not negatively affect their migration habits, aside from the construction period. It would also most likely be necessary to improve the gravel roads up to Platåberget to accommodate the transport of wind turbines.

Discussion

This case is the case that result in the least emissions of CO_2. Cost-wise it provides little benefits over the coal case, with an estimated NPC of 1,259 MNOK compared to the 1,281 MNOK of the coal case.

The heat curtailment is somewhat reduced compared to the coal case. With only a coal plant, the heat curtailment is caused by having to over-produce heat in order to meet the electricity demand. With a wind park that covers most of the electricity demand, it is possible to more finely tune the pellets production to fit the heat demand. If little heat is needed aside from that available through conversion of electricity to heat, it can be cost-beneficial to use the diesel boiler instead. Still, it can be said that the over-production of heat indicates that some form of heat storage might help reduce heat losses.

In the time series of early August 2021, it can be seen that the production of pellets is fluctuating heavily through the day, in order to use the battery to even out the output. This sort of fluctuations is, as was mentioned with regards to the battery case, not ideal for turbines. It contributes to more wear and tear.

As this case performs best with emissions, it is relevant to note that the extent to which pellets power plants contribute to CO_2 emissions has been a topic of debate. The combustion of pellets fuels release CO_2 like any other carbon-based fuel. Pellets can be counted as renewable if they are harvested in a sustainable way, where the biomass output harvested is smaller than or equal to the allowed tree growth of the source forest.

This case would make Longyearbyen more dependent on energy imports from the mainland, as there are no biomass sources for pellets locally. However, Longyearbyen would be less dependent on imports compared to the coal case if Mine 7 closes and all coal would have to be imported.

Case 3: Coal plant + wind

Technical description

In case 3, the coal plant will be kept in operation and replaced when worn out, similarly to case 1. The difference is that this case includes a 21 MW wind park, similar to case 2. A 5 MWh battery is installed in this case, and the diesel generator capacity is increased by 12 MW, and the boiler capacity by 5.2 MW. Like in case 2, this case includes a 20 MW electric boiler, necessary for the wind park. The installed capacities is summarised in table 11.5.

The technical solutions for the wind park and the coal plant will be similar to how they appear in case 1 and 2.

Case 3: Coal plant + wind		
	Electricity	**Heat**
Installed capacity: Coal plant	CHP turbine: 7.5 MW	CHP turbine: 19 MW
Installed capacity: Wind	14 x 1.5 MW turbines: 21 MW	
Installed capacity: Diesel	Genset: 12 MW	Boiler: 5.2 MW
Electric boiler		20 MW
Battery	5 MWh	
	Electricity	**Heat**
Annual production: Coal	11.415 GWh	48.027 GWh
Annual production: Wind	75.864 GWh	
Annual production: Diesel	2.745 MWh	3.877 GWh
Annual consumption: Coal	10,998 tonnes	
Annual consumption: Diesel	464,275 L	
Annual CO2 emissions	29,444 tonnes	

Table 11.5: Summary of generation capacities, expected production, fuel consumption and CO_2 emissions

Cost summary and nominal cash flow

Case 3: Coal power plant + wind park	Cost
Capital cost	334,959,000 NOK
Replacement cost	115,721,000 NOK
O&M cost	329,386,000 NOK
Fuel cost	165,962,000 NOK
Salvage revenue	-68,988,000 NOK
NPC	877,039,000 NOK

Table 11.6: Cost summary of case 2

The costs of case 3 are summarised in table 11.6. This case has the lowest NPC of all, at 877 MNOK. The capital cost of 335 MNOK mostly covers the wind park. The replacement costs of 116 MNOK covers renewal of the wind park after 20 years. It should be noted that in this scenario, the coal plant is never replaced, as can be seen from 11.16 and 11.17. HOMER bases the lifetime of the coal plant on the number of operating hours, not the number of years it is in existence. As the coal plant is not always used, HOMER expects it to last throughout the analysis period, despite the same input parameters as in case 1. In any case, if the plant had been replaced, the little usage would mean that most of the replacement costs would be returned as salvage value by year 30. It would not affect the NPC considerably. The wind park has generally low O&M costs. Most of these costs, which at 329 MNOK make up roughly 1/3 of the NPC, are for the coal plant and generator. Likewise, the fuel costs of 166 MNOk account for diesel and coal usage. This is a 46 % reduction in fuel consumption compared to case 1, from installing the wind park. The salvage value of 69 MNOK is mostly residual value in the wind park, which has a lifetime of 20 years, and will therefore have 10 more years by the end of the analysis.

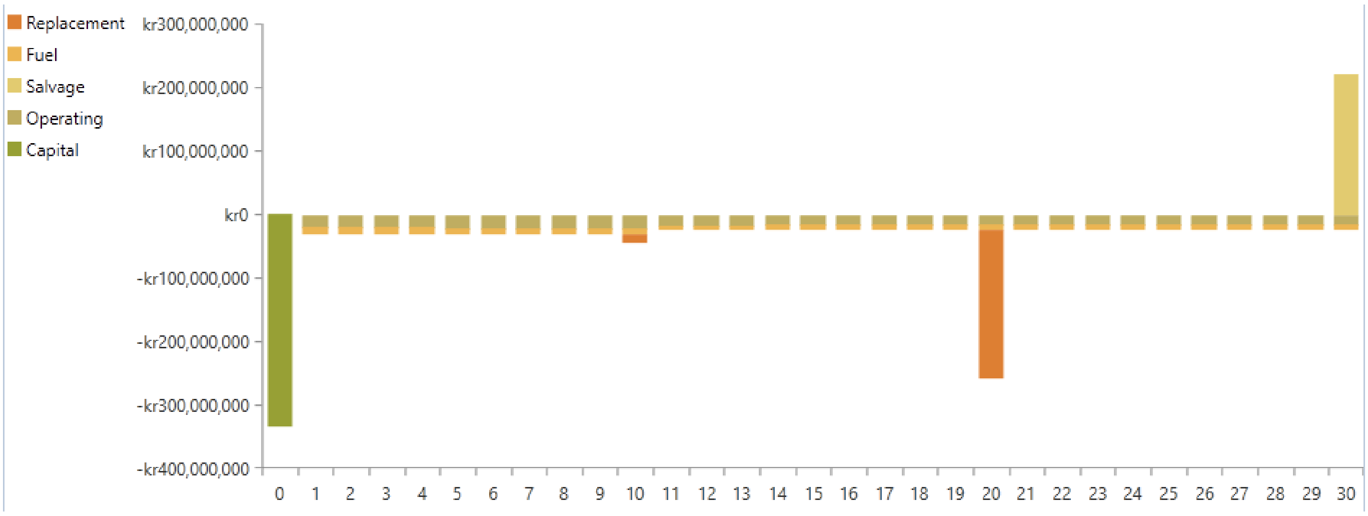


Figure 11.16: Nominal cash flow by cost type

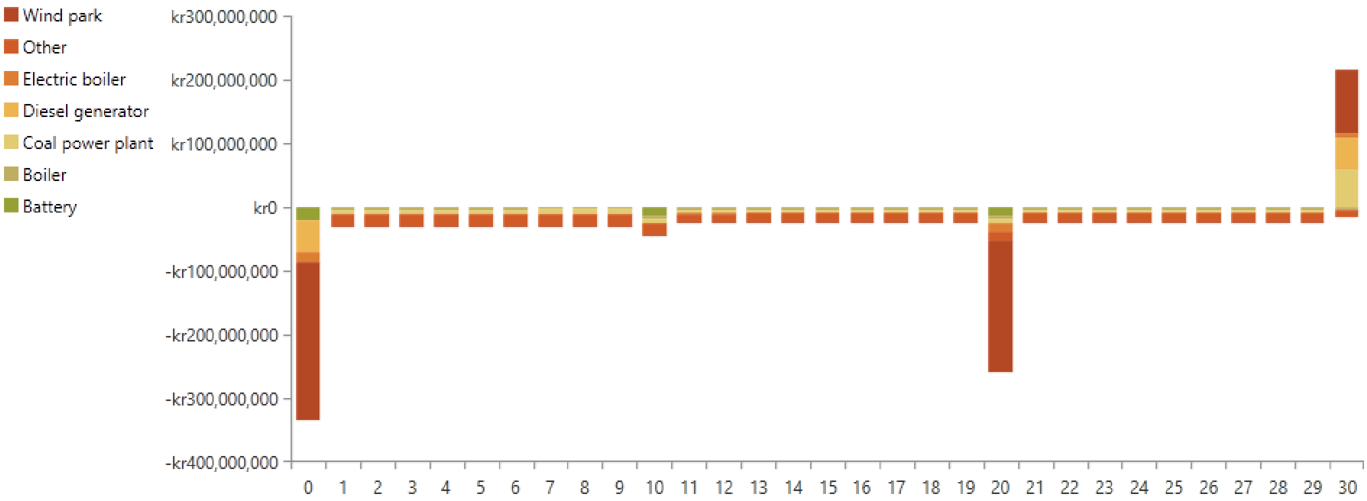


Figure 11.17: Nominal cash flow by component type

Monthly production profiles

Figure 11.18 and 11.19 show the average monthly electricity and heat output. Like for case 2, the wind park has a marginal cost almost 0 for producing power, and will therefore be the first priority for production technology. The wind park production profile is identical to that of case 2, as the wind park is the same. The wind park generates more electricity than necessary to cover the electricity load, but as described for case 2, there are times with up to several days with insufficient wind to meet the demand. This load is met using a combination of coal, generators and battery storage to save some energy for wind turbines. HOMER has the option to invest in enough batteries to save electricity for later consumption, but it is far cheaper to meet some load with fuel combustion technologies. Besides, it is also necessary to meet the thermal load. The coal power plant covers most of the unmet electricity and heat demand. Diesel generators provide a small amount of power every month. Diesel boilers are used extensively in winter to cover heat demand, but they are barely used in summer.

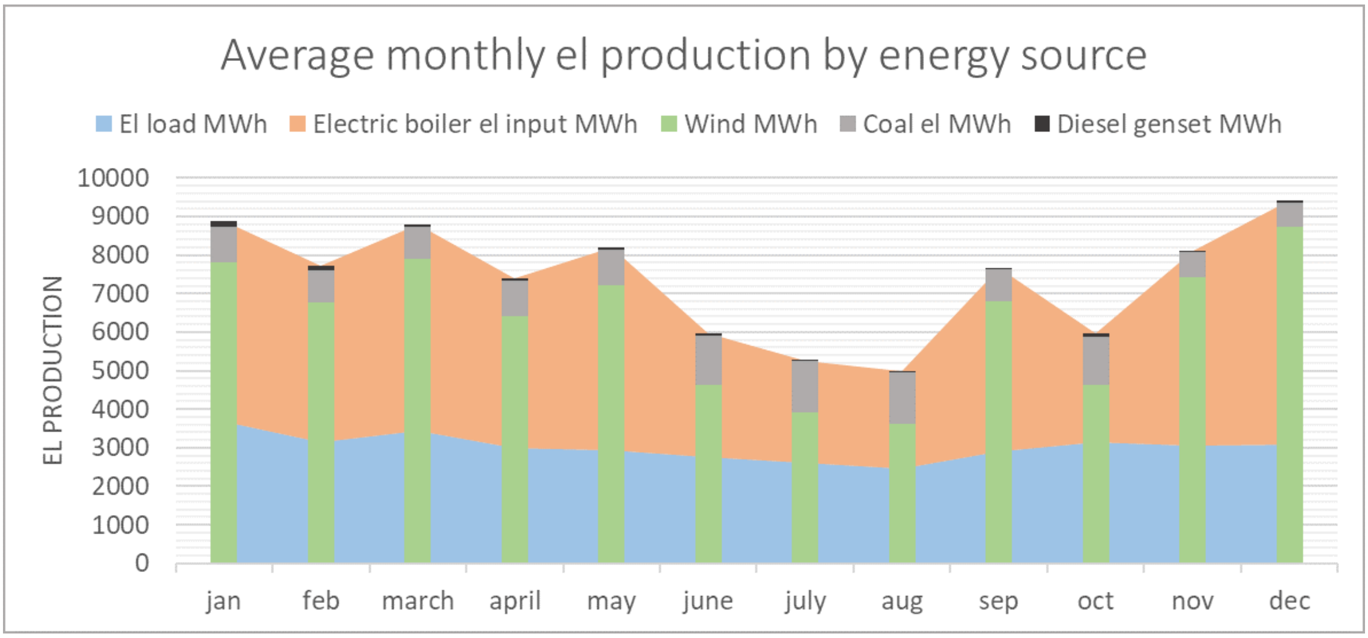


Figure 11.18: Average monthly electricity production by component

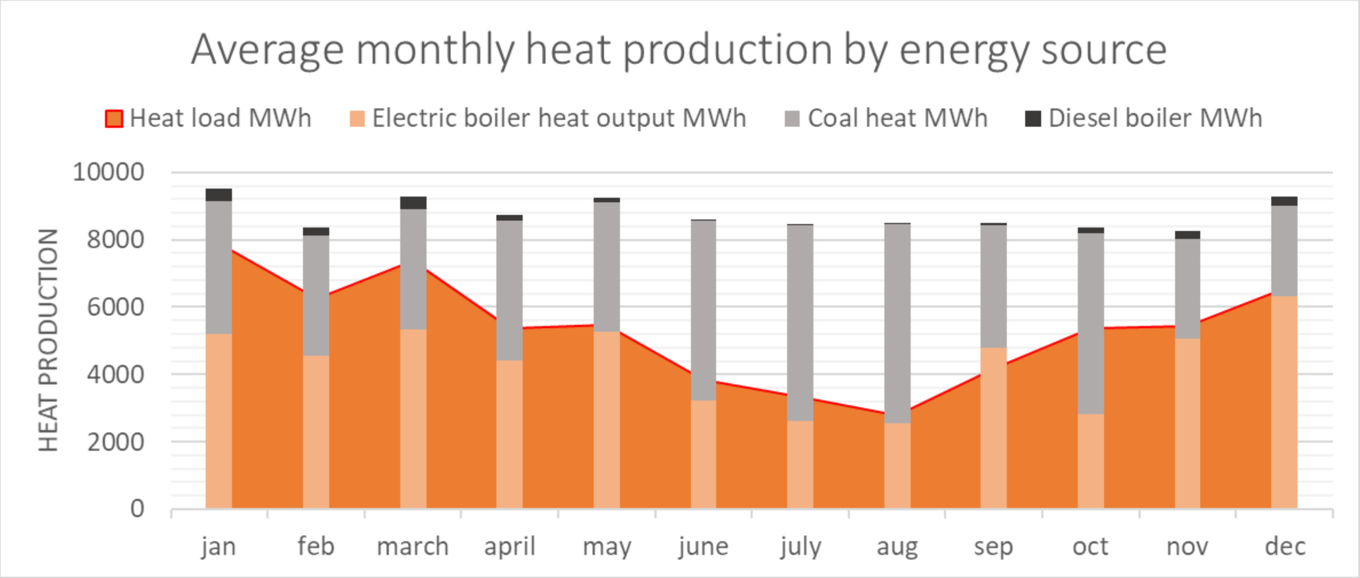
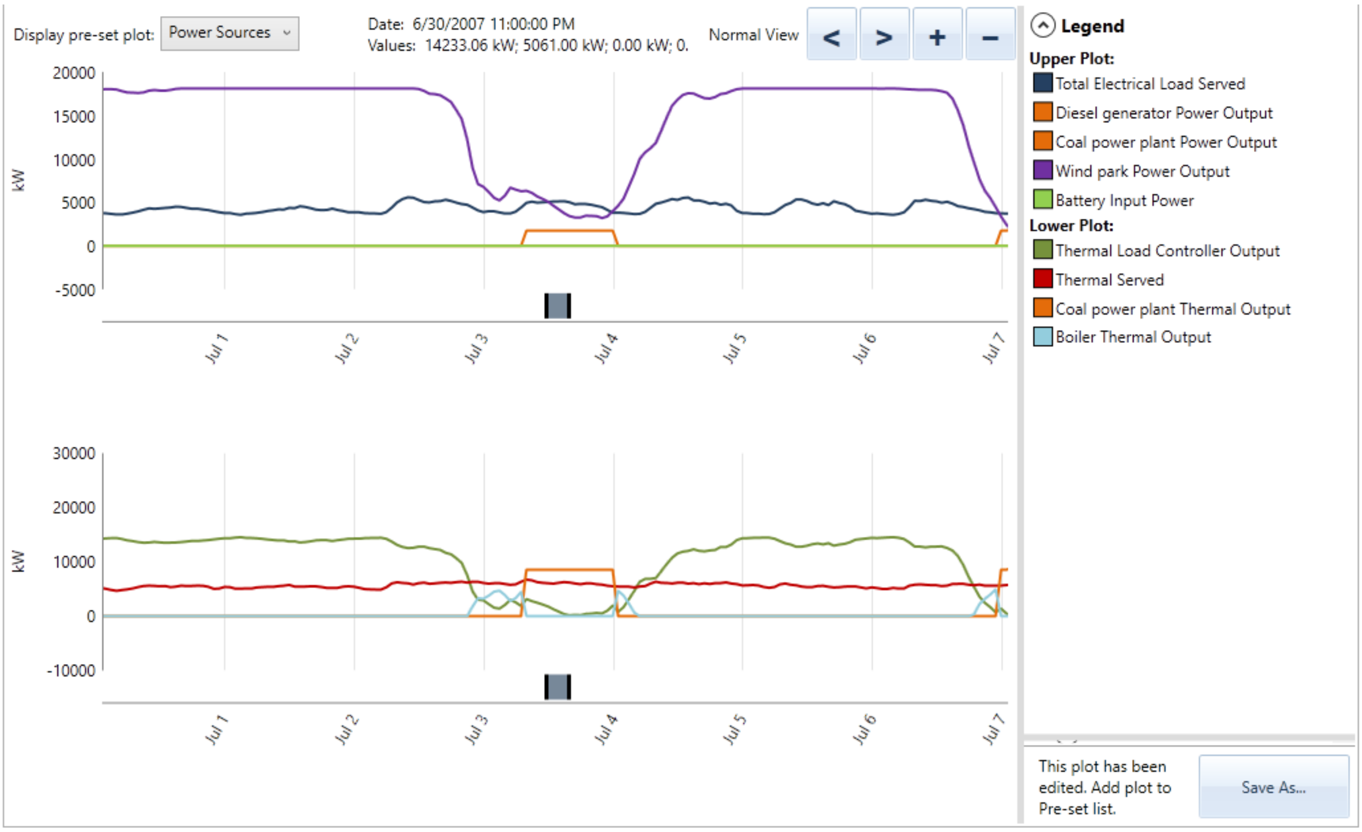


Figure 11.19: Average monthly heat production by component

Example days

Figure 11.20 and 11.21 shows the operation of the energy system during during early July and mid-August, and demonstrate how the different components of the energy system work together.



Display pre-set plot: Power Sources

Date: 6/30/2007 11:00:00 PM
Values: 14233.06 kW; 5061.00 kW; 0.00 kW; 0.

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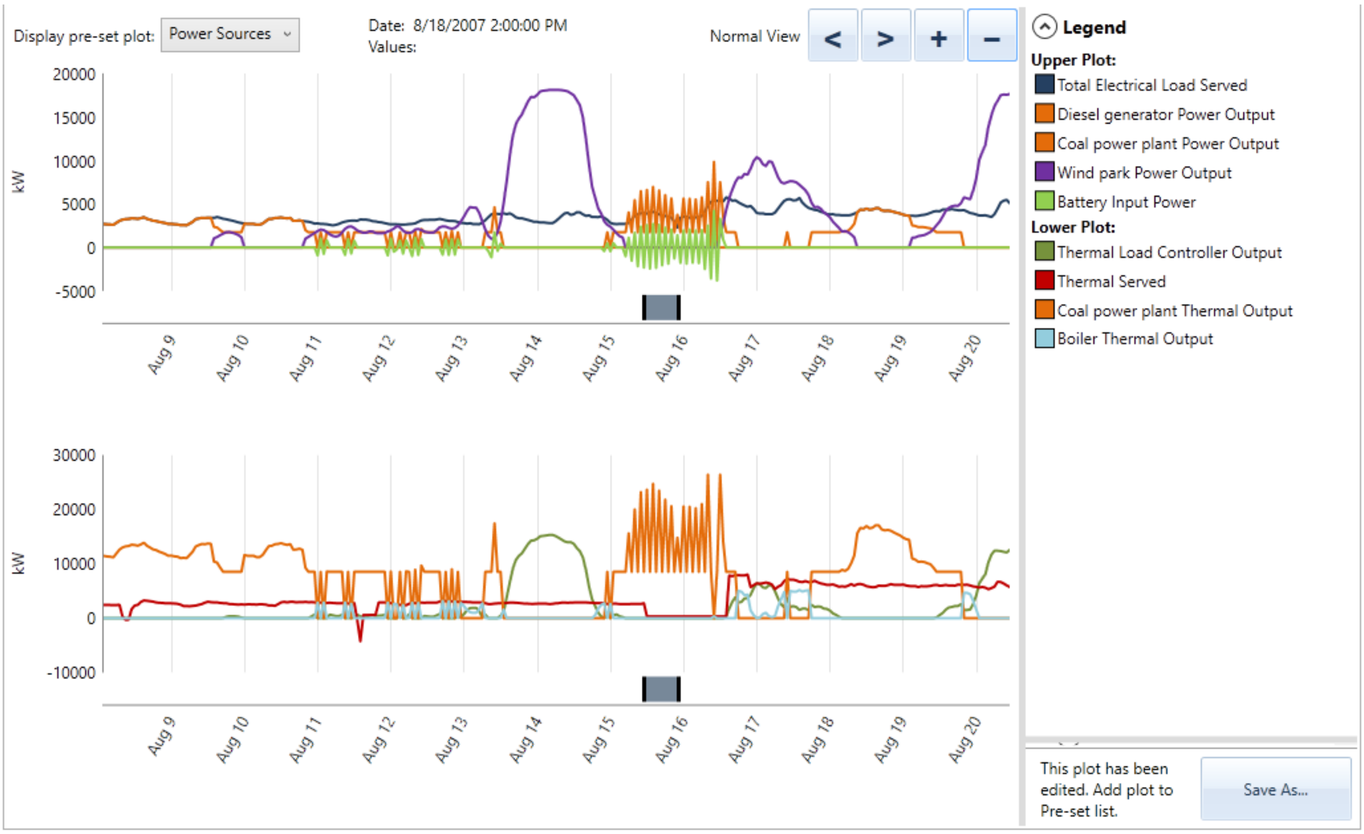
Figure 11.20: Time series of energy system operation in early August 2021

When there is ample wind, the wind covers the electricity load and through the electric boiler, it also covers the thermal load. When the wind speed begins to decrease on July 3rd, it can still initially cover the electric load, but it struggles with the thermal load. As the coal plant produces both electricity and heat, and only heat is needed, the thermal demand is met using the diesel boiler. When the wind power output drops below the electricity demand, the coal plant is turned on to provide electricity. The coal plant also provides heat, making the diesel boiler unnecessary. It is therefore shut off.

This example day illustrates how the system chooses the lowest marginal cost energy provider at all times. It also shows how the diesel boiler can help save money by covering small amounts of heat demand. Without it, the coal plant would otherwise have to be shut on, which would result in a waste of electricity as there was sufficient wind to meet the electricity demand.



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Values:

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Figure 11.21: Time series of energy system operation in late January and early February 2021

In August 2021, there are several days when there is little wind and the coal plant is used to meet the energy demand. The battery is continuously charged and discharged to balance the load when the coal plant has to provide all the electricity. This allows the coal plant to not be run more than necessary.

Environmental concerns

There are no environmental concerns relevant for this case that has not been described in case 1 and 2, seeing as this case is like case 1 with the added wind park from case 2.

Discussion

When comparing this case to the two previous cases, it becomes obvious that the wind park in itself is a worthwhile investment. Compared to the otherwise nearly identical case 1, the wind park allows for the reduction of the net present cost from 1,281 to 877 MNOK, which represents 32 % savings, and it allows the CO_2 emissions to be reduced by 35 % from 83,125 tonnes annually to 29,444 tonnes. While far from as low emissions as case 2 with just 1,342 tonnes, this indicates that a wind park of 21 MW may be the investment that contributes the most to reduced costs and emissions. For the wind park to work as intended, however, the electric boiler is absolutely necessary to utilise the potential in the wind park. Without an electric boiler, there would be times of considerable electricity waste.

Like the two previous cases, it must be noted there is significant curtailment of heat. Most of the discussion on the causes of this, and to what extent this reflects real life operation, has been done for case 1 and 2, and still applies here. It could be that thermal energy storage could alleviate some of these losses. Completely avoiding heat curtailment when using CHP turbines is difficult, as the heat demand to electricity demand ratio can and will vary.

Case 4: Diesel

Technical description

For this case, all electricity and heat is provided by a 12 MW diesel generator and a 15.2 MW boiler. This is sufficient to cover all thermal and electrical loads.

For this case, a battery system of 15 MWh and an electric boiler of 4 MW is installed. The generator has a minimum output when running, so these two components allow for excess energy to be stored and used later, instead of curtailment.

Generation capacities and storage, as well as annual production, fuel consumption and CO_2 emissions are displayed in table 11.7.

Case 4: Diesel		
	Electricity	**Heat**
Installed capacity: Diesel	Genset: 12 MW	Boiler: 15.2 MW
Electric boiler		4 MW
Battery	15 MWh	
	Electricity	**Heat**
Annual production: Diesel	40.917 GWh	63.851 GWh
Annual consumption: Diesel	17,923,337 L	
Annual CO2 emissions	46,916 tonnes	

Table 11.7: Summary of generation capacities, expected production, fuel consumption and CO_2 emissions

Cost summary and nominal cash flow

Case 4: Diesel generator and boiler	Cost
Capital cost	112,171,000 NOK
Replacement cost	324,885,000 NOK
O&M cost	505,055,000 NOK
Fuel cost	2,426,179,000 NOK
Salvage revenue	-2,576,000 NOK
NPC	3,365,714,000 NOK

Table 11.8: Cost summary of case 4

Case 4 has the lowest investment costs of any case, as shown in table 11.8, of only 112 MNOK. This investment covers the generator and the battery. HOMER does not include any investment costs for boilers, but would be roughly equal to the diesel generator. This case is, however, considerably higher than the three previous cases, with a total NPC of 3,366 MNOK. Most of these costs cover fuel. This cost structure of low NOK/MW costs but high NOK/MWh costs is typical for diesel generators and boilers, and the reason why they are beneficial for backup power or to cover peak loads, but extremely costly to use for all energy demands. As seen from the nominal cash flow by cost type in 11.22, the annual costs of operating the system is higher than the initial investment cost.

There are 325 MNOK of replacement costs during the analysis period. These cover a new battery every 10 years, and new generators as they get worn out, but as seen from 11.23, the batteries make out a very small part of the total NPC of the system.

Among the costs not included are the costs of diesel storage tanks, which would have to be substantial. Furthermore, diesel boiler investment costs are not included. Boilers are automatically installed in HOMER cases to meet any remaining thermal load, and only have O&M and fuel costs.

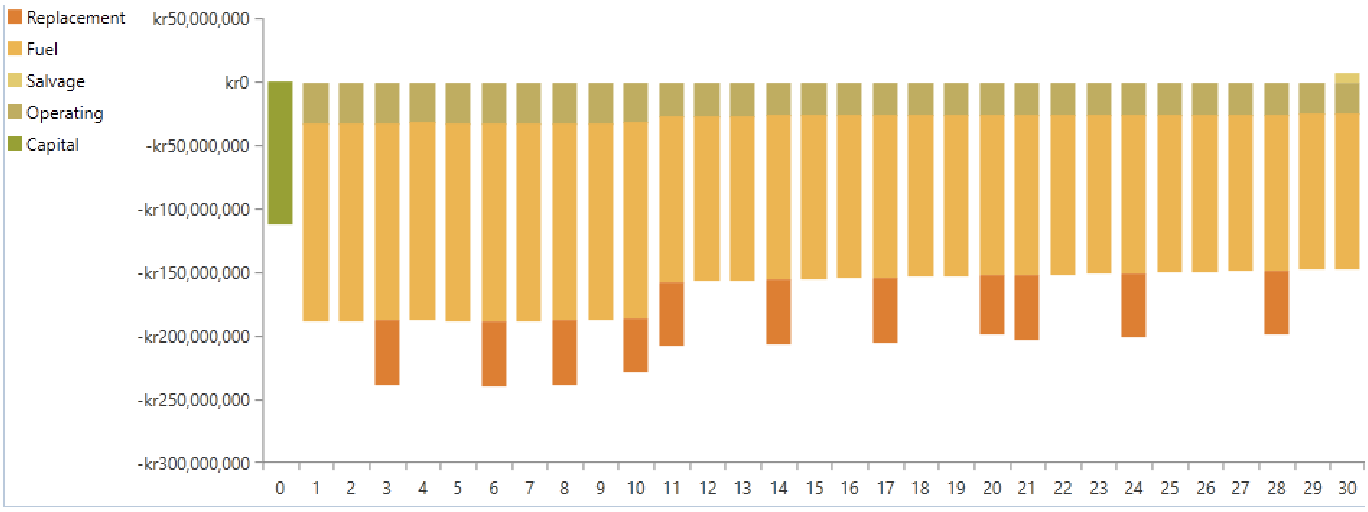


Figure 11.22: Nominal cash flow by cost type

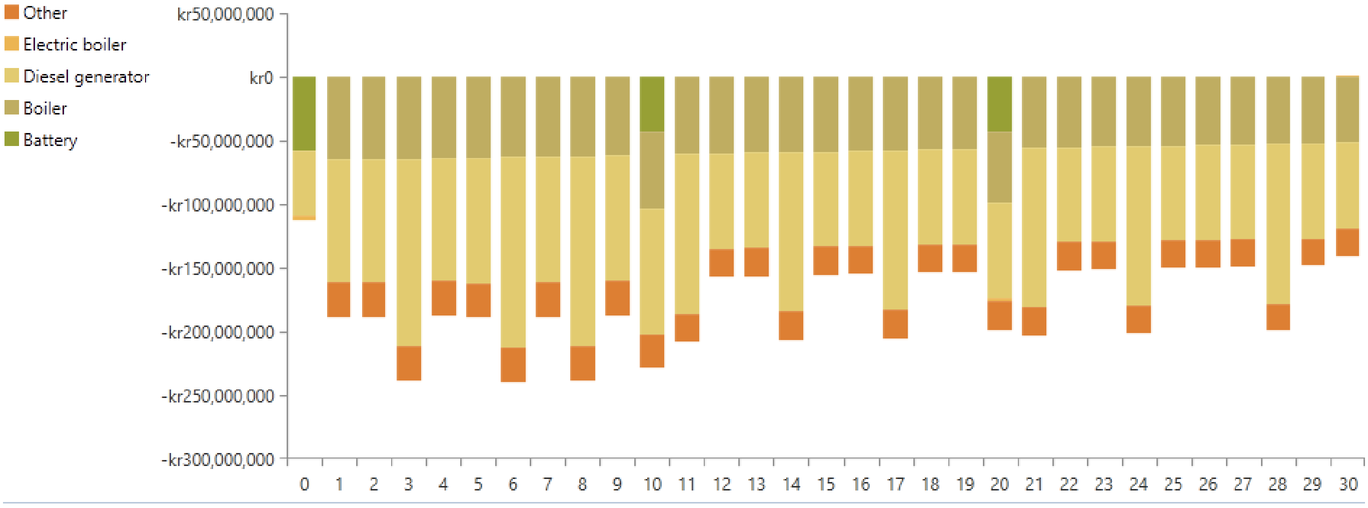


Figure 11.23: Nominal cash flow by component type

Monthly production profiles

Figure 11.24 and 11.25 shows how the electricity and heat loads are met each month by the diesel generator and diesel boiler. The production of the generator and diesel boiler follow their respective loads. It should be noted that there is overproduction of electricity every month. This might be partly caused by the system using a battery to even out the load, and the overproduction compensates for the losses in the battery charge and discharge cycle.

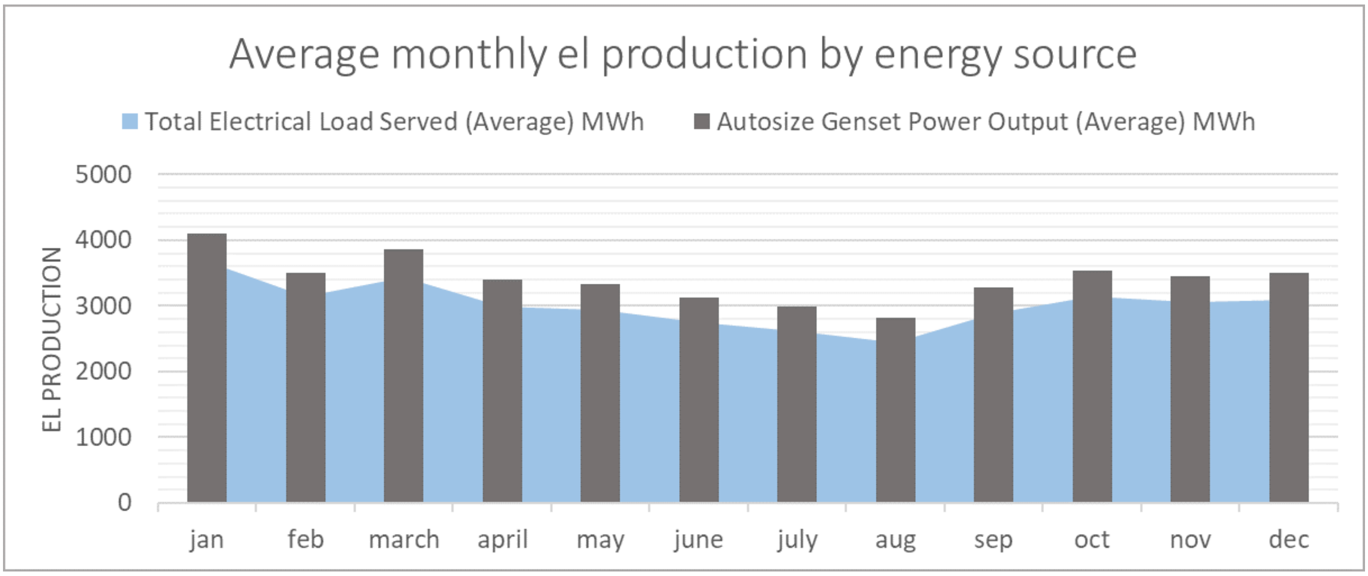


Figure 11.24: Average monthly electricity production by component

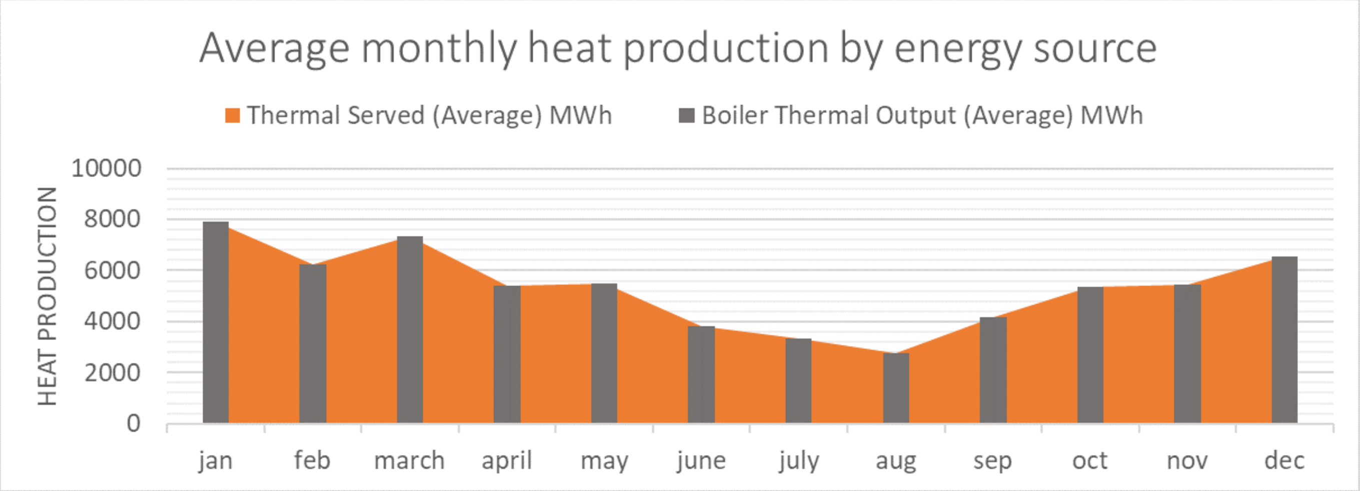
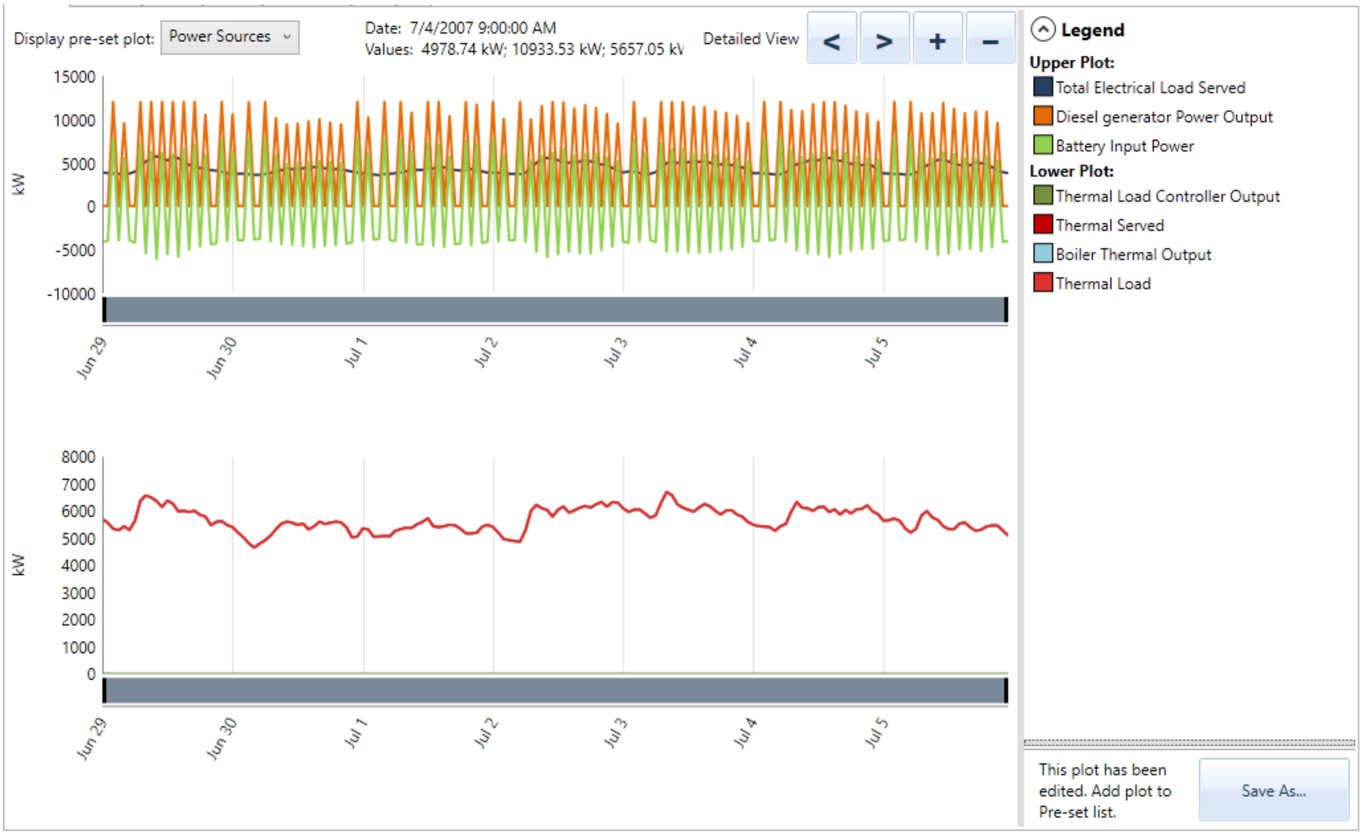


Figure 11.25: Installed heat capacity for the different cases

Example day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Values: 4978.74 kW; 10933.53 kW; 5657.05 kV

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Figure 11.26: Time series of energy system operation in early July 2021

In the time series from early July 2021, as seen in figure 11.26, one sees that the generator follows the electricity demand, but uses the battery actively to even out the load. The battery is always charging or discharging. The boiler output lines up exactly with the thermal demand, so they appear as one line.

Environmental concerns

The diesel generators, boilers and storage tanks should be built in Hotellneset. The construction would cause local emissions. Without any gas scrubber, the diesel combustion would contribute to local air pollution.

Discussion

This case was picked out and presented to showcase how the energy system in Longyearbyen would look if it was only run on diesel - with boilers providing heat and generators providing electricity. This is not a likely scenario, and does not hold much value as an alternative solution to this research question. It does, however, give a valuable demonstration of the costs of running the community on diesel. For example, one could consider the scenario of a complete failure of the coal power plant, such as if an avalanche made the current one unavailable. Due to the uncertainty of Longyearbyen's future population, Svalbard could decide to not invest in a new energy system. In such a scenario, diesel generators and boilers would likely be the best temporary solution.

This case is more than 2.5 times more expensive than continuing with coal power such as in the proposed case 1, and almost 4 times more expensive than the lowest NPC case of coal power in combination with a wind park (case 3). This system would make Longyearbyen completely dependent on imports for its energy system, and it is not more reliable than a coal plant. As this system is based entirely on imported fuels, the price on diesel will have a considerable effect on the NPC. Statistically, import diesel prices in Longyearbyen have been fairly stable, but this can change in the future. The only benefit in such a system would be the reduction of CO_2 emissions. Diesel has a higher heating value than coal, and releases less CO_2 per kWh generated electricity. CO_2 emissions are expected to diminish by 44 % down to 46,916 tonnes annually.

With regards to the technical solution, a few notes must be made. This case has been presented as HOMER suggested it, but some changes would realistically have to be made. Firstly, there should be a complete set of backup generator and boiler capacity. Longyearbyen is an isolated community, and must have a backup solution. Secondly, it was seen in this case that having a larger battery of 15 MWh was beneficial to even out the production from the diesel generators. Likewise, it seems probable that a steam accumulator would be advisable in this scenario. Generators and boilers are generally cheap to invest in, so there is no reason not to include a larger safety margin in generation capacities, to accommodate an increase in energy production.

Some notes must be made with regards to the cost data. HOMER operates with a component lifetime in operational hours for generators, and not a lifetime of a certain numbers of years in existence. For diesel generators, it was assumed a lifetime of 10 years. To most accurately model the costs of using the diesel generator as backup in Longyearbyen in the three previous cases and in case 5, the input was set to 10,950 hours, or 1.25 years. This was based on the assumption that the diesel generator would be active 12.5 % of the time. For this case, however, this is very incorrect, as the generators are the sole power components. However, when replacing them every 1.25 years, the total replacement costs were still only 325 MNOK out of an NPC of 3,366 MNOK, and that replacement cost included 2 battery pack replacements, each almost 50 MNOK. Furthermore, HOMER does not include the investment and replacement costs of the diesel boilers. Neither are costs for diesel storage tanks included. Therefore, it is assumed that the excess replacement costs for diesel generators account for the missing costs for replacing diesel boilers, and that the NPC of 3,366 MNOK is realistic for this case.

Case 5: Wind + PV

Technical description

In this case, the same wind park as in case 2 and 3 is installed on Platåberget, consisting of 14 turbines totalling 21 MW. The current coal plant is closed immediately. Instead, an extra 15 MW of electricity generation is installed in the form of rooftop PV panels. To reach 15 MW's of electricity, roughly 1/3 of Longyearbyen's building's rooftop area is covered.

With almost all the energy being harvested as electricity, extensive electric boiler capacity is necessary. In this case, a 28 MW electric boiler is installed, bigger than any of the other cases. A 15 MWh battery will help with short-term energy storage, and 12 MW of generator and 14.2 MW of boiler capacity will serve as backup power and heat, and help with peak loads.

The generation capacities, as well as annual energy generation, fuel consumption and emissions are displayed in table 11.9. This case has average annual CO_2 emissions of 13,975 tonnes. This is better than the case 3, but not as good as case 2.

Case 5: Wind + PV		
	Electricity	**Heat**
Installed capacity: Wind	14 x 1.5 MW turbines: 21 MW	
Installed capacity: PV	15 MW rooftop	
Installed capacity: Diesel	Genset: 12 MW	Boiler: 14.2 MW
Electric boiler		28 MW
Battery	15 MWh	
	Electricity	**Heat**
Annual production: PV	9.914 GWh	
Annual production: Wind	75.864 GWh	
Annual production: Diesel	6.975 GWh	29.881 GWh
Annual consumption: Diesel	5,338,957 L	
Annual CO2 emissions	13,975 tonnes	

Table 11.9: Summary of generation capacities, expected production, fuel consumption and CO_2 emissions

Cost summary and nominal cash flow

Case 5: Wind park and rooftop PV	Cost
Capital cost	511,333,000 NOK
Replacement cost	180,488,000 NOK
O&M cost	208,722,000 NOK
Fuel cost	738,456,000 NOK
Salvage revenue	36,581,000 NOK
NPC	1,602,418,000 NOK

Table 11.10: Cost summary of case 5

Table 11.10 summaries the costs for case 5. At 511 MNOK, the capital costs are high for this system. Roughly half of this cover the wind park, one quarter goes to the PV installation and one quarter covers the remaining components. The only substantial replacement costs are after 20 years when the wind turbines have to be replaced, as seen in figure 11.27 and 11.28 and some of that cost is returned among the salvage value of 37 MNOK at the end of the analysis period.

O&M costs are 209 MNOK for this system. In this system, diesel is used whenever there is not enough wind and/or sun for the system. Diesel consumption is therefore high, and at 738 MNOK, fuel costs account for almost half of the NPC of 1,602 MNOK. This case is more expensive than case 1, 2 and 3, but still considerably cheaper than case 4.

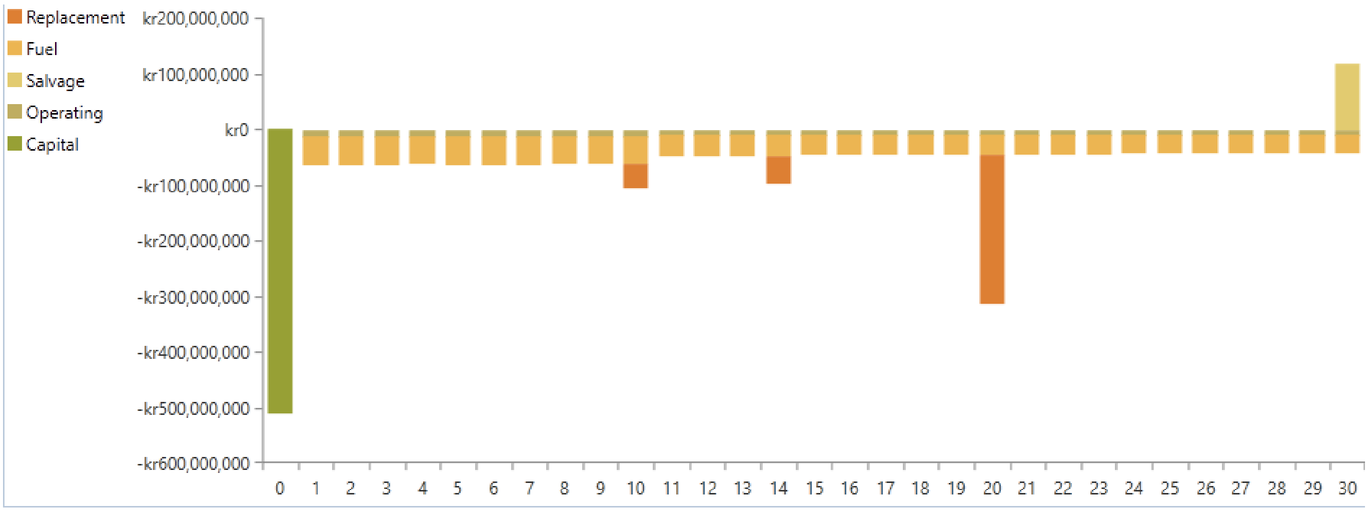


Figure 11.27: Nominal cash flow by cost type

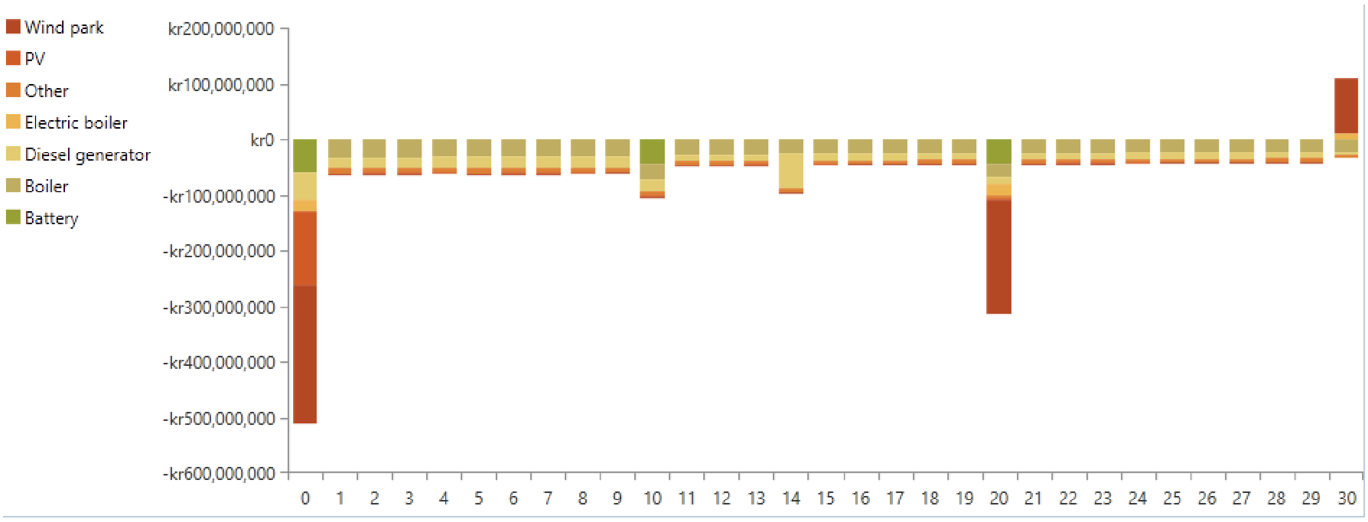


Figure 11.28: Nominal cash flow by component type

Monthly production profiles

Figure 11.29 and 11.30 show the monthly production from the different components, as well as the load profile.

The wind production for each month is equal to the other cases. PV production is at its highest in summer, and practically non-existent from October and through February. Wind production is, however, highest in winter. One can therefore see that the total monthly electricity output when combining 21 MW of wind and 15 MW of PV is fairly stable.

The system relies heavily on the electric boiler to convert excess electricity to heat. As seen in figure 11.29, the average monthly electricity production is more than twice that of the actual electricity load. From figure 11.30 one sees that this is enough to cover roughly 1/2 to 2/3 of the heat demand each month.

All remaining electricity and heat demand is covered using the diesel generator and boiler. Diesel consumption is highest in winter, when the heat demand is at the highest.

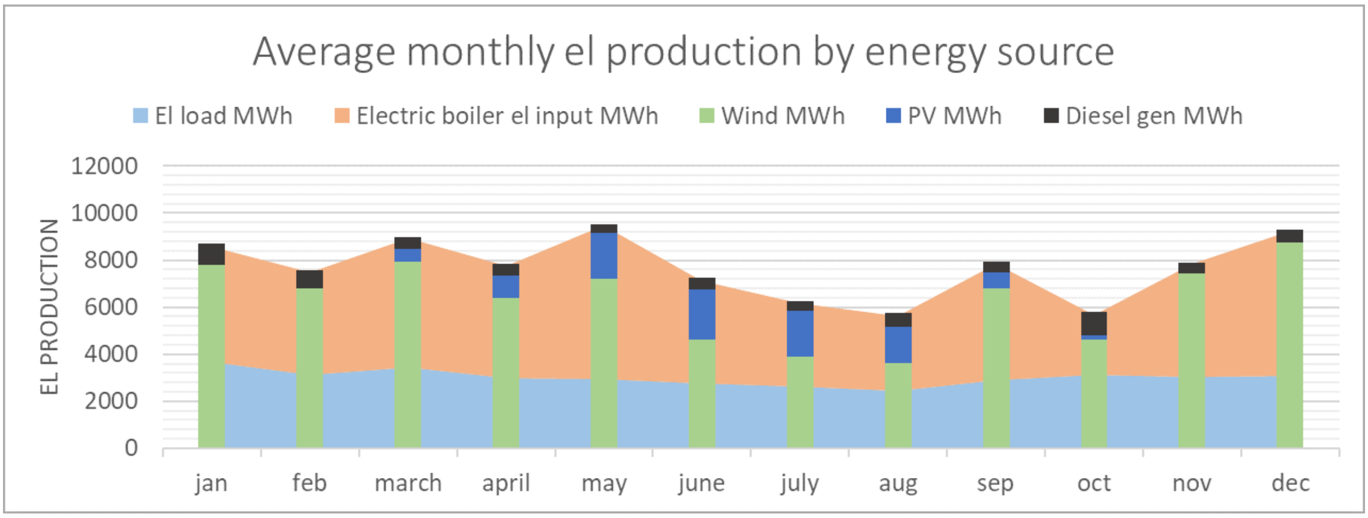


Figure 11.29: Average monthly electricity production by component

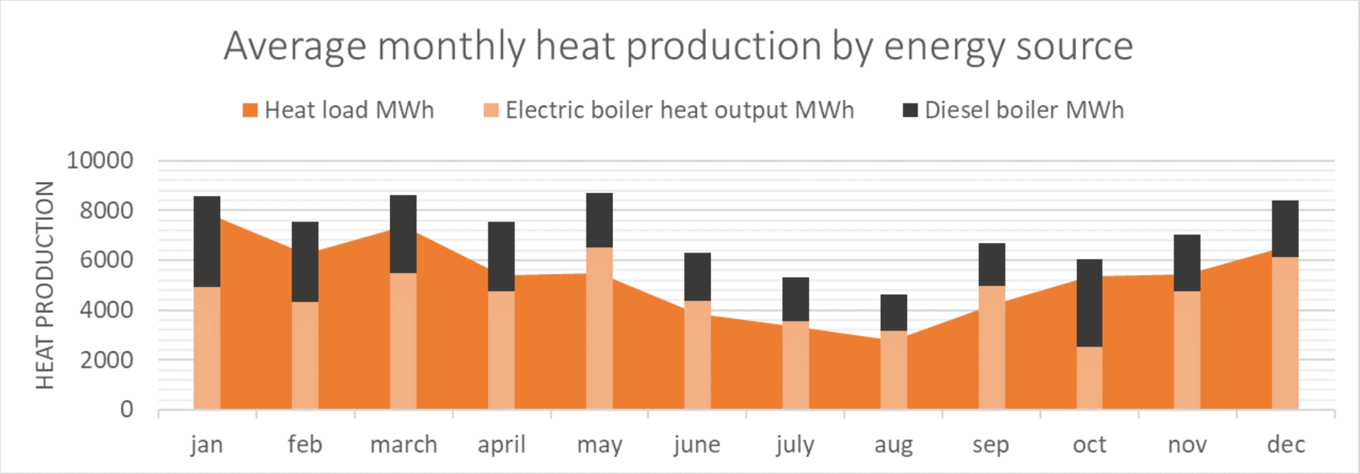
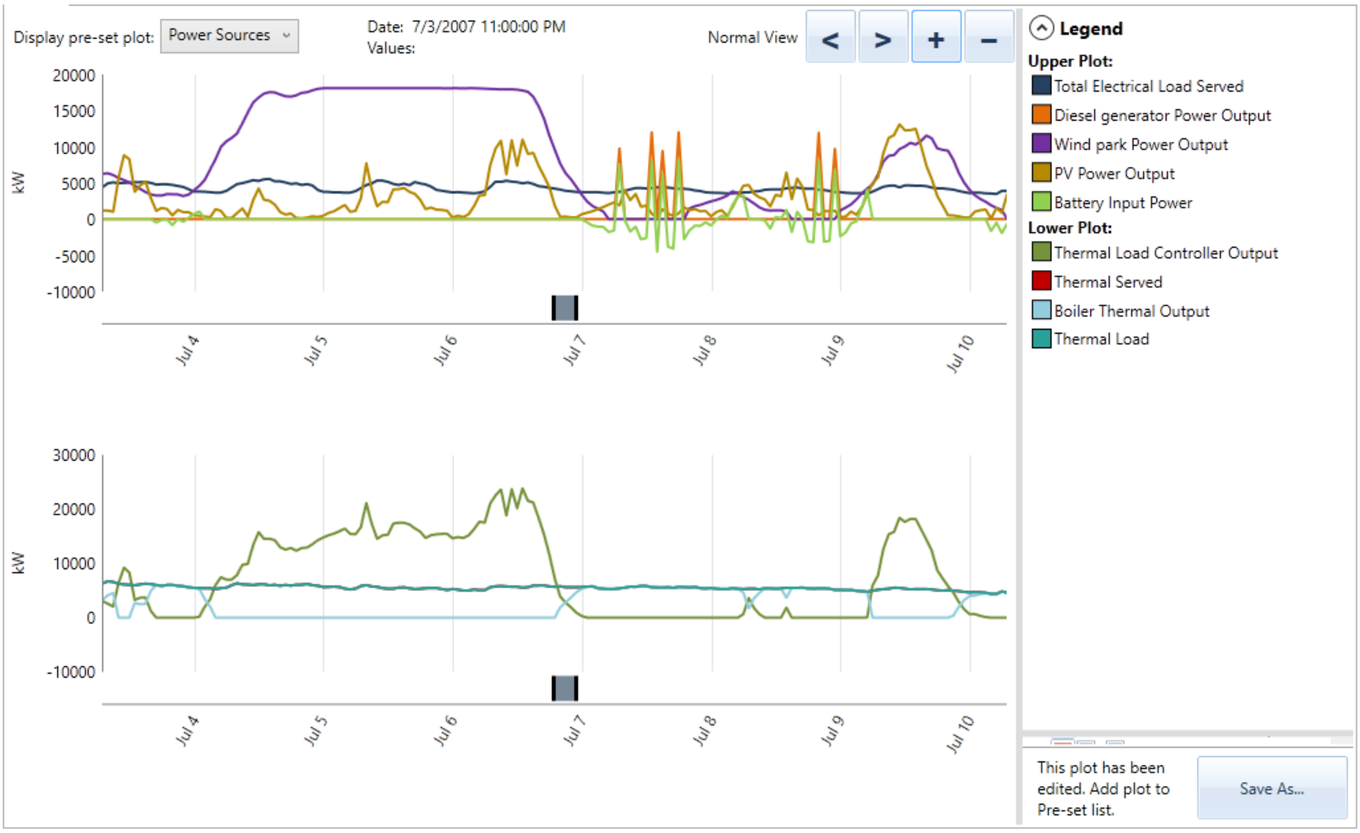


Figure 11.30: Installed heat capacity for the different cases

Example days

For this system, it is interesting to see how the components interact to meet the demand. Figure 11.31 and 11.32 show how the system behaves in early July and early January, respectively.



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Normal View

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Figure 11.31: Time series of energy system operation in early July 2021

On July 5th and 6th, there is both wind and sun, which gives a power output higher than necessary to meet the electricity demand. Using the electric boiler (thermal load controller), this is used to cover the heat demand, and both diesel generators and diesel boilers are inactive. Significant heat is curtailed. On the 7th, however, the wind subsides, and it is cloudy, resulting in no renewable production. To meet the electricity demand, the diesel generator is switched on, and the battery is actively used to stabilise the output. Boilers cover the heat demand. Early in the day on the 8th, there is again a little wind, but not enough to cover the electricity demand. The battery is therefore discharged to feed the rest, and the boiler still covers the heat demand. During the middle of the day, there is enough sun and wind in total to meet the electricity demand and convert a little to heat, so the boiler production is turned down somewhat.

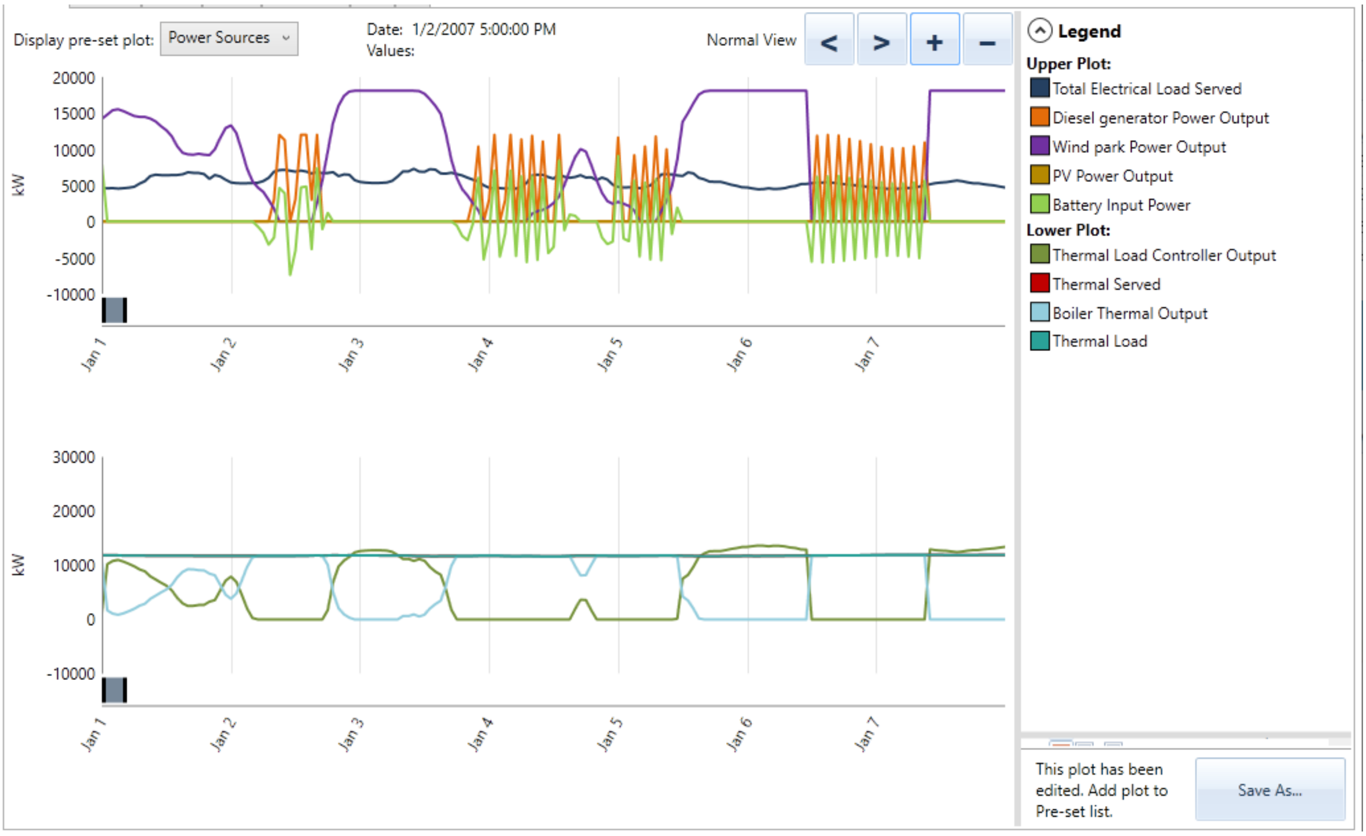
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Figure 11.32: Time series of energy system operation in early January 2021

In winter, there is no PV production, but the wind production is higher. Typically, there is either little wind or enough wind to allow for full production, as seen on the time series for early January. When the wind output is full, there is enough energy for both the electricity demand and the heat demand. When the wind calms, the generator and boiler engage, and the battery is continuously used to even out the electricity load.

Environmental concerns

There are no particular environmental concerns associated with rooftop PV installations. The installation will not contribute to any additional land use, cause any emissions, contribute to noise or in any other way negatively affect the local environment around Longyearbyen.

Discussion

This is the solution that would make the Longyearbyen community the least dependent on fuel imports, unless they continue mining their own coal and go for case 1. They would still have to import 5.3 millions of litres of diesel, but this is still less than 12.7 million kilograms of pellets for case 2 or 11 million kilograms of coal for case 1.

While still more expensive than case 1-3, this case demonstrates that it is feasible for Longyearbyen's energy system to be based around local renewable alternatives. At 14,000 tonnes of CO_2 annually, this case shows that there is potential for great energy savings.

A key benefit in basing parts of the system on PV panels is that solar power is easily scalable, and can be increased to accommodate a higher power demand in the future. PV panels require little maintenance and offer a long lifetime.

Case 6: Cable from Finnmark

The cable from Finnmark alternative was examined by ABB as a separate report [41], and was also included as a case in the Thema and Multiconsult report. This case has not been modelled in this thesis work, but is included to demonstrate how such a solution would compare to the alternatives presented in case 1-5.

Technical description

Case 6: Cable		
	Electricity	**Heat**
Installed capacity: Cable	> 25 MW	
Installed capacity: Diesel	Genset: 3.5 MW	
Electric boiler		15 MW
	Electricity	**Heat**
Annual transfer in cable	112 GWh	
Annual output electric boiler		77 GWh
Annual production: Diesel	1.0 GWh	21.5 GWh
Annual CO2 emissions	1,500 tonnes	

Table 11.11: Summary of transfer and generation capacities, expected production, fuel consumption and CO_2 emissions

The technical solution is based around a HVDC (high voltage direct current) cable from mainland Norway to Longyearbyen. A summary of installed components is found in table 11.11. Only electricity would be transmitted, and Longyearbyen would have to rely on electric boilers to feed the district heating system [4].

The cable would be about 930 km long, and would start around Hammerfest in Finnmark and reach Longyearbyen in Hotellneset where the transformer station would be placed. The cable would have a capacity of 25-30 MW of electricity, and a transfer voltage of 150 kV DC. Additionaly, there would be an investment of 3x5 MW elecctric boilers and a new diesel generator of 3.5 MW [4].

Cost summary

Case 6: Cable	Cost
Cable cost (incl. transformers)	3,000 MNOK
Electricity, O&M, other	1,360 MNOK
NPC	4,360 MNOK

Table 11.12: Cost summary of case 4

The costs of the cable solution are summarised in table 11.12. The cost of the cable, including transformer stations, is estimated to be 3,000 MNOK [41]. The net present cost is 4,360 MNOK [4]. The 1,360 MNOK unaccounted for would cover electricity costs, O&M, electric boilers, diesel costs and other things not included in the cable investment cost.

With an NPC og 4,360, this case is more than 3 times more expensive than continuing using coal as in case 1, and 5 times more expensive than case 3 which has an NPC of 877 MNOK.

Environmental concerns

The main environmental concerns associated with this solution is the disruption of marine life both during construction and during operation. The local consequences during construction can be significant, in the form whirling of sea floor sediments, noise, vibrations and pollutants. The operation of the cable will likely have minimal environmental effects [4]. There are also greenhouse gas emissions associated with the construction and installation of the cable.

Discussion

The diesel generator and diesel boiler capacity in this system is still too small to have a complete backup solution in case of a failure of the transmission cable, which could take considerable time to repair. This solution does not improve Longyearbyen's security of energy supply, and it does not make Longyearbyen less dependent on imports to cover the energy demand. This solution offers no scaleability, so it could be advisable to invest in larger capacity.

With regards to the cost, it must be noted that all the other cases were done under the assumption that the current electricity and heat demand covered by components outside of the coal power plant would still be run on diesel like before. These costs were separated from the NPC in the 5 cases from HOMER, meaning that the presented NPC's were not complete. The NPC of 4360 MNOK for the case 6 is calculated by Thema and Multiconsult to be a complete NPC for the entire analysis period of 30 years. The cable alternative is, in any case, obviously far more expensive than any of the other alternatives, aside from maybe case 4 with diesel generators only.

The cable alternative scores well with regards to CO_2 emissions, due to the low carbon intensity of the Norwegian mainland grid.

Due to the high costs of this solution and the fact that it leaves the Longyearbyen community vulnerable for technical failures, makes this solution less attractive than case 2, 3 and 5.

11.2 Using the HOMER case results as eTransport input

As explained in chapter 9, eTransport was allowed to choose between a 21 MW wind park, a 7.5 MW pellets power plant, a 15 MW PV installation, as well as batteries of 5 or 15 MWh and an electric boiler. Additionally, eTransport was used to test if there were any advantages of a 3.5 GWh hydrogen storage system, or a 30 MWh steam accumulator. The model was run and compiled in 31 hours.

Optimal investment plan

eTransport prefers to continue using the coal plant, with the addition of a 5 MWh battery, the electric boiler and a 21 MW wind park. No other investments were made during the 30 year analysis period. The steam accumulator and the hydrogen system is not beneficial to invest in.

This solution had an annuity of 62,568 MNOK/yr, which corresponds to a net present cost of 1,082 MNOK. The average annual emissions were found to be 22,3 tonnes of CO_2. The cost breakdown of the optimal investment plan is shown in table 11.13.

<table>
<tr><th colspan="7">Net present cost: 1,593 MNOK</th></tr>
<tr><th>Investment period</th><th colspan="2">2021 ⟶</th><th colspan="2">2036 ⟶</th><th colspan="2">2050</th></tr>
<tr><th>Cost</th><td>Inv.</td><td>O&M + fuel</td><td>Inv.</td><td>O&M + fuel</td><td>Inv.</td><td>O&M + fuel</td></tr>
<tr><th>kNOK/yr</th><td>27,155</td><td>41,433</td><td>0</td><td>35,855</td><td>23,061</td><td>39,507</td></tr>
</table>

Table 11.13: Cost of optimal investment plan

Discussion

eTransport choosees more or less exactly the same components as HOMER's case 3 - the optimal case with regards to NPC. This strengthens the case for a 21 MW wind park being a good investment, and likewise for the battery and the electric boiler.

The results do not include the steam accumulator or the hydrogen storage system. These results should be questioned, however, as eTransport is less than ideal for analysing the benefits of energy storage. The steam accumulator's main benefit is to even out differences and compensate for fluctuations in heat output. With the amount of curtailed heat seen from the HOMER results for several of the cases, it should be expected that a steam accumulator might provide benefits. eTransport models every consecutive day within each season as identical, and this limits the usefulness of the steam accumulator. The hydrogen storage system is expensive, but could be beneficial for longterm energy storage. In eTransport, stored hydrogen cannot be kept between seasons. It is therefore no surprise that eTransport found the hydrogen system to be a waste of money.

It is difficult to interpret the economic results presented in table 11.13 exactly, as it is not evident how eTransport handles residual values and replacement costs for worn out components. eTransport provides values for 2021-2035, 2036-2049, and 2050 separately. eTransport does not distinguish between an investment cost and a replacement cost. To model the fact that one can keep the coal plant for free for 18 years, it was set to have an investment cost of 0. From production data in 2036-2050, it is evident that the coal plant is still supplying power and heat, indicating that a new power plant with 0 investment costs has been built. The new power plant is then active for 12 years before the analysis period ends, but no residual values is returned either, so the omitted investment costs are equal to roughly 12/30 of the cost of a new power plant.

Why the eTransport case is almost twice as expensive as the similar HOMER case is also unclear. If anything, the lacking costs of the coal power plant replacement should make the solution cheaper. One theory could be that with the less precise demand modelling, the system has to rely considerably more on diesel imports. Diesel is expensive, and drives up the costs of systems substantially (see sensitivity analysis on diesel prices). This hypothesis is substantiated by the eTransport case having 7 million tonnes less CO_2 emissions annually, indicating that it uses considerably less coal and/or more diesel. Another theory is that the residual values has not been properly accounted for, and that no residual value is returned on the wind park that is re-invested in in year 2040.

11.3 Sensitivity analysis

Fuel prices

For all the cases, the price of one or more fuels heavily affect the net present cost of the system. All cases depend on the diesel price; case 1 and 3 also depend on the coal price; and case 2 depends on the pellets price.

Results

With 3 different fuel prices (-25 %, unchanged and +25 %), there were 27 different fuel price configurations. Figure 11.33 compares the NPC for the five analysed cases with all fuel prices at their lowest, at their highest, and unchanged.

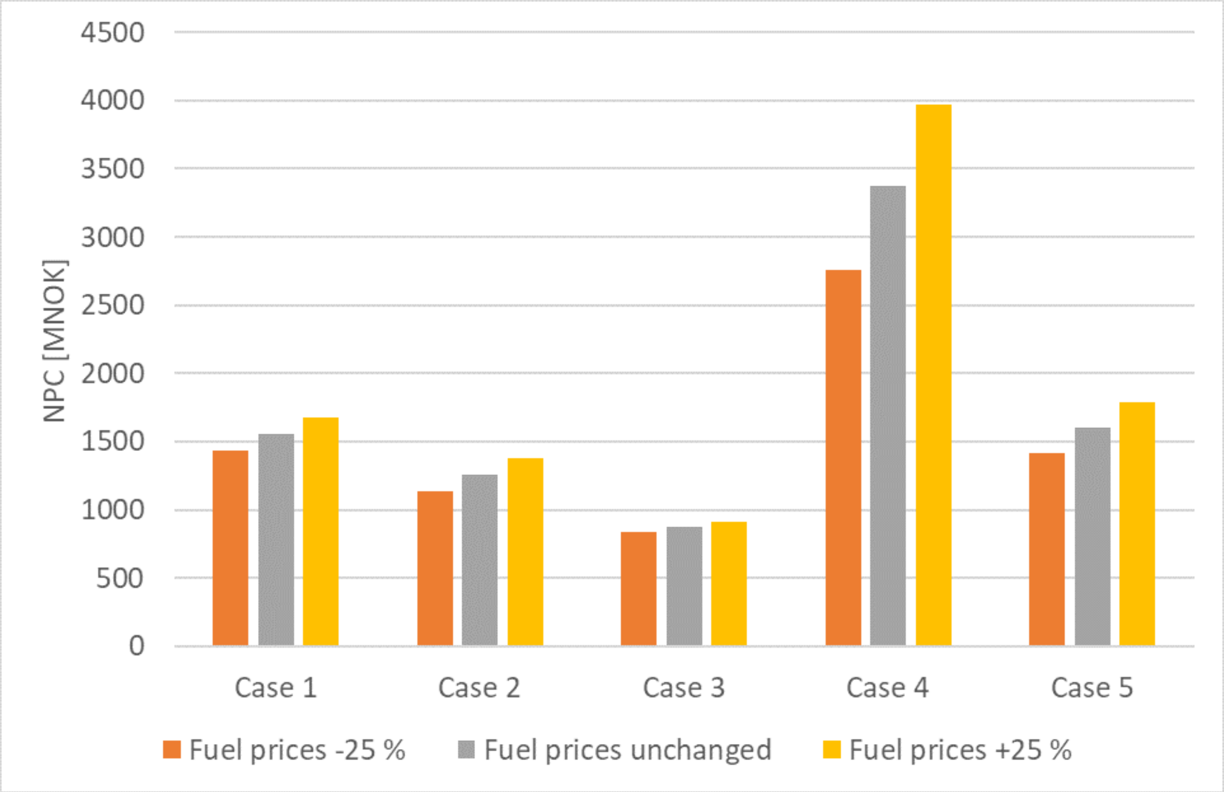

Figure 11.33: Fuel price sensitivity

Discussion

It is obviously more expensive to operate systems with higher fuel costs than lower. Case 4, the diesel case and the only one without any wind or solar power, is more affected than the other cases, both relatively and in absolute value. The other four cases handle price fluctuations better. Case 3 is always the cheapest solution, and case 2 is always the second cheapest. Case 5 is at normal fuel prices 40 MNOK more expensive than case 1. Case 5 is, however, heavily dependent on diesel, which is an expensive fuel. Case 1 relies more on coal, which is generally cheap and makes out a small part of the total system cost. When all fuel costs are lower, case 5 actually becomes 10 MNOK cheaper than case 1, instead of 40 MNOK more expensive. If fuel prices increase, however, case 5 becomes 110 MNOK more expensive.

To summarise, this sensitivity analysis confirms that case 3 followed by case 2 are the cheapest solutions for a new energy system. The analysis also indicated that if fuel price fluctuations is a concern, the diesel consumption should be limited in the design of the new system.

Including transport demand in energy system

Results

To replace all vehicles in Longyearbyen with electric vehicles is estimated to require an additional 7.7 GWh/yr of electricity. When this load is included, the costs and configurations of case 1-5 are changed as shown in table 11.14.

Case	**NPC (with transport)**	**NPC (without transport)**	**Cost of including transport**	**Changes in system**
1: Coal	1,474 MNOK	1,281 MNOK	193	Diesel genset increased from 12 to 15 MW Never uses boiler
2: Pellets + wind	1,344	1,259	85	Diesel genset increased from 12 to 15 MW Decrease el. boiler from 20 to 16 MW Decrease boiler from 6.8 to 6.3 MW
3: Coal + wind	957 MNOK	877 MNOK	80	Diesel genset increased from 12 to 15 MW Decrease el. boiler from 20 to 16 MW
4: Diesel	3,825 MNOK	3,366 MNOK	459	Diesel genset increased from 12 to 15 MW Increase battery from 15 to 20 MWh
5: PV + wind	1,819 MNOK	1,602 MNOK	217	Diesel genset increased from 12 to 15 MW

Table 11.14: Cost of including transport in the energy system

Discussion

As one might expect, the systems that are already more expensive to cover the demand, have a higher marginal cost for increasing the demand to cover the transport sector.

These results indicate that solution 2 and 3 are best prepared to also cover the load of a transition to electric vehicles. It is not necessary to increase the generation, aside from the backup power. This is most likely due to unused power from the wind park as well as unused battery potential, that allows a lot of the transport demand to be covered without the use of additional fuel. The remaining demand is covered by either coal or pellets, with the pellets solution being marginally more expensive.

12 | Discussion

12.1 Modelling results: Optimal energy system in Longyearbyen

The proposed cases were judged after their costs and emissions primarily, with improved energy independence as a secondary goal. The three best cases with this criteria are case 3, the cheapest, case 2, which has the lowest emissions, and case 5, which relies the least on importing fuels. All of these systems incorporate the 21 MW wind park. This makes the wind park a robust investment choice.

It is unlikely to build every part of an energy system at once. This is especially challenging as the town needs energy during the building stage, and the energy system is isolated. This calls for a gradual transition to a new system, so components are operating steadily before new ones are added. Evaluating the results in chapter 11, it seems promising to begin with a 5 MWh battery, which could help reduce fuel consumption in the current power plant, and could be expanded with more batteries later. The electric boiler should also be introduced early, as it can help reduce heat curtailment in summer. Just like the existing boiler houses, electric boilers can be spread around the DH system, and the electric boiler capacity could be expanded with more units later. A 4 MW electric boiler - the lowest of any of the cases - could be a good start. Among the big investments, a 21 MW wind park should be top priority, and installed as soon as possible, after a more thorough examination of the potential locations, and the technical details. These investments will already reduce costs and emissions, and allow for more efficient operation of the existing components.

A major concern is when and how to replace the coal plant. With a wind park, battery capacity and electric boiler capacity, this question is less urgent, allowing for some time to consider the different options. In the meantime, development in Longyearbyen might change beyond what was predicted in this thesis, due to more or less effort spent on energy efficiency measures, or considerable changes in the population size.

A new coal plant is expected to produce more emissions than a pellets plant or solar power, and is therefore not recommended. If the mining operations in Longyearbyen ceases, a new coal plant seems meaningless. A pellets plant, though more expensive, would be preferable to a new coal plant, under the condition that pellets is carbon neutral. However, there will still be emissions related to the harvesting, processing and transport of pellets to Longyearbyen. Among the economically competitive investments, the pellets solution would still likely be the one with the least emissions, based on this analysis. One alternative that has not been considered in this thesis is a natural gas plant, which is expected to be cheaper than a pellets plant, and fall somewhere between pellets and coal with regards to the carbon intensity [4].

Aside from the demand development, the other factor that could affect the optimal solution is the cost development of PV panels and storage technologies like batteries and hydrogen. It was assumed in the analysis that these would be reduced considerably during the analysis period, but if the technology becomes even cheaper than this, the PV solution might improve. The main barrier that hinders a PV and wind only solution from becoming the best seems to be the high cost of energy storage. The costs of the energy generation itself is acceptable, but to cover the demand during low-output days require either substantial energy storage capacity or extensive use of diesel boilers and generators, both of which are currently expensive. Diesel prices are not expected to decrease, but if storage options decrease more than expected, it might make solar power and storage more competitive compared to the pellets case.

Case 5 with PV and wind will cause more emissions than the pellets solution, due to the considerable diesel fuel consumption. An alternative to this is to employ pellets-fed boilers instead, as the technology behind a pellets boiler can be expected to be considerably cheaper than a pellets power plant. This was not tested in the analysis, but could make case 5 more competitive with regards to emissions.

A last point that could be considered in future work with the solution is that it might be beneficial to scrap the district heating system entirely, if the energy efficiency of the buildings is improved enough. The DH system is old and comes with considerable energy losses. It might be that electric radiators is a better solution for heating the buildings. In winter, the weather is often too cold for heat pumps to work with a high coefficient of performance (COP). However, throughout the year as a whole, heat pumps may be beneficial for warming private housings. This especially if the winter temperatures continue to increase at the same alarming rate due to climate change.

12.2 Discussion on the choice of modelling tools

As briefly explained in chapter 6 and 7, it was initially decided to solely use eTransport for the modelling of the Longyearbyen case. There were several challenges that made it difficult to use eTransport, which resulted in HOMER Energy being adopted as the main software analysis tool. As the experience with these two softwares was considered relevant findings on the subject of energy system analysis tools, this section has been included to describe and discuss the advantages and disadvantages of HOMER and eTransport.

Issues encountered while using eTransport

The main issue that prevented the use of eTransport in the case analysis was the software's inability to handle a large number of investment opportunities, as described in chapter 7. Both the exceedingly long runtimes and the time-consuming interface caused problems.

Two factors contributed to the long runtime. Firstly, due to eTransport's abilities to consider dependency relationships between investments and the optimal investment time, the logic becomes more complex to solve. The search-space can be reduced by applying constraints using the investment matrices, but bugs in the software made some of these constraints impossible to include. It should be noted that this error is being resolved by SINTEF, and is an example of how this thesis work has led to improvements of eTransport. Secondly, eTransport cannot utilise more than one logical core of a computer's processor, meaning that for the Intel i5-8250U used in this thesis, only 1/8 of the computer's processing power was used. When the systems got too complex, Visio frequently crashed. The long runtime also made it impossible to run any sensitivity analysis, as that would require running the model several times.

The interface made work with large energy systems difficult in several ways. It is cumbersome and time-consuming to set up different investments, as the entire process must be repeated for every investment, even when the only difference from other investments is the size. Applying or changing settings required many operations in non-intuitive menus hidden in other menus. The drag-and-drop interface was difficult to use, and made the energy system appear cluttered and confusing, and it was easy to accidentally connect nodes the wrong place. Many bugs cased issues when working with the interface.

Other negative aspects of eTransport includes the requirement for substantial pre- and post-processing of data to gain useful results. The user has to find a way to accurately model the loads and production profiles in representative days for each season. The output excel file of the model presents the operational data of the (by default) 10 proposed system alternatives. This is presented in a series of tabs, one for each season (segment) in each investment period, and for each of the system alternatives. With 4 seasons and 2 investment periods as here, the result is 80 tabs that has to be clicked through. No graphs, summaries or tables are created. This requires considerable effort from the user to compare the operation of the proposed system alternatives, which was found to be too time-consuming for this thesis. The results do not show how the costs are distributed on the different components, emission fees, fuels, or how replacement costs or residual values are handled. No complete manual is provided with eTransport. The technical documentation consists of a series of reports released at various stages of its development. The software itself has few explanations and labels, often requiring the user to consult the source code.

To summarise, the main downsides with eTrannsport are: 1) the software struggles, for numerous reasons, with handling complexity in the solution search-space, leading to software crashes and unacceptable runtimes; 2) the user interface is non-intuitive and time-consuming to work with; 3) the software requires extensive pre- and post-processing of data to get useful results; and 4) it is difficult for the user to keep track of how the software works, which is a potential source of error. In its current state, eTransport was found to be unsuitable to develop alternative energy systems for cases with the amount of investment options considered in Longyearbyen. The software seems more suited for a decision maker who has been presented with 2-4 specific options for energy systems, and wants to make a decision between them.

Comparison between HOMER and eTransport and discussion on HOMER's weaknesses

HOMER has several advantages compared to eTransport, that were discovered when working with eTransport.

HOMER offers considerably shorter runtimes. This is partly due to not considering any advanced investment dynamics and partly due to parallell processing which allows the entire computer processor to be utilised. The software also has logic built in to omit the analysis of some infeasible cases. It was found that HOMER usually only analysed 30-40 % of all hypothetical operational analysis, before it arrived at a solution. It was also beneficial to be able to estimate the runtime before starting the calculations, which could not be done in eTransport. No system crashes or bugs were experienced when using HOMER.

The user interface and functions in HOMER enables a low threshold for energy system analyses. There are built in features for uploading time series for heat and power demand, wind speeds and solar irradiance. For the wind and solar power, there are also built in libraries with reference data, based on the geographical locaton of the energy system. These features save considerable time, and combined with the high time resolution of HOMER, it makes for a precise analysis. All recorded fluctuations in demand and supply of both the district heating system and the power grid are modelled. Every year is also modelled separately, and the annual demand profiles can be adjusted with scaling factors. Adding investment opportunities only requires the techno-economical data of the technologies to be added and the search-space to be defined, both of which is fast and intuitive to do. Sensitivity analyses are done by adding multiple values for a parameter, upon which HOMER runs every value in one calculation, as opposed to eTransport that requires the model to be run multiple times and results processed for each time.

The main results from HOMER is a table of feasible solutions and can be sorted by almost any parameter. These results are often more interesting than the ones presented in eTransport. If a given case is the cheapest case, the 2nd cheapest is always the same case with the addition of *one* unit of the *least expensive* component. If the cheapest component available is 1 MW extra of electric boiler capacity, the 2nd best solution is the same as the best, but with the addition of 1 MW electric boiler capacity, regardless of whether the extra capacity is used. eTransport only presents the 10 overall best cases, of which only the best case is usually of interest. HOMER deliberately shows how different combinations of technologies can work together, which is more suited for a case analysis. The HOMER results contain more detailed data than in eTransport. E.g., there are graphs showing how the system operates throughout the year, and it is clear how the costs are spread on the system components.

HOMER comes with a complete, online manual with a search function, that explains how every feature works and the math that lies behind. HOMER also has simple explanations of terms pop up when hovering over buttons. This helps prevent mistakes because the user misunderstood what a function did, and it saves considerable time when using the software. This is in starch contrast to eTransport where the only information available is scattered over a series of overlapping reports.

HOMER contains many features relevant for an energy system analysis that are not present in eTransport, such as costs and constraints for unmet load, maintenance scheduling for components and requirements for operating reserve when renewables are used. HOMER does not, however, support modelling of thermal storage, which eTransport can. Generally, HOMER treats thermal energy demand as less important than power demand. A boiler with only O&M and fuel costs, with infinite lifetime and generation capacity, is automatically included in all systems to help serve the thermal demand. HOMER can get heat from CHP turbines or excess electricity converted to heat using an electric boiler, but does not invest in more generation capacity than necessary to meet the electricity demand. If this is insufficient to also meet the electricity demand, the auto-sized boiler is used. This means that all costs in serving the heat demand is not covered, and HOMER is not designed to find the ideal way of meeting the heat demand. While the designed solution is guaranteed to meet the demand, it might be more beneficial to choose other components to rely less on the auto-sized boiler. eTransport treats heat demand with the same importance as electricity. .

The main weakness in HOMER compared to eTransport is that it does not allow changes in the system during the analysis period. The system chosen in year 1 is operated the entire analysis period. When components get worn out, they are replaced with identical ones, with a specified replacement cost. This limitation made it impossible to model a solution in which the coal power plant that already exists is used for 18 years, then scrapped, which are the kind of decisions eTransport is made for.

HOMER also operates with lifetime for generators by operating hours, and not years of existence. This is not exclusively negative, as it is realistic that a backup diesel generator used every day would get worn out sooner than one almost never used, but it does cause some unfortunate effects. It appears that HOMER adapts a strategy where it turns the generators (coal, pellets or diesel) on and off rapidly throughout the day, to use them as little as possible and conserve them for a longer time before they have to be replaced. This would not be a realistic solution in real life, as the wear and tear from switching a coal power plant on and off frequently is higher than that of a steady operation. It also affects the prices, as there are no costs in HOMER for keeping a generator turned off. In reality, there are other active costs when a generator is turned off, as well as start-up costs and shut-down costs.

In this thesis work, a software tool was necessary to model several alternative energy systems to consider viable options for Longyearbyen. This was found to be an impossible task in eTransport. eTransport's main benefit compared to HOMER is that it can model more complicated investment plans, by including the ability to scrap components or postpone investments expected to decrease in cost. These features are difficult to draw any benefits from when the software itself struggles with handling the complexity of such investment opportunities. HOMER is faster and more intuitive to work with. Less pre- and post-processing of data is necessary to gain and compare results, and setting up demand profiles, components and investment opportunities takes less time. HOMER can handle considerably more investment opportunities while maintaining acceptable runtimes and avoiding system crashes. The main downsides with HOMER is that it lacks the ability to do changes in the system during the analysis period, and there are limitations in how it handles the thermal demand.

12.3 Error sources

There are many potential error sources in the analyses performed in this thesis. Some of them are covered in this section.

General

When it comes to general error sources in this thesis, the biggest one is the limited platform of knowledge in Longyearbyen. The fact that the total energy demand is not known makes designing an optimal energy system challenging. To remedy this, the analysis has only concerned itself with replacing the known parts of the demand, and ignoring the parts covered by the backup diesel boilers and diesel generators today. The estimates of the energy efficiency measures implemented in the future were on the conservative side. It is possible that the demand is reduced enough for the diesel boilers and diesel generators to be unnecessary under normal operation.

A general error source that could have affected all the results is that the demand assessment were based on just one year of time series from the power plant, as this was the only data that could be gathered. It is possible that 2017 was a particularly warm or cold year, so the time series is not necessarily representative for a normal year. Likewise, it is hard to assess the precision of the wind power output profiles acquired from Ninja Renewables, or the PV power output profiles shared by Einar Boman Rinde, which he had simulated in PVsyst.

There is also considerable uncertainty around prices of installations in Longyearbyen. Generally, installations end up costing 25-35 % more, but this varies greatly, and makes cost estimates difficult. Especially the import costs of pellets is uncertain, as there is no cost history to draw estimates from in Svalbard.

Many of the lifetime estimates for different components are based around the guaranteed lifetime from the manufacturer, but it could be expected that many components, especially components such as PV panels, could be used for a considerable time beyond its expected lifetime.

The emission estimates for this thesis are based entirely around expected CO_2 emissions from the combustion of fuels. In reality, there are considerable emissions related to the technical installations themselves, both due to raw material extraction, manufacturing, end-of-lifetime demolition, transport and maintenance. These are the kind of emissions that should be considered in a lifecycle assessment, but such assessments were beyond the scope of this thesis.

In addition to the fuel and O&M costs for the existing diesel boilers and generators, there are other costs not taken into account in this analysis. Necessary grid upgrades and O&M costs of the electric grid and the district heating system is not taken into account. For the systems with a wind park installation in Platåberget, new roads might be necessary.

HOMER

There are several error sources connected to how HOMER functions. All energy system analysis tool will have to be based around some simplifications. A dedicated subchapter will cover the benefits and disadvantages of HOMER compared to eTransport. This section will describe the most prominent error sources that could have negatively altered the results.

The biggest error source in HOMER is most likely how it handles the thermal demand. HOMER is adapted to electricity demands. It models thermal demands exactly the same way, but it optimalises the production towards the electricity demand. HOMER automatically includes a boiler that can run on any specified fuel, with infinite capacity, and no other costs than fuel costs. For electricity, there is a constraint on maximum unmet load, and there are fees for failing to meet the load. No such thing exists for heat, as the boiler automatically covers whatever is left of the heat demand at all times. While this approach is somewhat similar to how it might realistically be done in Longyearbyen, by having a diesel boiler that covers the left-over heat demand, it is still negative to not be able to include investment and O&M costs for the boilers.

The way HOMER covers CHP dynamics is not ideal either. HOMER allows the user to design the electricity and heat efficiency curves freely, as functions of the fuel input, the system cannot vary the ratio between heat and electricity production based on the demand, as one can to some extent in reality. For every given fuel input, the heat-to-electricity ratio is fixed. With no way of varying this, the user is often forced to choose between having the CHP plant model the heat and electricity efficiencies correctly, or the maximum heat and power outputs correctly. Here, the former was chosen, which led to a too high heat output for both the coal and pellets plant. This was somehow remedied by not including the existing diesel boiler in the coal plant, but a similar strategy could not be used for the pellets plant.

HOMER does not have any O&M costs for just having a coal or pellets power plant. The O&M costs are per hour of operation, meaning that if the coal plant is only used half the time, it would only incur half the O&M costs. In reality, the power plant has expenditure related to upkeep, employee salaries, control and measurement systems, amongst other things, that will be present even if the plant is not currently active.

Generally, HOMER focuses on the long-term planning of energy systems, concerning itself with whether or not there is enough energy generation at any given time. It does not consider issues such as grid stability. This also makes HOMER less than ideal for modelling energy storage solutions, especially short-term components such as batteries. It might be that more battery potential is beneficial, but HOMER cannot detect this.

For PV power output, HOMER's built in simulation based on coordinates was used. The precision of this simulation is unknown.

eTransport

The biggest error source in the eTransport software is how it handles demands and seasonal variations. As it was set up with three seasons and a peak day, the entire year consists of three different series of identical days. In winter, every day is identical, and likewise for the other seasons. The production profiles of wind and solar power were modelled the same way. In practice, there are no day-to-day fluctuations in the system for heat and electricity demand, as well as wind power output and solar power output. This is an unrealistic assumption. This also makes eTransport poorly suited to examine the usefulness of short-term energy storage solutions. One of the main benefits with energy storage is compensating for naturally occurring fluctuations in demand or supply. When the model does not include these, it follows that it does not see the benefit in storage. eTransport's modelling of seasons and demand could be well-suited to model long-term energy storage such as hydrogen, were it not for the fact that the H_2 created by electrolysis does not carry over to the next season. With all these factors, it is difficult to establish for certain if the proposed energy system could, in fact, meet the demand.

With the extensive data processing that was required to generate demand and production curves for the different seasons, there is also a high chance that some error may have been committed somewhere.

Furthermore, it is often difficult for the user to know exactly what a feature does or how it works. E.g., it is not obvious when setting the fuel prices in NOK/MWh whether or not the prices are per energy output or per energy input. The latter was assumed, but such things were often difficult to find out, and required reading the source code. Mistakes caused by such issues can seriously affect the end results, and is a potential source of error.

12.4 Further research

The following topics of research are suggested as a continuation of the proposed plans for a new energy system in Longyearbyen.

- With regards to the proposed solution, there should be designed a detailed plan for how the transition to a new energy system should be made smoothly, with minimal supply interruptions

- The technical details of the wind park should be laid out. This includes detailed surveys of potential locations to find the ideal location, that maximises power output compared to the investment costs, and that minimises negative local consequences. This should include environmental reports and an assessment of how a wind park in Platåberget could affect KSAT/Svalsat. Then, the optimal type and number of turbines should be decided, with Svalbard's harsh climate in mind.
- Likewise, detailed technical plans for the other proposed components should be formed.
- It is necessary to map the bottlenecks in the DH system and electrical grid, and find out where it is necessary to make improvements to enable new components.
- A detailed plan for a pellets power plant or a rooftop mounted PV installation should also be formed, to eventually replace the coal power plant.

There are also other topics related to Longyearbyen that could be researched, such as:

- A more precise measurement of energy efficiency in buildings. There could also be a cost comparison of running the DH system compared to electrical heating separately in each building, with or without heat pumps.
- The energy use in sea transport, and how the emissions from this sector can be reduced.

13 | Conclusion

In this Master's thesis, the future energy system of Longyearbyen towards 2050 is analysed using the HOMER and eTransport modelling tools. Both models find total system costs, including investments and operational costs for the thermal and electric energy systems in Longyearbyen. Based on the initial results from HOMER, five cases were developed: a base case with continued coal power (1), a 7.5 MW pellets plant in combination with a 21 MW wind park (2), coal power combiner with a 21 MW wind park (3), diesel boilers and generators only (4), and a 15 MWp PV system with a 21 MW wind park (5). These were analysed in eTransport to find an investment plan.

On the way to transition Longyearbyen from coal power towards renewables, the findings of this master's thesis show that it is highly recommended to use wind power in future energy systems. Longyearbyen's surrounding mountain plateaus provide favourable wind conditions. The results from HOMER showed that a 21 MW wind park is the best choice both in terms of lowest net present cost, lowest emissions and lowest reliance on energy imports. Additionally, some battery storage capacity in the form of a 5 MWh/1.5 MW battery should be introduced, as well as 4 MW of electric boiler capacity, to convert excess electricity to heat for the district heating system. An extra diesel generator capacity of 12 MW and a diesel boiler capacity of 5.2 MW should be added to have sufficient backup power and heat to ensure security of energy supply. These components should immediately be invested in, and is expected to reduce costs and emissions compared to the existing energy system.

The second big investment decision comes when either the coal plant is worn out or the mine shuts down. Two solutions are presented as viable alternatives, based on case 2 and 5. In case 2, a new 7.5 MW pellets CHP plant can be constructed in Hotellneset. Running on imported bio fuels, it provides a renewable option for flexible and controllable power and heat generation. For this solution, it would be beneficial to increase the electric boiler capacity from 5 MW to 20 MW. Compared to continuing to run Longyearbyen on coal (case 1), the total costs of the energy system is reduced by 20 MNOK and the global greenhouse gas emissions are reduced from 83,000 tonnes to 1,300 tonnes annually. This is the only case analysed that could provide a close to 100 % renewable energy system.

The other alternative is based on case 5, and includes 15 MWp rooftop mounted PVs combined with a 21 MW wind park. As the wind power output is lower in summer, and the PV output higher in summer, they compliment each other well and provide a steadier total output throughout the year. With this solution, electric boiler capacity should be increased to 28 MW, to accommodate the large amount of excess electricity that will occur at certain times. Additionally, the battery capacity should be increased from 5 to 15 MWh, with a 4.5 MW output. This system would cost 320 MNOK more over 30 years than continued coal use, but would reduce emissions from 83 000 tonnes to 14 000 tonnes annually. The emissions come mostly from the necessary occasional use of fossil fuels for periods of time with little wind and sun. Due to the high prices of energy storage, it was found to be cheaper to accept some emissions from diesel combustion to ensure security of energy supply.

A sensitivity analysis in HOMER showed that it is possible to replace Longyearbyen's land vehicles with their electrical counterparts. The HOMER results showed that case w (pellets and wind) was better suited tro handle the increased electricity demand, when compared to case 5 (PV and wind). The added system cost (NPC) increased by 85 MNOK and 217 MNOK for case 2 and 5, respectively.

The eTransport results indicated that a steam accumulator or a hydrogen storage system was not cost-efficient here. However, as eTransport has limited abilities for modelling the benefits of energy storage, it is difficult to draw any clear conclusions from this. Based on the amounts of curtailed excess heat from the HOMER cases, it is expected that a steam accumulator might be advantageous.

With regards to the optimal modelling tool for the Longyearbyen case, it was found that HOMER was overall faster and simpler to use than eTransport, especially with regards to runtime, sensitivity analyses and demand modelling. eTransport is, in theory, better adapted for modelling the decisions necessary to do in Longyearbyen, as it handles more complicated investment dynamics, such as the benefits of postponing an investment expected to decrease in price. eTransport is, however, exceedingly cumbersome to use, and entirely unable to handle the number of investment opportunities necessary to consider for Longyearbyen. Due to extremely long runtimes and software crashes, the tool had to be abandoned for the main analysis of this thesis work. In its current state, it is not recommended to use eTransport for cases with similar complexity as the energy system of Longyearbyen.

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A | Potential for energy savings

During the project thesis, research was done to map the energy use in Longyearbyen's buildings. This was used to make an assumption on the potential for energy savings. The following are excerpts from the project thesis, albeit with minor amendments of language.

Energy use in buildings

It has been estimated that the district heat demand in Norway proper is on average 40 % lower than in Longyearbyen, when accounting for the latter's colder climate. Passive houses in Longyearbyen would use 75 % less heating energy than the current buildings [4]. This suggests a substantial potential for reducing heat demand through energy efficiency measures.

The current trend is that Longyearbyen is moving from a typical company town, where the majority of the population is single men living there for a few years, and into a more typical Norwegian municipality. The company town history of Longyearbyen is visible in the residential buildings, which are mostly simple, small and cheap temporary housing for workers. More families with children are moving to the town, and the variety in business life is increasing. If this trend continues, it might be expected that citizens will look at their homes as more permanent, and have higher expectations for the buildings they reside in.

Currently, many buildings are planned to be demolished, as they are placed in avalanche terrain or they do not have a sufficiently deep foundation in the permafrost. Both of these issues become more pressing due to the warming climate in Svalbard. Longyearbyen got its first building code in 2012 [42], which was updated in 2016 [43]. This fact, combined with changes in the demographic composition of Longyearbyen and the attitude towards living in the town, suggests that new buildings in Longyearbyen will be of higher quality and more energy efficient than many of the existing ones.

Energy use in Store Norske and Statsbygg buildings

An effort has therefore been made to contact the main building owners and developers in Longyearbyen, to try to map the planned future buildings. Positive replies were gathered from Store Norske Kullkompani AS, represented by property manager Sveinung Lystrup Thesen, and from Statsbygg represented by William Holberg Engesland and Bente Næverdal. The companies are two of Longyearbyen's largest owners of residential buildings, owning 41 % of the town's residential building area, as seen in figure A.0.1, and the companies provided address list of their buildings, with some facts about their area and year of construction.

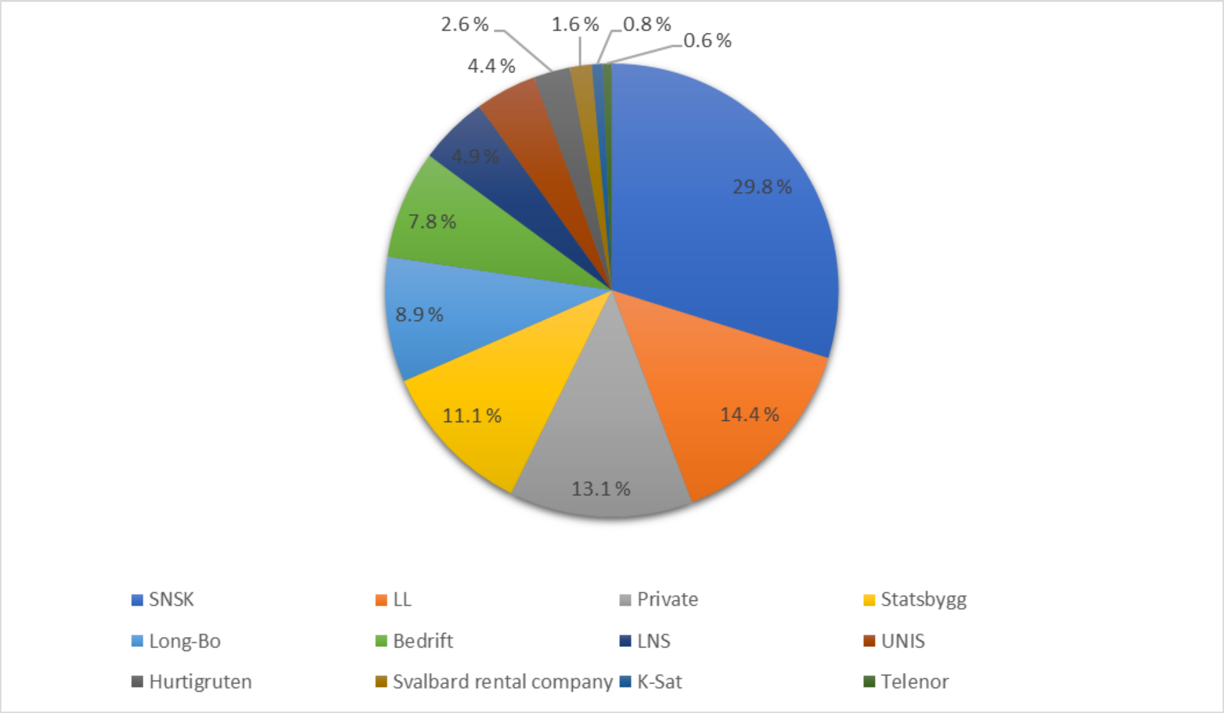


Figure A.0.1: Residential building area in Longyearbyen by owner [44]

In 2018, there were a total of 200,000 m^2 of buildings connected to the DH system, of which 49 % were residential buildings [4].

The address list of Statsbygg's properties include both values for total area and for living area, but both values are not provided for all buildings. It is assumed that only the living area is heated. For the buildings where both area values are given, the total area is 13.6 % higher than the net living area. Assuming this is representative for the other buildings, the net living area could be calculated for the buildings where only the total area was provided. A total of 15,700 m^2 of Statsbygg owned residential buildings are connected to the DH system.

In the address list provided by SNSK the buildings were listed with the exact area that is heated by the district heating area. SNSK is by far Longyearbyen's biggest property owner, a reflection on the importance coal mining has had on employment in the town. They won 28 % of DH connected residential buildings

As of 2019, about 97 % of Statsbygg and SNSK's properties were in usage [44]. The address lists also provide data on the properties' build year, which is illustrated in figure A.0.2.

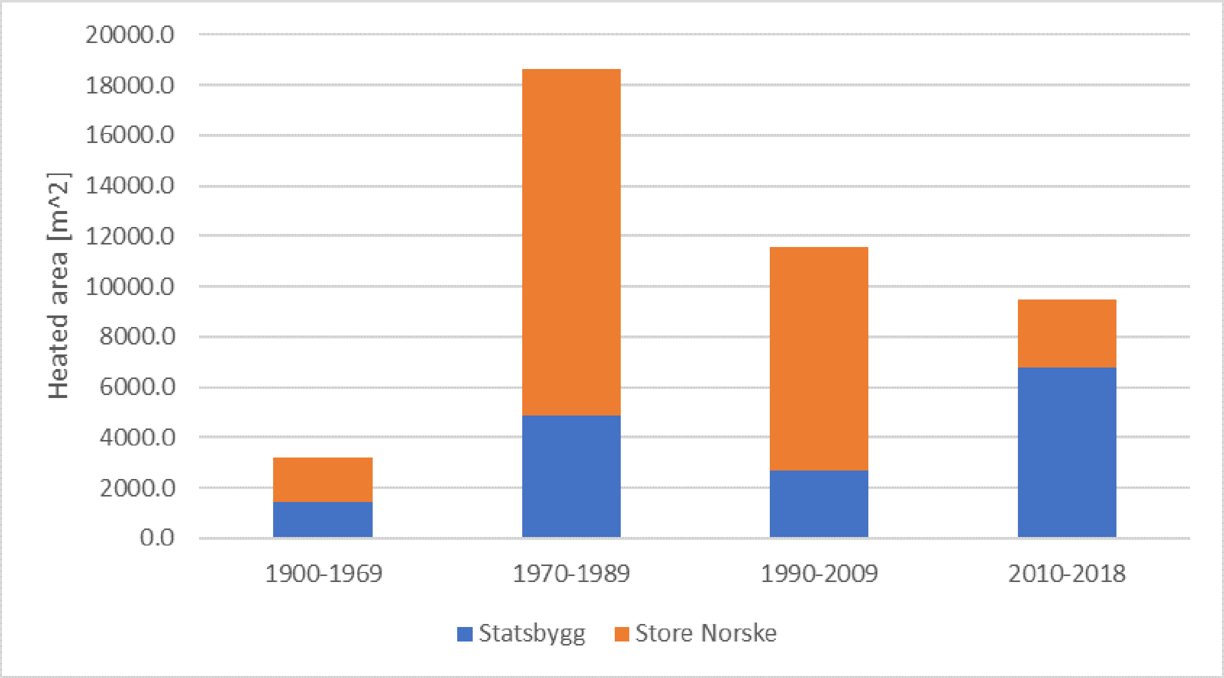


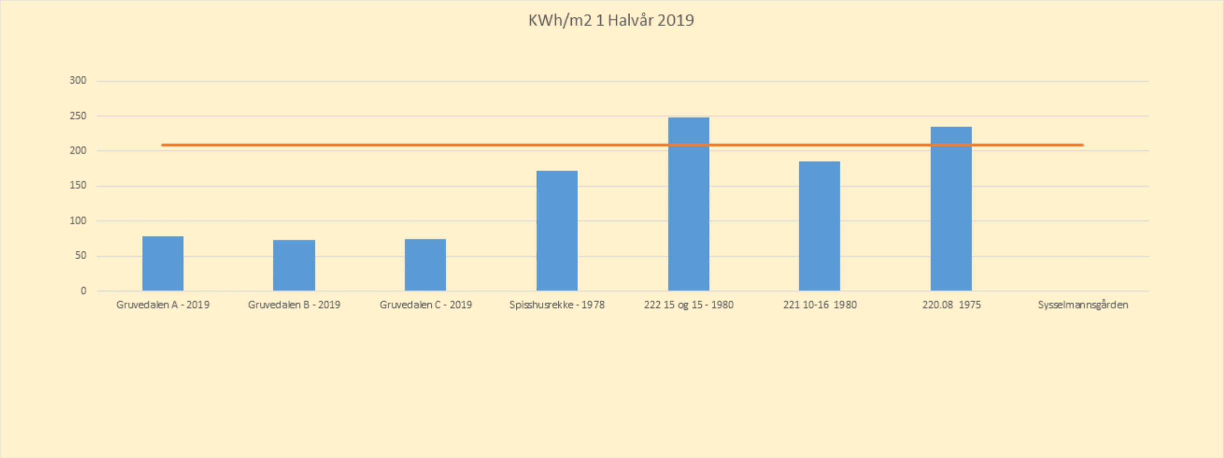
Figure A.0.2: Heated area [m^2] of SNSK and Statsbygg owned residential buildings

Still, SNSK and Statsbygg, despite being among the town's largest property owner, only own 44 % of DH connected residential buildings (by area), and 21 % of all DH connected building area.

Statsbygg has provided some information about energy use in their buildings. These insights confirm that it is reasonable to expect that the energy use per resident for heating might decline in the future, due to more efficient buildings.

Figure A.0.3 show measurements of the heat consumption in their buildings in the first half of 2019. Statsbygg's goal is for all of their buildings to use less than 200 $kWh/m^2/yr$, marked by the orange line in the figure. As can be seen, their newer buildings are more energy efficient than the older ones. Their 60 latest residential units, built between 2018-2019, follow passive house standards. As can be seen from the chart, the new buildings from 2019 used roughly 70-80 kWh/m^2. These buildings are also prepared for rooftop PV installations.

Figure A.0.3: Heat use in Statsbygg buildings for the first half of 2019 [Statsbygg]

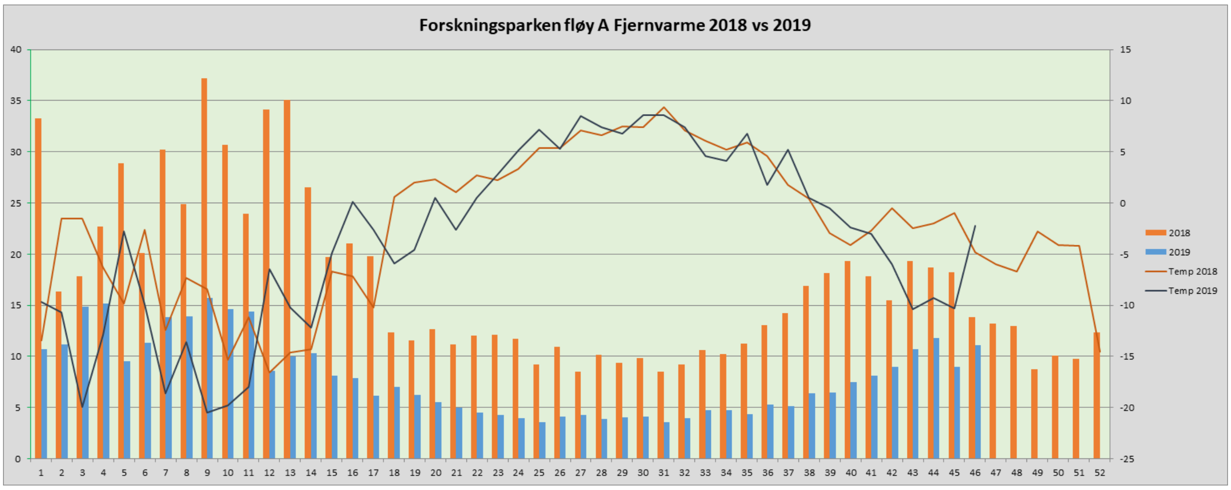


Heat control functionality have been installed in Svalbard Forskningspark. The administration building of the Governor (Sysselmannen) and 10 of Statsbygg's houses are scheduled to get heat control installed in

2020.

Statsbygg also provided a diagram - see figure A.0.4 - showing the energy efficiency improvements in Forskningsparken after the installation of the heat control. The building is divided into wing A-D. The heat control was only installed in wing A, but is planned to be expanded to wing B-D. The installation in wing A costed 600,000 NOK. The total area of wing A is 3300 m^2, while wing B-D cover 8500 m^2. The chart covers the first 46 weeks of 2019, and shows that the energy consumption for district heat was 368,760 kWh in this time period, whereas for the same period in 2018 was 818 760 kWh. This example illustrates that there is substantial potential for energy savings by operating the district heating more efficiently. Statsbygg estimates that for most of their buildings there is potential to reduce their district heat demand by 25-40 %.

Figure A.0.4: Energy use before and after installation of heat control in Forskningsparken, wing A [Statsbygg]



B | Maps

B.1 Overview

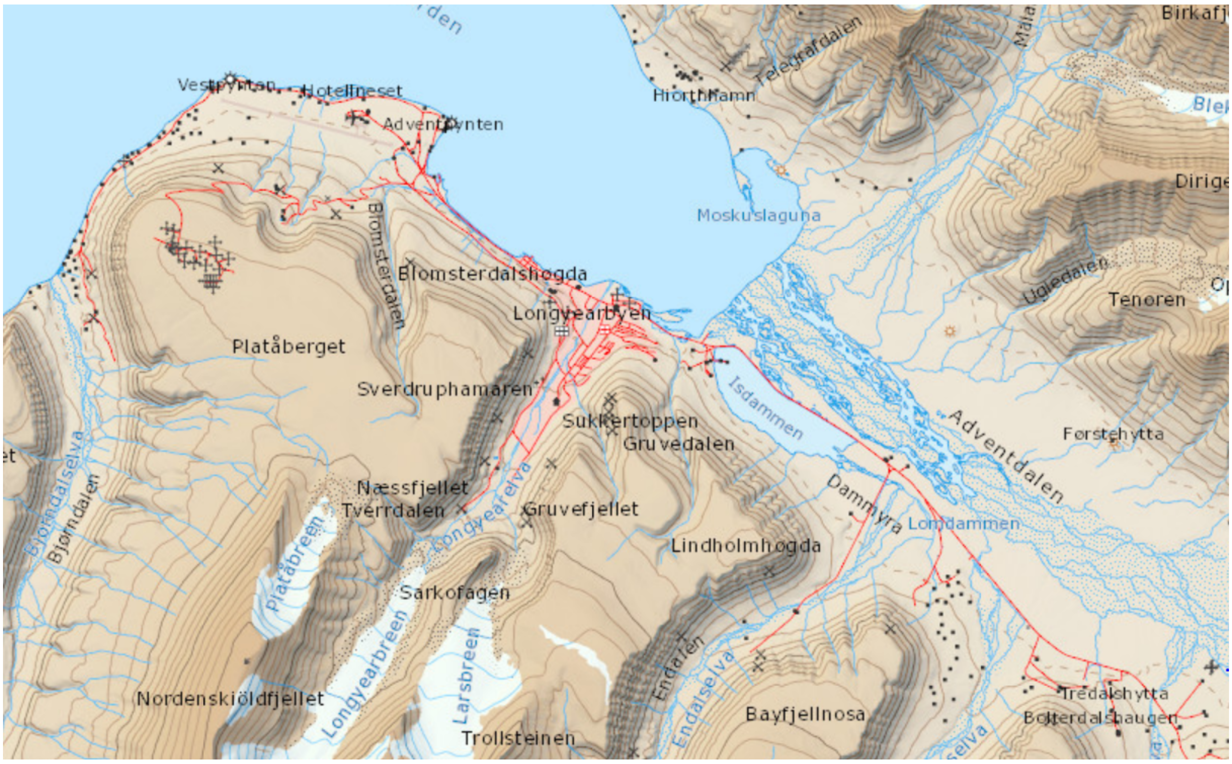


Figure B.1.1: Longyearbyen and surrounding areas

B.2 Detailed maps

Figure B.2.2: Northern parts of Longyearbyen

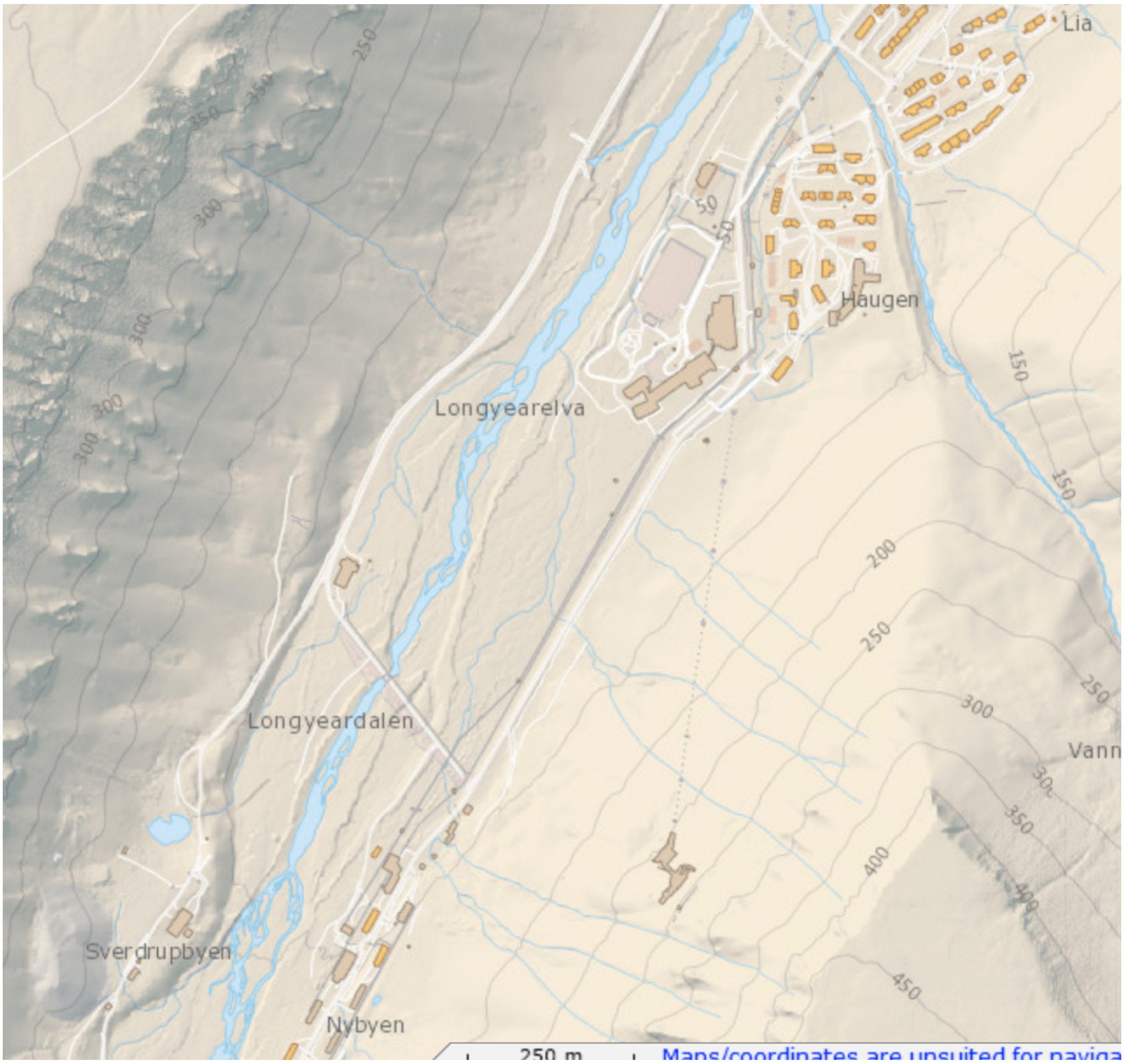


Figure B.2.3: Southern parts of Longyearbyen

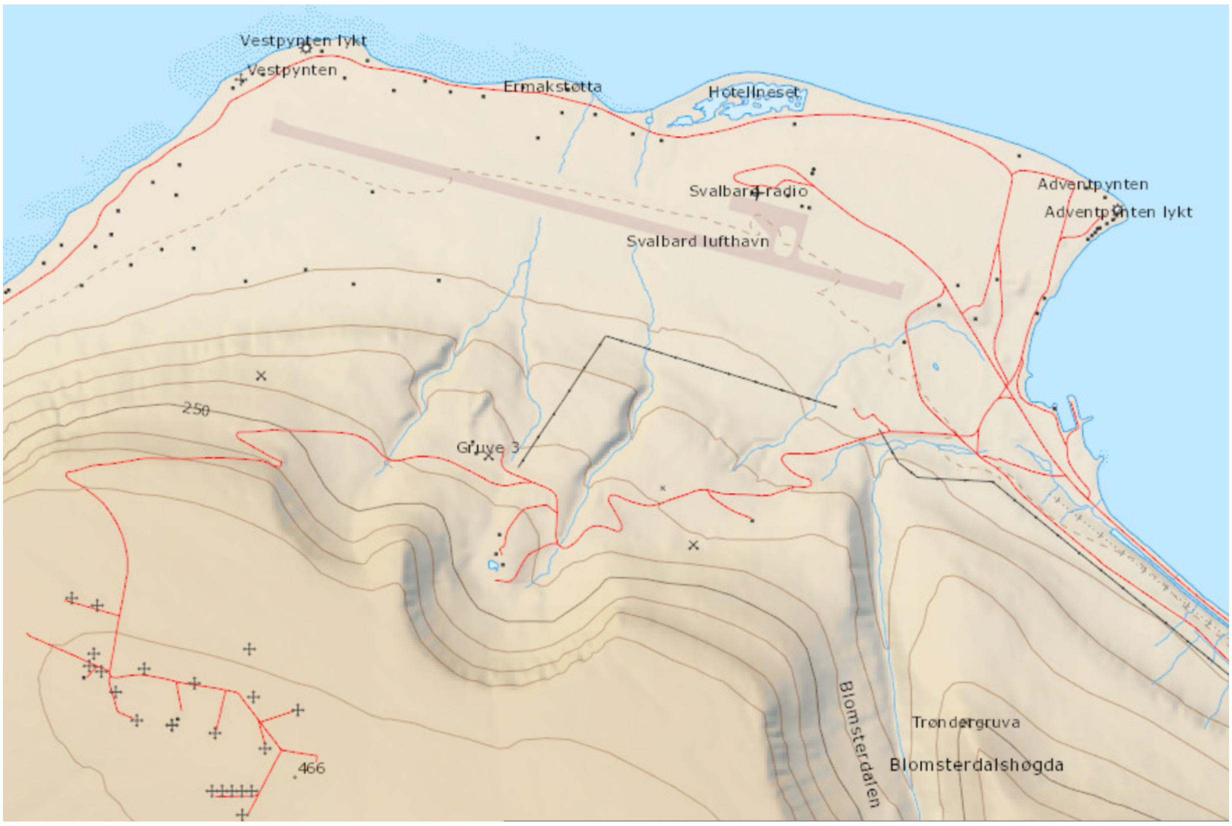


Figure B.2.4: Hotellneset, the airport and KSAT/Svalsat

C | HOMER

C.1 Input

The input report for the HOMER simulation is presented below.

Input Summary

Project title	Longyearbyen
Author	
Notes	

Project Location

Location	Vei 305 - Burmaveien, Longyearbyen, Svalbard and Jan Mayen
Latitude	78 degrees 13.23 minutes North
Longitude	15 degrees 34.40 minutes East
Time zone	Arctic/Longyearbyen

Load: Thermal1

Data source	Imported

Daily noise	23%
Hourly noise	18%
Scaled annual average	186,039.456 kWh/d
Scaled peak load	14,410.0000 kW
Load factor	0.5379

Load: Electric1

Data source	Imported
Daily noise	9%
Hourly noise	6%
Scaled annual average	115,981.200 kWh/d
Scaled peak load	7,905.0000 kW

Load factor	0.6113

Microgrid Controller: HOMER Cycle Charging

Quantity	Capital	Replacement	O&M
1	kr0.00	kr0.00	kr0.00

Minimization strategy	Economic
Setpoint state of charge	80
Allow multiple generators to operate simultaneously	Yes
Allow systems with generator capacity less than peak load	Yes
Allow diesel off operation	Yes

Microgrid Controller: HOMER Load Following

Quantity	Capital	Replacement	O&M

Quantity	Capital	Replacement	O&M
1	kr0.00	kr0.00	kr0.00

Minimization strategy	Economic
Allow multiple generators to operate simultaneously	Yes
Allow systems with generator capacity less than peak load	Yes
Allow diesel off operation	Yes

PV:PV

Size	Capital	Replacement	O&M

Sizes to consider	0,15000,20000,25000
Lifetime	30 yr
Derating factor	90%

Tracking system	No Tracking
Slope	25.000 deg
Azimuth	0.000 deg
Ground reflectance	50.0%

Solar Resource

Scaled annual average	1.66 kWh/m2/d

;

Wind Turbine:Wind park

Quantity	Capital	Replacement	O&M
1	kr17,823,000.00	kr14,509,000.00	kr163,600.00

Wind Resource

Scaled annual average	9.00

;

Generator:Diesel generator

Size	Capital	Replacement	O&M
1.00	kr4,218.50	kr4,218.50	kr0.10

Sizes to consider	12000
Lifetime	10,950 hrs
Min. load ratio	25%
Heat recovery ratio	0%
Fuel used	Diesel
Fuel curve intercept	0.0147 L/hr/kW
Fuel curve slope	0.2360 L/hr/kW

Generator:Coal power plant

Generator:Coal power plant

Size	Capital	Replacement	O&M
7,500.00	kr0.00	kr286,051,500.00	kr266.99

Sizes to consider	0,7500
Lifetime	157,680 hrs
Min. load ratio	23%
Heat recovery ratio	78%
Fuel used	Coal
Fuel curve intercept	0.0800 L/hr/kW
Fuel curve slope	0.7500 L/hr/kW

Generator:Pellets power plant

Size	Capital	Replacement	O&M
7,500.00	kr337,500,000.00	kr337,500,000.00	kr342.00

Sizes to consider	0,7500,10000
Lifetime	262,800 hrs
Min. load ratio	25%
Heat recovery ratio	69%
Fuel used	Pellets
Fuel curve intercept	0.1200 L/hr/kW
Fuel curve slope	0.8000 L/hr/kW

Fuel: Diesel

Price	kr 7.59/L

Lower heating value	43.2 MJ/kg
Density	820.00 kg/m3
Carbon content	88.0%
Sulfur content	0.4%

Fuel: Coal

Price	kr 0.53/kg
Lower heating value	24.0 MJ/kg
Density	1,346.00 kg/m3
Carbon content	70.0%
Sulfur content	1.6%

Fuel: Pellets

Price	kr 1.81/kg
Lower heating value	18.5 MJ/kg
Density	1,200.00 kg/m3
Carbon content	0.0%
Sulfur content	0.0%

Fuel: Stored Hydrogen

Price	kr 1.00/kg
Lower heating value	120.0 MJ/kg
Density	0.09 kg/m3
Carbon content	0.0%
Sulfur content	0.0%

Battery:Battery

Battery.Battery

Quantity	Capital	Replacement	O&M
1	kr3,899,000.00	kr2,831,400.00	kr32,931.00

Quantities to consider	0,5,10,15,20,25,30

Converter

Size	Capital	Replacement	O&M
1.00	kr0.00	kr0.00	kr0.00

Sizes to consider	0,9999999 kW
Lifetime	15 yr
Inverter can parallel with AC generator	Yes

Economics

Annual real interest rate	4%
Project lifetime	30 yr
Capacity shortage penalty	kr2/kWh
System fixed capital cost	0
System fixed O&M cost	0

System control

Timestep length in minutes	60
Multi-Year enabled	Yes
Allow systems with multiple generators	Yes
Allow systems with multiple wind turbine types	Yes
Battery autonomy threshold	2
Maximum renewable penetration threshold	55

Warn about renewable penetration	Yes

Optimizer

Maximum simulations	10000
System design precision	0.01
NPC precision	0.01
Minimum spacing	0
Focus factor	50
Optimize category winners	Yes
Use base case	No

Emissions

Carbon dioxide penalty	kr 500/t

Carbon monoxide penalty	kr 0/t
Unburned hydrocarbons penalty	kr 0/t
Particulate matter penalty	kr 0/t
Sulfur dioxide penalty	kr 0/t
Nitrogen oxides penalty	kr 0/t

Constraints

Maximum annual capacity shortage	2
Minimum renewable fraction	0
Operating reserve as percentage of hourly load	10
Operating reserve as percentage of peak load	25
Operating reserve as percentage of solar power output	20

Operating reserve as percentage of wind power output	20

C.2 Results

The results from running the HOMER Pro calculation is presented below. Each row represents a feasible technical solution for a new energy system. The solutions marked in green are the ones presented in the case analysis, as, numbered from the top of the table, case 3, case 2, case 1, case 5 and case 4. The other solutions were not examined further.

Inst./PV (kW)	Inst./Wind (x1.5 MW)	Inst./Genset (kW)	Inst./Coal (kW)	Inst./Pellets (kW)	Inst./Batt (x1 MWh)	Inst./El. boiler (kW)	Inst./Conv (kW)	Inst./Dispatch	Cost/NPC (kr)	Cost/COE (kr)	Cost/Operating cost (kr/yr)
	14	12000	7500		5	20000	9999999	CC	8.77E+08	-0.4986227	3.13E+07
	14	12000	7500			20000		CC	8.94E+08	-0.4731468	3.34E+07
15000	14	12000	7500		5	28000	9999999	CC	9.56E+08	-0.377648	2.80E+07
15000	14	12000	7500			28000	9999999	CC	9.68E+08	-0.3582137	2.98E+07
	14	12000	7500	7500		20000		CC	1.10E+09	-0.1523855	2.60E+07
	14	12000	7500	7500	5	20000	9999999	CC	1.11E+09	-0.1367924	2.55E+07
15000	14	12000	7500	7500		28000	9999999	CC	1.18E+09	-0.02586261	2.28E+07
15000	14	12000	7500	7500	5	28000	9999999	CC	1.19E+09	-0.01584739	2.21E+07
	14	12000		7500	5	20000	9999999	CC	1.26E+09	0.08782226	3.39E+07
15000		12000	7500		5	12000	9999999	CC	1.27E+09	0.1097639	6.15E+07
		12000	7500		5	4000	9999999	CC	1.28E+09	0.1211362	6.98E+07
	14	12000		7500		20000		CC	1.29E+09	0.1284389	3.66E+07
15000	14	12000		7500	5	28000	9999999	CC	1.33E+09	0.1974113	3.01E+07
15000	14	12000		7500		28000	9999999	CC	1.36E+09	0.2359207	3.27E+07
15000		12000	7500			12000	9999999	CC	1.48E+09	0.4239559	7.44E+07
15000		12000	7500	7500	5	12000	9999999	CC	1.51E+09	0.4730349	5.56E+07
		12000	7500	7500	5	4000	9999999	CC	1.52E+09	0.4844072	6.40E+07
15000		12000	7500	7500		12000	9999999	CC	1.55E+09	0.5347106	5.91E+07
		12000	7500			4000		CC	1.56E+09	0.5436473	8.69E+07
		12000	7500	7500		4000		CC	1.56E+09	0.5561832	6.78E+07
		12000	7500		5		9999999	LF	1.59E+09	0.5960042	8.79E+07
		12000	7500	7500	5		9999999	LF	1.60E+09	0.60854	6.88E+07
15000	14	12000			15	28000	9999999	CC	1.60E+09	0.6152781	6.31E+07
	18	12000			15	24000	9999999	CC	1.62E+09	0.6469063	6.79E+07
15000		12000		7500	5	12000	9999999	CC	1.64E+09	0.6793964	6.34E+07
		12000		7500	5	4000	9999999	CC	1.65E+09	0.6839703	7.15E+07
		12000		10000		4000		CC	1.82E+09	0.9556866	7.64E+07
15000		12000		10000		12000	9999999	CC	1.85E+09	0.9959788	6.99E+07
	18	12000				24000		CC	2.01E+09	1.239494	9.36E+07
15000	14	12000				28000	9999999	CC	2.05E+09	1.306833	9.25E+07
25000		12000			15	20000	9999999	CC	3.01E+09	2.78183	1.54E+08
		12000			15	4000	9999999	CC	3.37E+09	3.323018	1.88E+08
25000		12000				20000	9999999	CC	3.56E+09	3.624571	1.90E+08
		12000				4000		CC	3.73E+09	3.88114	2.13E+08

Cost/Initial capital (kr)	Cost/Fuel cost (kr/yr)	Cost/O&M (kr/yr)	System/Ren Frac (%)	System/Unmet load (%)	System/CO2 (kg/yr)	Genset/Hours	Genset/Production (kWh)	Genset/Fuel (L)	Genset/O&M Cost (kr/yr)
3.35E+08	9352955	1.83E+07	36.99665	3.22E-16	2.94E+07	0.5333334	2745.031	741.6408	640
3.15E+08	9622165	1.94E+07	34.6504	2.98E-16	3.09E+07	240.0667	724681.9	213265.1	288080
4.72E+08	8793939	1.62E+07	49.29228	3.40E-16	2.35E+07	0.7333333	2433.996	703.4492	880
4.53E+08	8267314	1.78E+07	44.38984	3.32E-16	2.63E+07	166.2	500273.3	147307.8	199440
6.53E+08	9061479	1.91E+07	32.44922	3.02E-16	3.09E+07	0	0	0	0
6.72E+08	9351722	1.83E+07	36.98783	3.21E-16	2.94E+07	0	0	0	0
7.90E+08	7856927	1.77E+07	42.89688	3.35E-16	2.62E+07	0	0	0	0
8.10E+08	8793525	1.62E+07	49.28572	3.41E-16	2.35E+07	0	0	0	0
6.72E+08	2.76E+07	4559843	46.56396	1.84E-16	1342131	0.4333333	2216.694	599.3635	520
2.11E+08	1.59E+07	3.82E+07	0	7.71E-16	6.99E+07	0	0	0	0
7.32E+07	1.72E+07	4.41E+07	0	5.45E-18	8.31E+07	0	0	0	0
6.53E+08	2.93E+07	4869014	43.82492	1.44E-16	1238506	240.0667	724681.9	213265.1	288080
8.10E+08	2.34E+07	5454290	56.39064	2.99E-16	1658738	0.6333333	1935.709	568.2631	760
7.90E+08	2.53E+07	5549725	51.57839	1.78E-16	1118214	166.2	500273.3	147307.8	199440
1.91E+08	2.12E+07	3.86E+07	0	7.12E-16	6.81E+07	1039.867	3163634	929583.6	1247840
5.48E+08	1.59E+07	3.82E+07	0	7.71E-16	6.99E+07	0	0	0	0
4.11E+08	1.72E+07	4.41E+07	0	5.45E-18	8.31E+07	0	0	0	0
5.29E+08	1.88E+07	3.76E+07	0	7.06E-16	6.79E+07	0	0	0	0
5.37E+07	2.54E+07	4.31E+07	0	1.68E-19	7.82E+07	1417.733	4339011	1273458	1701280
3.91E+08	2.23E+07	4.18E+07	0	0	7.79E+07	0	0	0	0
7.01E+07	2.54E+07	4.33E+07	0	8.31E-16	7.82E+07	1417.733	4339011	1273458	1701280
4.08E+08	2.23E+07	4.20E+07	0	5.90E-16	7.79E+07	0	0	0	0
5.11E+08	4.05E+07	1.16E+07	63.34904	1.19E-15	1.40E+07	684.1334	6974955	1766344	820960
4.48E+08	4.34E+07	1.20E+07	62.29366	1.35E-15	1.50E+07	809.5333	9051558	2278446	971440
5.48E+08	5.79E+07	3904611	0	5.26E-16	63678.11	0	0	0	0
4.11E+08	6.65E+07	2786196	0	5.41E-18	-774829.9	0	0	0	0
5.04E+08	7.14E+07	3638685	0	2.93E-18	-793029.6	20.53333	61600	18150.49	24640
6.41E+08	6.44E+07	4576392	0	2.49E-16	-619015.8	20.33333	61000	17973.7	24400
3.90E+08	5.16E+07	1.69E+07	63.01846	2.50E-17	1.78E+07	4124.067	1.40E+07	4027470	4948880
4.53E+08	5.07E+07	1.71E+07	63.69329	9.55E-17	1.75E+07	4167.867	1.36E+07	3941273	5001440
3.43E+08	1.11E+08	2.44E+07	10.32472	4.60E-15	3.83E+07	2612.867	2.95E+07	7423131	3135440
1.12E+08	1.36E+08	2.83E+07	0	5.92E-15	4.69E+07	3600.8	4.09E+07	1.03E+07	4320960
2.85E+08	1.17E+08	3.15E+07	13.52032	1.08E-16	4.03E+07	8106	3.12E+07	8799302	9727200
5.37E+07	1.35E+08	3.38E+07	0	0	4.65E+07	8760	3.65E+07	1.01E+07	1.05E+07

Genset/Fuel Cost (kr/yr)	Coal/Hours	Coal/Production (kWh)	Coal/Fuel (kg)	Coal/O&M Cost (kr/yr)	Coal/Fuel Cost (kr/yr)	Pellets/Hours	Pellets/Production (kWh)	Pellets/Fuel (kg)	Pellets/O&M Cost (kr/yr)	Pellets/Fuel Cost (kr/yr)
5629.054	4061.7	1.14E+07	1.10E+07	1084433	5829104					
1618682	4675.567	1.17E+07	1.16E+07	1248330	6142164					
5339.179	3392.633	8732622	8585046	905799.2	4550075					
1118066	4268.467	9699698	9835854	1139638	5213003					
0	4677.633	1.20E+07	1.18E+07	1248881	6251166	240.0667	450125	576160	82102.8	1039969
0	4061.7	1.14E+07	1.10E+07	1084433	5829587	0.533333	1733.32	1866.656	182.4	3369.313
0	4269.333	9886366	9976375	1139869	5287479	166.2	311625	398880	56840.4	719978.4
0	3392.467	8732790	8585073	905754.7	4550089	0.733333	2081.972	2325.577	250.8	4197.667
4549.169						3956.733	1.15E+07	1.27E+07	1353203	2.30E+07
0	8015.267	2.96E+07	2.70E+07	2139996	1.43E+07					
0	8751.333	3.62E+07	3.24E+07	2336519	1.72E+07					
1618682						4652.867	1.20E+07	1.38E+07	1591280	2.48E+07
4313.117						3273.7	8757551	9952371	1119605	1.80E+07
1118066						4243.5	9995533	1.18E+07	1451277	2.13E+07
7055540	8483.967	2.72E+07	2.55E+07	2265134	1.35E+07					
0	8015.267	2.96E+07	2.70E+07	2139996	1.43E+07	0	0	0	0	0
0	8751.333	3.62E+07	3.24E+07	2336519	1.72E+07	0	0	0	0	0
0	8502.366	2.84E+07	2.64E+07	2270047	1.40E+07	1039.867	1949750	2495680	355634.4	4504703
9665547	8723.467	3.18E+07	2.91E+07	2329079	1.54E+07					
0	8760	3.35E+07	3.04E+07	2338833	1.61E+07	1417.733	2658250	3402560	484864.8	6141621
9665547	8723.467	3.18E+07	2.91E+07	2329079	1.54E+07					
0	8760	3.35E+07	3.04E+07	2338833	1.61E+07	1417.733	2658250	3402560	484864.8	6141621
1.34E+07										
1.73E+07										
0						7960.867	2.97E+07	3.09E+07	2722617	5.58E+07
0						8751.333	3.62E+07	3.68E+07	2992956	6.65E+07
137762.2						8760	3.62E+07	3.95E+07	3994560	7.12E+07
136420.4						8500	3.16E+07	3.55E+07	3876000	6.40E+07
3.06E+07										
2.99E+07										
5.63E+07										
7.81E+07										
6.68E+07										
7.70E+07										

PV/Capital Cost (kr)	PV/Production (kWh/yr)	Wind/Capital Cost (kr)	Wind/Production (kWh/yr)	Wind/O&M Cost (kr)	Batt/Quantity	Batt/Autonomy (hr)	Batt/Annual Throughput (kWh/yr)	Batt/Operating hours (hours)	Batt/Nominal Capacity (kWh)
		2.50E+08	7.59E+07	2290400	5	0.9874602	255248.5	0	0
		2.50E+08	7.59E+07	2290400					
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.9874602	362851.8	0	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400					
		2.50E+08	7.59E+07	2290400					
		2.50E+08	7.59E+07	2290400	5	0.9874602	257612.7	0	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400					
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.9874602	362601.9	0	0
		2.50E+08	7.59E+07	2290400	5	0.9874602	345271.8	0	0
1.31E+08	9913834				5	0.9874602	371977.2	0	0
					5	0.9874602	19791.34	0	0
		2.50E+08	7.59E+07	2290400					
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.9874602	482406.3	0	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400					
1.31E+08	9913834								
1.31E+08	9913834				5	0.9874602	371977.2	0	0
					5	0.9874602	19791.34	0	0
1.31E+08	9913834								
					5	0.9874602	267.8767	0	0
					5	0.9874602	267.8767	0	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	15	2.962381	4798857	0	0
		3.21E+08	9.75E+07	2944800	15	2.962381	5889155	0	0
1.31E+08	9913834				5	0.9874602	559377	0	0
					5	0.9874602	19326.42	0	0
1.31E+08	9913834								
		3.21E+08	9.75E+07	2944800					
1.31E+08	9913834	2.50E+08	7.59E+07	2290400					
2.19E+08	1.65E+07				15	2.962381	1.75E+07	0	0
					15	2.962381	2.28E+07	0	0
2.19E+08	1.65E+07								

Batt/Usable Nominal Capacity (kWh)	Conv/Capacity	Conv/Rectifier Mean Output (kW)	Conv/Inverter Mean Output (kW)	El. boiler/Capacity	El. boiler/Mean Output (kW)	BOILER/Fuel Consumption (L)
0	9999999	30.72414	26.26056	20000	5827.972	463533.8
				20000	5950.31	245233.2
0	9999999	29.70676	291.5011	28000	6638.238	558435.4
	9999999	0	200.3288	28000	6816.204	255104.9
				20000	5950.083	233247.1
0	9999999	31.00862	26.5038	20000	5827.939	463605.4
	9999999	0	200.3845	28000	6815.975	243671.9
0	9999999	29.74637	291.5517	28000	6638.215	558529.5
0	9999999	41.55665	35.52236	20000	5830.237	615759.4
0	9999999	23.74287	772.4034	12000	337.9176	205385.8
0	9999999	2.391523	2.036179	4000	0.007688281	846.1246
				20000	5979.959	371977.4
0	9999999	40.92017	302.5783	28000	6638.421	714167.5
	9999999	0	191.0316	28000	6850.464	376107.1
	9999999	0	661.17	12000	435.7754	79915.13
0	9999999	23.74287	772.4034	12000	337.9176	205385.8
0	9999999	2.391523	2.036179	4000	0.007688281	846.1246
	9999999	0	661.2535	12000	435.6875	39873.43
				4000	0.027597	41030.31
				4000	0.027597	0
0	9999999	0.02621715	0.02755978			41030.31
0	9999999	0.02621715	0.02755978			0
0	9999999	516.5171	785.8256	28000	6332.309	3572612
0	9999999	708.6732	605.8899	24000	7898.202	3445073
0	9999999	37.68335	782.7668	12000	338.6935	275955.3
0	9999999	2.335579	1.988347	4000	0.01123654	3855.078
				4000	7.254551	203.1547
	9999999	0	525.5354	12000	585.2216	34295.08
				24000	8602.145	2766490
	9999999	0	110.6281	28000	7208.259	2738312
0	9999999	1936.084	2799.05	20000	665.4401	7203789
0	9999999	2739.021	2341.837	4000	2.89E-17	7634033
	9999999	0	589.9927	20000	1292.048	6615115
				4000	31.42027	7605272

C.3 Results with EV

The results from running the HOMER Pro calculation with an extra added electrical load that represents the extra demand if all land vehicles is converted to electric vehicles, is presented below. Each row represents a feasible technical solution for a new energy system. The solutions marked in green are the ones presented in the case analysis, as, numbered from the top of the table, case 3, case 2, case 1, case 5 and case 4. The other solutions were not examined further. Note that there are some changes in the system architecture for the different systems.

Inst./PV (kW)	Inst./Wind (x1.5 MW)	Inst./Genset (kW)	Inst./Coal (kW)	Inst./Pellets (kW)	Inst./Batt (x1 MWh)	Inst./El. boiler (kW)	Inst./Conv (kW)	Inst./Dispatch	Cost/NPC (kr)	Cost/COE (kr)
	14	15000	7500		5	16000	9999999	CC	9.57E+08	-0.3115616
15000	14	15000	7500		5	28000	9999999	CC	1.03E+09	-0.2130856
	14	15000	7500			16000		CC	1.10E+09	-0.1258504
15000	14	15000	7500			28000	9999999	LF	1.15E+09	-0.0677416
	14	15000	7500	7500	5	16000	9999999	CC	1.19E+09	-0.010543
	14	15000	7500	7500		16000		CC	1.20E+09	0.0038661
15000	14	15000	7500	7500	5	28000	9999999	CC	1.27E+09	0.0871057
15000	14	15000	7500	7500		28000	9999999	LF	1.28E+09	0.0997129
	14	15000		7500	5	16000	9999999	CC	1.34E+09	0.1815536
15000	14	15000		7500	5	28000	9999999	CC	1.41E+09	0.2708595
15000		15000	7500		5	12000	9999999	CC	1.46E+09	0.328208
		15000	7500		5		9999999	CC	1.47E+09	0.3414783
		15000	7500		5	4000	9999999	CC	1.47E+09	0.3469181
	14	15000		10000		16000		CC	1.50E+09	0.3764035
15000	14	15000		7500		28000	9999999	LF	1.54E+09	0.4337239
15000		15000	7500	7500	5	12000	9999999	CC	1.69E+09	0.6240386
		15000	7500	7500	5		9999999	CC	1.70E+09	0.6373152
		15000	7500	7500	5	4000	9999999	CC	1.71E+09	0.642755
15000		15000	7500	10000		12000	9999999	CC	1.81E+09	0.7793481
15000	14	15000			15	28000	9999999	CC	1.82E+09	0.7867552
		15000	7500	10000				CC	1.82E+09	0.7931216
		15000	7500	10000		4000		CC	1.83E+09	0.7985613
	18	15000			15	24000	9999999	CC	1.84E+09	0.8079035
15000		15000		7500	5	12000	9999999	CC	1.86E+09	0.8444205
		15000		7500	10		9999999	CC	1.88E+09	0.8648295
		15000		7500	5	4000	9999999	CC	1.88E+09	0.8660759
		15000		10000		4000		CC	2.06E+09	1.096542
15000		15000		10000		12000	9999999	CC	2.07E+09	1.109404
20000		15000	7500			16000	9999999	CC	2.19E+09	1.255338
	18	15000				24000		CC	2.36E+09	1.47958
		15000	7500			4000		LF	2.38E+09	1.498864
15000	14	15000				28000	9999999	LF	2.43E+09	1.567692
25000		15000			20	20000	9999999	CC	3.44E+09	2.85761
		15000			20	4000	9999999	CC	3.82E+09	3.344118
25000		15000				20000	9999999	CC	4.13E+09	3.727994
		15000				4000		LF	4.30E+09	3.945722

Cost/Operating cost (kr/yr)	Cost/Initial capital (kr)	Cost/Fuel cost (kr/yr)	Cost/O&M (kr/yr)	System/Ren Frac (%)	System/Unmet load (%)	System/CO2 (kg/yr)	Genset/Hours	Genset/Production (kWh)	Genset/Fuel (L)
3.54E+07	3.45E+08	1.01E+07	2.14E+07	29.77301	3.93E-16	3.55E+07	0.2333333	954.4847	276.5759
3.18E+07	4.85E+08	9392310	1.91E+07	42.17635	4.33E-16	2.91E+07	0.5333334	3575.742	961.1384
4.50E+07	3.25E+08	1.42E+07	2.22E+07	32.39706	3.55E-16	3.49E+07	687.0667	2591948	762813.1
3.95E+07	4.66E+08	1.20E+07	2.04E+07	41.4379	3.92E-16	3.02E+07	515.5333	1942816	571891
2.96E+07	6.82E+08	1.01E+07	2.14E+07	29.77066	3.93E-16	3.55E+07	0	0	0
3.14E+07	6.63E+08	1.16E+07	2.14E+07	25.38715	3.74E-16	3.50E+07	0	0	0
2.59E+07	8.22E+08	9388966	1.91E+07	42.16645	4.33E-16	2.91E+07	0	0	0
2.76E+07	8.03E+08	9923312	1.99E+07	36.23151	4.09E-16	3.03E+07	0	0	0
3.83E+07	6.82E+08	3.19E+07	4549055	41.3379	2.19E-16	1068734	6.2	23656.24	6946.495
3.42E+07	8.22E+08	2.73E+07	5466720	51.16481	3.39E-16	1358991	6.033333	23836.64	6952.392
7.15E+07	2.23E+08	1.87E+07	4.54E+07	0	6.59E-16	8.40E+07	17.53333	65750	19373.29
8.02E+07	8.28E+07	2.03E+07	5.15E+07	0	9.67E-19	9.79E+07	17.53333	65750	19373.29
8.03E+07	8.58E+07	2.03E+07	5.15E+07	0	9.67E-19	9.79E+07	17.53333	65750	19373.29
4.17E+07	7.75E+08	3.66E+07	4740150	30.24528	1.54E-16	211757.8	24.93333	93500	27549.85
4.27E+07	8.03E+08	3.08E+07	6781105	49.04251	2.51E-16	2204092	515.5333	1942859	571901.1
6.54E+07	5.61E+08	1.86E+07	4.53E+07	0	6.58E-16	8.40E+07	0	0	0
7.41E+07	4.20E+08	2.03E+07	5.15E+07	0	2.07E-19	9.79E+07	0	0	0
7.42E+07	4.23E+08	2.03E+07	5.15E+07	0	2.07E-19	9.79E+07	0	0	0
6.70E+07	6.54E+08	4.11E+07	2.82E+07	0	6.48E-16	4.87E+07	0	0	0
7.49E+07	5.24E+08	4.85E+07	1.35E+07	61.32555	1.28E-15	1.67E+07	892.5333	1.02E+07	2600061
7.58E+07	5.13E+08	4.87E+07	2.93E+07	0	0	5.24E+07	0	0	0
7.59E+07	5.16E+08	4.87E+07	2.93E+07	0	0	5.24E+07	0	0	0
7.95E+07	4.61E+08	5.10E+07	1.39E+07	60.78132	1.37E-15	1.76E+07	1053.567	1.22E+07	3110239
7.54E+07	5.61E+08	6.88E+07	4202070	0	5.15E-16	189947.4	123.5667	496473.8	144344.3
8.33E+07	4.40E+08	7.76E+07	2850280	0	9.76E-17	-879245.5	3.633333	13794.74	4054.672
8.43E+07	4.23E+08	7.82E+07	3143360	0	9.64E-17	-477021.8	138.3	567822.8	164422.8
8.94E+07	5.16E+08	8.30E+07	4165086	0	2.14E-17	-329525	213.4667	807398.8	237495.9
8.20E+07	6.54E+08	7.50E+07	5096182	0	4.17E-16	-198400.5	204.2667	772898.8	227330.5
1.12E+08	2.51E+08	3.89E+07	4.34E+07	0	4.85E-16	7.11E+07	2917.933	1.11E+07	3258175
1.13E+08	4.02E+08	6.15E+07	2.03E+07	61.49533	2.06E-17	2.12E+07	4447	1.84E+07	5331705
1.34E+08	6.63E+07	4.70E+07	4.91E+07	0	0	8.26E+07	3660.467	1.39E+07	4091300
1.14E+08	4.66E+08	6.14E+07	2.07E+07	61.6578	1.12E-16	2.12E+07	4539.933	1.84E+07	5329756
1.77E+08	3.75E+08	1.27E+08	2.81E+07	8.743966	4.84E-15	4.38E+07	2603.3	3.77E+07	9458101
2.13E+08	1.44E+08	1.53E+08	3.22E+07	0	6.07E-15	5.28E+07	3445.3	4.99E+07	1.25E+07
2.21E+08	2.97E+08	1.34E+08	3.70E+07	12.48322	1.47E-16	4.61E+07	8189.867	3.91E+07	1.10E+07
2.45E+08	6.63E+07	1.51E+08	3.93E+07	0	0	5.22E+07	8760	4.42E+07	1.23E+07

Genset/O&M Cost (kr/yr)	Genset/Fuel Cost (kr/yr)	Coal/Hours	Coal/Production (kWh)	Coal/Fuel (kg)	Coal/O&M Cost (kr/yr)	Coal/Fuel Cost (kr/yr)	Pellets/Hours	Pellets/Production (kWh)	Pellets/Fuel (kg)	Pellets/O&M Cost (kr/yr)	Pellets/Fuel Cost (kr/yr)
350	2099.211	4425	1.44E+07	1.34E+07	1181440	7112136					
800	7295.04	3814.6	1.14E+07	1.08E+07	1018451	5741093					
1030600	5789751	4958.5	1.28E+07	1.26E+07	1323879	6672685					
773300	4340653	4595.7	1.09E+07	1.09E+07	1227015	5798622					
0	0	4425	1.44E+07	1.34E+07	1181440	7112142	0.233333	954.4847	973.5878	79.8	1757.326
0	0	4968.9	1.40E+07	1.35E+07	1326638	7138954	687.0667	1288250	1648960	234976.8	2976373
0	0	3814.8	1.14E+07	1.08E+07	1018513	5741939	0.5	1630.737	1754.59	171	3167.035
0	0	4602.3	1.18E+07	1.16E+07	1228777	6143367	515.5333	966625	1237280	176312.4	2233291
9300	52723.89						4346	1.44E+07	1.54E+07	1486332	2.78E+07
9050	52768.65						3724.033	1.14E+07	1.25E+07	1273619	2.25E+07
26300	147043.3	8143.8	3.69E+07	3.25E+07	2174322	1.72E+07					
26300	147043.3	8760	4.38E+07	3.81E+07	2338833	2.02E+07					
26300	147043.3	8760	4.38E+07	3.81E+07	2338833	2.02E+07					
37400	209103.4						4917.7	1.67E+07	1.93E+07	2242471	3.48E+07
773300	4340730						4578.533	1.12E+07	1.31E+07	1565858	2.36E+07
0	0	8143.9	3.69E+07	3.26E+07	2174340	1.73E+07	17.53333	33711.27	42749.01	5996.4	77161.97
0	0	8760	4.38E+07	3.81E+07	2338833	2.02E+07	17.53333	33711.27	42749.01	5996.4	77161.97
0	0	8760	4.38E+07	3.81E+07	2338833	2.02E+07	17.53333	33711.27	42749.01	5996.4	77161.97
0	0	5757.4	2.08E+07	1.91E+07	1537177	1.01E+07	3010.067	1.68E+07	1.71E+07	1372590	3.08E+07
1338800	1.97E+07										
0	0	5313	2.32E+07	2.06E+07	1418518	1.09E+07	3660.467	2.07E+07	2.09E+07	1669173	3.78E+07
0	0	5313	2.32E+07	2.06E+07	1418518	1.09E+07	3660.467	2.07E+07	2.09E+07	1669173	3.78E+07
1580350	2.36E+07										
185350	1095573						8104.067	3.66E+07	3.65E+07	2771591	6.60E+07
5450	30774.96						8640.767	4.40E+07	4.29E+07	2955142	7.75E+07
207450	1247969						8753.7	4.34E+07	4.26E+07	2993766	7.69E+07
320200	1802594						8758	4.31E+07	4.50E+07	3993648	8.12E+07
306400	1725438						8560.267	3.78E+07	4.05E+07	3903482	7.31E+07
4376900	2.47E+07	8306.5	2.56E+07	2.42E+07	2217744	1.28E+07					
6670500	4.05E+07										
5490700	3.11E+07	8662	3.02E+07	2.78E+07	2312676	1.48E+07					
6809900	4.05E+07										
3904950	7.18E+07										
5167950	9.51E+07										
1.23E+07	8.37E+07										
1.31E+07	9.37E+07										

PV/Capital Cost (kr)	PV/Production (kWh/yr)	Wind/Capital Cost (kr)	Wind/Production (kWh/yr)	Wind/O&M Cost (kr)	Batt/Quantity	Batt/Autonomy (hr)	Batt/Annual Throughput (kWh/yr)	Batt/Operating hours (hours)
		2.50E+08	7.59E+07	2290400	5	0.8093017	127599.8	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.8093017	212144.2	0
		2.50E+08	7.59E+07	2290400				
1.31E+08	9913834	2.50E+08	7.59E+07	2290400				
		2.50E+08	7.59E+07	2290400	5	0.8093017	127672.1	0
		2.50E+08	7.59E+07	2290400				
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.8093017	212142.9	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400				
		2.50E+08	7.59E+07	2290400	5	0.8093017	200952.3	0
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	5	0.8093017	306826.2	0
1.31E+08	9913834				5	0.8093017	176379.4	0
					5	0.8093017	17472.22	0
					5	0.8093017	17472.22	0
		2.50E+08	7.59E+07	2290400				
1.31E+08	9913834	2.50E+08	7.59E+07	2290400				
1.31E+08	9913834				5	0.8093017	172966.5	0
					5	0.8093017	15913.07	0
					5	0.8093017	15913.07	0
1.31E+08	9913834							
1.31E+08	9913834	2.50E+08	7.59E+07	2290400	15	2.427905	6544055	0
		3.21E+08	9.75E+07	2944800	15	2.427905	7405039	0
1.31E+08	9913834				5	0.8093017	729454.1	0
					10	1.618603	492741.6	0
					5	0.8093017	529419	0
1.31E+08	9913834							
1.75E+08	1.32E+07							
		3.21E+08	9.75E+07	2944800				
1.31E+08	9913834	2.50E+08	7.59E+07	2290400				
2.19E+08	1.65E+07				20	3.237207	2.29E+07	0
					20	3.237207	2.88E+07	0
2.19E+08	1.65E+07							

Batt/Nominal Capacity (kWh)	Batt/Usable Nominal Capacity (kWh)	Conv/Capacity	Conv/Rectifier Mean Output (kW)	Conv/Inverter Mean Output (kW)	El. boiler/Capacity	El. boiler/Mean Output (kW)	BOILER/Fuel Consumption (L)
0	0	9999999	15.36413	13.12776	16000	5287.087	396333.2
0	0	9999999	15.61091	315.0152	28000	6064.193	480095.2
					16000	5410.983	234719.5
		9999999	0	235.2855	28000	6238.331	240240.9
0	0	9999999	15.37284	13.1352	16000	5287.087	396333.2
					16000	5395.12	195316.4
0	0	9999999	15.60412	315.0083	28000	6064.194	480086.9
		9999999	0	239.2949	28000	6225.084	203775.3
0	0	9999999	24.19066	20.67444	16000	5291.908	526928.3
0	0	9999999	23.8109	320.8243	28000	6067.972	613923.3
0	0	9999999	12.2239	804.9748	12000	294.4659	172399.1
0	0	9999999	2.112464	1.797583			0
0	0	9999999	2.112464	1.797583	4000	0	0
					16000	5571.402	210365.2
		9999999	0	225.2563	28000	6274.299	376792.1
0	0	9999999	11.83721	804.6276	12000	294.4857	172363.5
0	0	9999999	1.924851	1.637174			0
0	0	9999999	1.924851	1.637174	4000	0	0
		9999999	0	712.3976	12000	381.824	29159
0	0	9999999	711.8724	990.2118	28000	5777.808	3785879
							0
					4000	0	0
0	0	9999999	891.0548	761.8476	24000	7342.357	3609810
0	0	9999999	68.4045	850.6171	12000	295.9468	225805
0	0	9999999	59.31175	50.6944			9820.667
0	0	9999999	63.71513	54.46786	4000	6.08E-20	380.2961
					4000	0.1691286	2813.725
		9999999	0	608.3464	12000	491.4441	26639.77
		9999999	0	833.7877	16000	645.1097	176827.9
					24000	8231.911	2768850
					4000	27.84938	157197.8
		9999999	0	101.2719	28000	6873.111	2764746
0	0	9999999	2559.537	3404.488	20000	586.5963	7258094
0	0	9999999	3464.419	2962.044	4000	8.44E-18	7634033
		9999999	0	570.6351	20000	1308.603	6606271
					4000	32.87881	7603126

D | eTransport

D.1 Input

eTransport has a function called "Export input data to excel". The output file of this function is too extensive to be featured in the appendix, but parts of it necessary to recreate the eTransport analysis is presented below.

El load, heat load, wind production and PV production

Timestep	Heat load (kW)	Heat load peak (kW)	El load (kW)	El load power plant (MW)	El load peak (kW)	Wind winterPeak 21 MW (kW)	Wind springAutumn 21 MW (kW)	Wind summer 21 MW (kW)	PV springAutumn 15 MW (kW)	PV summer 15 MW (kW)
1	5 347	11 770	3 814	0,200	4 710	10 730	7 057	5 919	0,000	3 002
2	5 262	11 610	3 756	0,200	4 590	10 766	7 128	5 908	0,000	3 387
3	5 226	11 560	3 706	0,200	4 560	10 783	7 219	5 914	0,000	4 005
4	5 193	11 390	3 688	0,200	4 920	10 742	7 191	5 906	0,011	4 983
5	5 195	11 290	3 663	0,200	4 940	10 689	7 129	5 919	0,147	6 549
6	5 203	11 180	3 670	0,200	5 040	10 713	7 109	5 932	0,383	8 273
7	25 420	11 480	3 879	0,200	5 330	10 690	7 051	5 916	0,755	10 141
8	5 781	12 230	4 212	0,200	5 720	10 660	6 974	5 907	1 196	11 908
9	6 016	9 850	4 725	0,200	6 020	10 608	6 915	5 919	1 825	13 632
10	6 068	8 400	4 942	0,200	6 350	10 331	6 702	5 816	2 540	15 152
11	5 937	11 640	5 025	0,200	6 520	10 312	6 570	5 786	3 014	16 084
12	6 006	12 090	4 969	0,200	6 480	10 209	6 465	5 761	3 138	16 082
13	5 911	14 410	4 925	0,200	6 520	10 197	6 436	5 763	3 021	16 125
14	5 834	13 710	5 040	0,200	6 600	10 302	6 454	5 778	2 818	15 855
15	5 791	13 380	5 103	0,200	7 905	10 400	6 491	5 798	2 484	14 684
16	5 786	13 430	4 938	0,200	3 710	10 506	6 652	5 920	1 914	13 134
17	5 849	13 440	4 875	0,200	6 320	10 582	6 792	6 036	1 345	11 212
18	5 881	13 370	4 820	0,200	6 215	10 558	6 815	6 101	0,733	9 626
19	5 833	13 240	4 738	0,200	5 995	10 498	6 817	6 131	0,336	7 983
20	5 795	12 900	4 613	0,200	5 900	10 441	6 809	6 139	0,122	6 355
21	5 705	12 730	4 468	0,200	5 670	10 397	6 793	6 122	0,004	5 089
22	5 687	12 520	4 465	0,200	4 745	10 448	6 824	6 050	0,000	4 081
23	5 579	12 210	4 301	0,200	4 745	10 549	6 885	6 001	0,000	3 581
24	5 525	12 180	4 026	0,200	4 470	10 613	6 965	5 935	0,000	3 218

Segment info

Segment	Weight	El_coefficient__dwellings	El_load_coefficient	El_price_coefficient	Gas_load_coefficient	Gas_price_coefficient	Heat_coefficient__dwellings	Heat_load_coefficient	Oil_price_coefficient	Storage_Capacity_Factor	Temperature_coefficient	Warm_water_coefficient__dwellings	Warm_water_load_coefficient
Summer	158	1	1	1	1	1	1	1	1	1	1	1	1
Winter	64	1	1.237	1	1	1	1	1.603	1	1	1	1	1
SpringAutumn	142	1	1.131	1	1	1	1	1.433	1	1	1	1	1
Peak	1	1	1	1	1	1	1	1	1	1	1	1	1

Year info

Year	El_change_factor	El_change_factor__dwellings	El_price_change_factor	Gas_change_factor	Gas_price_change_factor	Heat_change_factor	Heat_change_factor__dwellings	Oil_price_change_factor	Warm_water_change_factor	Warm_water_change_factor__dwellings
2021	0.94199	1	1	1	1	0.996983	1	1	1	1
2036	0.767199	1	1	1	1	0.883456	1	1	1	1
2050	0.765287	1	1	1	1	0.84432	1	1	1	1

Costs of investment packages

	Annual expenses	Cost	Life
Pellets plant	1,200,000,000	225,000,000,000	30
Battery 5 MWh 2021	217,910,000	19,495,000,000	10
Battery 5 MWh 2036	164,655,000	14,157,000,000	10
Electric boiler	112,000,000	21,448,000,000	20
Coal (pre-existing)	6,704,780,000	0,000	15
Steam accumulator	147,000,000	29,500,000,000	40
Hydrogen from 2036	13,513,600,000	430,497,000,000	15
Wind 21 MW 2021	2,289,000,000	249,522,000,000	20
Wind 21 MW 2036	1,848,000,000	201,726,000,000	20
PV 15 MW 2021	1,110,000,000	221,520,000,000	30
PV 15 MW 2036	615,000,000	122,220,000,000	30
Extra diesel genset	5,552,400,000	50,622,000,000	30
Extra diesel boiler	7,403,200,000	67,496,000,000	30
Battery 15 MWh 2021	653,730,000	58,485,000,000	10
Battery 15 MWh 2036	493,965,000	42,471,000,000	10

Table D.1: Costs of investment packages

D.2 Results

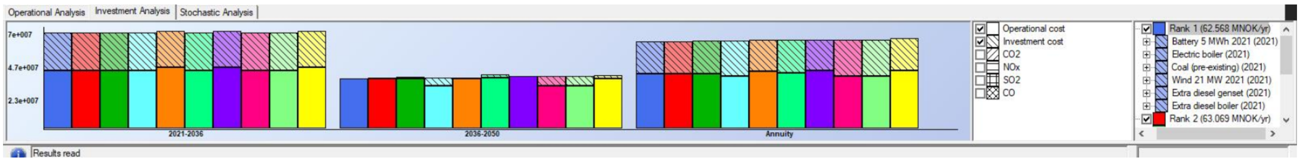


Figure D.2.1: eTransport analysis results

Figure D.2.1 show the economic results of the optimal eTransport investment plan, as presented in the Visio interface.

eTransport has a function called "Export output data to excel". The following tables are the main content of this export file. "Investment plans" show the technology composition, investment times and associated costs and emissions for the 10 best solutions. For the best solution, Rank1, detailed production data is presented for all four segments (summer, winter, spring/autumn and peak) in the two time periods 2021-2036 and 2036-2050.

Column1	Invest_2021	Invest_2036	Invest_2050	OpCost_2021	OpCost_2036	OpCost_2050
Name	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler			41433421.99	35855183.44	39506976.87
Rank 1	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Battery 5 MWh 2036		41433421.99	36019838.44	39563840.48
Rank 2	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Steam accumulator		41433421.99	36002183.44	39557743.33
Rank 3	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	PV 15 MW 2036		41433421.99	30676567.84	37718541.56
Rank 4	Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Battery 5 MWh 2036		44146813.22	35801928.44	41264906.6
Rank 5	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Battery 5 MWh 2036, Steam accumulator		41433421.99	36166838.44	39614606.95
Rank 6	Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler			44146813.22	37427910.67	41826439.69
Rank 7	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Battery 5 MWh 2036, PV 15 MW 2036		41433421.99	30841222.84	37775405.17
Rank 8	Battery 5 MWh 2021, Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Steam accumulator, PV 15 MW 2036		41433421.99	30823567.84	37769308.02
Rank 9	Electric boiler, Coal (pre-existing), Wind 21 MW 2021, Extra diesel genset, Extra diesel boiler	Battery 5 MWh 2036, Steam accumulator		44146813.22	35948928.44	41315673.06
Rank 10						

InvCost_2021	InvCost_2036	InvCost_2050	Emit_CO2_2021	Emit_CO2_2036	Emit_CO2_2050
27154700.66	0	23060581.56	26149248.96	18368327.23	22258788.1
27154700.66	1011214.286	23505627.78	26149248.96	18368327.23	22258788.1
27154700.66	1316208.235	23639858.88	26149248.96	18368327.23	22258788.1
27154700.66	6041276.014	25719411.74	26149248.96	10166601.95	18157925.46
25855033.99	1011214.286	22401912.09	25270657.52	18368327.23	21819492.37
27154700.66	2327422.52	24084905.1	26149248.96	18368327.23	22258788.1
25855033.99	0	21956865.87	25270657.52	17833680.42	21552168.97
27154700.66	7052490.3	26164457.97	26149248.96	10166601.95	18157925.46
27154700.66	7357484.249	26298689.07	26149248.96	10166601.95	18157925.46
25855033.99	2327422.52	22981189.41	25270657.52	18368327.23	21819492.37

Name	Unit	1	2	3	4	5
Battery 5 MWh, Battery Variable		1005.88	1005.88	1005.88	1005.88	1005.88
Electric boiler, Fuel consumption	MWh/h	2.72396	2.7408	2.77543	2.77532	2.80499
Boiler in coal plant, Fuel consumption	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	2.66948	2.68599	2.71992	2.71982	2.74889
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	0.80751	0.77689	0.7558	0.74588	0.73772
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	0.76501	0.736	0.71602	0.70662	0.69889
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	4.25003	4.08891	3.9779	3.92569	3.88272
Extra diesel genset, Fuel consumption	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	2.67752	2.57601	2.50608	2.47318	2.44611
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11484, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11082, LoadPower		0.00509	0.00501	0.00498	0.00495	0.00495
DH_Load_points_11484, LoadPower		0	0	0	0	0
DH_Pipe_lines_11084, DH_Waterflow		0.03637	0.0358	0.03555	0.03533	0.03534
DH_Pipe_lines_11263, DH_Waterflow		0.03637	0.0358	0.03555	0.03533	0.03534
DH_Pipe_lines_11485, DH_Waterflow		0	0	0	0	0
DH_Pipe_lines_11084, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11263, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11485, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0.02312	0.02272	0.02255	0.0224	0.02241
DH_Pipe_lines_11263, PipePower		0.02312	0.02272	0.02255	0.0224	0.02241
DH_Pipe_lines_11485, PipePower		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		5.347	5.262	5.226	5.193	5.195

DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		5.347	5.262	5.226	5.193	5.195
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		5.347	5.262	5.226	5.193	5.195
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		5.347	5.262	5.226	5.193	5.195
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081, DH_deficit1	MWh/h	0	0	0	0	0
DH_Production_points_11081, DH_dump_load	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	3.814	3.756	3.706	3.688	3.663
El load power plant, El load	MWh/h	0.1884	0.1884	0.1884	0.1884	0.1884
Wind summer 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind summer 21 MW, El usage	MWh/h	5.91885	5.90831	5.91403	5.90584	5.91867
Wind summer 21 MW, Max outtake	MW	5.91885	5.90831	5.91403	5.90584	5.91867
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	5.347	5.262	5.226	5.193	5.195
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	4.25003	4.08891	3.9779	3.92569	3.88272
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
1005.88	1000	1000	1000	1000	1000	1000	1000	1000	1000
2.81169	11.6531	2.5085	2.17696	1.9419	1.8243	1.86365	1.87711	1.78267	1.7392
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2.75546	11.42	2.45833	2.13342	1.90307	1.78782	1.82638	1.83956	1.74701	1.70442
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.73815	4.22222	1.00208	1.17094	1.25609	1.25134	1.26052	1.22789	1.23258	1.23246
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.6993	4	0.94934	1.10931	1.18998	1.18548	1.19418	1.16327	1.16771	1.1676
0	0	0	0	0	0	0	0	0	0
3.88499	22.2222	5.27408	6.16283	6.61101	6.58601	6.63432	6.4626	6.48728	6.48664
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2.44754	14	3.32267	3.88258	4.16494	4.14918	4.17962	4.07144	4.08699	4.08658
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.00496	0.02421	0.00551	0.00573	0.00578	0.00565	0.00572	0.00563	0.00556	0.00552
0	0	0	0	0	0	0	0	0	0
0.0354	0.17293	0.03933	0.04093	0.04128	0.04039	0.04086	0.04021	0.03969	0.0394
0.0354	0.17293	0.03933	0.04093	0.04128	0.04039	0.04086	0.04021	0.03969	0.0394
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.02244	0.11773	0.02517	0.02627	0.02652	0.0259	0.02623	0.02578	0.02542	0.02521
0.02244	0.11773	0.02517	0.02627	0.02652	0.0259	0.02623	0.02578	0.02542	0.02521
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5.203	25.42	5.781	6.016	6.068	5.937	6.006	5.911	5.834	5.791

5.203	25.42	5.781	6.016	6.068	5.937	6.006	5.911	5.834	5.791
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5.203	25.42	5.781	6.016	6.068	5.937	6.006	5.911	5.834	5.791
5.203	25.42	5.781	6.016	6.068	5.937	6.006	5.911	5.834	5.791
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.67	3.879	4.212	4.725	4.942	5.025	4.969	4.925	5.04	5.103
0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884
0	0	0	0	0	0	0	0	0	0
5.93194	5.91612	5.90682	5.91942	5.81621	5.78636	5.76053	5.76261	5.77848	5.79814
5.93194	5.91612	5.90682	5.91942	5.81621	5.78636	5.76053	5.76261	5.77848	5.79814
0	0	0	0	0	0	0	0	0	0
5.203	25.42	5.781	6.016	6.068	5.937	6.006	5.911	5.834	5.791
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
3.88499	22.2222	5.27408	6.16283	6.61101	6.58601	6.63432	6.4626	6.48728	6.48664
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
1000	1000	1000	1000	1000	1003.02	1005.88	1005.88	1005.88
1.95967	2.11203	2.21256	2.28733	2.3811	0	0.07402	2.46565	2.61449
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.92047	2.06979	2.16831	2.24158	2.33347	0	0.07254	2.41634	2.5622
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.16579	1.13976	1.1197	1.08313	1.04395	1.72056	1.69325	0.95382	0.89354
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.10444	1.07978	1.06077	1.02612	0.98901	1.63	1.60413	0.90362	0.84651
0	0	0	0	0	0	0	0	0
6.13576	5.99875	5.89316	5.70066	5.49449	9.05556	8.91185	5.0201	4.70285
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
3.86553	3.77922	3.71269	3.59142	3.46153	5.705	5.61446	3.16266	2.9628
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.00551	0.00557	0.0056	0.00556	0.00552	0.00543	0.00542	0.00531	0.00526
0	0	0	0	0	0	0	0	0
0.03936	0.03979	0.04001	0.03968	0.03942	0.03881	0.03869	0.03795	0.03759
0.03936	0.03979	0.04001	0.03968	0.03942	0.03881	0.03869	0.03795	0.03759
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.02519	0.02549	0.02564	0.02541	0.02523	0.02481	0.02472	0.02422	0.02396
0.02519	0.02549	0.02564	0.02541	0.02523	0.02481	0.02472	0.02422	0.02396
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.786	5.849	5.881	5.833	5.795	5.705	5.687	5.579	5.525

5.786	5.849	5.881	5.833	5.795	5.705	5.687	5.579	5.525
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.786	5.849	5.881	5.833	5.795	5.705	5.687	5.579	5.525
5.786	5.849	5.881	5.833	5.795	5.705	5.687	5.579	5.525
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
4.938	4.875	4.82	4.738	4.613	4.468	4.465	4.301	4.026
0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884	0.1884
0	0	0	0	0	0	0	0	0
5.92027	6.03566	6.10126	6.1306	6.13854	6.12209	6.05027	6.00123	5.93535
5.92027	6.03566	6.10126	6.1306	6.13854	6.12209	6.05027	6.00123	5.93535
0	0	0	0	0	0	0	0	0
5.786	5.849	5.881	5.833	5.795	5.705	5.687	5.579	5.525
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
6.13576	5.99875	5.89316	5.70066	5.49449	9.05556	8.91185	5.0201	4.70285
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	**Unit**	**1**	**2**	**3**	**4**	**5**
Battery 5 MWh, Battery Variable		1010.3	1010.3	1018.35	1018.35	1018.35
Electric boiler, Fuel consumption	MWh/h	0	6.50745	0	6.52787	6.51197
Boiler in coal plant, Fuel consumption	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	0	6.3773	0	6.39732	6.38173
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	2.58498	0.62057	2.52648	0.58118	0.58685
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	2.44893	0.58791	2.39351	0.55059	0.55596
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	13.6051	3.26617	13.2973	3.05883	3.08866
Extra diesel genset, Fuel consumption	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	8.57124	2.05768	8.37728	1.92706	1.94586
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11484, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11082, LoadPower		0.00816	0.00803	0.00798	0.00793	0.00793
DH_Load_points_11484, LoadPower		0	0	0	0	0
DH_Pipe_lines_11084, DH_Waterflow		0.05831	0.05738	0.05699	0.05663	0.05665
DH_Pipe_lines_11263, DH_Waterflow		0.05831	0.05738	0.05699	0.05663	0.05665
DH_Pipe_lines_11485, DH_Waterflow		0	0	0	0	0
DH_Pipe_lines_11084, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11263, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11485, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0.03832	0.03768	0.0374	0.03715	0.03717
DH_Pipe_lines_11263, PipePower		0.03832	0.03768	0.0374	0.03715	0.03717
DH_Pipe_lines_11485, PipePower		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		8.57124	8.43499	8.37728	8.32438	8.32759
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		8.57124	8.43499	8.37728	8.32438	8.32759
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		8.57124	8.43499	8.37728	8.32438	8.32759
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		8.57124	8.43499	8.37728	8.32438	8.32759
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081, DH_deficit1	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	4.71792	4.64617	4.58432	4.56206	4.53113
El load power plant, El load	MWh/h	0.23305	0.23305	0.23305	0.23305	0.23305
Wind winterPeak 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind winterPeak 21 MW, El usage	MWh/h	10.7301	10.7661	10.783	10.7418	10.6893
Wind winterPeak 21 MW, Max outtake	MW	10.7301	10.7661	10.783	10.7418	10.6893
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	8.57124	8.43499	8.37728	8.32438	8.32759
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	13.6051	3.26617	13.2973	3.05883	3.08866
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15	16
1018.35	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
6.52656	27.2941	6.18353	5.74134	5.3399	5.19741	5.19674	5.19412	5.13686	5.136	5.37326
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
6.39603	26.7483	6.05986	5.62652	5.2331	5.09346	5.09281	5.09024	5.03412	5.03328	5.26579
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.5864	4.22222	0.96722	1.21152	1.3553	1.33409	1.36764	1.32249	1.30219	1.28166	1.20911
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.55554	4	0.91631	1.14775	1.28397	1.26387	1.29566	1.25289	1.23365	1.2142	1.14548
0	0	0	0	0	0	0	0	0	0	0
3.08632	22.2222	5.09062	6.3764	7.13318	7.0215	7.19811	6.96047	6.85362	6.74555	6.36375
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
1.94438	14	3.20709	4.01713	4.4939	4.42355	4.53481	4.3851	4.31778	4.2497	4.00916
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.00794	0.03881	0.00883	0.00918	0.00926	0.00906	0.00917	0.00902	0.00891	0.00884	0.00883
0	0	0	0	0	0	0	0	0	0	0
0.05674	0.2772	0.06304	0.0656	0.06617	0.06474	0.06549	0.06446	0.06362	0.06315	0.0631
0.05674	0.2772	0.06304	0.0656	0.06617	0.06474	0.06549	0.06446	0.06362	0.06315	0.0631
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.03723	0.18998	0.0416	0.04337	0.04377	0.04278	0.0433	0.04258	0.042	0.04167	0.04164
0.03723	0.18998	0.0416	0.04337	0.04377	0.04278	0.0433	0.04258	0.042	0.04167	0.04164
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
8.34041	40.7483	9.26694	9.64365	9.727	9.51701	9.62762	9.47533	9.3519	9.28297	9.27496
8.34041	40.7483	9.26694	9.64365	9.727	9.51701	9.62762	9.47533	9.3519	9.28297	9.27496
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
8.34041	40.7483	9.26694	9.64365	9.727	9.51701	9.62762	9.47533	9.3519	9.28297	9.27496
8.34041	40.7483	9.26694	9.64365	9.727	9.51701	9.62762	9.47533	9.3519	9.28297	9.27496
0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
4.53979	4.79832	5.21024	5.84483	6.11325	6.21593	6.14665	6.09223	6.23448	6.31241	6.10831
0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305
0	0	0	0	0	0	0	0	0	0	0
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998	10.5055
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998	10.5055
0	0	0	0	0	0	0	0	0	0	0
8.34041	40.7483	9.26694	9.64365	9.727	9.51701	9.62762	9.47533	9.3519	9.28297	9.27496
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
3.08632	22.2222	5.09062	6.3764	7.13318	7.0215	7.19811	6.96047	6.85362	6.74555	6.36375
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

17	18	19	20	21	22	23	24
1000	1000	1000	1000	1000	1000	1000	1002.36
5.51558	5.56198	5.57605	5.63737	5.70797	5.74379	5.93796	4.30617
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
5.40527	5.45074	5.46453	5.52463	5.59381	5.62891	5.8192	4.22005
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1.19751	1.19926	1.1719	1.1354	1.07103	1.05174	0.94214	1.39832
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1.13448	1.13615	1.11022	1.07565	1.01466	0.99639	0.89255	1.32472
0	0	0	0	0	0	0	0
6.30266	6.31192	6.1679	5.97581	5.637	5.53548	4.95864	7.35957
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
3.97068	3.97651	3.88577	3.76476	3.55131	3.48735	3.12394	4.63653
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0.00893	0.00898	0.00891	0.00885	0.00871	0.00868	0.00852	0.00844
0	0	0	0	0	0	0	0
0.06378	0.06413	0.06361	0.06319	0.06221	0.06202	0.06084	0.06025
0.06378	0.06413	0.06361	0.06319	0.06221	0.06202	0.06084	0.06025
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0.04211	0.04235	0.04199	0.0417	0.04102	0.04089	0.04007	0.03966
0.04211	0.04235	0.04199	0.0417	0.04102	0.04089	0.04007	0.03966
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
9.37595	9.42724	9.3503	9.28939	9.14512	9.11626	8.94314	8.85658
9.37595	9.42724	9.3503	9.28939	9.14512	9.11626	8.94314	8.85658
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
9.37595	9.42724	9.3503	9.28939	9.14512	9.11626	8.94314	8.85658
9.37595	9.42724	9.3503	9.28939	9.14512	9.11626	8.94314	8.85658
0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
6.03038	5.96234	5.86091	5.70628	5.52692	5.52321	5.32034	4.98016
0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305	0.23305
0	0	0	0	0	0	0	0
10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
0	0	0	0	0	0	0	0
9.37595	9.42724	9.3503	9.28939	9.14512	9.11626	8.94314	8.85658
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000
6.30266	6.31192	6.1679	5.97581	5.637	5.53548	4.95864	7.35957
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Name	**Unit**	**1**	**2**	**3**	**4**	**5**
Battery 5 MWh, Battery Variable		1017.088	1017.088	1017.088	1017.088	1017.088
Electric boiler, Fuel consumption	MWh/h	3.736872	3.813637	3.915463	3.898657	3.873177
Boiler in coal plant, Fuel	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	3.662135	3.737364	3.837154	3.820684	3.795714
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	1.206384	1.146961	1.101307	1.092013	1.100408
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	1.14289	1.086595	1.043344	1.034539	1.042492
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	6.349391	6.036637	5.796355	5.747437	5.791621
Extra diesel genset, Fuel	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	4.000116	3.803082	3.651704	3.620885	3.648721
Extra diesel genset, Heat	MWh/h	0	0	0	0	0
DH_Load_points_11082,	MWh/h	0	0	0	0	0
DH_Load_points_11484,	MWh/h	0	0	0	0	0
DH_Load_points_11082,		0.007297	0.007181	0.007132	0.007087	0.00709
DH_Load_points_11484,		0	0	0	0	0
DH_Pipe_lines_11084,		0.052124	0.051296	0.050945	0.050623	0.050642
DH_Pipe_lines_11263,		0.052124	0.051296	0.050945	0.050623	0.050642
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0	0	0	0	0
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084,		0.034033	0.033459	0.033216	0.032993	0.033007
DH_Pipe_lines_11263,		0.034033	0.033459	0.033216	0.032993	0.033007
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		7.662251	7.540446	7.488858	7.441569	7.444435
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		7.662251	7.540446	7.488858	7.441569	7.444435
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		7.662251	7.540446	7.488858	7.441569	7.444435
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		7.662251	7.540446	7.488858	7.441569	7.444435
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	4.313634	4.248036	4.191486	4.171128	4.142853
El load power plant, El load	MWh/h	0.213078	0.213078	0.213078	0.213078	0.213078
Wind springAutumn 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind springAutumn 21 MW, El	MWh/h	7.0572	7.12779	7.21872	7.19085	7.1287
Wind springAutumn 21 MW, Max	MW	7.0572	7.12779	7.21872	7.19085	7.1287
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	7.662251	7.540446	7.488858	7.441569	7.444435
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	6.349391	6.036637	5.796355	5.747437	5.791621
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
1017.088	1000	1000	1000	1000	1000	1000	1000	1000	1002.855
3.854174	22.88455	3.469733	3.054728	2.718815	2.500508	2.491405	2.475773	2.363132	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.77709	22.42686	3.400338	2.993633	2.664438	2.450498	2.441577	2.426257	2.315869	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1.109482	4.222222	1.472903	1.697121	1.818875	1.826781	1.859292	1.822856	1.82287	2.502723
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1.051088	4	1.395381	1.607799	1.723144	1.730635	1.761435	1.726916	1.726929	2.371001
0	0	0	0	0	0	0	0	0	0
5.839379	22.22222	7.752119	8.932214	9.573025	9.614639	9.785748	9.593977	9.594052	13.17223
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.678809	14	4.883835	5.627295	6.031006	6.057223	6.165021	6.044206	6.044253	8.298503
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.007101	0.034692	0.00789	0.00821	0.008281	0.008103	0.008197	0.008067	0.007962	0.007903
0	0	0	0	0	0	0	0	0	0
0.05072	0.247802	0.056355	0.058646	0.059153	0.057876	0.058548	0.057622	0.056872	0.056452
0.05072	0.247802	0.056355	0.058646	0.059153	0.057876	0.058548	0.057622	0.056872	0.056452
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.033061	0.169609	0.036965	0.038552	0.038903	0.038018	0.038484	0.037843	0.037323	0.037032
0.033061	0.169609	0.036965	0.038552	0.038903	0.038018	0.038484	0.037843	0.037323	0.037032
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7.455899	36.42686	8.284173	8.620928	8.695444	8.507721	8.606598	8.470463	8.360122	8.298503
7.455899	36.42686	8.284173	8.620928	8.695444	8.507721	8.606598	8.470463	8.360122	8.298503
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7.455899	36.42686	8.284173	8.620928	8.695444	8.507721	8.606598	8.470463	8.360122	8.298503
7.455899	36.42686	8.284173	8.620928	8.695444	8.507721	8.606598	8.470463	8.360122	8.298503
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4.15077	4.387149	4.763772	5.343975	5.589402	5.683275	5.619939	5.570175	5.70024	5.771493
0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078
0	0	0	0	0	0	0	0	0	0
7.10854	7.05143	6.97368	6.91466	6.70242	6.57008	6.46513	6.43617	6.45358	6.49148
7.10854	7.05143	6.97368	6.91466	6.70242	6.57008	6.46513	6.43617	6.45358	6.49148
0	0	0	0	0	0	0	0	0	0
7.455899	36.42686	8.284173	8.620928	8.695444	8.507721	8.606598	8.470463	8.360122	8.298503
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
5.839379	22.22222	7.752119	8.932214	9.573025	9.614639	9.785748	9.593977	9.594052	13.17223
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
1002.855	1002.855	1002.855	1002.855	1006.539	1006.539	1010.352	1012.737	1017.088
2.589473	2.773356	2.849589	2.907061	0	3.081196	0	1.316014	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2.537684	2.717888	2.792597	2.848919	0	3.019572	0	1.289693	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.735229	1.708109	1.699407	1.661677	2.504452	1.554892	2.457777	2.022147	2.387765
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.643901	1.618208	1.609965	1.57422	2.372639	1.473055	2.32842	1.915718	2.262093
0	0	0	0	0	0	0	0	0
9.132785	8.990045	8.944247	8.745666	13.18133	8.18364	12.93567	10.64288	12.56718
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.753654	5.663729	5.634876	5.50977	8.304235	5.155693	8.149471	6.705014	7.917325
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.007897	0.007982	0.008026	0.007961	0.007909	0.007786	0.007761	0.007614	0.00754
0	0	0	0	0	0	0	0	0
0.056404	0.057018	0.05733	0.056862	0.056491	0.055614	0.055439	0.054386	0.053859
0.056404	0.057018	0.05733	0.056862	0.056491	0.055614	0.055439	0.054386	0.053859
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.036998	0.037424	0.03764	0.037316	0.037059	0.036451	0.03633	0.0356	0.035236
0.036998	0.037424	0.03764	0.037316	0.037059	0.036451	0.03633	0.0356	0.035236
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.291338	8.381617	8.427473	8.358689	8.304235	8.175265	8.149471	7.994707	7.917325
8.291338	8.381617	8.427473	8.358689	8.304235	8.175265	8.149471	7.994707	7.917325
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.291338	8.381617	8.427473	8.358689	8.304235	8.175265	8.149471	7.994707	7.917325
8.291338	8.381617	8.427473	8.358689	8.304235	8.175265	8.149471	7.994707	7.917325
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.584878	5.513625	5.45142	5.358678	5.217303	5.053308	5.049915	4.864431	4.553406
0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078	0.213078
0	0	0	0	0	0	0	0	0
6.6522	6.79195	6.81468	6.81714	6.80862	6.79269	6.82442	6.88548	6.96545
6.6522	6.79195	6.81468	6.81714	6.80862	6.79269	6.82442	6.88548	6.96545
0	0	0	0	0	0	0	0	0
8.291338	8.381617	8.427473	8.358689	8.304235	8.175265	8.149471	7.994707	7.917325
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
9.132785	8.990045	8.944247	8.745666	13.18133	8.18364	12.93567	10.64288	12.56718
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	Unit	1	2	3	4	5
Battery 5 MWh, Battery Variable		5000	5000	5000	5000	5000
Electric boiler, Fuel consumption	MWh/h	7.241206	7.324372	7.348933	6.999685	6.920446
Boiler in coal plant, Fuel	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	7.096382	7.177884	7.201955	6.859692	6.782037
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	1.409504	1.33667	1.314331	1.366283	1.359544
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	1.335319	1.266319	1.245156	1.294374	1.287989
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	7.418442	7.035104	6.917533	7.190965	7.155496
Extra diesel genset, Fuel	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	4.673618	4.432116	4.358045	4.530308	4.507963
Extra diesel genset, Heat	MWh/h	0	0	0	0	0
DH_Load_points_11082,	MWh/h	0	0	0	0	0
DH_Load_points_11484,	MWh/h	0	0	0	0	0
DH_Load_points_11082,		0	0	0	0	0
DH_Load_points_11484,		0.01121	0.011057	0.01101	0.010848	0.010752
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0.080068	0.07898	0.078639	0.077483	0.076803
DH_Pipe_lines_11485,		0.080068	0.07898	0.078639	0.077483	0.076803
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0	0	0	0	0
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0	0	0	0	0
DH_Pipe_lines_11263, PipePower		0.053394	0.05264	0.052405	0.051603	0.051132
DH_Pipe_lines_11485, PipePower		0.053394	0.05264	0.052405	0.051603	0.051132
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		11.77	11.61	11.56	11.39	11.29
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		11.77	11.61	11.56	11.39	11.29
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		11.77	11.61	11.56	11.39	11.29
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		11.77	11.61	11.56	11.39	11.29
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load peak, Deficit	MWh	0	0	0	0	0
El load power plant, El load	MWh/h	0.188398	0.188398	0.188398	0.188398	0.188398
El load peak, El load	MWh/h	4.71	4.59	4.56	4.92	4.94
Wind winterPeak 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind winterPeak 21 MW, El usage	MWh/h	10.7301	10.7661	10.783	10.7418	10.6893
Wind winterPeak 21 MW, Max	MW	10.7301	10.7661	10.783	10.7418	10.6893
Heat load peak, Deficit	MWh/h	0	0	0	0	0
Heat load peak, Heat load	MWh/h	11.77	11.61	11.56	11.39	11.29
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	7.418442	7.035104	6.917533	7.190965	7.155496
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
6.835946	6.664496	6.514282	5.688631	4.88272	5.491373	5.547113	6.047116	5.903694	4.894919
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
6.699227	6.531206	6.383997	5.574858	4.785066	5.381545	5.43617	5.926174	5.78562	4.797021
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1.351344	1.492494	1.76308	1.289329	1.090218	1.887471	2.006711	2.558614	2.389892	2.588517
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1.280221	1.413941	1.670287	1.221469	1.032838	1.78813	1.901094	2.42395	2.264108	2.45228
0	0	0	0	0	0	0	0	0	0
7.112338	7.855229	9.27937	6.78594	5.737991	9.934055	10.56163	13.46639	12.57838	13.62378
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4.480773	4.948794	5.846003	4.275142	3.614934	6.258455	6.65383	8.483826	7.92438	8.582979
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.010648	0.010933	0.011648	0.009381	0.008	0.011086	0.011514	0.013724	0.013057	0.012743
0	0	0	0	0	0	0	0	0	0
0.076054	0.078095	0.083197	0.067007	0.057143	0.079184	0.082245	0.098027	0.093265	0.09102
0.076054	0.078095	0.083197	0.067007	0.057143	0.079184	0.082245	0.098027	0.093265	0.09102
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.050614	0.052028	0.055562	0.044345	0.037511	0.052782	0.054903	0.065837	0.062538	0.060983
0.050614	0.052028	0.055562	0.044345	0.037511	0.052782	0.054903	0.065837	0.062538	0.060983
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
11.18	11.48	12.23	9.85	8.4	11.64	12.09	14.41	13.71	13.38
11.18	11.48	12.23	9.85	8.4	11.64	12.09	14.41	13.71	13.38
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
11.18	11.48	12.23	9.85	8.4	11.64	12.09	14.41	13.71	13.38
11.18	11.48	12.23	9.85	8.4	11.64	12.09	14.41	13.71	13.38
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398
5.04	5.33	5.72	6.02	6.35	6.52	6.48	6.52	6.6	7.905
0	0	0	0	0	0	0	0	0	0
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
0	0	0	0	0	0	0	0	0	0
11.18	11.48	12.23	9.85	8.4	11.64	12.09	14.41	13.71	13.38
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
7.112338	7.855229	9.27937	6.78594	5.737991	9.934055	10.56163	13.46639	12.57838	13.62378
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
5000	5000	5000	5000	5000	5000	5000	5000	5000
8.226139	6.272549	6.319238	6.412475	6.362813	6.466499	7.171267	7.176985	7.431125
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.061616	6.147098	6.192853	6.284226	6.235557	6.337169	7.027842	7.033445	7.282503
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.619037	2.199447	2.164536	2.097773	2.009911	1.927997	1.656365	1.561183	1.477023
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.533824	2.083686	2.050613	1.987364	1.904127	1.826523	1.569188	1.479016	1.399285
0	0	0	0	0	0	0	0	0
8.521245	11.57604	11.3923	11.04091	10.57848	10.14735	8.717711	8.216753	7.773805
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.368384	7.292902	7.177147	6.955774	6.664443	6.392831	5.492158	5.176555	4.897497
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.01279	0.0128	0.012733	0.01261	0.012286	0.012124	0.011924	0.011629	0.0116
0	0	0	0	0	0	0	0	0
0.091361	0.091429	0.090952	0.090068	0.087755	0.086599	0.08517	0.083061	0.082857
0.091361	0.091429	0.090952	0.090068	0.087755	0.086599	0.08517	0.083061	0.082857
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.061218	0.061266	0.060936	0.060323	0.05872	0.057919	0.056929	0.055468	0.055327
0.061218	0.061266	0.060936	0.060323	0.05872	0.057919	0.056929	0.055468	0.055327
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
13.43	13.44	13.37	13.24	12.9	12.73	12.52	12.21	12.18
13.43	13.44	13.37	13.24	12.9	12.73	12.52	12.21	12.18
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
13.43	13.44	13.37	13.24	12.9	12.73	12.52	12.21	12.18
13.43	13.44	13.37	13.24	12.9	12.73	12.52	12.21	12.18
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398	0.188398
3.71	6.32	6.215	5.995	5.9	5.67	4.745	4.745	4.47
0	0	0	0	0	0	0	0	0
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
0	0	0	0	0	0	0	0	0
13.43	13.44	13.37	13.24	12.9	12.73	12.52	12.21	12.18
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
8.521245	11.57604	11.3923	11.04091	10.57848	10.14735	8.717711	8.216753	7.773805
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	Unit	1	2	3	4	5
Battery 5 MWh, Battery Variable		1001.98	1001.98	1001.98	1001.98	1001.98
Electric boiler, Fuel consumption	MWh/h	3.15546	3.16626	3.19468	3.19286	3.2189
Boiler in coal plant, Fuel	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	3.09235	3.10293	3.13078	3.12901	3.15452
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	0.49635	0.47044	0.45242	0.44414	0.43698
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	0.47022	0.44568	0.42861	0.42076	0.41398
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	2.61235	2.476	2.38116	2.33756	2.29988
Extra diesel genset, Fuel	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	1.64578	1.55988	1.50013	1.47266	1.44893
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11484, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11082, LoadPower		0.00451	0.00444	0.00441	0.00438	0.00438
DH_Load_points_11484, LoadPower		0	0	0	0	0
DH_Pipe_lines_11084,		0.03223	0.03172	0.0315	0.0313	0.03132
DH_Pipe_lines_11263,		0.03223	0.03172	0.0315	0.0313	0.03132
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0	0	0	0	0
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0.02025	0.0199	0.01975	0.01961	0.01962
DH_Pipe_lines_11263, PipePower		0.02025	0.0199	0.01975	0.01961	0.01962
DH_Pipe_lines_11485, PipePower		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		4.73813	4.66281	4.63091	4.60167	4.60344
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		4.73813	4.66281	4.63091	4.60167	4.60344
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		4.73813	4.66281	4.63091	4.60167	4.60344
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		4.73813	4.66281	4.63091	4.60167	4.60344
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	3.10629	3.05906	3.01833	3.00367	2.98331
El load power plant, El load	MWh/h	0.15344	0.15344	0.15344	0.15344	0.15344
Wind summer 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind summer 21 MW, El usage	MWh/h	5.91885	5.90831	5.91403	5.90584	5.91867
Wind summer 21 MW, Max outtake	MW	5.91885	5.90831	5.91403	5.90584	5.91867
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	4.73813	4.66281	4.63091	4.60167	4.60344
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	2.61235	2.476	2.38116	2.33756	2.29988
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
1001.98	1000	1000	1000	1000	1000	1000	1000	1000	1000
3.22639	8.6994	2.9855	2.72121	2.51585	2.41361	2.44311	2.45278	2.37685	2.34356
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.16186	8.52541	2.92579	2.66678	2.46554	2.36534	2.39425	2.40373	2.32932	2.29668
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.4369	4.22222	0.66256	0.80348	0.87807	0.87328	0.883	0.85475	0.85662	0.85497
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.41391	4	0.62769	0.76119	0.83186	0.82732	0.83653	0.80977	0.81153	0.80997
0	0	0	0	0	0	0	0	0	0
2.29948	22.2222	3.48718	4.22884	4.62142	4.59621	4.64737	4.4987	4.50851	4.49983
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1.44867	14	2.19692	2.66417	2.9115	2.89561	2.92784	2.83418	2.84036	2.83489
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.00439	0.02145	0.00488	0.00508	0.00512	0.00501	0.00507	0.00499	0.00492	0.00489
0	0	0	0	0	0	0	0	0	0
0.03136	0.15323	0.03485	0.03627	0.03658	0.03579	0.03621	0.03563	0.03517	0.03491
0.03136	0.15323	0.03485	0.03627	0.03658	0.03579	0.03621	0.03563	0.03517	0.03491
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.01965	0.10409	0.02206	0.02305	0.02326	0.02272	0.023	0.02261	0.02229	0.02211
0.01965	0.10409	0.02206	0.02305	0.02326	0.02272	0.023	0.02261	0.02229	0.02211
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4.61053	22.5254	5.12271	5.33096	5.37703	5.26095	5.32209	5.23791	5.16968	5.13158
4.61053	22.5254	5.12271	5.33096	5.37703	5.26095	5.32209	5.23791	5.16968	5.13158
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4.61053	22.5254	5.12271	5.33096	5.37703	5.26095	5.32209	5.23791	5.16968	5.13158
4.61053	22.5254	5.12271	5.33096	5.37703	5.26095	5.32209	5.23791	5.16968	5.13158
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2.98901	3.15923	3.43044	3.84825	4.02499	4.09259	4.04698	4.01114	4.1048	4.15611
0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344
0	0	0	0	0	0	0	0	0	0
5.93194	5.91612	5.90682	5.91942	5.81621	5.78636	5.76053	5.76261	5.77848	5.79814
5.93194	5.91612	5.90682	5.91942	5.81621	5.78636	5.76053	5.76261	5.77848	5.79814
0	0	0	0	0	0	0	0	0	0
4.61053	22.5254	5.12271	5.33096	5.37703	5.26095	5.32209	5.23791	5.16968	5.13158
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
2.29948	22.2222	3.48718	4.22884	4.62142	4.59621	4.64737	4.4987	4.50851	4.49983
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
1000	1000	1000	1000	1000	1000	1001.98	1001.98	1001.98
2.54052	2.68219	2.774	2.83829	2.91516	2.97505	1.31082	2.96076	3.07164
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2.48971	2.62854	2.71852	2.78152	2.85686	2.91555	1.2846	2.90154	3.01021
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.79542	0.77038	0.7518	0.71997	0.6871	0.64534	1.13241	0.61589	0.56869
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.75355	0.72984	0.71223	0.68208	0.65093	0.61138	1.07281	0.58348	0.53876
0	0	0	0	0	0	0	0	0
4.18641	4.05465	3.95684	3.78932	3.61629	3.39654	5.96003	3.24155	2.9931
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2.63744	2.55443	2.49281	2.38727	2.27826	2.13982	3.75482	2.04218	1.88565
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.00488	0.00494	0.00496	0.00492	0.00489	0.00482	0.0048	0.00471	0.00466
0	0	0	0	0	0	0	0	0
0.03488	0.03526	0.03545	0.03516	0.03493	0.03439	0.03428	0.03363	0.03331
0.03488	0.03526	0.03545	0.03516	0.03493	0.03439	0.03428	0.03363	0.03331
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.02209	0.02235	0.02248	0.02228	0.02212	0.02175	0.02167	0.02122	0.021
0.02209	0.02235	0.02248	0.02228	0.02212	0.02175	0.02167	0.02122	0.021
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.12715	5.18297	5.21133	5.16879	5.13512	5.05537	5.03942	4.94372	4.89587
5.12715	5.18297	5.21133	5.16879	5.13512	5.05537	5.03942	4.94372	4.89587
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.12715	5.18297	5.21133	5.16879	5.13512	5.05537	5.03942	4.94372	4.89587
5.12715	5.18297	5.21133	5.16879	5.13512	5.05537	5.03942	4.94372	4.89587
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
4.02173	3.97042	3.92563	3.85884	3.75704	3.63894	3.6365	3.50293	3.27896
0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344
0	0	0	0	0	0	0	0	0
5.92027	6.03566	6.10126	6.1306	6.13854	6.12209	6.05027	6.00123	5.93535
5.92027	6.03566	6.10126	6.1306	6.13854	6.12209	6.05027	6.00123	5.93535
0	0	0	0	0	0	0	0	0
5.12715	5.18297	5.21133	5.16879	5.13512	5.05537	5.03942	4.94372	4.89587
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
4.18641	4.05465	3.95684	3.78932	3.61629	3.39654	5.96003	3.24155	2.9931
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	**Unit**	**1**	**2**	**3**	**4**	**5**
Battery 5 MWh, Battery Variable		1012.38	1012.38	1012.38	1012.38	1012.38
Electric boiler, Fuel consumption	MWh/h	6.9379	6.98268	7.02271	6.99399	6.97357
Boiler in coal plant, Fuel consumption	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	6.79914	6.84303	6.88225	6.85411	6.8341
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	0.24009	0.19044	0.16319	0.15754	0.16443
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	0.22745	0.18042	0.1546	0.14925	0.15578
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	1.26363	1.00232	0.85889	0.82915	0.86543
Extra diesel genset, Fuel consumption	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	0.79609	0.63146	0.5411	0.52237	0.54522
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11484, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11082, LoadPower		0.00723	0.00712	0.00707	0.00703	0.00703
DH_Load_points_11484, LoadPower		0	0	0	0	0
DH_Pipe_lines_11084, DH_Waterflow		0.05167	0.05085	0.0505	0.05018	0.0502
DH_Pipe_lines_11263, DH_Waterflow		0.05167	0.05085	0.0505	0.05018	0.0502
DH_Pipe_lines_11485, DH_Waterflow		0	0	0	0	0
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0	0	0	0	0
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0.03372	0.03315	0.03291	0.03269	0.0327
DH_Pipe_lines_11263, PipePower		0.03372	0.03315	0.03291	0.03269	0.0327
DH_Pipe_lines_11485, PipePower		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		7.59523	7.47449	7.42335	7.37648	7.37932
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		7.59523	7.47449	7.42335	7.37648	7.37932
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		7.59523	7.47449	7.42335	7.37648	7.37932
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		7.59523	7.47449	7.42335	7.37648	7.37932
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	3.84248	3.78405	3.73368	3.71554	3.69036
El load power plant, El load	MWh/h	0.18981	0.18981	0.18981	0.18981	0.18981
Wind winterPeak 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind winterPeak 21 MW, El usage	MWh/h	10.7301	10.7661	10.783	10.7418	10.6893
Wind winterPeak 21 MW, Max outtake	MW	10.7301	10.7661	10.783	10.7418	10.6893
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	7.59523	7.47449	7.42335	7.37648	7.37932
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	1.26363	1.00232	0.85889	0.82915	0.86543
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
1012.38	1000	1000	1000	1000	1000	1000	1000	1000	1000
6.98907	22.5594	6.71749	6.35621	5.99101	5.86879	5.85527	5.84888	5.81527	5.8274
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
6.84928	22.1082	6.58314	6.22909	5.87119	5.75141	5.73816	5.73191	5.69897	5.71085
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.16328	4.22222	0.49116	0.69861	0.82882	0.80882	0.84238	0.80357	0.78052	0.75851
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.15469	4	0.46531	0.66184	0.7852	0.76625	0.79805	0.76128	0.73944	0.71859
0	0	0	0	0	0	0	0	0	0
0.85936	22.2222	2.58503	3.67688	4.36222	4.25697	4.43358	4.22931	4.10799	3.99217
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.5414	14	1.62857	2.31643	2.7482	2.68189	2.79316	2.66447	2.58803	2.51507
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.00704	0.03439	0.00782	0.00814	0.00821	0.00803	0.00813	0.008	0.00789	0.00783
0	0	0	0	0	0	0	0	0	0
0.05028	0.24563	0.05586	0.05813	0.05864	0.05737	0.05804	0.05712	0.05637	0.05596
0.05028	0.24563	0.05586	0.05813	0.05864	0.05737	0.05804	0.05712	0.05637	0.05596
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.03275	0.16811	0.03662	0.0382	0.03855	0.03767	0.03813	0.03749	0.03698	0.03669
0.03275	0.16811	0.03662	0.0382	0.03855	0.03767	0.03813	0.03749	0.03698	0.03669
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7.39068	36.1082	8.21171	8.54552	8.61939	8.4333	8.53132	8.39637	8.287	8.22592
7.39068	36.1082	8.21171	8.54552	8.61939	8.4333	8.53132	8.39637	8.287	8.22592
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7.39068	36.1082	8.21171	8.54552	8.61939	8.4333	8.53132	8.39637	8.287	8.22592
7.39068	36.1082	8.21171	8.54552	8.61939	8.4333	8.53132	8.39637	8.287	8.22592
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.69741	3.90797	4.24346	4.76029	4.97891	5.06253	5.00611	4.96178	5.07764	5.14111
0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981
0	0	0	0	0	0	0	0	0	0
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
0	0	0	0	0	0	0	0	0	0
7.39068	36.1082	8.21171	8.54552	8.61939	8.4333	8.53132	8.39637	8.287	8.22592
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.85936	22.2222	2.58503	3.67688	4.36222	4.25697	4.43358	4.22931	4.10799	3.99217
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
1000	1000	1000	1000	1000	1000	1000	1007.98	1012.38
6.03564	6.16412	6.19941	6.201	6.24179	6.29052	6.32657	0	3.16487
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5.91493	6.04084	6.07543	6.07698	6.11696	6.16471	6.20004	0	3.10157
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.69482	0.68384	0.68712	0.66609	0.63775	0.58479	0.56643	2.39001	1.43148
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.65825	0.64785	0.65095	0.63103	0.60418	0.55401	0.53661	2.26422	1.35614
0	0	0	0	0	0	0	0	0
3.65696	3.59914	3.6164	3.50571	3.35657	3.07785	2.98118	12.579	7.53413
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2.30389	2.26746	2.27833	2.2086	2.11464	1.93905	1.87815	7.92478	4.7465
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.00783	0.00791	0.00796	0.00789	0.00784	0.00772	0.00769	0.00755	0.00747
0	0	0	0	0	0	0	0	0
0.05591	0.05652	0.05683	0.05636	0.056	0.05513	0.05495	0.05391	0.05339
0.05591	0.05652	0.05683	0.05636	0.056	0.05513	0.05495	0.05391	0.05339
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.03666	0.03708	0.03729	0.03697	0.03672	0.03611	0.03599	0.03527	0.03491
0.03666	0.03708	0.03729	0.03697	0.03672	0.03611	0.03599	0.03527	0.03491
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.21881	8.3083	8.35376	8.28558	8.2316	8.10376	8.07819	7.92478	7.84807
8.21881	8.3083	8.35376	8.28558	8.2316	8.10376	8.07819	7.92478	7.84807
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.21881	8.3083	8.35376	8.28558	8.2316	8.10376	8.07819	7.92478	7.84807
8.21881	8.3083	8.35376	8.28558	8.2316	8.10376	8.07819	7.92478	7.84807
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
4.97488	4.91141	4.856	4.77339	4.64745	4.50137	4.49835	4.33312	4.05607
0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981	0.18981
0	0	0	0	0	0	0	0	0
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
0	0	0	0	0	0	0	0	0
8.21881	8.3083	8.35376	8.28558	8.2316	8.10376	8.07819	7.92478	7.84807
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
3.65696	3.59914	3.6164	3.50571	3.35657	3.07785	2.98118	12.579	7.53413
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	Unit	1	2	3	4	5
Battery 5 MWh, Battery Variable		1006.38	1006.38	1011.73	1011.73	1011.73
Electric boiler, Fuel consumption	MWh/h	4.1821	4.2527	0	4.32933	4.29972
Boiler in coal plant, Fuel consumption	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	4.09846	4.16765	0	4.24274	4.21373
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	0.81166	0.75824	2.00136	0.70917	0.71869
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	0.76894	0.71833	1.89603	0.67184	0.68086
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	4.27188	3.99074	10.5335	3.73247	3.78255
Extra diesel genset, Fuel	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	2.69129	2.51417	6.6361	2.35146	2.38301
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082,	MWh/h	0	0	0	0	0
DH_Load_points_11484,	MWh/h	0	0	0	0	0
DH_Load_points_11082,		0.00647	0.00636	0.00632	0.00628	0.00628
DH_Load_points_11484,		0	0	0	0	0
DH_Pipe_lines_11084,		0.04619	0.04545	0.04514	0.04486	0.04488
DH_Pipe_lines_11263,		0.04619	0.04545	0.04514	0.04486	0.04488
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084,		0	0	0	0	0
DH_Pipe_lines_11263,		0	0	0	0	0
DH_Pipe_lines_11485,		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0.02992	0.02941	0.0292	0.029	0.02901
DH_Pipe_lines_11263, PipePower		0.02992	0.02941	0.0292	0.029	0.02901
DH_Pipe_lines_11485, PipePower		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		6.78975	6.68181	6.6361	6.59419	6.59673
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		6.78975	6.68181	6.6361	6.59419	6.59673
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		6.78975	6.68181	6.6361	6.59419	6.59673
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		6.78975	6.68181	6.6361	6.59419	6.59673
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load, Deficit	MWh	0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load, El load	MWh/h	3.51322	3.45979	3.41374	3.39715	3.37413
El load power plant, El load	MWh/h	0.17354	0.17354	0.17354	0.17354	0.17354
Wind springAutumn 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind springAutumn 21 MW, El	MWh/h	7.0572	7.12779	7.21872	7.19085	7.1287
Wind springAutumn 21 MW, Max	MW	7.0572	7.12779	7.21872	7.19085	7.1287
Heat load, Deficit	MWh/h	0	0	0	0	0
Heat load, Heat load	MWh/h	6.78975	6.68181	6.6361	6.59419	6.59673
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	4.27188	3.99074	10.5335	3.73247	3.78255
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
1011.73	1000	1000	1000	1000	1000	1000	1000	1000	1000
4.28155	18.652	3.96295	3.62211	3.31938	3.11949	3.0987	3.07955	2.98846	2.96021
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4.19592	18.2789	3.88369	3.54967	3.25299	3.0571	3.03672	3.01795	2.92869	2.901
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.72712	4.22222	1.04264	1.23337	1.34276	1.35167	1.38424	1.35352	1.35095	1.34283
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.68885	4	0.98776	1.16845	1.27209	1.28053	1.31138	1.28228	1.27985	1.27216
0	0	0	0	0	0	0	0	0	0
3.82695	22.2222	5.48756	6.49141	7.06714	7.11403	7.28546	7.12377	7.11026	7.06753
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2.41098	14	3.45716	4.08959	4.4523	4.48184	4.58984	4.48797	4.47946	4.45254
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.00629	0.03074	0.00699	0.00728	0.00734	0.00718	0.00726	0.00715	0.00706	0.007
0	0	0	0	0	0	0	0	0	0
0.04495	0.21958	0.04994	0.05197	0.05242	0.05129	0.05188	0.05106	0.0504	0.05002
0.04495	0.21958	0.04994	0.05197	0.05242	0.05129	0.05188	0.05106	0.0504	0.05002
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.02906	0.15006	0.03252	0.03393	0.03424	0.03345	0.03387	0.0333	0.03284	0.03258
0.02906	0.15006	0.03252	0.03393	0.03424	0.03345	0.03387	0.0333	0.03284	0.03258
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
6.60689	32.2789	7.34085	7.63926	7.70529	7.53894	7.62656	7.50593	7.40815	7.35355
6.60689	32.2789	7.34085	7.63926	7.70529	7.53894	7.62656	7.50593	7.40815	7.35355
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
6.60689	32.2789	7.34085	7.63926	7.70529	7.53894	7.62656	7.50593	7.40815	7.35355
6.60689	32.2789	7.34085	7.63926	7.70529	7.53894	7.62656	7.50593	7.40815	7.35355
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
3.38057	3.57309	3.87983	4.35237	4.55226	4.62872	4.57713	4.5366	4.64253	4.70056
0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354
0	0	0	0	0	0	0	0	0	0
7.10854	7.05143	6.97368	6.91466	6.70242	6.57008	6.46513	6.43617	6.45358	6.49148
7.10854	7.05143	6.97368	6.91466	6.70242	6.57008	6.46513	6.43617	6.45358	6.49148
0	0	0	0	0	0	0	0	0	0
6.60689	32.2789	7.34085	7.63926	7.70529	7.53894	7.62656	7.50593	7.40815	7.35355
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
3.82695	22.2222	5.48756	6.49141	7.06714	7.11403	7.28546	7.12377	7.11026	7.06753
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
1000	1000	1000	1000	1000	1000	1004.47	1006.38	1006.38
3.2001	3.37138	3.43749	3.4835	3.55457	3.61877	0	2.21863	4.01317
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
3.1361	3.30396	3.36874	3.41383	3.48348	3.54639	0	2.17426	3.9329
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.27002	1.24352	1.23623	1.20425	1.1687	1.11526	2.17791	1.48082	0.92976
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.20317	1.17807	1.17117	1.14087	1.10719	1.05656	2.06328	1.40288	0.88082
0	0	0	0	0	0	0	0	0
6.68429	6.54483	6.50649	6.33817	6.15103	5.86977	11.4627	7.79379	4.89345
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
4.2111	4.12324	4.09909	3.99305	3.87515	3.69795	7.22149	4.91009	3.08287
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.007	0.00707	0.00711	0.00705	0.00701	0.0069	0.00688	0.00675	0.00668
0	0	0	0	0	0	0	0	0
0.04998	0.05053	0.0508	0.05039	0.05006	0.04928	0.04913	0.04819	0.04773
0.04998	0.05053	0.0508	0.05039	0.05006	0.04928	0.04913	0.04819	0.04773
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.03255	0.03293	0.03312	0.03283	0.0326	0.03206	0.03196	0.03131	0.03099
0.03255	0.03293	0.03312	0.03283	0.0326	0.03206	0.03196	0.03131	0.03099
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
7.3472	7.4272	7.46783	7.40688	7.35863	7.24434	7.22149	7.08435	7.01578
7.3472	7.4272	7.46783	7.40688	7.35863	7.24434	7.22149	7.08435	7.01578
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
7.3472	7.4272	7.46783	7.40688	7.35863	7.24434	7.22149	7.08435	7.01578
7.3472	7.4272	7.46783	7.40688	7.35863	7.24434	7.22149	7.08435	7.01578
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
4.54858	4.49054	4.43988	4.36435	4.24921	4.11564	4.11288	3.96181	3.7085
0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354	0.17354
0	0	0	0	0	0	0	0	0
6.6522	6.79195	6.81468	6.81714	6.80862	6.79269	6.82442	6.88548	6.96545
6.6522	6.79195	6.81468	6.81714	6.80862	6.79269	6.82442	6.88548	6.96545
0	0	0	0	0	0	0	0	0
7.3472	7.4272	7.46783	7.40688	7.35863	7.24434	7.22149	7.08435	7.01578
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
6.68429	6.54483	6.50649	6.33817	6.15103	5.86977	11.4627	7.79379	4.89345
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Name	**Unit**	**1**	**2**	**3**	**4**	**5**
Battery 5 MWh, Battery Variable		5000	5000	5000	5000	5000
Electric boiler, Fuel consumption	MWh/h	7.630782	7.701003	7.722592	7.429412	7.355688
Boiler in coal plant, Fuel consumption	MWh/h	0	0	0	0	0
Extra diesel boiler, Fuel consumption	MWh/h	0	0	0	0	0
Electric boiler, Prod	MWh/h	7.478167	7.546983	7.568141	7.280824	7.208574
Boiler in coal plant, Prod	MWh/h	0	0	0	0	0
Extra diesel boiler, Prod	MWh/h	0	0	0	0	0
T1 (CHP), El price (surplus)	NOK/MWh	0	0	0	0	0
Extra diesel genset, El price (surplus)	NOK/MWh	0	0	0	0	0
T1 (CHP), El production	MWh/h	0.890158	0.826645	0.806901	0.848121	0.843186
Extra diesel genset, El production	MWh/h	0	0	0	0	0
T1 (CHP), El Surplus	MWh/h	0	0	0	0	0
Extra diesel genset, El Surplus	MWh/h	0	0	0	0	0
T1 (CHP), Energy loss	MWh/h	0.843308	0.783137	0.764433	0.803483	0.798808
Extra diesel genset, Energy loss	MWh/h	0	0	0	0	0
T1 (CHP), Fuel consumption	MWh/h	4.685043	4.350762	4.24685	4.463794	4.437822
Extra diesel genset, Fuel consumption	MWh/h	0	0	0	0	0
T1 (CHP), Heat Dump	MWh/h	0	0	0	0	0
Extra diesel genset, Heat Dump	MWh/h	0	0	0	0	0
T1 (CHP), Heat production	MWh/h	2.951577	2.74098	2.675515	2.81219	2.795828
Extra diesel genset, Heat production	MWh/h	0	0	0	0	0
DH_Load_points_11082, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11484, DH_deficit2	MWh/h	0	0	0	0	0
DH_Load_points_11082, LoadPower		0	0	0	0	0
DH_Load_points_11484, LoadPower		0.009933	0.009798	0.009756	0.009612	0.009528
DH_Pipe_lines_11084, DH_Waterflow		0	0	0	0	0
DH_Pipe_lines_11263, DH_Waterflow		0.070951	0.069986	0.069685	0.06866	0.068057
DH_Pipe_lines_11485, DH_Waterflow		0.070951	0.069986	0.069685	0.06866	0.068057
DH_Pipe_lines_11084, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11263, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11485, DH_WaterflowN		0	0	0	0	0
DH_Pipe_lines_11084, PipePower		0	0	0	0	0
DH_Pipe_lines_11263, PipePower		0.047077	0.046409	0.0462	0.04549	0.045073
DH_Pipe_lines_11485, PipePower		0.047077	0.046409	0.0462	0.04549	0.045073
DH_Pipe_lines_11084, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11084, Qless, DH_BACK, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_THIS		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11263, Qless, DH_BACK, DH_THIS		10.42974	10.28796	10.24366	10.09301	10.0044
DH_Pipe_lines_11263, Qless, DH_BACK, DH_FAR		10.42974	10.28796	10.24366	10.09301	10.0044
DH_Pipe_lines_11485, Qless, DH_OUT, DH_THIS		0	0	0	0	0

DH_Pipe_lines_11485, Qless, DH_OUT, DH_FAR		0	0	0	0	0
DH_Pipe_lines_11485, Qless, DH_BACK, DH_THIS		10.42974	10.28796	10.24366	10.09301	10.0044
DH_Pipe_lines_11485, Qless, DH_BACK, DH_FAR		10.42974	10.28796	10.24366	10.09301	10.0044
DH_Production_points_11081,	MWh/h	0	0	0	0	0
DH_Production_points_11081,	MWh/h	0	0	0	0	0
El busbar_11089, Phase angle		0	0	0	0	0
El load power plant, Deficit	MWh	0	0	0	0	0
El load peak, Deficit	MWh	0	0	0	0	0
El load power plant, El load	MWh/h	0.15344	0.15344	0.15344	0.15344	0.15344
El load peak, El load	MWh/h	3.836036	3.738302	3.713869	4.007069	4.023358
Wind winterPeak 21 MW, El cost	NOK/MWh	0	0	0	0	0
Wind winterPeak 21 MW, El usage	MWh/h	10.7301	10.7661	10.783	10.7418	10.6893
Wind winterPeak 21 MW, Max outtake	MW	10.7301	10.7661	10.783	10.7418	10.6893
Heat load peak, Deficit	MWh/h	0	0	0	0	0
Heat load peak, Heat load	MWh/h	10.42974	10.28796	10.24366	10.09301	10.0044
Coal, Cost	NOK/MWh	79.46	79.46	79.46	79.46	79.46
Diesel boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel4, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Diesel for boiler, Cost	NOK/MWh	771.3	771.3	771.3	771.3	771.3
Coal, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel4, Max usage	MWh/h	1000	1000	1000	1000	1000
Diesel for boiler, Max usage	MWh/h	1000	1000	1000	1000	1000
Coal, Oil usage	MWh/h	4.685043	4.350762	4.24685	4.463794	4.437822
Diesel boiler, Oil usage	MWh/h	0	0	0	0	0
Diesel4, Oil usage	MWh/h	0	0	0	0	0
Diesel for boiler, Oil usage	MWh/h	0	0	0	0	0

6	7	8	9	10	11	12	13	14	15
5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
7.288426	7.150558	7.036322	6.316725	5.596515	6.143631	6.181714	6.625949	6.51254	5.699421
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7.142657	7.007547	6.895596	6.19039	5.484585	6.020758	6.05808	6.49343	6.382289	5.585432
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.833669	0.95459	1.188787	0.765424	0.59078	1.294952	1.403957	1.89267	1.739117	1.891248
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.789791	0.904348	1.126219	0.725138	0.559686	1.226797	1.330064	1.793056	1.647585	1.791708
0	0	0	0	0	0	0	0	0	0
4.38773	5.024158	6.256774	4.028547	3.109369	6.815537	7.389247	9.961421	9.153247	9.953936
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2.76427	3.165219	3.941767	2.537985	1.958902	4.293789	4.655225	6.275695	5.766546	6.27098
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.009435	0.009688	0.010321	0.008313	0.007089	0.009823	0.010203	0.012161	0.01157	0.011292
0	0	0	0	0	0	0	0	0	0
0.067394	0.069202	0.073724	0.059377	0.050636	0.070167	0.07288	0.086865	0.082645	0.080656
0.067394	0.069202	0.073724	0.059377	0.050636	0.070167	0.07288	0.086865	0.082645	0.080656
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.044613	0.045866	0.048999	0.039058	0.033002	0.046534	0.048414	0.058103	0.05518	0.053802
0.044613	0.045866	0.048999	0.039058	0.033002	0.046534	0.048414	0.058103	0.05518	0.053802
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
9.906927	10.17277	10.83736	8.728375	7.443487	10.31455	10.71331	12.76913	12.14884	11.85641
9.906927	10.17277	10.83736	8.728375	7.443487	10.31455	10.71331	12.76913	12.14884	11.85641
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
9.906927	10.17277	10.83736	8.728375	7.443487	10.31455	10.71331	12.76913	12.14884	11.85641
9.906927	10.17277	10.83736	8.728375	7.443487	10.31455	10.71331	12.76913	12.14884	11.85641
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344
4.104803	4.340992	4.658625	4.902959	5.171725	5.310181	5.277603	5.310181	5.375337	6.438187
0	0	0	0	0	0	0	0	0	0
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
10.713	10.6904	10.6596	10.6077	10.3309	10.3123	10.2088	10.1969	10.3022	10.3998
0	0	0	0	0	0	0	0	0	0
9.906927	10.17277	10.83736	8.728375	7.443487	10.31455	10.71331	12.76913	12.14884	11.85641
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
4.38773	5.024158	6.256774	4.028547	3.109369	6.815537	7.389247	9.961421	9.153247	9.953936
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24
5000	5000	5000	5000	5000	5000	5000	5000	5000
8.428488	6.848449	6.881956	6.947129	6.892873	6.968123	7.545976	7.559911	7.77546
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
8.259918	6.71148	6.744317	6.808187	6.755016	6.828761	7.395057	7.408713	7.61995
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.098019	1.567681	1.539071	1.485066	1.410238	1.342566	1.115657	1.028692	0.956969
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1.040229	1.485171	1.458067	1.406905	1.336015	1.271905	1.056938	0.974551	0.906602
0	0	0	0	0	0	0	0	0
5.779048	8.250952	8.100372	7.816139	7.422308	7.066138	5.87188	5.414171	5.036677
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
3.640801	5.1981	5.103234	4.924167	4.676054	4.451667	3.699284	3.410928	3.173107
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.011334	0.011342	0.011283	0.011174	0.010887	0.010743	0.010566	0.010304	0.010279
0	0	0	0	0	0	0	0	0
0.080957	0.081018	0.080596	0.079812	0.077762	0.076738	0.075472	0.073603	0.073422
0.080957	0.081018	0.080596	0.079812	0.077762	0.076738	0.075472	0.073603	0.073422
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.05401	0.054052	0.05376	0.053217	0.051797	0.051087	0.05021	0.048915	0.04879
0.05401	0.054052	0.05376	0.053217	0.051797	0.051087	0.05021	0.048915	0.04879
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
11.90072	11.90958	11.84755	11.73235	11.43107	11.28043	11.09434	10.81964	10.79306
11.90072	11.90958	11.84755	11.73235	11.43107	11.28043	11.09434	10.81964	10.79306
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
11.90072	11.90958	11.84755	11.73235	11.43107	11.28043	11.09434	10.81964	10.79306
11.90072	11.90958	11.84755	11.73235	11.43107	11.28043	11.09434	10.81964	10.79306
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344	0.15344
3.021591	5.147292	5.061775	4.882597	4.805225	4.617903	3.864541	3.864541	3.640569
0	0	0	0	0	0	0	0	0
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
10.5055	10.5815	10.5581	10.4981	10.4413	10.3969	10.4483	10.5492	10.6125
0	0	0	0	0	0	0	0	0
11.90072	11.90958	11.84755	11.73235	11.43107	11.28043	11.09434	10.81964	10.79306
79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46	79.46
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3	771.3
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
1000	1000	1000	1000	1000	1000	1000	1000	1000
5.779048	8.250952	8.100372	7.816139	7.422308	7.066138	5.87188	5.414171	5.036677
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

E Powershell script for season segmenting in eTransport

The following script was used to find representative profiles of wind power generation. It is written in Powershell, based on the .NET framework. The same script, with small modifications, was also used to find the the PV profiles. A similar script with the same logic was also used to find the seasonal demand profiles.

```
    class HourlyMeasurement {
    [DateTime]$Date
    [int]$Time
    [decimal]$Power
}

class Season {
    [DateTime]$StartDate
    [DateTime]$EndDate
    [String]$Name
    [System.Collections.Generic.List[HourlyMeasurement]]$HourlyMeasurements
}

class AvgHour {
    [String]$Name
    [int]$Time
    [decimal]$Power
}

$Seasons = @(
    (New-Object -TypeName Season -Property @{ StartDate =
        (Get-Date -Year 1990 -Month 01 -Day 01); EndDate =
            (Get-Date -Year 1990 -Month 02 -Day 01); Name="Winter"}),
    (New-Object -TypeName Season -Property @{ StartDate =
        (Get-Date -Year 1990 -Month 11 -Day 29); EndDate =
            (Get-Date -Year 1990 -Month 12 -Day 31); Name="Winter"}),
    (New-Object -TypeName Season -Property @{ StartDate =
        (Get-Date -Year 1990 -Month 02 -Day 02); EndDate =
            (Get-Date -Year 1990 -Month 04 -Day 13); Name="Autumn"}),
    (New-Object -TypeName Season -Property @{ StartDate =
        (Get-Date -Year 1990 -Month 09 -Day 19); EndDate =
            (Get-Date -Year 1990 -Month 11 -Day 28); Name="Autumn"}),
    (New-Object -TypeName Season -Property @{ StartDate =
        (Get-Date -Year 1990 -Month 04 -Day 14); EndDate =
            (Get-Date -Year 1990 -Month 09 -Day 18); Name="Summer"})
```

```
)

$HourlyData = Get-Content "C:\Users\Emil\Jottacloud\NTNU\Masteroppgave\wind
    \5kwVestasV150_4000_input.csv" |ConvertFrom-Csv -Delimiter ";"

$HourlyMeasurementPoints = @()
foreach($HourlyDataPoint in $HourlyData) {
    $DateTime = [datetime]::parseexact($HourlyDataPoint.Datetime, "dd/MM/yyyy HH:mm", $null)
    $HourlyPoint = New-Object -TypeName "HourlyMeasurement" -Property @{
        Date = $DateTime
        Time = $DateTime.Hour
        Power = [Convert]::ToDecimal(($HourlyDataPoint.kW -replace "\.",","))
    }
    $HourlyMeasurementPoints += $HourlyPoint
}

Foreach($Season in $Seasons) {
    $Season.HourlyMeasurements = [System.Collections.Generic.List[HourlyMeasurement]]::new()
    $SeasonHours = $HourlyMeasurementPoints |
        Where-Object { $_.Date -ge $Season.StartDate -and $_.Date -le $Season.EndDate }
    Foreach($DataPoint in $SeasonHours) {
        $Season.HourlyMeasurements.Add($DataPoint)
    }
}

$SeasonNames = $Seasons | Select-Object -ExpandProperty "Name" -Unique
$MergedSeasons = @()
Foreach($SeasonName in $SeasonNames) {
    $FoundSeasons = $Seasons | Where-Object { $_.Name -eq $SeasonName }
    $MergedSeason = New-Object -TypeName "Season" -property @{
        Name = $SeasonName;
        StartDate = $FoundSeasons[0].StartDate;
        EndDate = $FoundSeasons[0].EndDate;
        HourlyMeasurements = [System.Collections.Generic.List[HourlyMeasurement]]::new()
    }
    foreach($FoundSeason in $FoundSeasons) {
        Foreach($HourlyMeasurement in $FoundSeason.HourlyMeasurements) {
            $MergedSeason.HourlyMeasurements.Add($HourlyMeasurement)
        }
    }
    $MergedSeasons += $MergedSeason
}

$Hours = $MergedSeasons.HourlyMeasurements.Time | Select-Object -Unique
$AvgValues = @()
Foreach($Season in $MergedSeasons) {
    Foreach($Hour in $Hours) {
        $HourlyMeasurementPoints = $Season.HourlyMeasurements|
            Where-Object { $_.Time -eq $Hour}
        $TotalPwr = 0
        foreach($Measurement in $HourlyMeasurementPoints) {
            $TotalPwr += $Measurement.Power
        }
```

```
        $AvgPower = $TotalPwr/$HourlyMeasurementPoints.Count
        $AvgHour = New-Object -TypeName AvgHour -Property @{
            Time = $Hour;
            Name = $Season.Name;
            Power = $AvgPower
        }
        $AvgValues += $AvgHour
    }
}
$AvgValues | ConvertTo-Csv | Out-File "C:\Users\Emil\Jottacloud\NTNU\Masteroppgave\wind\
    5kwVestasV150_4000_output.csv"
```

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Renewable Energy in Longyearbyen

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