Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Electric Power Engineering

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# A Study of How Integration of Solar Photovoltaic Impact a Housing Cooperative in Norway

Master's thesis in Energy and Environmental Engineering
Supervisor: Magnus Korpås
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# Preface

This Master's thesis is the conclusion of my Master of Science in Energy and Environmental Engineering with the Department of Electric Power Engineering at the Norwegian University of Science and Technology (NTNU), and marks the end of 5 years of studying. I would like to thank my supervisor Magnus Korpås for motivational words and great guidance throughout the semester. The input and help you have offered have been highly appreciated. I would also like to express gratitude to my co-supervisor Ove Wolfgang, and Magnus Askeland at SINTEF for help with simulations model. I am very grateful for the fast responses and assist.

I would also like to express gratitude towards my friends and family for all your support, love and laughs. A special thanks to my study companions for help when it was needed, enjoyable lunch breaks and for sharing their input and experiences.

Finally, a special thanks to my friends in Start NTNU who always make me smile, I am genuinely grateful for all of your encouragements.

Emilie Kjenstadbakk

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Trondheim, June 2020

# Abstract

Photovoltaic solar panels are the fastest-growing energy source in the world at the moment. Solar power in Norway has traditionally been used to cover electricity need for locations without a connection to the electricity grid, such as cabins. Over the last couples of years, an increase in the grid-connected solar PV systems have been seen. As the sun provides free and environmentally-friendly energy, it is an attractive energy source to utilize. Even in Norway, the solar-resources are sufficient enough for solar PV to become expedient. As the Norwegian power generation consists of mainly hydropower, a flexible energy source, the power flow can withstand the implementation of more unregulated power sources, such as wind and solar PV.

In this thesis, an evaluation of how the integration of solar photovoltaics (PV) impact different accounts of a housing cooperative in Trondheim, Risvollan, is conducted. A simulation of the energy demand system with different energy supply investment options are done in eTransport. Primarily two main scenarios are looked into, a solar PV system which utilizes all the available roof area at Risvollan and one scenario where half of the area is used. Then simulations are conducted for the two scenarios when the electricity price for the power from the grid is varied, and when charging of electric vehicles is added to the demand in various amounts. Calculations of $CO_2$ emissions are also done for the housing cooperatives, with and without solar PV. Furthermore, estimations of self-consumption and self-sufficiency for Risvollan with the two different solar PV systems and when electric vehicles are added.

The main results reveal that with the current system units cost and grid electricity prices, the solar PV systems researched was not able to match the price of grid electricity. When the self-consumption is high, and the predicted worst-case electricity price is used, the solar PV is close to matching the annual costs of the fully electric system. Furthermore, an LCOE calculations shows that the system unit price for solar PV is too high to make solar PV profitable, a decrease from 12 NOK/$W_p$ to 8,8 NOK/$W_p$ must be introduced before the solar PV could match the electricity price. The results showed that the waterborne district heating systems is the least economical system analyzed, but it is discussed that if flexibility is emphasized the district heating system may be of more interest, especially from a socio-economic view.

A limitation of this research is that income from selling surplus generated electricity from the solar PV is not taken into account; this could affect the amount of decrease in system unit price before profitability is reached.

# Sammendrag

Solenergi er den raskest voksende energikilden i verden for øyeblikket. Solenergi har i Norge tradisjonelt blitt brukt til å dekke strømbehovet til steder uten tilknytning til strømnettet, som for eksempel hytter. I løpet av de siste par årene har man sett en økning i nettkoblede solcelle-systemer. Siden solen gir gratis og miljøvennlig energi, er det en attraktiv energikilde å utnytte. Selv i Norge er solressursene tilstrekkelig til at solcelleanlegg er hensiktsmessig. Ettersom den norske kraftproduksjonen hovedsakelig består av vannkraft, en fleksibel energikilde, kan kraftstrømmen tåle implementering av mer uregulerte kraftkilder, som for eksempel vind og sol.

I denne oppgaven gjennomføres en evaluering av hvordan integrering av solcelleanlegg påvirker forskjellige regnskap for et borettslag i Trondheim, Risvollan. En simulering av energibehovet med forskjellige investeringsalternativer for energiforsyning gjøres i eTransport. Primært blir det sett på to hovedscenarier, et solcelleanlegg som benytter alt det tilgjengelige takområdet på Risvollan og ett scenario der halvparten av takarealet brukes. Deretter gjennomføres simuleringer for de to scenariene når strømprisen for strømmen fra nettet varieres, og når lading av elektriske biler blir lagt til energietterspørselen. Beregninger av $CO_2$-utslipp gjøres også for borettslaget, med og uten solcelleanlegg. Videre er det gjort estimater av hvor mye av den genererte solelekstristeten som blir dirkete brukt av borettslaget og hvor høy selvforsyningsgrad de oppnår for de to forskjellige solcelleanleggene og når elektriske biler legges til.

Hovedresultatene viser at med de nåværende systemenhetens kostnader og strømpriser, er solcelle-systemene som ble undersøkt ikke i stand til å bli like lønnsomt som et system som kjøper all strømmen fra nettet. Når egenforbruket er høyt, og den høyeste spådde prisen for strøm brukes, er solcelle systemet nære med å ha like lave årlige kostnader som det helelektriske systemet. Videre viser en LCOE-beregning at system-enhetsprisen for solcelleanlegg er for høy til å gjøre solcelleanlegg lønnsomt, slik de er nå. Det må innføres en nedgang fra 12 NOK/ $W_p$ til 8,8 NOK/ $W_p$ før prisen på solceller elektristiten var tilsvarende strømprisen. Resultatene viste at det vannbårne fjernvarmeanleggene er det minst økonomiske systemet som er analysert. Imidlertid blir det diskutert at hvis fleksibilitet vektlegges, kan fjernvarmesystemet være av mer interesse, spesielt fra et samfunnsøkonomisk ståsted.

En begrensning i denne oppgaven er at det ikke tas hensyn til inntekter fra salg av overskuddsgenerert strøm fra solcelleanlegget; dette kan påvirke hvor stor reduksjon av systemenhetspris som må til før lønnsomheten er nådd for solcellene.

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# Acronyms

**PV** Photovoltaic

**AMS** Advanced measurement and control system

**AMPL** A Mathematical Programming Language

**ZEN** Zero Emission Neighborhood

**EV** Electric vehicle

**EPBD** Energy Performance of buildings directive

**EU** European Union

**NVE** Norwegian Water Resources and Energy Directorate

**GHG** Green House Gases

**LCOE** Levelized Cost of Electricity

**SC** Self-consumption

**SS** Self-sufficiency

**AC** Alternating current

**DC** Direct current

**DSO** Distribution System Operator

**TSO** Transmission System Operator

**LCA** Life Cycle Analysis

**DP** Dynamic programming

**LP** Linear programming

**MIP** Mixed integer programming

**NREL** National Renewable Energy Laboratory

**V2G** Vehicle to Grid

# Chapter 1

# Introduction

## 1.1 Background and objective

### 1.1.1 Solar power

There has been an increase of installed solar power in the world, well beyond what was expected, in the last ten years [11]. The installed Photovoltaic (PV) capacity in Norway make up 68 MWp, an increase of the accumulated power capacity by 52 percent compared to the year before [12]. The driving forces in the market, leading to these observed and assumed future growth are difficult to determine. However, increased interest in technology and environment, decreasing prices of Solar PV systems, need of power for Electric vehicle (EV) charging, and increased efficiency are suggested as contributed factors [4]. Solar power is an unpredictable energy resource, and therefore Solar PV installations can lead to integration problems in the power grid. However, in Norway hydropower provides the largest share of the power production, since it is easy and fast to regulate, hydropower enables a more significant amount of unregulated energy sources (PV, wind etc.) to be allowed in the Norwegian power system [11].

Due to the digitization of the power industry, new forms of communication, new business models and new management systems are introduced [4]. Advanced measurement and control system (AMS) have been installed in households in Norway, enabling hour-by-hour measurements of electricity demand and also generation where applicable. A datahub shall form a common platform for measurement values and market processes in the Norwegian power market, and is called Elhub [13]. Elhub can be used as a local marketplace for the power exchange, and companies such as Otovo is planning to use Elhub to visualize trade of energy between costumers with solar PV and consumers who want locally produced renewable energy [11]. Otovo is planning to buy surplus electricity from solar PV through the project called ”Nabostrøm”. Such new business models can motivate consumers to become prosumers, and to install larger PV systems with higher capacity.

### 1.1.2 The Risvollan energy system

The housing cooperatives Risvollan, located in Trondheim, need to upgrade their current energy system. The current system consists of a district heating system supplied by Statkraft Varme to cover the heat demand fro tap-water and room heating, and electricity from the grid to cover the rest of the energy usage, provided by TrønderEnergi. Since the system is old and starting to malfunctioning, an investment needs to be carried out. As Risvollan is Norway's biggest freestanding housing cooperatives, it is an exciting system to analyze and solutions found and decisions made could be transferred to other housing cooperatives which may lack the funds to explore different energy system possibilities. Risvollan is considered included in FME ZEN, and therefore other aspects than just economics are of interest. Also, exploring the possibilities of implementing on-site generation is interesting in the context of FME ZEN.

### 1.1.3 Objective

This master thesis aims to assess how the implementation of solar PV affects the housing cooperatives Risvollan, and if such an energy system could be a profitable investment. This is done by building a model of the housing cooperative energy system of Risvollan, integrating solar power, and conduct analyzes with the aim to identify the effects of solar PV. The objectives of the thesis include:

- Give a brief introduction to relevant theory and system information
- Formulate a model for implementation of solar PV generation in the housing cooperatives
- Analyze the impact of solar PV integration in the energy system by using real load demand and photovoltaic power generation data
- Perform analysis of electricity prices, carbon accounting and solar PV integration prices and research at which system price solar PV becomes profitable compared to the other energy systems.
- Investigate if a local energy system contribute to the reduction of $CO_2$-emissions
- Study what economic value the local energy production represents for the housing cooperative

- Investigate how the introduction of EVs affect the self-consumption and self-sufficiency levels of the housing cooperatives with on-site electricity generation from solar PV

## 1.2 Approach

The system theory is used to form the simulations model and formulate the mathematical equations used in the calculations. Some quantitative calculations have been carried out using the optimization model eTransport developed by SINTEF Energy. Energy demand data is provided by Sørensen and Wolfgang [7] [14]. The solar PV generation data is acquired using *Renewables.ninja* [15]. The simulations results are exported to Excel, and then presentable plots and graphs are made.

## 1.3 Limitations

The possibility to sell surplus generated electricity from solar PV is not taken into account in the simulations done in this thesis. Other assumptions and limitations are given in section 9.7.

## 1.4 Thesis outline

Chapter 2, *Energy sources*, gives an introduction of different energy systems analyzed in this thesis. An explains important research aspects of the solar PV system.

Chapter 3, *The Norwegian Power System*, presents an overview of the power system in Norway and different details that are relevant for the research conducted in this thesis.

Chapter 4, *Other definitions and technologies of relevance*, explains the basis of the research conducted with electric vehicles and defines a zero-emissions neighbourhood and describes its relevance in this thesis.

Chapter 5, *Mathematical formulation of the problem*, presents the mathematical formulas used in the calculations conducted.

Chapter 6, *Computer simulation*, explains the model made in eTransport and insight into eTransport and how it is used.

Chapter 7, *Case study description*, presents the load demand, PV power generation and other relevant data used in the study.

The results of the studies conducted in this thesis are presented in Chapter 8 , *Results*.

Then the findings from the results are discussed in Chapter 9, *Discussion*.

Chapter 10, *Conclusion*, summarizes and concludes the main findings.

Chapter 11, *Further work*, provides suggestions for further work and analyses.

# Chapter 2

# Energy sources

## 2.1 Solar power

When it comes to installing capacity, solar power is the fastest-growing energy source in the world at the current time [12]. The sun is a free, environmentally and climate-friendly energy source making it an attractive resource. Providing the world with 15 000 times the energy the world's population uses, it has the potential to become the most important renewable energy source in the future. To utilize solar power, two main solar-technologies can be used: solar PV and solar collectors. Solar PV convert sunlight into electricity, while solar collectors convert sunlight into heat.

Even though Norway is located in the north, the solar-resources available is great enough that building solar PV makes sense. The solar irradiance on a horizontal surface is between 700 and 1000 kWh/sqm per year, and to compare a building following TEK10 has an energy demand of 95 to 225 kWh/heated usable area per year [16]. The challenge in Norway is that the solar radiation varies a great deal through the year. By optimizing the tilt of the solar panel, the sun can be utilized during a more significant part of the year. The cold climate, on the other hand, is an advantage, as the solar panels are more effective when cold.

There are many other advantages of solar power:

- It is a climate-friendly energy source that entails little or none interventions in nature.
- Electricity and heat can be produced on-site, without loss in the grid.
- It is an attractive solution for both new and older buildings with short building time.

- The operating and maintenance costs are low during the first 20 to 30 years after installation.
- By more significant implementation in Norway, it can contribute to released electricity in the grid that currently is used in buildings, to instead be used in industry, the transport sector or replace electricity from fossil energy sources in other countries.

### 2.1.1 Driving forces in the Norwegian Solar power market

If one looked at profitability from a building-industry perspective energy effectiveness could be identified as a reason for installing solar PV [4]. Different main motivations for installing solar PV in commercial buildings are identified and illustrated in Figure 2.1.

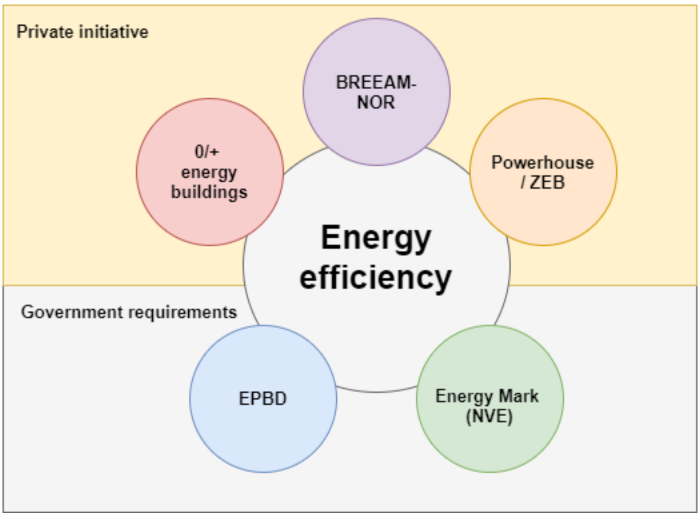


**Figure 2.1:** Motivational factors for the solar PV market in commercial buildings divided in private initiative and public demands, figure adapted from [4]

The public demands motivational factors, seen in the grey area in Figure 2.1, are identified as Energy Performance of buildings directive (EPBD) and the Energy Mark. EPBD is a legislative framework to boost energy performance of buildings established by the European Union (EU), and it consists of policies and supportive measures to help the EU governments [17]. In this directive, a goal is that every rehabilitated and new building as of 2020 should be ”close to a zero energy building” [4]. The Energy Mark grades buildings from A to G based on demands from the Energy Act established by Norwegian Water Resources and Energy Directorate (NVE), which evaluate both the energy use and source [18]. The Energy marking system The system is designed, determined, operated and developed by Enova SF [19].

The private initiative, seen in the yellow area in the Figure 2.1, are identified as the environmental certification BREEAM-NOR, increased focus on plus- and zero energy buildings as well as attention around Powerhouses and zero emission buildings and neighbourhoods [4]. BREEAM-NOR is the Norwegian customization of the BREEAM environmental certification tool whose goal is to measure environmental performance and motivate sustainable design and construction. The certification is a BREEAM-NOR certificate is issued in five levels where Outstanding is the highest and Pass is the lowest. These grades are based on environmental achievements in nine different categories; management, health and indoor environment, energy, transport, water, materials, waste, land use and ecology as well as pollution [20].

There has been an increased focus on zero- and plus energy buildings [4]. The Powerhouse-alliance consisting of Skanska, Asplan Viak, Snøhetta, Sapa, Entra and Zero focuses on building powerhouses that produce more energy than they use where solar PV has been a part of all of the projects [21].

When talking about Zero Emission Neighborhood (ZEN) a neighbourhood which aims to reduce its direct and indirect Green House Gases (GHG) emissions toward zero over the analysis period, is meant based on Wiik [22].

Although these public demands were not meant to serve as a solar PV initiative, the reality is that solar cells are an essential part of the energy system needed to satisfy the energy performance evaluation. Since local production of energy is subtracted from the buildings, total energy usage in the calculation method used for The Energy Mark, building solar PV would lift the grade on the scale.

## 2.2 PV Modules

The fundamental components needed in a photovoltaic system are the solar panels and the appurtenant mounting system, as well as inverts, monitoring systems and bidirectional power meter [5].

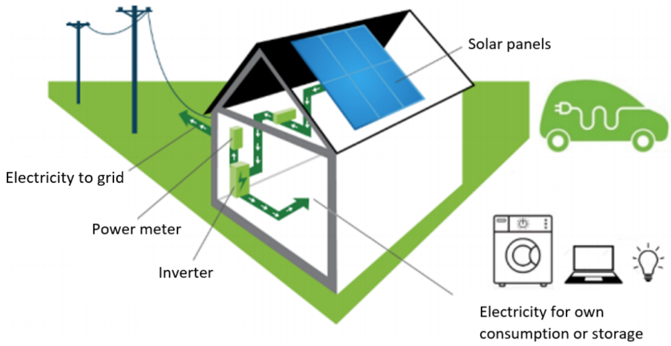


**Figure 2.2:** A solar PV energy system, based on figure from [5].

For flat roofs, there is mounting systems that allow one to avoid to screw on the ceiling. Making the installation process less invasive.

To be able to utilize the electricity from the solar panels, it is necessary to transform the Direct current (DC) to Alternating current (AC), this is done by an inverter. A solar panel delivers current at a low voltage, typically 12-40 V, while the electronics in a house is customized to the voltage from the grid, usually at 230V in Norway. The inverter also does this transforming of voltage [5].

Many inverters also have functions for monitoring photovoltaic data and display it through the Internet or Bluetooth on computers or smartphones, making it easy to oversee the power production or errors [5].

In Norway, there is a requirement that all housing units have individual measuring of the power consumption, and every household should have an AMS, often referred to as a smart meter, within the end of 2019 [23]. This new meter continually measures how much power is consumed and automatically reports the usage every hour to the Distribution System Operator (DSO) [24]. It is also a bidirectional power meter, meaning that it can measure how much power you put into the grid as well as how much is delivered from the grid. This is necessary to get paid for the surplus power delivered to the local grid, which may be desirable for solar PV.

Smart meters enable many other possibilities other than selling power to the grid, such as adjust energy consumption in relation to solar power generation and grid electricity prices. This load adjustment can be made by turning on and off consumption loads such as water heater, washing machine, heat pump and EV-charging [5].

### 2.2.1 Sustainability

A solar panel emits no carbon dioxide during its years of operation. The little emissions it is reasonable of are indirectly $CO_2$-emissions during other periods of the life-cycle. Solar cells are usually made up of either silicon or thin film. Silicon is energy-intensive to make, but it is one of the most common element in the earth's crust, and it is neither hazardous to health or the environment. Even though it is energy-consuming to make, a silicon solar panel will produce the same amount of energy it demands during production during less than its first two years of operation.

Thin-film can be produced in numerous different ways; some of these can, therefore, contain substances that are hazardous to health and the environment [25]. The most prevalent solar panel technology is the one containing silicon.

A way of examine the environmental impact of different energy sources is by conducting Life Cycle Analysis (LCA). LCA means an analysis of the whole life cycle from extraction of raw materials, production, distribution, use, maintenance, recycling - to final disposal; including all transport involved along the lifetime [26]. The purpose of such an inspection is to make it possible to compare different alternatives to judge, which gives the least environmental repercussions.

In Norway, there is a requirement that all housing units have individual measuring of the power consumption, and every household should have an AMS, often referred to as a smart meter, within the end of 2019 [23]. This new meter continually measures how much power is consumed and automatically reports the usage every hour to the DSO [24]. It is also a bidirectional power meter, meaning that it can measure how much power you put into the grid as well as how much is delivered from the grid. This is necessary to get paid for the surplus power delivered to the local grid, which may be desirable for solar PV.

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### 2.2.2 Cost development for solar cells

There has been an increase in installed capacity for solar PV from 2010 to 2017, and in the same time there has been an reduction in investment cost on around 10-20% [27]. Some predictions indicates that the system cost of solar PV can be reduced with up to

59% towards 2025 [28]. Since 2009 a reduction in average solar power cost of 62% has been reported, and this is mainly due to considerable reduction in module cost [11]. Also increased efficiency has a positive impact on expense reduction. If two solar panels are considered, they are the same size but with one have a much higher efficiency. The cost of installing the two panels are the same, but the one with higher efficiency will produce more power and thus will give lower production costs. An overview of the efficiency records of solar cells are kept by National Renewable Energy Laboratory (NREL), and includes who set the efficiency record[29].

When looking at the records overview it can be seen that most of the earlier records often where set by universities and research centers, compared to the newer records which are often set by corporation such as SunPower and Panasonic [4]. This is also one of the reasons why the development pace of solar panes have been so fast-moving, as the road from laboratory until production reduces whit corporations in charge.

### 2.2.3 Self-sufficiency and Self-consumption

#### Self-consumption

Self-consumption can be defines as the share of the total PV production that is consumed directly by the PV system owner [6]. Meaning, that if the self-consumption rate is high, little electricity is exported to the electricity grid.

The relative size of both the demand and the solar PV generation affect the self-consumption rate, as shown in figure 2.3.

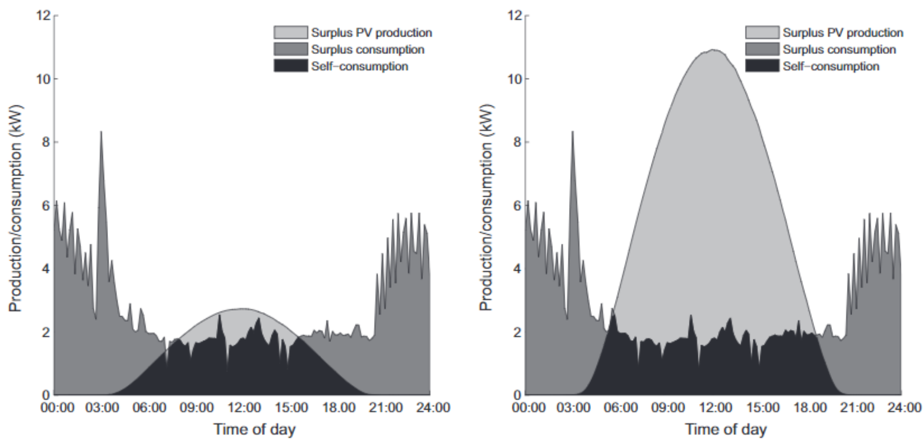



**Figure 2.3:** Example of two different solar PV systems covering the same demand with high self-consumption rate (left) and lower self-consumption rate (right) [6].

Increasing the PV generation relative to the demand will lead to decreased self-consumption rate. Since the Norwegian tariffs is makes it unfavorable to sell the surplus PV production, it is desirable to bring the self-consumption to an optimum.

The electricity produced by the solar PV can be sold to the grid in Norway at the applicable spot price on Nord Pool. When buying electricity from the grid both grid tariffs and other fees are added to the spot price. Due to this structure it is more profitable to use the produced electricity from the solar panels directly. In other words, high SC is preferable.

The time resolution used will also effect the self-consumption result. It is most common to determine self-consumption based on hourly values for demand and generation. If a lower resolution is used the fluctuations causing mismatch between the demand and the generation is evened out by averaging, thus the self-consumption will be overestimated [6].

#### Self-sufficiency

Self-sufficiency can be defined as the rate of how much of the total demand that is being covered by the locally produced energy [30]. The self-sufficiency rate will therefore increase or remain unchanged if the total power generation is increased as in Figure 2.3. The level of self-sufficiency will always increase if a stationary battery or other forms of energy storage is added [30].

## 2.3 District heating

District heating is a energy system which utilizes renewable energy to heat a water, and is thus a waterborne system [31]. Often local resources are used for heating such as biofuel, waste and surplus heat from industry. The way a DH-systems works is that the hot water circulates between the heating plant and the customer's heat central placed on site, and this circulation happens in buried and insulated pipes. Then the consumer can use the waterborne heat to floor heating, in the ventilation system and radiators for room heating and heating of tap water.

District heating waterborne systems offers a possibility of flexibility, since it can utilize many different energy sources. Thus, the source that is most economical or the source that is most conveniently can be used [32]. By covering demand for heat the district heating system also relieves the power grid.

The following paragraphs are based on my project thesis [33]; the housing cooperatives Risvollan is connected to the district heating grid through one main station which then supplies 20 sub-stations around the area. These sub-stations are owned and operated by staff from Risvollan housing cooperative and deliver heat to both tap water and room heating as can be seen in Figure 2.4.

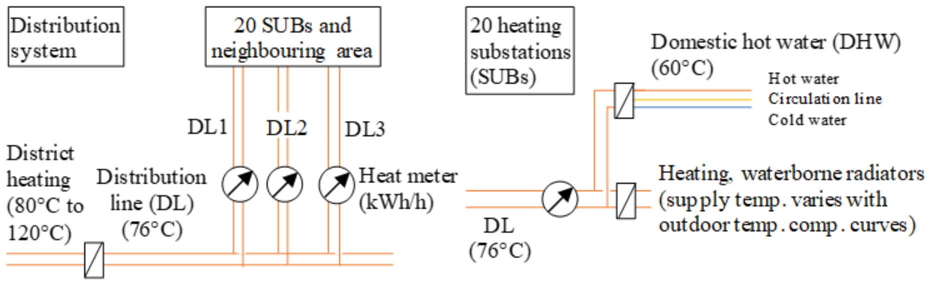



**Figure 2.4:** The district heating system at Risvollan [7]

## 2.4 Hydropower

The term hydropower is generally understood to mean electricity generated from waterfall energy, and a hydropwer plant is where this transformation of energy takes place [34]. A hydropower plant consist of the power station (turbine, generator and transformer) which together with the regulators (dams, hatches, transmission tunnels) constitute a complete facility [35].To ensure power generation through out the year the water flow is regulated through dams and water reservoirs.

In Norway a total of 1609 hydropower plants contributes to 94.3% of the total production capacity, making it possible to say that the electricity in the gird is almost 100% renewable. As hydropower has the lowest GHG-emissions of all power generation technologies and does not contribute to any air pollutants [34]. One of the advantages of hydropower besides that it is climate-friendly, is the fact that it is possible to store energy. Water can be stored in large reservoirs and utilized when needed, making hydropower a very flexible energy source. As much as half of the reservoir capacity in Europe is located in Norway

# Chapter 3

# The Norwegian power system

The flexibility that the Norwegian hydropower reservoir gives are essential when balancing the Norwegian power system, as there needs to be an equilibrium between the demand and the produced electricity. When introducing more unregulated power generation, the need for available flexibility in the grid is even higher. The term unregulated power is here used to refer to solar-, wind and other power production methods that is dependent on the weather and can not be adjusted based on how the demand differ.

The Norwegian power system is connected, both physically and commercially, to the other Nordic countries in a common power market [8]. Further, this Nordic power system is integrated through grid interconnections an transmission link to the European power system.

Even though most of the electricity produced in Norway comes from renewable sources, these interconnections with the European power system makes it difficult to decide whether the electricity demand in the Norwegian power system is covered by the same green energy. Green energy can broadly be defined as energy from renewable energy sources. When power is fed into the grid, there is no way to tell where the power was produced or how, as the power follows the physical laws and flows the way with least resistance.

As there is no way to recognize where the power comes from when it has entered the grid, the Transmission System Operator (TSO)s keeps the accounts of how much the power producers deliver and how much the customers uses [8]. Accordingly, the producers get paid for the electricity generated and the end users pay for their consumption. The system price of power is calculated and determined for the upcoming day by the stock exchange of power Nord Pool, for the Nordic power market [36]. A figure of the power market can be seen underneath:

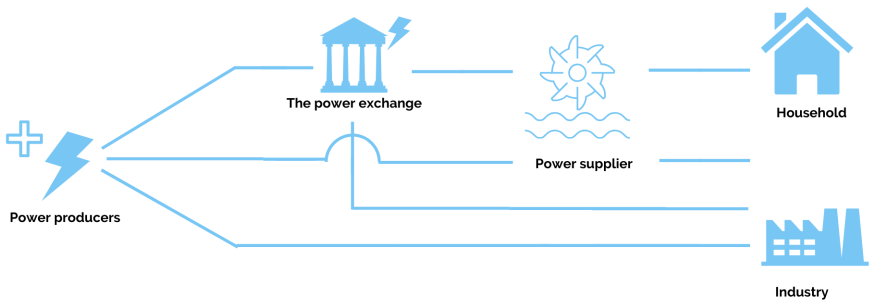



**Figure 3.1:** Illustration of the power market. Figure based on [8]

In the figure 3.1 power producers refer to power companies ie. companies than owns power plants and operates power generation. The largest in Norway is Statkraft AS [37]. From the figure above the term power supplier refers to the companies that consumers buy the electricity from, also known as electricity supplier [38].

Due to the interconnections in the grid between Europe and Norway the electricity covering the the Norwegian consumers usage is a mix of both Norwegian and imported power [39]. From NVEs National goods declaration for 2018 it can be seen that 58% of the power mix in Norway came from fossil energy, 33% from nuclear power and 9% from renewable energy. The $CO^2$-emission from power generation differs from energy source to energy source.

Emission connected to energy usage is complex, since the emissions factor will differ depending of season and the time of day [40]. The reason for this is that the spot-price for electricity affect whether electricity is imported from abroad, since this in turn influence the profitability of the national water reservoirs. For Norway, low spot-price equals more import and thus higher emissions factor. While higher spot-price means a larger amount of hydro power in the electricity mix and lowered emissions factor.

## 3.1 Regulatory framework in Norway

The regulatory framework in Norway opens up for end-users to sell locally produced energy to the grid [40]. An end-user producing energy that is mainly self-consumed a prosumer (no: plusskunde) agreement can be signed [41]. The definition of a prosumer is a costumer that both uses and deliverers electricity to the grid, and where the electricity delivered to the grid should not exceed 100 KWh. The prosumer is responsible to find a power supplier interested in both delivering power when it is needed and buying the excess power. The current agreement for prosumers entails that the grid tariff should not include more than an energy part for the electricity fed into the grid [42]. Currently there is no agreement for housing cooperatives or other customers in common buildings, but one goal is to get this in place by the end of 2020 [41].

## 3.2 New power grid tariffs

There is a suggestion to change the tariffs structure, in Norway, to lower load demand from the grid. This because there could be a great value in reducing peak load, since this could save infrastructural cost in the power system [40]. The changes are related to changing the power part of the grid tariff, thus making the grid part of the electricity bill more dependent on the power flow, and not just energy. The reason behind this proposal is that the peak load is the basis of future gird investments [42].

The grid tariffs for residential costumers, before the change, consist of an energy grid fixed part (NOK/year) and an energy part (NOK/kWh):

$$\text{Energy tariff} = \text{Fixed part} + \text{Energy part}$$

The new power grid tariff, which is capacity based could be consisting of fixed part (NOK/year), an energy part (NOK/kWh) that only covers marginal grid losses and a power part (NOK/kWh/h):

$$\text{Power tariff} = \text{Fixed part} + \text{Energy part} + \text{Power part}$$

This suggested change is an incentive to import electricity from the grid before expected peak periods. Furthermore, it will make it more attractive to invest in energy storage to either store energy from the gird or from local energy production [40]. With a power-based grid tariff it would still be more attractive to self-consume the locally generated energy. Fats charging of EVs will also be more expensive with a power-based grid tariff.

Chapter 4

# Other definitions and technologies of relevance

## 4.1 Electric vehicles

In 2019 9,31% of the 2,8 million passenger car stock in Norway was EVs, according to the Norwegian electric vehicle association [43]. The term EV is generally understood to mean cars that are powered by electricity, in comparison to cars using fossil fuel to power the engine. Of all the new cars bought in Norway in 2017, 40% was electric vehicles. In the National Transportation Plan 2018-2029 adopted by the Norwegian Parliament, one of the goals is that all new passenger cars and light vans must be zero emission cars from 2025. Predictions made by NVE suggests that in 2030 half of the car fleet in Norway consists of EVs.

If the share of EVs increases as much as the predictions indicates the result is an energy need increase of 4 TWh. This can lead to a capacity related problem in the grid due to charging of vehicles if all households charge at the same time.

EVs can be a source of flexibility in the demand for the owner, since it can be flexible with respect to charging duration, starting-time and charging power [44]. The flexibility of a demand source varies in terms of what type of load it is. For example, demand from cooking, lights and television is dependent on the consumers behaviour and will require a change from the user in terms of when these activities are conducted. EV charging on the other hand can happen independently from the consumer [14]. Furthermore, the battery in the EV can be used in a Vehicle to Grid (V2G)-solution, meaning that the battery deliverers electricity back to the grid/owner when needed.

## 4.2 Zero Emissions Neighbourhoods

A ZEN is neighborhood aiming to reduce its direct and indirect emissions towards zero over an analysis period. To fulfill this aim, many factors needs to be taken into consideration [22]. The main focus points for a zero emissions neighborhood involves, among other things:

- Plan, design operate buildings and their associated infrastructure components towards minimized life cycle GHG emissions [40].
- Focus on becoming highly energy efficient and getting power from mainly renewable energy.
- Manage energy in a flexible way, within the buildings, between them and between the neighborhood and the surroundings.
- Encourage sustainable transport patterns.
- Have economic sustainability also in focus during planning, designing and operation, done by minimizing total life cycle costs.

In this thesis the focus is upon points regarding energy efficiency, renewable energy, flexibility and economic sustainability. Although Risvollan is not jet included in FME ZEN it is interesting to start analysing the energy system with these aims in mind. Also since Norway has set out to cut its emission by 40% before the end of 2030, compared to 2005, making big housing cooperatives zero emission can be of interest [45].

Chapter 5

# Mathematical formulation of the problem

The purpose of this thesis is to investigate the impact of integration of solar PV in a housing cooperative. This is approached by calculated the LCOE, self-consumption and self-sufficiency amongst other things. This chapter will give the mathematical formulation of these problems.

| **Parameters** | | |
|---|---|---|
| A(t) | - | Annual costs |
| E(t) | - | Annual energy production |
| M(t) | - | Electricity generated from PV panels that are used in-house |
| P(t) | - | The instantaneous PV electricity generation within the household |
| L(t) | - | The total electricity demand for the household |
| C | - | Investment cost at start-up |
| $L_f$ | - | Annual loss factor |
| n | - | Year no. |
| i | - | The (expected) lifetime of the power system |
| r | - | The Discount Rate |

## 5.1 Levelized Cost of Electricity

Levelized Cost of Electricity (LCOE) is a much used method for calculating costs for production of electricity. It is calculated as per unit energy cost and is based on the net present value of the total lifetime cost of the project. The LCOE calculations done in this thesis is real, meaning that the discount rate is not adjusted for inflation.

$$\text{LCOE} = \frac{\text{Total lifetime cost [NOK]}}{\text{Total lifetime output [kWh]}}$$

This can be rewritten to:

$$LCOE = \frac{C + \sum_{n=1}^{i} \frac{A(t)}{(1+r)^n}}{\sum_{n=1}^{i} \frac{E(t)*(1-L_f)^n}{(1+r)^n}} \tag{5.1}$$

## 5.2 Self-sufficiency and self-consumption

SC is a measure of how much of the electricity that is produced that is directly consumed in the home or building, and is expressed as:

$$\text{SC} = \frac{\text{self-consumed PV electricity [kWh]}}{\text{Total electricity generation from PV [kWh]}}$$

Which in turn can be expressed as:

$$SC = \frac{\int_{t=t_1}^{t_2} M(t)dt}{\int_{t=t_1}^{t_2} P(t)dt} \tag{5.2}$$

SS is defined by Luthander, Widén, Nilsson and Palm as the share of total demand that is being supplied by in-house-generated electricity [46], giving the following:

$$\text{SS} = \frac{\text{self-consumed PV electricity [kWh]}}{\text{Total electricity demand [kWh]}}$$

This can be again be represented as:

$$SS = \frac{\int_{t=t_1}^{t_2} M(t)dt}{\int_{t=t_1}^{t_2} L(t)dt} \tag{5.3}$$

# Chapter 6

# Computer simulation

Simulations in eTransport are done for the energy system with different energy source investment options. This to calculate annual costs of the different energy systems. The main task of eTransport is to optimize investments for a given energy infrastructure over a set period of time, ensuring that the end users energy demands are covered in the best way possible.

## 6.1 eTransport

The following section is based on my project thesis [33]; The PC Tool eTransport has a windows-based graphically interface in MS Visio. It uses a combination of Linear programming (LP), Mixed integer programming (MIP) and Dynamic programming (DP) to calculate the annuity energy cost for the different scenarios in the model made. The calculations for operational costs of all the years, all the components and system designs are done by LP and MIP in AMPL with CPLEX-solver. To calculate the optimal investment plan DP in C++ are used.

## 6.2 Modelling in eTransport

The model is prepared in collaboration with Ove Wolfgang, SINTEF. The following model is used in the simulations conducted in this thesis:

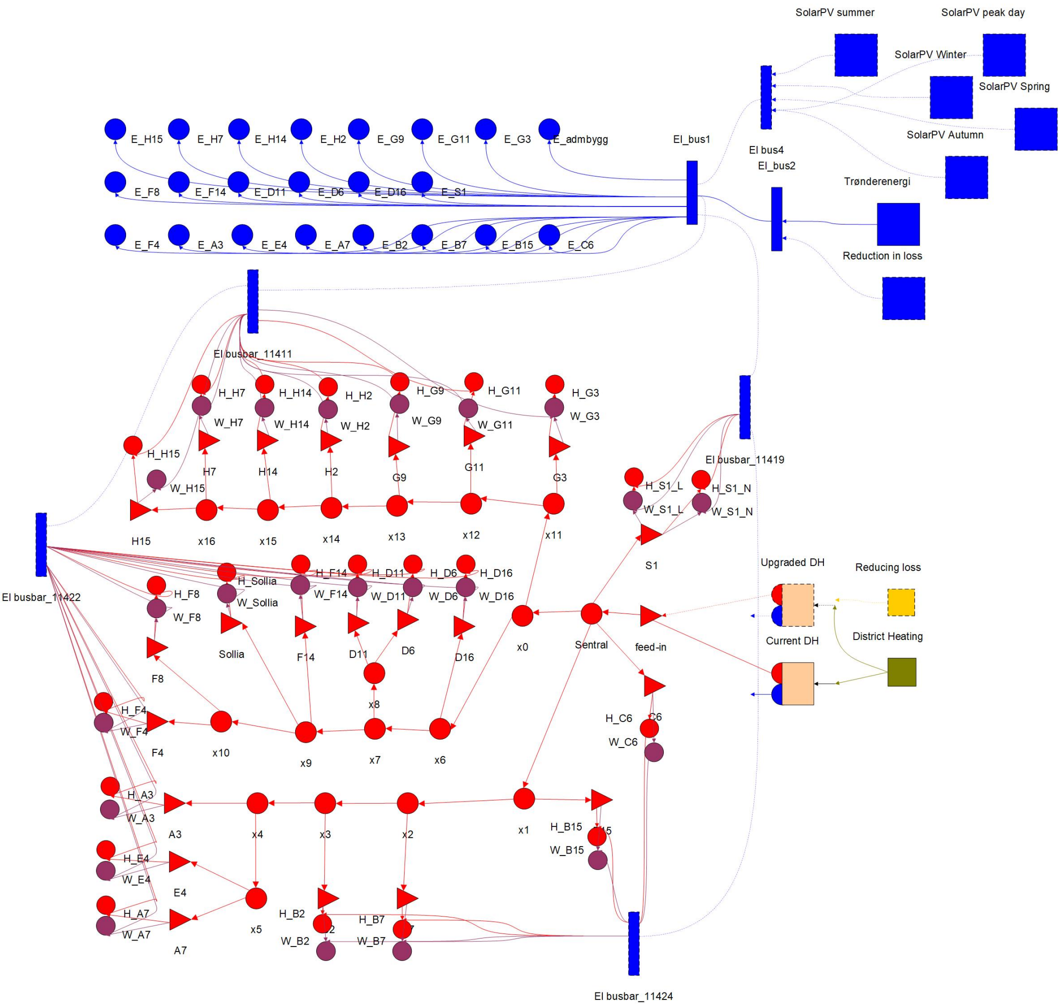



**Figure 6.1:** Model for simulations in eTransport

The load is represented in this model by the blue, burgundy and red circles. The solar PV energy system is represented by the five blue square modules in the right corner. The blue square named TrønderEnergi is representing electricity from the grid, and the square named "Reduction in loss" represent the reduction in needed demand when the energy system is fully electric. The two modules named "Upgraded DH" and "Current DH" represent the two different district heating systems.

The load data obtained is categorized in three different parts; heating of tap water, heating of room and electricity use, this is because the two first parts are covered by the district heating system. Therefor the module is structured so that the load data for tap-water heating from the district heating system is entered in the burgundy load points, the room heating from the DH system is entered in the red circles and the electricity use in the blue circles.

When making a scenario where the system is fully electric all the demand covered by the district heating to the electricity system, by connecting them to El busbars. This way they can be covered by the electricity from the grid (TrønderEnergi). Also a reduction in demand is presumed, and this is represented in the model by the ”Reduction in loss” module. This reduction is due to avoided loss of heat in the pipes when switched from a distract heating system to a fully electric systems, which have minimal loss during transportation in the grid.

connect all the district heating losses to the electricity grid, by the Elbusbars and then

There are four different energy systems, that can cover the demand, represented in the model;

1. The current system which is the district heating system in need of an upgrade in combination with electricity coverage from the grid.
2. A fully electric system where all the load is covered with electricity from the grid.
3. A solar PV system, where a share of the demand is covered by electricity from rooftop solar panels and the rest of the demand with electricity from the grid.
4. The final energy system is an upgraded district heating system along with electricity from the grid.

### 6.2.1 Fixed model input parameters

The following data was used as input for the simulations in eTransport.

**Table 6.1:** Overview of investments and expenses related to the the different energy system options

| | Investment [MNOK] | Annual expenses [MNOK] | Lifetime [Years] | Valid |
|---|---|---|---|---|
| Current system | 0 | 2,4 | - | 2018 - 2020 |
| Fully Electric system | 57,9 | 0 | 25 | 2020 - |
| Upgraded district heating system | 119,3 | 2,4 | 50 | 2020 - |
| 100% Solar PV system | 35,5 | 0,2 | 30 | 2020 - |
| 50% Solar PV system | 17,8 | 0,1 | 30 | 2020 - |

The investment expenses shown in Table 6.1 are based on calculations done by Wolfgang [47], and numbers presented in Section 7.2.3.

Chapter 7

# Case study description

The Risvollan housing cooperate and its energy supply system is the basis of this study. The load data for the electricity and heat use was provided by Statkraft Varme, NTE and TrønderEnergi Nett and further systematized by Sørensen and Wolfgang [14], [48] and [7]. The solar generation data is provided through simulations using *Renewables.ninja* [15].

| **Unit** | | **Meaning** |
|---|---|---|
| kW | - | The effect of the system |
| $W_p$ | - | Watt-peak, which is rated power |
| kWh | - | Energy from the system |

## 7.1 Description of energy system

The housing cooperative consists of 1113 apartments. These are divided into 22 consumer nodes for electricity use, tap-water heating and room heating demands. The current energy system is an outdated district heating system in need of an upgrade.

### 7.1.1 Time period of the analysis

The time period of the analysis is set to be from 2018-2040, where the current energy system is set to stop existing from 2020. Meaning that an investment in a new energy system must be done in 2020, with an analysis period from 2020 to 2040.

In the model the year is represented as 4 seasons and a peak day. The peak day is chosen to be a cold winter day; February 26th. The following distribution is used in the model:

**Table 7.1:** The breakdown of the year

| Season | Days |
|---|---|
| Spring (March - May) | 92 |
| Summer ( June - August) | 92 |
| Autumn (September - November) | 91 |
| Winter ( December - February) | 89 |
| Peak day (February 26th) | 1 |

### 7.1.2 Load data

The 22 consumer nodes have their own average consummation profiles for the three energy uses. These profiles are scaled up and down based on the seasons and peak day in the model, by the following factors:

**Table 7.2:** Scaling factors for the three different energy demands

| | Electricity factor | Room heating factor | Tap-water heating factor |
|---|---|---|---|
| Spring | 1,02 | 1,03 | 1,00 |
| Summer | 0,84 | 0,17 | 1,00 |
| Autumn | 1,05 | 1,03 | 1,00 |
| Winter | 1,10 | 1,78 | 1,00 |
| Peak day | 1,06 | 2,99 | 1,00 |

The annual electricity load was found to be 5318 MWh for the total system. The average demand profiles used in the simulations can be seen in the Appendix A.

### 7.1.3 Electricity prices

The electricity price is varied based on the prediction done by NVE in a long-term power market analysis, as shown in figure 7.1.

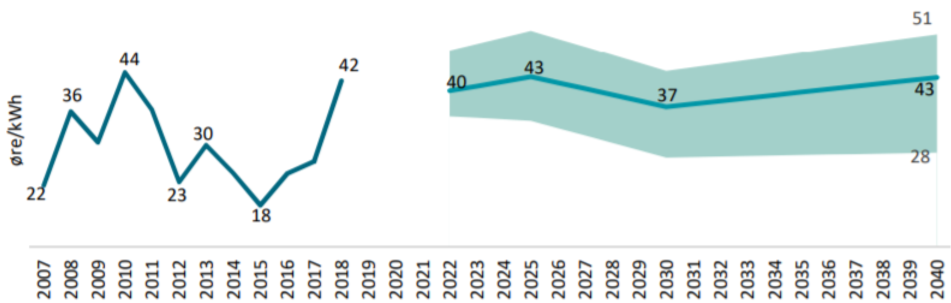



**Figure 7.1:** The Norwegian power price estimates as a results of NVE's analysis [9].

In the analysis both the worst case and the best case predictions are taken into account, giving the following electricity prices:

**Table 7.3:** The electricity price, including all fees, for the case scenarios and base case used in the analysis.

| | Spot price electricity [NOK/kWh] | Electricity price [NOK/kWh] |
|---|---|---|
| Base case | 0,37 | 0,85 |
| High price | 0,51 | 0,99 |
| Low price | 0,28 | 0,76 |

The price for electricity from the grid includes fees such as grid costs, electricity certificates and premiums from supplier. These are added to the spot price, thus giving the total cost of the electricity from the grid.

These electricity prices are converted into 24-hours profiles by scaling them according to the average daily profile from NordPool for 2004 to 2018. The profiles are then adjusted for the seasons by the factors seen in table 7.4.

**Table 7.4:** Factor for electricity price used in eTransport

| | Electricity price factor |
|---|---|
| Spring | 0,984 |
| Summer | 0,976 |
| Autumn | 1,021 |
| Winter | 1,019 |
| Peak day | 1,019 |

The 24-hours profiles used in the eTransport simulations are shown in Appendix B.

### 7.1.4 Electric vehicles

In the research conducted in this thesis a scenario where 50% of the households in housing cooperative had EVs, meaning 557 EVs. This is a likely scenario based on the predictions represented in section 4.1. Also a scenario where all the cars are EVs, a number of 1113 EVs, are investigated. The following profile of EV charging was used:

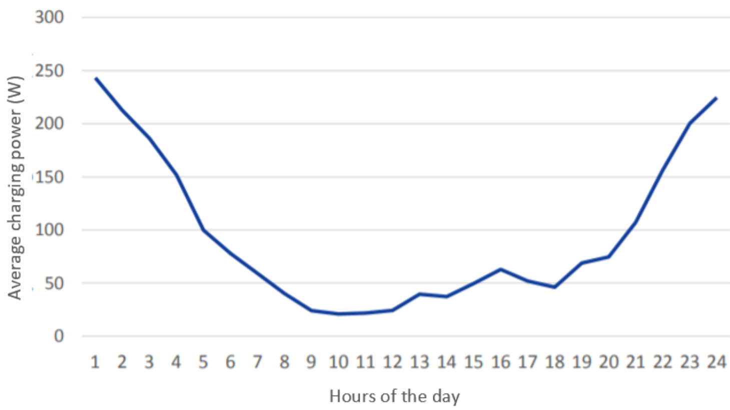



**Figure 7.2:** An average charging profile for one electric vehicle at home [10]

The electricity demand for EV-charging was not scaled up and down in terms of seasons and peak day, since this is not conducive to significant changes [49]. This profile is not based on any smart charging either; it is a typically charging profile for EVs without any influence.

### 7.1.5 Energy system investments

In the model it is possible to invest in three different energy systems in 2020:

1. A fully electric system
2. A new district heating system
3. A solar PV system

The two first energy system investment base cases where calculated and prepared by Ove Wolfang and investigated in my project thesis autumn 2019. The Solar PV system data is described in the following section.

## 7.2 Solar PV generation data

A PV power data generation for Trondheim is found by using *Renewables.ninja*. The data generated in *Renewables.ninja* is for the year 2014 and represent the data output for a capacity of 1 kWp. Then this hourly data is multiplied with the total capacity for the simulated scenario for Risvollan. Then 24-hours profiles is made for the four seasons and the peak day. The following data was used in to generate the generation data for the solar PV.

**Table 7.5:** The input values used in *Renewables.ninja*

| Input parameter | Input value |
|---|---|
| PV panel tilt | 15° |
| Capacity factor | 9,63% |
| System loss (fraction) | 0,1 |

### 7.2.1 Installed solar PV

The find the possible capacity of the solar panels an evaluation of accessible and favorable roof area was done by looking at and using the measurement function on google maps. In this thesis it is calculated that 20 425 $m^2$ of roof area is available for solar panels.

Two Solar PV scenarios are modelled in this thesis. These are one where all the available roof area is utilized for solar panels, referred to as the 100% Solar PV-scenario. The other is a scenario where half of the available roof area is used, referred to as the 50% Solar PV-scenario. The sizes of the two different Solar PV-systems are presented in Table 7.6.

**Table 7.6:** Key figures for the 100% and the 50% Solar PV scenario

| | Unit | 100% Solar PV scenario | 50% Solar PV scenario |
|---|---|---|---|
| Roof area | $m^2$ | 20 425 | 10 213 |
| Capacity | $W_p$ /$m^2$ | 145 | 145 |
| Total Capacity | $kW_p$ | 2962 | 1481 |
| Annual production factor | kWh /$kW_p$ | 850 | 850 |
| Annual total production | MWh | 2517 | 1258 |

### 7.2.2 Solar energy provided

For both solar PV-scenarios 24-hour production profiles are made by finding the average from the data provided by *Renewables.ninja* for the months related to each season in the model.

### 7.2.3 Levelized Cost of Electricity

The LCOE is calculated by the formula presented in section 5.1, and the following numbers are used:

**Table 7.7:** Assumptions in energy cost calculations (LCOE) based on [1]

| **What** | **Nb** | **Unit** |
|---|---|---|
| Installed effect | 2962 | $kW_p$ |
| System cost per unit | 12 | kNOK/$kW_p$ |
| Total system cost | 35,5 | mNOK |
| Annual operating and maintenance costs | 0,17 | mNOK |
| Inverter change after 15 years | 6,2 | mNOK |
| The expected lifetime | 30 | years |
| The discount rate | 5 | % |
| The degradation rate | 0,4 | % |

To find the system cost where solar PV became profitable compared to electricity from the grid, linear optimization of the system cost per unit was adjusted until the desired LCOE for solar PV was found.

### 7.2.4 Self-consumption and self-sufficiency

The SS and SC is calculated for each of the seasons and the peak day for both the Solar PV-scenarios. Furthermore, SS and SC for the two scenarios is calculated when EV charging is added to the electricity demand, both the case where half and all the apartments have EVs.

### 7.2.5 $CO_2$ calculations

There are different ways to take into account that the power mix in the Norwegian grid consist of not only green energy. One way is to use $CO_2$-factors, which are calculated based on LCA of the generation technology as explained in Section 2.2.1. The $CO_2$-factor used in the calculations in this thesis was the following:

**Table 7.8:** The $CO_2$-factors for different energy sources and power mixes. Data based on [2] and [3]

| Energy source | $CO_2$ factor of electricity [g/kWh] |
|---|---|
| Gird- European el mix | 350 |
| Grid - Nordic el mix | 130 |
| Grid - Norwegian el mix | 0 |
| Solar PV | 14 |

The $CO_2$-factors for the grid are based on [2], where historical values for demand and emissions are used to calculate the factors. The Solar PV data is based on LCA-calculations and found in [3].

Chapter 8

# Results

In this chapter results from the simulations done in eTransport and calculations done i Excel are presented. The simulations are carried out on the energy system described in Section 6 with respective load and generation data presented in Section 7. The equations are presented in Section 5.

Section 8.1, *Solar PV profiles*, presents the calculated average profiles for consumption and production throughout a year, for both the 100% and the 50% solar PV-scenarios.

In Section 8.2, *Profitability*, the results from the LCOE calculations are presented. The system unit price is adjusted until profitability is reach compared to the three different grid electricity prices, introduced in Section 7.1.3.

In Section 8.3, *Self-consumption and Self-sufficiency*, the results from calculations of self-consumption and self-sufficiency for different objectives are presented. First, results for the two different solar PV systems are provided. Then, results for the SS and SC calculations when 50% EVs and 100% EVs are added to the housing cooperatives demand are provided.

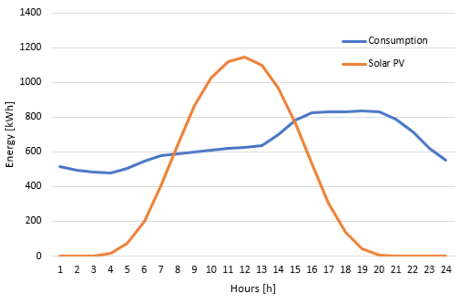
In Section 8.4, *$CO_2$ calculations*, results for the emissions calculations when the 100% and 50% solar PV systems are added and compared to the emissions without solar PV. Different $CO_2$-factors for the electricity is considered; European, Nordic and Norwegian power mix, and the results compared.

In Section 8.5, *eTransport*, the results from the simulations done i eTransport is presented. Firstly the results for when the 100% solar PV system is added, and then the results when the electricity price is regulated and at last when EVs are added. Furthermore, the same simulations are done for the 50% solar PV system. Lastly the LCOE for all the scenarios in eTransport are presented.

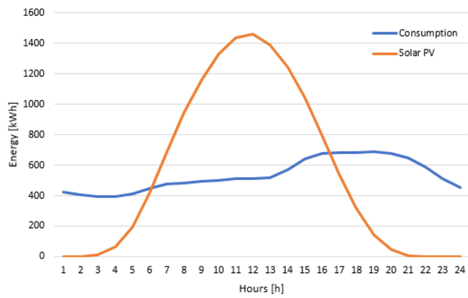
## 8.1 Solar PV profiles

### 8.1.1 The 100% Solar PV-scenario

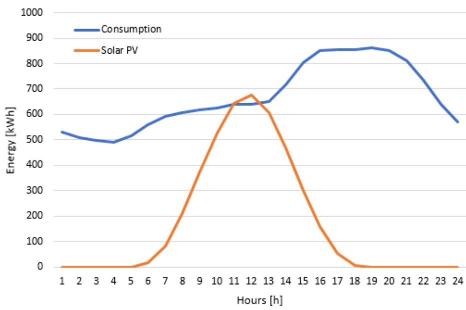
The solar PV profiles and corresponding energy demand profiles for the four seasons and the peak day for the 100% solar PV-scenario can be seen in the following figures.



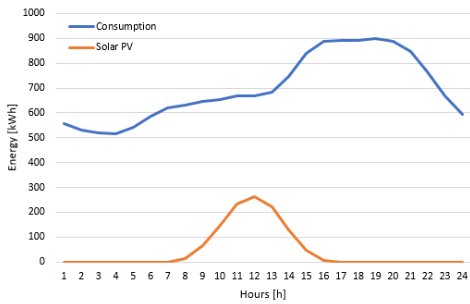

**(a)** Spring



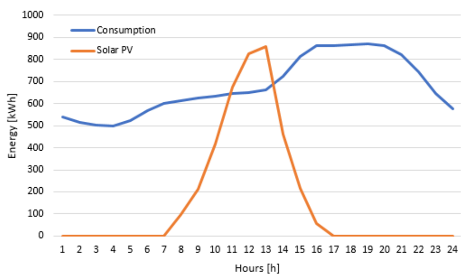

**(b)** Summer




**(c)** Autumn




**(d)** Winter



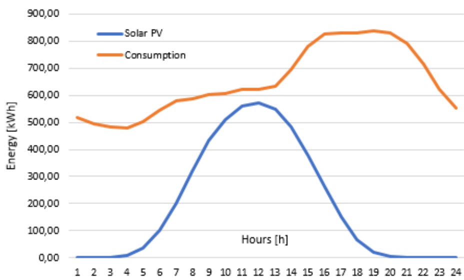

**(e)** Peak load

**Figure 8.1:** Delivered energy from the simulated solar PV compared to the loads from the housing cooperative, daily profile

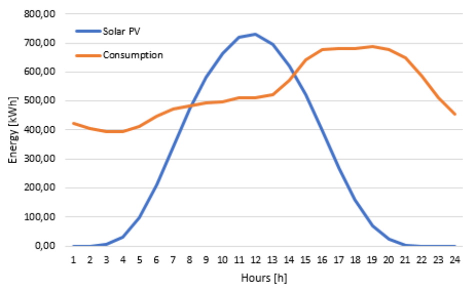
In Figure 8.1 it can be seen that for the 100% solar PV-scenario the production top for the solar system surpasses the consumption, at that time, for all the seasons except winter.

### 8.1.2 The 50% Solar PV-scenario

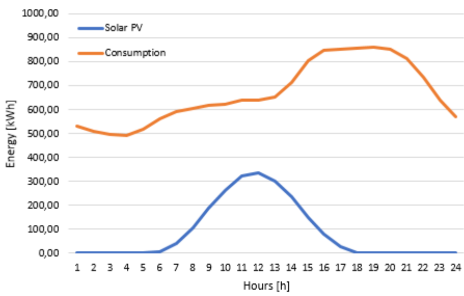
Production profile for the 50% solar PV-system and corresponding demand profile for the housing cooperative Risvollan for the four seasons and peak day are shown in following figures.



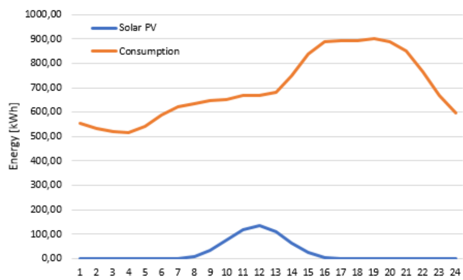

**(a)** Spring



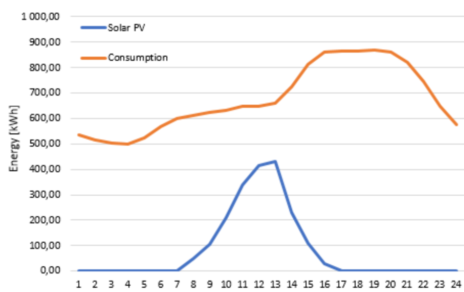

**(b)** Summer




**(c)** Autumn




**(d)** Winter




**(e)** Peak load

**Figure 8.2:** Delivered energy from the simulated 50% solar PV-scenario compared to the loads from the housing cooperative, daily profile

The Figure 8.2 illustrates that when the solar PV is cut in half the production profiles is lower than the demand, except during the summer. Most of the solar PV produced electricity was consumed locally, and export is only happening during summer.

## 8.2 Profitability

Table 8.1 present the calculated LCOE of the solar PV system for different system unit prices.

**Table 8.1:** Results for LCOE of solar PV for the different unit system prices

| System cost per unit [NOK/$W_p$] | 12 | 11 | 10,5 | 10,4 | 10 | 9 | 8,8 | 8 | 7,8 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| Price [NOK/$m^2$] | 1740 | 1595 | 1523 | 1508 | 1450 | 1305 | 1276 | 1160 | 1131 | 1015 |
| LCOE Solar PV [NOK/kWh] | 1,13 | 1,04 | 1,00 | 0,99 | 0,95 | 0,87 | 0,85 | 0,78 | 0,76 | 0,69 |

It can be seen that the unit price that is applicable in this thesis gives a LCOE that is not competitive compared to the current electricity price.

The calculated LCOE compared to the three main electricity prices used in this thesis, presented in section 7.1.3, can be seen in the following figure.

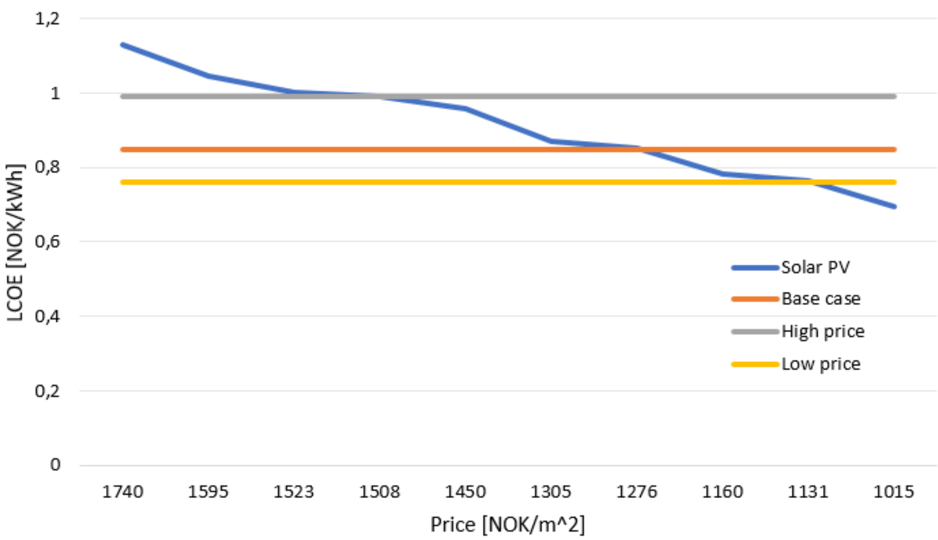



**Figure 8.3:** The LCOE of solar PV for different square meter prices compared to three different prices for electricity from the grid

From the Figure 8.3 it can be seen that the system unit price of Solar PV must decrease to make it profitable compared to the grid electricity prices used. The solar PV becomes equated with electricity from the grid at a system cost equal to 8,8 NOK/$W_p$ for the base case, 10,5 NOK/$W_p$ for the high electricity price and 7,8 NOK/$W_p$ for the low electricity price. The actual system unit price used in this thesis is 12 NOK/kWh, but this is not profitable compared to the grid electricity price.

## 8.3 Self-consumption and self-sufficiency

Table 8.2 present the self-consumption and the self-sufficiency factor of the 100% solar PV-scenario. Similar results for the 50% solar PV-scenario can be seen in 8.3.

**Table 8.2:** Result for SS and SC for the 100% solar PV-scenario base case

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 0,73 | 0,54 | 0,99 | 1 | 0,89 |
| Self-sufficiency | 0,43 | 0,56 | 0,26 | 0,07 | 0,21 |

It can be seen that the self-consumption percentage is 100 for the winter season and close to 100 for the in the autumn. The self-sufficiency is on the other hand low during the the winter and autumn months, including the peak load day.

**Table 8.3:** Result for SS and SC for the 50% solar PV-scenario base case

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 1 | 0,86 | 1 | 1 | 1 |
| Self-sufficiency | 0,30 | 0,45 | 0,13 | 0,03 | 0,12 |

For the 50% solar PV-scenario it can be seen that the self-consumption is 100% for all the seasons and the peak day, except in the summer. The self-sufficiency is under 20% during the winter months and the peak day.

### 8.3.1 SC and SS when electric vehicles are added

Electric vehicle are added to the demand, as described in Section 7.1.4 then SC and SC are calculated. Result for the 100% Solar PV-scenario when half of the residents have EVs and all of them have EVs are shown in Table 8.4 and 8.5, respectively.

**Table 8.4:** Result for SS and SC when EV-charging is added to the energy consumption

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 0,75 | 0,56 | 0,99 | 1 | 0,91 |
| Self-sufficiency | 0,41 | 0,52 | 0,24 | 0,06 | 0,20 |

**Table 8.5:** Result for SS and SC when EV-charging is added to the energy consumption (when everybody drive EVs)

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 0,74 | 0,57 | 0,99 | 1 | 0,92 |
| Self-sufficiency | 0,38 | 0,49 | 0,22 | 0,06 | 0,19 |

By comparing the two Tables 8.4 and 8.5 to Table 8.2 a very slight increase in self-consumption can be seen, and a little decrease in self-sufficiency. The difference between all having EVs and half having EVs are not that great. The self-consumption is generally higher or equal for the scenario where all drive EVs, expect from in the spring. The self-sufficiency is, on the other hand, lower for the scenario where all drive EVs compared to the scenario where only half have EVs.

When half of the solar PV system is considered, the results for the scenarios where half of the car fleet are EVs and where all are EVs are provided in the Table 8.6 and 8.7, respectively.

**Table 8.6:** Result for SS and SC when solar power is cut in half is, and EVs are added

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 1 | 0,88 | 1 | 1 | 1 |
| Self-sufficiency | 0,28 | 0,41 | 0,12 | 0,03 | 0,11 |

**Table 8.7:** Result for SS and SC when solar power is cut in half is, and everybody have EVs are added

| | Spring | Summer | Autumn | Winter | Peak day |
|---|---|---|---|---|---|
| Self-consumption | 1 | 0,90 | 1 | 1 | 1 |
| Self-sufficiency | 0,22 | 0,39 | 0,11 | 0,03 | 0,10 |

It can be seen by comparing the results in Table 8.6 and 8.7 to 8.3 that the self-consumed is still 100% for all the seasons and that it has slightly increased for the summer. Furthermore, the results show that the self-sufficiency has decreased for all the seasons but the largest decrease can be seen in the spring. When looking at the self-consumption it can be seen that it is lower in the tables above compared to Table 8.3.

## 8.4 $CO_2$ calculations

The purpose of this thesis is to investigate how integration of solar PV effect the various accounts of the housing cooperative Risvollan, such as the emissions accounting. In this section the main finding for the $CO_2$ calculations are presented and compared considering the purpose of the study. The emission factors used in the following section are presented in Section 7.2.5.

The emissions reduction of the 100% solar PV-scenario for the housing cooperative is shown in Table 8.8, and the $CO_2$-factor for the same scenario is shown in Table 7.8.

**Table 8.8:** The total emissions result with and without solar PV, when the 100% solar PV system is implemented. Results given in [$tCO_2$]

| | Without Solar PV | With Solar PV |
|---|---|---|
| European mix | 1861 | 1015 |
| Nordic mix | 691 | 399 |
| Norwegian mix | 0 | 35 |

**Table 8.9:** The $CO_2$-factors for the different scenarios, results given in [$gCO_2/kWh$]

| | Without Solar PV | With Solar PV |
|---|---|---|
| European mix | 350 | 191 |
| Nordic mix | 130 | 75 |
| Norwegian mix | 0 | 7 |

From the Table 8.8 it can be seen that a 45% reduction in emissions is achieved by installing the 100% solar PV system, if European electricity mix is considered. A 43% decrease can be seen for when Nordic electricity mix is regarded. If a Norwegian mix is considered the emissions increase when solar PV is added, for these calculations. When inspecting the emissions factors, shown in Table 7.8, an almost bisect can be seen for the European and Nordic mix. Table 7.8 also presents an increase in emissions factor for added solar PV, when Norwegian mix is considered.

Then the 50% solar PC-scenario is considered. Both the emissions reduction and the emissions factors when the solar capacity is halved is shown in Table 8.10 and 8.11, respectively.

**Table 8.10:** The total emissions result with and without solar PV, when the 50% solar PV system is implemented. Results given in [$tCO_2$]

| | Without Solar PV | With Solar PV |
|---|---|---|
| European mix | 1861 | 1438 |
| Nordic mix | 691 | 545 |
| Norwegian mix | 0 | 18 |

**Table 8.11:** The $CO_2$-factors for the different scenarios, results given in [$gCO_2$/kWh]

| | Without Solar PV | With Solar PV |
|---|---|---|
| European mix | 350 | 271 |
| Nordic mix | 130 | 103 |
| Norwegian mix | 0 | 3 |

When studying Table 8.10 a 23% reduction in emissions can be seen for when the European mix is considered, and a 21% when the Nordic electricity mix is regarded. An increase of 18 $tCO_2$ is presented for the scenario where Norwegian power mix is used. A reduction in emissions factor can be seen in Table 8.11 for the European and Nordic power mix, and a small increase when Norwegian mix is used in the calculations.

## 8.5 eTransport

A simulation of different energy systems were preformed for the energy demand of Risvollan in eTransport to see the different annual costs of the different energy supply methods. Results for a fully electric system, solar PV and district heating are presented along with the current system.

### The whole plant

Figure 8.4 show the annual cost for the 4 different energy supply systems, when the 100% PV scenario is used. The annual costs for the three different expense records are presented in Table 8.12.

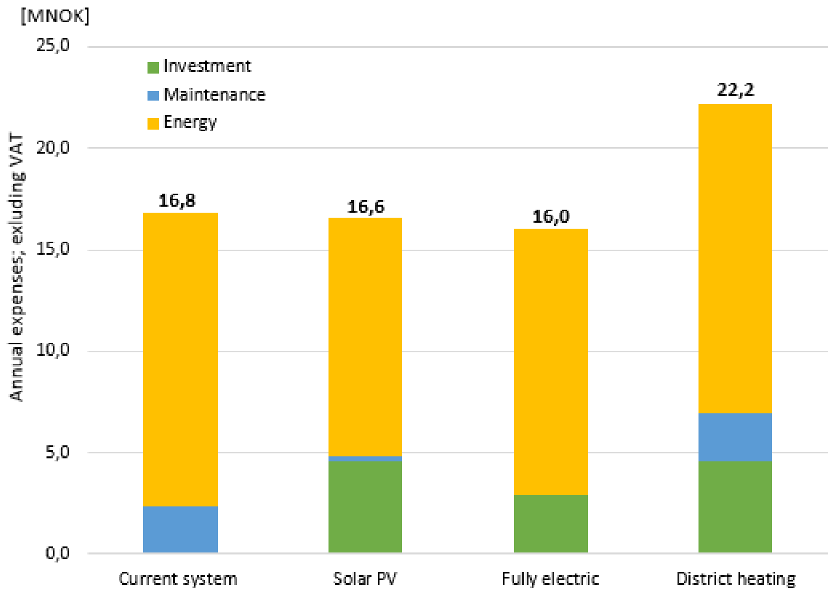



**Figure 8.4:** The annual expenses for the different energy systems

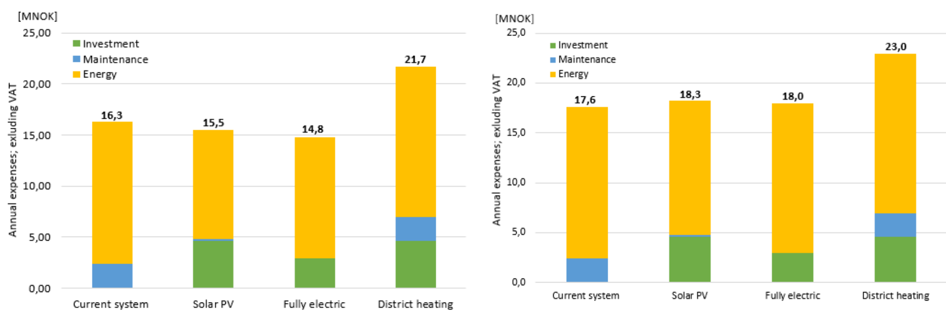
The most expensive alternative is the upgraded district heating system, as seen from Figure 8.4. The best option in terms of finance is the fully electric, yet also the solar PV system is cheaper than the current energy system.

**Table 8.12:** Results for the base case for the 100% solar PV-scenario

| | Current system | Solar PV | Fully electric | District heating |
|---|---|---|---|---|
| Investment | 0,0 | 4,6 | 3,0 | 4,6 |
| Maintenance | 2,4 | 0,2 | 0,0 | 2,4 |
| Energy | 14,4 | 11,8 | 13,1 | 15,2 |
| SUM | 16,8 | 16,6 | 16,0 | 22,2 |

From the data in Table 8.12 it can be seen that the energy cost for the solar PV system is less than that of the fully electric, but the investment and maintenance costs are higher for the solar PV.

Figures 8.5b and 8.5a presents the annual costs for the different energy supply systems when the electricity price is altered as described in section 7.1.3.



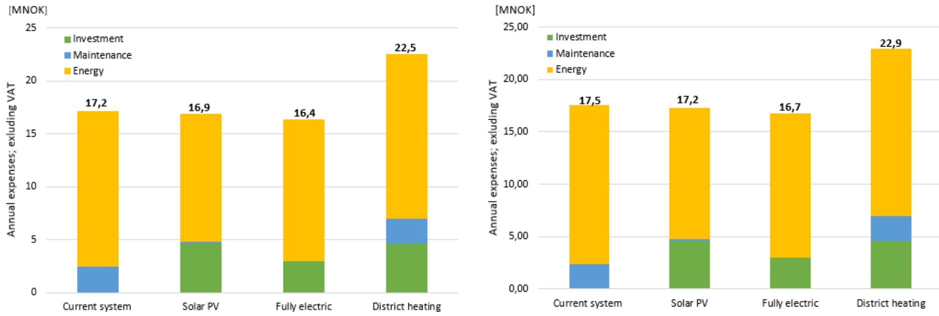

**(a)** with low electricity price

**(b)** with high electricity price

**Figure 8.5:** The annual expenses for the different energy systems, with different electricity price

Figure 8.8b shows that the difference between the fully electric system and solar PV have decreased for the higher electricity price compared to the base case. The deviation between the district heating system and the other two energy supply options are reduced when the electricity price is increased. When the elasticity price is lowered, results shown in Figure 8.5a, It can be seen that the solar PV becomes slightly more expensive compared to the base case shown in Figure 8.4.

The results from the 100% solar PV-scenario as 50% and 100% EVs are added are presented in Figure 8.6a and 8.6b, respectively.




**(a)** with half with EVs

**(b)** with everyone with EVs

**Figure 8.6:** The annual expenses for the different energy systems when EVs are added

By comparing the results shown in the figures above with those for the base case shown in Figure 8.4 a small decline in the difference between the solar PV and fully electric supply system annual costs for both EV-scenarios can be seen. The value difference between the current system and the solar PV and the fully electric energy system is slightly greater when EVs are added. Furthermore the upgraded district heating system annual costs increases relative to the other systems.

### Half of the plant

The results obtained from the simulation done when the solar PV capacity is cut in half are presented in the following figure. Table 8.13 provides an overview of the different cost constituents for the energy supply systems.

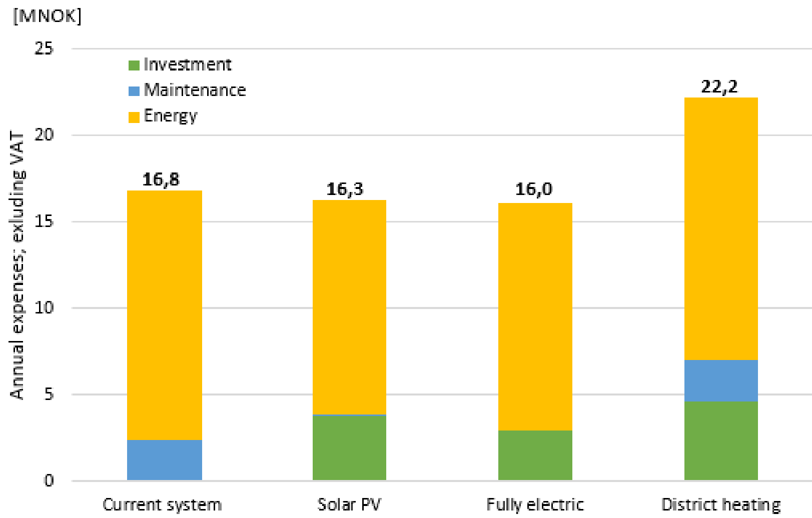


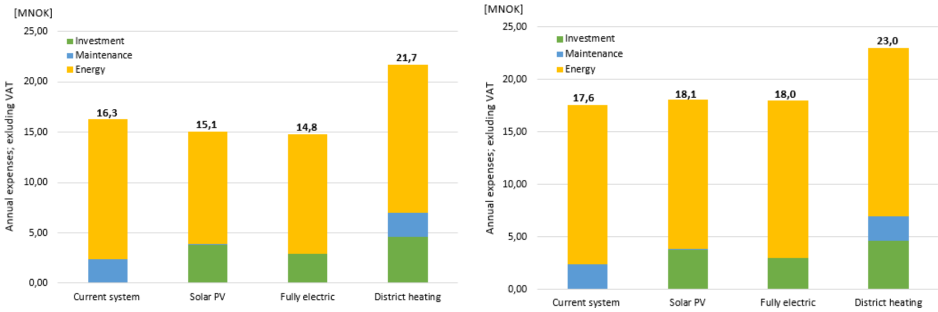

**Figure 8.7:** The annual expenses for the different energy systems with half of the solar PV plant

**Table 8.13:** Breakdown of the cost elements for the 50% solar PV base case

| | Current system | Solar PV | Fully electric | District heating |
|---|---|---|---|---|
| Investment | 0,0 | 3,8 | 3,0 | 4,6 |
| Maintenance | 2,4 | 0,1 | 0,0 | 2,4 |
| Energy | 14,4 | 12,4 | 13,1 | 15,2 |
| SUM | 16,8 | 16,3 | 16,0 | 22,2 |

By comparing the results in Figure 8.7 to those found in Figure 8.4, it is apparent that the cost inequality between the solar PV and the fully electric has reduced for the 50% solar PV-system. From Table 8.13 show that the reduction in investment for solar PV, compared to the one presented in Table 8.12, has decreased more than the energy cost has increased.

Figure 8.8a and 8.8b presents the annual cost when the electricity price is lowered and increased, respectively.



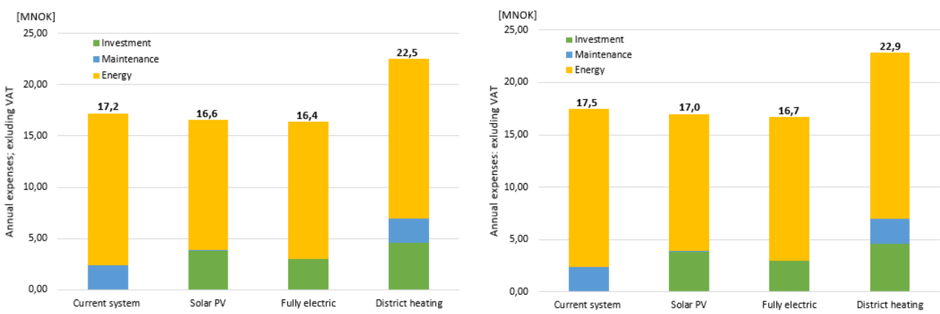

**(a)** with low electricity price

**(b)** with high electricity price

**Figure 8.8:** The annual expenses for the different energy systems, with different electricity price

What is striking about the results in 8.8b is that the difference between the fully electric and solar PV is minor. When comparing with the 100% solar PV-scenario, presented in Figure 8.5, it can be seen that there is generally less difference between the solar PV and the fully electric annual costs for the 50% solar PV-scenario.

The results for the 50% solar PV-scenario when 50% and 100% EVs is added to the demand is shown in Figure 8.9a and 8.9b, respectively.




**(a)** Half of the EVs added

**(b)** All the EVs added

**Figure 8.9:** The annual expenses

When comparing the results in 8.9 with the ones found in Figure 8.6, it can be seen that difference between the solar PV and fully electric energy system has been reduced, but the fully electric is still the most profitable.

### LCOE

Th table below presents the electricity price per kWh for the different energy systems in the different analysis done.

**Table 8.14:** The results for the electricity cost, given in NOK/kWh, for the different energy systems for the different scenarios run in eTransport

| | Current system | Fully electric | District heating | 100% Solar PV | 50% Solar PV |
|---|---|---|---|---|---|
| Base case | 0,75 | 0,75 | 0,99 | 0,77 | 0,76 |
| Increased el price | 0,79 | 0,84 | 1,03 | 0,85 | 0,85 |
| Decreased el price | 0,73 | 0,69 | 0,97 | 0,72 | 0,71 |
| 50% EVs | 0,77 | 0,77 | 1,01 | 0,79 | 0,78 |
| 100% EVs | 0,78 | 0,78 | 1,02 | 0,81 | 0,79 |

From the data shown in Table 8.14 it can be seen that the 50% solar PV-scenario generally is a less expensive alternative, compared to the 100% solar PV. Regardless, the fully electric is the most profitable alternative when considering economy.

# Chapter 9

# Discussion

This study set out with the aim of assessing how solar PV would affect the economic and environmental accounts of a housing cooperative. As solar PV is relatively easy to install in an already existing building stock, the effect of two sizes of solar PV was examined along with a fully electric and a district heating system as realistic investment opportunities. The two solar PV scenarios, a 50% and 100% scenario, are formulated with regards to installed PV capacities, as described in Section 7.2.1. The simulations and calculations are performed for the housing cooperatives Risvollan, with simulated solar PV generation data and demand for that area. In this following chapter, the main findings in Chapter 8 are discussed.

## 9.1 Base cases

In the 100% PV base case scenario, all the available roof area is covered with solar panels, and the installed capacity is 2962 $kW_p$. This scenario results in overproduction during the middle of the day in the spring and summer, and a little bit during autumn, shown in Figure 8.4. Also in the peak day an overproduction can be seen around noon. For the base case of the 50% solar PV scenario, results shown in Figure 8.7, half of the available roof was utilized, leading to a total capacity of 1481 $kW_p$. This reduction in capacity leads to a decrease in production profiles such that overproduction only occurred during summer.

It is desired to have a high self-consumption rate, due to the Norwegian grid tariffs as described in Section 2.2.3. In the 100% solar PV-scenario, the SC is 1 only for the winter, and close to one, 0,99, in the autumn, as shown in table 8.2. For the 50% solar PV-scenario, on the other hand, the result presented in Table 8.3 show that the self-consumption was 1 for all the seasons besides summer. The higher the self-consumption rate is, the more of the produced electricity is directly used on site. It is expected that when lowering the size of the solar PV system, cutting the capacity in half, that the self-consumption increases. This can be seen by comparing the results in Table 8.2 and 8.3.

With a low degree of export of generated electricity, the value of the solar PV system is through the saved import from the grid, since the system has close to zero operational and maintenance costs. The return of the investment is therefore close to entirely dependent on the saved expenses due to the use of solar PV generated electricity compared to that bought electricity from the grid.

When comparing the annual costs for the different energy systems for both solar PV scenarios, shown in Figure 8.4 and 8.7, it can be seen that the most expensive system is the upgraded district heating system. From the results, provided in Table 8.12 and 8.13, it is presented that the district heating system as a much higher annual maintenance cost than the other two systems. Due to loss in the pipes, a higher energy demand is to expected, as described in Section 6, and therefore a higher annual energy cost. The total investment cost for the upgraded district heating system is also the highest of the three, presented in Section 6.2.1. Since this high investment cost did not lead to a more significant reduction in energy cost, the energy system becomes uneconomical compared to the other energy options.

## 9.2 Effect of including EVs

When increasing the demand, by adding EVs, the self-consumption rates barely increases. This can be seen in Table 8.4 and 8.5 for the 100% solar PV-scenario and in Table 8.6 and 8.6 for the 50% solar PV-system. As the demand profile for EVs, shown in Figure 7.2, does not coincide with the production profile for solar PV in the way that the solar cells produce the most when the charging is at a minimum. Thus, the EV-charging has little impact on the self-consumption rates for both solar PV-scenarios. These results are consistent with data obtained in previous studies, which indicates that there is a mismatch between solar PV and EV charging demand, leading to a limited increase in self-consumption when introducing EVs.

Since the EV-charging added demand outside of the solar PVs main production period, the self-sufficiency also increased with the added load. This can be seen by comparing the results shown in Figure 8.12 and 8.3 to Figures 8.4, 8.5, 8.6 and 7.2, respectively. Since the including of EV-charging of the demand essentially added on the demand needed to be covered by electricity from the grid, with the charging profile used in this thesis, the results had little impact on whether solar PV was profitable or not. In other words, the increase in electricity demand from charging EVs outweighs the increase in self-consumption and thus, the self-sufficiency decreases.

The result of this study indicates that a typical charging profile for EVs, which is to charge after one come home for the day, is not compatible with solar PV. If the EV charging is going to contribute to increased self-consumption and self-sufficiency, an other charging schedule must be introduced. This, on the other hand, could be difficult to implement as one, for practical reasons, recharges at night and utilize during the daytime to drive to and from work etc.

When looking at the results from eTransport when EVs are added for both the 100% and the 50% solar PV scenarios, Figure 8.6 and 8.9 respectively, an almost equal increase in annual energy cost can be seen for all the energy systems, compared to the base case in Figure 8.4. This may be explained by the fact that the demand for the charging of the EVs must be covered by the electricity from the grid for all the systems, and hence the cost is equal for all the systems. Thus, this underpins the results found for the SC- and SS-calculations when EVs are added.

## 9.3 Effect of differing electricity price

The result of the simulations when the electricity price was adjusted shows that for the for the 100% and 50% Solar PV systems, Figure 8.5b and 8.8b, the increase in grid electricity price lead to shrinking of the gap between the fully electric and solar PV-systems. Meaning, that the solar PV systems are more economically desirable compared to the base case, presented in Figure 8.4 and 8.7, when the grid electricity price is higher, but the fully electric system is still the most profitable alternative.

By comparing the results in Figure 8.5a and 8.8a to those in Figure 8.4 and 8.7, respectively, it can be seen that by decreasing the grid electricity price the difference between the total annual cost for the fully electric system and the solar power is barely increased. Nevertheless, the results show that the fully electrical system is still the best investment options for the housing cooperatives.

As described in Section 9.1, the return of investment in solar PV is dependent on the saved cost due to avoided purchased electricity from the grid. In other words, the return of investment is also reliant on the grid electricity price. The payback time for the solar PV system is therefore linked to the spot price, and the cheaper the electricity from the grid, the longer it takes for the return on the investment.

It is interesting to note that when the electricity price is lowered the impact on the result is not as great as when it is increased. By this it is meant that when increasing the electricity price the results for the 100% solar PV system show a difference in annual cost between the fully electric and the solar PV system reducing from 0,6 MNOK to 0,3 MNOK. While when the electricity price is decreased an increase from 0,6 MNOK to 0,7 MNOK can be seen for the two systems. So, the increase in percentage is not as significant when the price is lowered as the reduction is when it is increased. For the 50% solar PV system, the same can be seen, a reduction in difference from 0,3 MNOK to 0,1 MNOK is found when the electricity price is increased. When the grid electricity price is lowered the difference between the two systems is still 0,3 MNOK. This might indicate that the system is most vulnerable to price increase and this is positive for the solar PV system, as it gives positive prospects for solar power as the indications from NVE is that the electricity price will increase. And regardless, a decrease in grid electricity price does not make solar PV hardly any more expensive compared to the fully electric system.

Looking at Table 8.14 shows that the cheapest way to cover the energy demand is by investing in the fully electric system, regardless of the scenarios. The 50% solar PV system is the second-best option for the housing cooperatives, based on the LCOE for all the scenarios. Then, the 100% solar PV system and lastly the upgraded district heating system. The reasons why the 50% solar PV system is the more economical choice to make, over the 100% solar PV is affected by the fact that the overproduced electricity is not sold in the simulations. Had this been taken into account, the profitability for the 100% solar PV had increased and might have been lower than that of the 50% system.

## 9.4 System unit price profitability study

The system unit price where solar cells became profitable, compared with the electricity prices, was found for three different el prices. Table 7.7 shows that the actual system unit price, 12 NOK/$W_p$, resulted in an LCOE equal to 1,13 NOK/kWh, which is more expensive than the base case electricity price used in this thesis, 0,85 NOK/kWh. When the system unit price was lowered to 8,8 NOK/$W_p$, the solar system was able to match the base case electricity price. That is a reduction in price of 27%, which is a relative sharply reduction. On the other hand, as described in Section 2.2.2, the system unit price for solar panels in Norway has been reduced a considerable amount over the last few years, and this trend is likely to continue. Therefore the matching LCOE might not be completely unlikely.

When comparing the LCOE for solar PV with the increased electricity price, the result was a system unit price of 10,4 NOK/kWh to make it economically attractive, which is a price per kWh which according to NVE is a plausible price in the near future. With lowered electricity price predictions as the basis, the system unit price must drop to 7,8 NOK/$W_p$ to become financially matching to the grid electricity price.

In these calculations any subsidies that may be applicable are not considered. If such is added a decrease in LCOE is expected to be seen. Also an income from sold overproduced electricity is not considered. This would also affect the profitability of the solar PV system.

## 9.5 Impact on the $CO_2$-footprint when implementing solar PV

When comparing the $CO_2$-factors for the energy supply system with and without solar PV, this study found that if a Norwegian power mix is used as a basis, the positive environmental impact of solar PV is minimal. In contrast, if a European mix and Nordic mix is considered solar PV can almost cut the emission factor in half, for the 100% scenario. For the 50% solar PV-scenario, a 23% reduction in the the $CO_2$-factor can be seen compared to the European mix, and a 20% reduction if using Nordic electricity mix as the basis.

The emission factor for Solar PV used here was based on LCA, and could have been set to zero, as described in Section 2.2.1, then a more significant positive environmental impact would have been expected to be seen. Besides, it could be argued that hydropower also should have an emission factor higher than zero due to its own emission during construction. This would also affect the results, but depending on whether the LCA emissions factor for hydropower is larger or smaller than that of solar PV a more or less positive environmental impact for implementing solar power can be seen. Compared to the current results, any increase in emissions factor for the hydropower will lead to a reduction in the difference between the two. If the emissions factor for hydropower exceeds that of solar PV, a positive environmental impact could be expected from investing in solar power.

Another environmental impact that can be considered is the need for interventions in the natural surroundings and landscape for the two energy generation methods. When making hydropower plants dams and reservoirs are often built, and the water flow in the watercourses can be affected. Reducing natural water flow in the rivers can be detrimental and destroy the habitat of plants and animals in the affected waterways. These are environmental impacts not taken into consideration when looking at the emissions factors. Rooftop solar PV exploits area which are already there, and is not taken advantages of. Since these negative consequences of hydropower is challenging to convert into numerical values, it becomes difficult to see them in the context of different emission factors. But, it can be argued that solar PV is better for the environment than hydropower, when it comes to the destruction of nature and environmental impact that follows from construction.

## 9.6 Energy flexibility

Many of the renewable and environmentally friendly power generation technologies are unregulated power sources, meaning sources that vary depending on the weather and can not be turned on and off depending on the energy demand. Hydropower, on the other hand, is a flexible energy source and can be quickly turned on and off depending on the demand. Since Norway has much flexible hydropower, implementing unregulated power is not as challenging as for many other countries where the majority of the energy generation sources are unregulated. Nevertheless, the power demand increases and an elevated expectation to supply security is noticeable, additional flexible energy sources is important also in Norway [50] [51].

A water-borne district heating system is also a flexible energy source, due to the fact that several energy sources can be used [52]. The district heating can be used to relieve the power grid by taking over the heating load. This load relief is especially desirable during peak hours, for example during a cold winter day mornings when everybody demand energy at the same time for showering, room heating, lights and so on [50]. The district heating system can also turn off its electricity demand and switch over to other energy sources, thus lower the electricity demand.

Also, by using energy sources such as solar PV and district heating, energy that would otherwise have been drawn from the grid is now covered by other sources, and thus the power demand may not increase as much as feared. Furthermore, it can be argued that EVs are a source of flexibility for the electricity demand in the housing cooperatives, as described in Section 4.1. However, EVs, as a flexible source or storage, is not examined in this thesis.

## 9.7 Limitation and assumptions

Several limitations and assumptions have been made for this study, and thus have influenced the results.

- The simulations done in eTransport does not take into account that produced surplus power from the solar cells can be sold to the grid, meaning that this possible income is not taken into consideration in this thesis.
- The study is performed on one specific housing cooperatives with specific consumption data and PV generation data. Other input data might give different results. However, the data used here are characteristics generation profiles and thus, the result show characteristics trends.
- The cost of the solar PV system is just an assumption without any investigations in connection with the housing cooperatives, Risvollan.
- It also only assumed that the roof area is suitable for rooftop solar PV without any inspection conducted, and the area is measured with measuring tools in Google maps and may, therefore, be somewhat inaccurate.

Chapter 10

# Conclusion

In this project, different aspects of implementing solar PV in a housing cooperative is analyzed, and also an evaluation of which of the 4 different energy source investments are the most profitable for the same housing cooperatives. The various aspects of the solar PV systems evaluated are LCOE, self-consumption, self-sufficiency, emissions, the annual cost of the system and how implementing of EVs and adjustments of grid electricity price affects the profitability.

Two different scenarios for PV generation where conducted; (i) the 100% solar PV scenario where all available roof area was used for rooftop solar PV, and (ii) the 50% solar PV system where the area utilized was cut in half. Neither of the solar PV systems were able to beat the fully electric alternative when it came to profitability. But they were both cheaper than the upgraded district heating system.

Although the fully electric system was the most economical choice for the housing cooperatives Risvollan, based on the simulations conducted in this thesis, nevertheless, the results were generally encouraging for solar PV even though the scenarios set up were not particularly solar PV optimistic. By this, the fact that selling surplus electricity generated by the solar PV is not taken into consideration, LCA is used as the basis for the emissions factor instead of 0 and the highest system unit price is considered for the eTransport simulations. The results indicate that in a few years with decreasing system unit price, income from sold electricity, and if lucky increased grid electricity price, solar PV is able to match the fully electric system and maybe surpass it.

The results also underpin what was presented in the theory chapter, that EVs and solar PV is somewhat of a mismatch. They do not coincide, meaning that the demand peak time do no match the production peak time. This indicates that it is not a natural correlation between investing in solar PV if you are going to buy an EV, or vice versa.

Even though the simulations suggest that the fully electric system is the most economical choice for the housing cooperatives, compared to the other energy systems defined, there are other factors also to be evaluated. Such as the environmental impact. The emissions factor calculations show that for any other grid mix than the Norwegian, the solar PV implementation results in an emissions decrease for the housing cooperatives. Also, it can be argued that the destruction of nature caused by hydropower makes solar PV the better choice if the environment and nature is emphasized.

If the focus is on flexibility in the energy system, the district heating system can bring a power relief to the electricity grid, and therefore is a more attractive choice. Especially in a socio-economic perspective if it can lead to a reduction in the need for upgrade investment in the power grid. Furthermore, the waterborne district heating is a renewable energy source. Still, since Norway has such a large amount of renewable energy sources, the environmental aspect does not out weight the missing economic sustainability aspect of the investment.

So, to conclude, the thesis shows that with the current investment expenses and grid electricity prices, the solar PV system is not financially competitive against a fully electric system with full demand coverage from the grid. Furthermore, this study also adds to the research suggesting that there is a mismatch in time between the EV-charging demand and the solar PV generation. The thesis also shed light on other important factors, such as environmental impact, that needs to be considered before an investment option is chosen. All in all, the findings contribute to see an opportunity for solar cells to become a profitable alternative for housing cooperatives in the future.

Chapter 11

# Further work

The simulations conducted in this thesis have used simple methods for calculating generation from solar PV, since only one tilt and orientation of the solar PV was investigated. Also, only simple assumptions was the base for the calculated expenses for the solar PV system. Anyway, the simulations and calculations conducted have given a better understanding of how implementing solar PV will affect the housing cooperatives given a starting point to see if such an investment can be financially profitable. Furthermore, the environmental impact have been studied and discussed. To further investigate which the best energy system options for the housing cooperatives and whether solar PV could be profitable, it would be interesting if the further works included:

- Implementing simulations with more realistic production data based on location, roof area, tilt and orientation.
- The simulations model should also be tested for alternative systems cost for the PV model system, as those used in this thesis are rough assumptions without any inspection of the area.
- Investigate how income from sold surplus electricity from the solar PV will affect the profitability of the solar PV.
- Investigate how introduction of energy storage will affect the self-consumption and whether it is profitable to make such an investment.
- Test the simulations model for different solar PV sizes to find the optimal size. Also testing of facade solar PV could be interesting, perhaps that is more effective.
- The implementation of EVs are also very simple and it could be interesting to look into what happens if the EV-charging profile changes.

- As it currently is no way for housing cooperatives to become prosumers, alternatives for how a housing cooperatives can utilize solar PV can be studied, i.e. by making the solar PV generated electricity cover the demand of the common areas.

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# Appendix A - Load profiles


**Figure 11.1:** Overview over Risvollan and the connection to the load points in the eTransport model

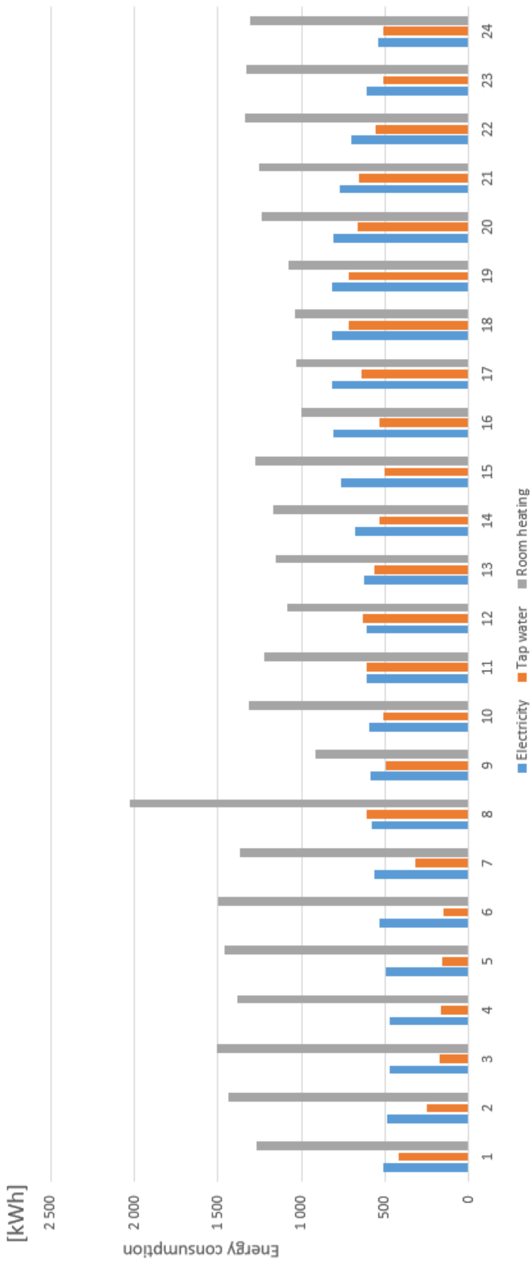



**Figure 11.2:** The average daily energy demand of the housing cooperatives Risvollan, used in the simulations in eTransport

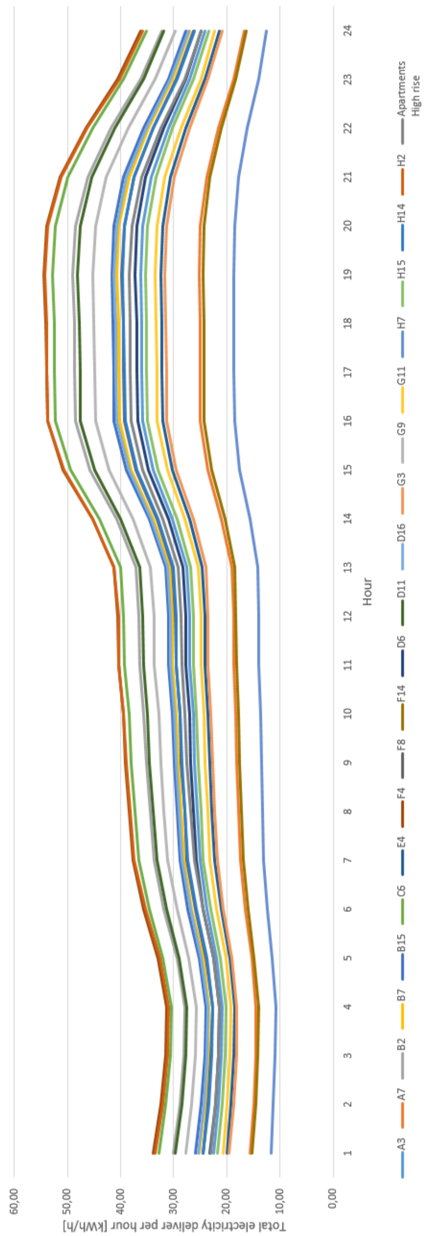



**Figure 11.3:** The total electricity daily profile for the different nodes used in eTransport

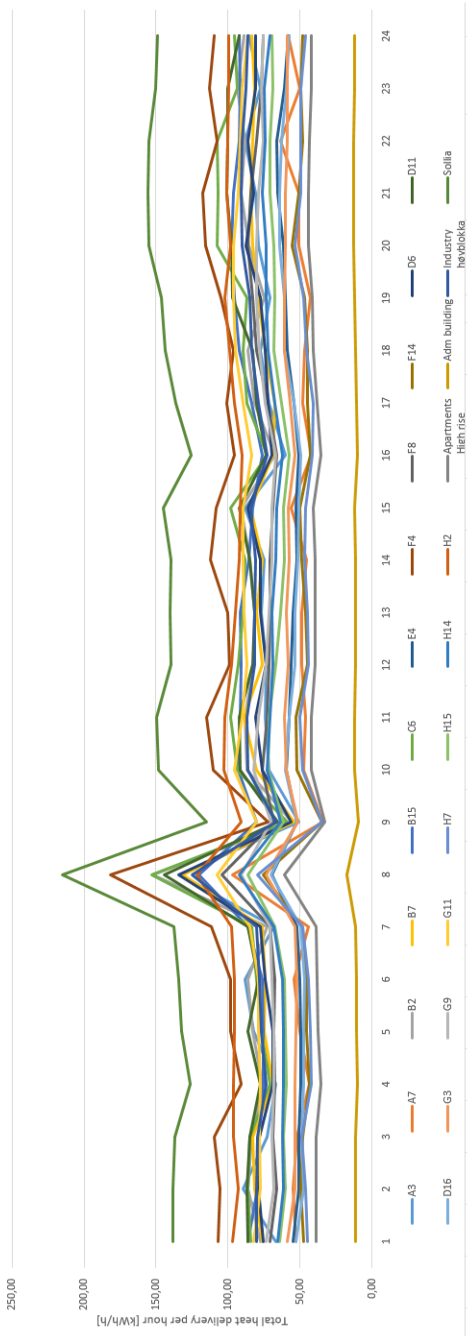
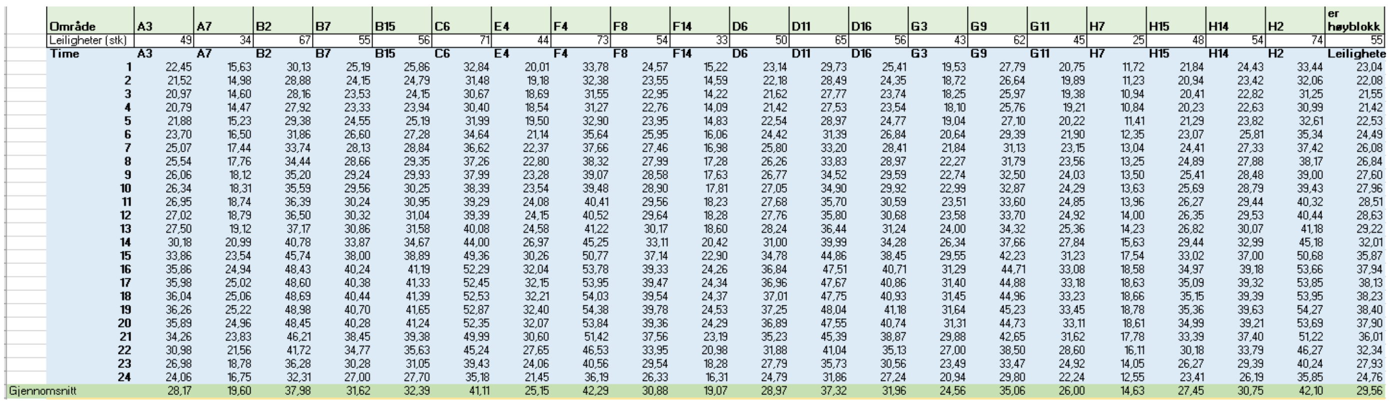



**Figure 11.4:** The total heat daily profile for the different nodes used in eTransport



| Område | A3 | A7 | B2 | B7 | B15 | C6 | E4 | F4 | F8 | F14 |
|---|---|---|---|---|---|---|---|---|---|---|
| Leiligheter (stk) | 49 | 34 | 67 | 55 | 56 | 71 | 44 | 73 | 54 | 33 |
| Time | A3 | A7 | B2 | B7 | B15 | C6 | E4 | F4 | F8 | F14 |
| 1 | 22,45 | 15,63 | 30,13 | 25,19 | 25,86 | 32,84 | 20,01 | 33,78 | 24,57 | 15,22 |
| 2 | 21,52 | 14,98 | 28,88 | 24,15 | 24,79 | 31,48 | 19,18 | 32,38 | 23,55 | 14,59 |
| 3 | 20,97 | 14,60 | 28,16 | 23,53 | 24,15 | 30,67 | 18,69 | 31,55 | 22,95 | 14,22 |
| 4 | 20,79 | 14,47 | 27,92 | 23,33 | 23,94 | 30,40 | 18,54 | 31,27 | 22,76 | 14,09 |
| 5 | 21,88 | 15,23 | 29,38 | 24,55 | 25,19 | 31,99 | 19,50 | 32,90 | 23,95 | 14,83 |
| 6 | 23,70 | 16,50 | 31,86 | 26,60 | 27,28 | 34,64 | 21,14 | 35,64 | 25,95 | 16,06 |
| 7 | 25,07 | 17,44 | 33,74 | 28,13 | 28,84 | 36,62 | 22,37 | 37,66 | 27,46 | 16,98 |
| 8 | 25,54 | 17,76 | 34,44 | 28,66 | 29,35 | 37,26 | 22,80 | 38,32 | 27,99 | 17,28 |
| 9 | 26,06 | 18,12 | 35,20 | 29,24 | 29,93 | 37,99 | 23,28 | 39,07 | 28,58 | 17,63 |
| 10 | 26,34 | 18,31 | 35,59 | 29,56 | 30,25 | 38,39 | 23,54 | 39,48 | 28,90 | 17,81 |
| 11 | 26,95 | 18,74 | 36,39 | 30,24 | 30,95 | 39,29 | 24,08 | 40,41 | 29,56 | 18,23 |
| 12 | 27,02 | 18,79 | 36,50 | 30,32 | 31,04 | 39,39 | 24,15 | 40,52 | 29,64 | 18,28 |
| 13 | 27,50 | 19,12 | 37,17 | 30,86 | 31,58 | 40,08 | 24,58 | 41,22 | 30,17 | 18,60 |
| 14 | 30,18 | 20,99 | 40,78 | 33,87 | 34,67 | 44,00 | 26,97 | 45,25 | 33,11 | 20,42 |
| 15 | 33,86 | 23,54 | 45,74 | 38,00 | 38,89 | 49,36 | 30,26 | 50,77 | 37,14 | 22,90 |
| 16 | 35,86 | 24,94 | 48,43 | 40,24 | 41,19 | 52,29 | 32,04 | 53,78 | 39,33 | 24,26 |
| 17 | 35,98 | 25,02 | 48,60 | 40,38 | 41,33 | 52,45 | 32,15 | 53,95 | 39,47 | 24,34 |
| 18 | 36,04 | 25,06 | 48,69 | 40,44 | 41,39 | 52,53 | 32,21 | 54,03 | 39,54 | 24,37 |
| 19 | 36,26 | 25,22 | 48,98 | 40,70 | 41,65 | 52,87 | 32,40 | 54,38 | 39,78 | 24,53 |
| 20 | 35,89 | 24,96 | 48,45 | 40,28 | 41,24 | 52,35 | 32,07 | 53,84 | 39,36 | 24,29 |
| 21 | 34,26 | 23,83 | 46,21 | 38,45 | 39,38 | 49,99 | 30,60 | 51,42 | 37,56 | 23,19 |
| 22 | 30,98 | 21,56 | 41,72 | 34,77 | 35,63 | 45,24 | 27,65 | 46,53 | 33,95 | 20,98 |
| 23 | 26,98 | 18,78 | 36,28 | 30,28 | 31,05 | 39,43 | 24,06 | 40,56 | 29,54 | 18,28 |
| 24 | 24,06 | 16,75 | 32,31 | 27,00 | 27,70 | 35,18 | 21,45 | 36,19 | 26,33 | 16,31 |
| Gjennomsnitt | 28,17 | 19,60 | 37,98 | 31,62 | 32,39 | 41,11 | 25,15 | 42,29 | 30,88 | 19,07 |

| Område | D6 | D11 | D16 | G3 | G9 | G11 | H7 | H15 | H14 | H2 | er høyblokk |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Leiligheter (stk) | 50 | 65 | 56 | 43 | 62 | 45 | 25 | 48 | 54 | 74 | 55 |
| Time | D6 | D11 | D16 | G3 | G9 | G11 | H7 | H15 | H14 | H2 | Leilighete |
| 1 | 23,14 | 29,73 | 25,41 | 19,53 | 27,79 | 20,75 | 11,72 | 21,84 | 24,43 | 33,44 | 23,04 |
| 2 | 22,18 | 28,49 | 24,35 | 18,72 | 26,64 | 19,89 | 11,23 | 20,94 | 23,42 | 32,06 | 22,08 |
| 3 | 21,62 | 27,77 | 23,74 | 18,25 | 25,97 | 19,38 | 10,94 | 20,41 | 22,82 | 31,25 | 21,55 |
| 4 | 21,42 | 27,53 | 23,54 | 18,10 | 25,76 | 19,21 | 10,84 | 20,23 | 22,63 | 30,99 | 21,42 |
| 5 | 22,54 | 28,97 | 24,77 | 19,04 | 27,10 | 20,22 | 11,41 | 21,29 | 23,82 | 32,61 | 22,53 |
| 6 | 24,42 | 31,39 | 26,84 | 20,64 | 29,39 | 21,90 | 12,35 | 23,07 | 25,81 | 35,34 | 24,49 |
| 7 | 25,80 | 33,20 | 28,41 | 21,84 | 31,13 | 23,15 | 13,04 | 24,41 | 27,33 | 37,42 | 26,08 |
| 8 | 26,26 | 33,83 | 28,97 | 22,27 | 31,79 | 23,56 | 13,25 | 24,89 | 27,88 | 38,17 | 26,84 |
| 9 | 26,77 | 34,52 | 29,59 | 22,74 | 32,50 | 24,03 | 13,50 | 25,41 | 28,48 | 39,00 | 27,60 |
| 10 | 27,05 | 34,90 | 29,92 | 22,99 | 32,87 | 24,29 | 13,63 | 25,69 | 28,79 | 39,43 | 27,96 |
| 11 | 27,68 | 35,70 | 30,59 | 23,51 | 33,60 | 24,85 | 13,96 | 26,27 | 29,44 | 40,32 | 28,51 |
| 12 | 27,76 | 35,80 | 30,68 | 23,58 | 33,70 | 24,92 | 14,00 | 26,35 | 29,53 | 40,44 | 28,63 |
| 13 | 28,24 | 36,44 | 31,24 | 24,00 | 34,32 | 25,36 | 14,23 | 26,82 | 30,07 | 41,18 | 29,22 |
| 14 | 31,00 | 39,99 | 34,28 | 26,34 | 37,66 | 27,84 | 15,63 | 29,44 | 32,99 | 45,18 | 32,01 |
| 15 | 34,78 | 44,86 | 38,45 | 29,55 | 42,23 | 31,23 | 17,54 | 33,02 | 37,00 | 50,68 | 35,87 |
| 16 | 36,84 | 47,51 | 40,71 | 31,29 | 44,71 | 33,08 | 18,58 | 34,97 | 39,18 | 53,66 | 37,94 |
| 17 | 36,96 | 47,67 | 40,86 | 31,40 | 44,88 | 33,18 | 18,63 | 35,09 | 39,32 | 53,85 | 38,13 |
| 18 | 37,01 | 47,75 | 40,93 | 31,45 | 44,96 | 33,23 | 18,66 | 35,15 | 39,39 | 53,95 | 38,23 |
| 19 | 37,25 | 48,04 | 41,18 | 31,64 | 45,23 | 33,45 | 18,78 | 35,36 | 39,63 | 54,27 | 38,40 |
| 20 | 36,89 | 47,55 | 40,74 | 31,31 | 44,73 | 33,11 | 18,61 | 34,99 | 39,21 | 53,69 | 37,90 |
| 21 | 35,23 | 45,39 | 38,87 | 29,88 | 42,65 | 31,62 | 17,78 | 33,39 | 37,40 | 51,22 | 36,01 |
| 22 | 31,88 | 41,04 | 35,13 | 27,00 | 38,50 | 28,60 | 16,11 | 30,18 | 33,79 | 46,27 | 32,34 |
| 23 | 27,79 | 35,73 | 30,56 | 23,49 | 33,47 | 24,92 | 14,05 | 26,27 | 29,39 | 40,24 | 27,93 |
| 24 | 24,79 | 31,86 | 27,24 | 20,94 | 29,80 | 22,24 | 12,55 | 23,41 | 26,19 | 35,85 | 24,76 |
| Gjennomsnitt | 28,97 | 37,32 | 31,96 | 24,56 | 35,06 | 26,00 | 14,63 | 27,45 | 30,75 | 42,10 | 29,56 |

**Figure 11.5:** The daily demand profile used in the simulations

| Med Elbiler | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Område** | **A3** | **A7** | **B2** | **B7** | **B15** | **C6** | **E4** | **F4** | **F8** | **F14** |
| **Antall biler** | 24,5 | 17 | 33,5 | 27,5 | 28 | 35,5 | 22 | 36,5 | 27 | 16,5 |
| **Time** | | | | | | | | | | |
| **1** | 28,5 | 19,8 | 38,3 | 31,9 | 32,7 | 41,5 | 25,4 | 42,7 | 31,2 | 19,3 |
| **2** | 27,0 | 18,8 | 36,4 | 30,3 | 31,1 | 39,5 | 24,1 | 40,6 | 29,6 | 18,3 |
| **3** | 25,9 | 18,0 | 34,9 | 29,0 | 29,8 | 37,8 | 23,1 | 38,8 | 28,4 | 17,5 |
| **4** | 24,6 | 17,1 | 33,1 | 27,6 | 28,3 | 35,9 | 21,9 | 36,9 | 26,9 | 16,6 |
| **5** | 24,3 | 16,9 | 32,7 | 27,3 | 28,0 | 35,5 | 21,7 | 36,6 | 26,6 | 16,5 |
| **6** | 25,7 | 17,9 | 34,5 | 28,8 | 29,5 | 37,5 | 22,9 | 38,6 | 28,1 | 17,4 |
| **7** | 26,4 | 18,4 | 35,6 | 29,6 | 30,4 | 38,6 | 23,6 | 39,7 | 28,9 | 17,9 |
| **8** | 26,5 | 18,4 | 35,8 | 29,8 | 30,5 | 38,7 | 23,7 | 39,8 | 29,1 | 17,9 |
| **9** | 26,8 | 18,6 | 36,2 | 30,1 | 30,8 | 39,1 | 23,9 | 40,2 | 29,4 | 18,1 |
| **10** | 27,0 | 18,8 | 36,5 | 30,3 | 31,0 | 39,4 | 24,2 | 40,5 | 29,7 | 18,3 |
| **11** | 27,7 | 19,2 | 37,4 | 31,0 | 31,8 | 40,3 | 24,7 | 41,5 | 30,3 | 18,7 |
| **12** | 27,8 | 19,3 | 37,5 | 31,1 | 31,9 | 40,5 | 24,8 | 41,6 | 30,5 | 18,8 |
| **13** | 28,5 | 19,8 | 38,5 | 32,0 | 32,7 | 41,5 | 25,5 | 42,7 | 31,3 | 19,3 |
| **14** | 31,1 | 21,6 | 42,1 | 34,9 | 35,7 | 45,3 | 27,8 | 46,6 | 34,1 | 21,0 |
| **15** | 35,1 | 24,4 | 47,4 | 39,4 | 40,3 | 51,1 | 31,4 | 52,6 | 38,5 | 23,7 |
| **16** | 37,3 | 26,0 | 50,4 | 41,9 | 42,9 | 54,4 | 33,4 | 56,0 | 41,0 | 25,2 |
| **17** | 37,3 | 25,9 | 50,3 | 41,8 | 42,8 | 54,3 | 33,3 | 55,8 | 40,9 | 25,2 |
| **18** | 37,2 | 25,9 | 50,3 | 41,8 | 42,7 | 54,2 | 33,3 | 55,8 | 40,8 | 25,2 |
| **19** | 37,9 | 26,4 | 51,3 | 42,6 | 43,6 | 55,3 | 33,9 | 56,9 | 41,6 | 25,7 |
| **20** | 37,7 | 26,2 | 51,0 | 42,3 | 43,3 | 55,0 | 33,7 | 56,6 | 41,4 | 25,5 |
| **21** | 36,7 | 25,5 | 49,6 | 41,2 | 42,2 | 53,5 | 32,8 | 55,1 | 40,3 | 24,8 |
| **22** | 34,8 | 24,2 | 46,9 | 39,0 | 40,0 | 50,7 | 31,1 | 52,2 | 38,1 | 23,5 |
| **23** | 31,5 | 21,9 | 42,5 | 35,4 | 36,2 | 46,0 | 28,1 | 47,3 | 34,5 | 21,3 |
| **24** | 29,6 | 20,6 | 39,8 | 33,2 | 34,0 | 43,2 | 26,4 | 44,4 | 32,4 | 20,0 |
| Gjennomsnitt | 30,5 | 21,2 | 41,2 | 34,3 | 35,1 | 44,5 | 27,3 | 45,8 | 33,5 | 20,7 |

| Med Elbiler | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Område** | **D6** | **D11** | **D16** | **G3** | **G9** | **G11** | **H7** | **H15** | **H14** | **H2** | **heter høyb** |
| **Antall biler** | 25 | 32,5 | 28 | 21,5 | 31 | 22,5 | 12,5 | 24 | 27 | 37 | 27,5 |
| **Time** | | | | | | | | | | | |
| **1** | 29,3 | 37,7 | 32,3 | 24,8 | 35,4 | 26,3 | 14,8 | 27,7 | 31,0 | 42,5 | 29,8 |
| **2** | 27,8 | 35,8 | 30,7 | 23,6 | 33,6 | 25,0 | 14,0 | 26,3 | 29,5 | 40,4 | 28,3 |
| **3** | 26,6 | 34,3 | 29,3 | 22,5 | 32,2 | 23,9 | 13,4 | 25,2 | 28,2 | 38,6 | 27,1 |
| **4** | 25,3 | 32,6 | 27,9 | 21,4 | 30,6 | 22,7 | 12,8 | 24,0 | 26,8 | 36,7 | 25,7 |
| **5** | 25,0 | 32,2 | 27,6 | 21,2 | 30,2 | 22,5 | 12,7 | 23,7 | 26,5 | 36,3 | 25,3 |
| **6** | 26,4 | 34,0 | 29,1 | 22,4 | 31,9 | 23,7 | 13,4 | 25,0 | 28,0 | 38,3 | 26,7 |
| **7** | 27,2 | 35,0 | 30,0 | 23,0 | 32,8 | 24,4 | 13,7 | 25,7 | 28,8 | 39,5 | 27,6 |
| **8** | 27,3 | 35,1 | 30,1 | 23,1 | 33,0 | 24,5 | 13,8 | 25,8 | 29,0 | 39,7 | 27,9 |
| **9** | 27,5 | 35,5 | 30,4 | 23,4 | 33,4 | 24,7 | 13,9 | 26,1 | 29,3 | 40,1 | 28,4 |
| **10** | 27,7 | 35,8 | 30,7 | 23,6 | 33,7 | 24,9 | 14,0 | 26,4 | 29,5 | 40,5 | 28,7 |
| **11** | 28,4 | 36,6 | 31,4 | 24,1 | 34,5 | 25,5 | 14,3 | 27,0 | 30,2 | 41,4 | 29,3 |
| **12** | 28,5 | 36,8 | 31,5 | 24,2 | 34,6 | 25,6 | 14,4 | 27,1 | 30,3 | 41,6 | 29,5 |
| **13** | 29,2 | 37,7 | 32,4 | 24,9 | 35,6 | 26,3 | 14,7 | 27,8 | 31,1 | 42,7 | 30,3 |
| **14** | 32,0 | 41,2 | 35,3 | 27,2 | 38,8 | 28,7 | 16,1 | 30,3 | 34,0 | 46,6 | 33,1 |
| **15** | 36,0 | 46,5 | 39,8 | 30,6 | 43,8 | 32,4 | 18,2 | 34,2 | 38,4 | 52,5 | 37,2 |
| **16** | 38,3 | 49,5 | 42,4 | 32,6 | 46,6 | 34,4 | 19,3 | 36,4 | 40,8 | 55,9 | 39,6 |
| **17** | 38,3 | 49,4 | 42,3 | 32,5 | 46,5 | 34,4 | 19,3 | 36,3 | 40,7 | 55,8 | 39,6 |
| **18** | 38,2 | 49,3 | 42,3 | 32,5 | 46,5 | 34,3 | 19,3 | 36,3 | 40,7 | 55,7 | 39,5 |
| **19** | 39,0 | 50,3 | 43,1 | 33,1 | 47,3 | 35,0 | 19,6 | 37,0 | 41,5 | 56,8 | 40,3 |
| **20** | 38,8 | 50,0 | 42,8 | 32,9 | 47,1 | 34,8 | 19,5 | 36,8 | 41,2 | 56,5 | 40,0 |
| **21** | 37,7 | 48,6 | 41,7 | 32,0 | 45,8 | 33,9 | 19,0 | 35,8 | 40,1 | 54,9 | 38,8 |
| **22** | 35,8 | 46,1 | 39,5 | 30,3 | 43,3 | 32,1 | 18,0 | 33,9 | 38,0 | 52,0 | 36,6 |
| **23** | 32,4 | 41,7 | 35,7 | 27,5 | 39,2 | 29,1 | 16,4 | 30,7 | 34,4 | 47,1 | 33,0 |
| **24** | 30,4 | 39,2 | 33,5 | 25,8 | 36,8 | 27,3 | 15,4 | 28,8 | 32,3 | 44,2 | 30,9 |
| Gjennomsnitt | 31,4 | 40,5 | 34,7 | 26,6 | 38,0 | 28,2 | 15,8 | 29,8 | 33,4 | 45,7 | 32,2 |

**Figure 11.6:** The daily demand profile when half of the residents drive EVs, input in eTransport

| Område | A3 | A7 | B2 | B7 | B15 | C6 | E4 | F4 | F8 | F14 |
|---|---|---|---|---|---|---|---|---|---|---|
| Antall leiliheter | 49 | 34 | 67 | 55 | 56 | 71 | 44 | 73 | 54 | 33 |
| Antall biler | 49 | 34 | 67 | 55 | 56 | 71 | 44 | 73 | 54 | 33 |
| Time | | | | | | | | | | |
| 1 | 34,46 | 23,96 | 46,55 | 38,67 | 39,58 | 50,23 | 30,79 | 51,66 | 37,80 | 23,31 |
| 2 | 32,55 | 22,63 | 43,96 | 36,52 | 37,39 | 47,45 | 29,08 | 48,80 | 35,70 | 22,02 |
| 3 | 30,77 | 21,40 | 41,56 | 34,53 | 35,35 | 44,87 | 27,49 | 46,15 | 33,75 | 20,82 |
| 4 | 28,39 | 19,74 | 38,31 | 31,85 | 32,62 | 41,40 | 25,36 | 42,58 | 31,13 | 19,21 |
| 5 | 26,78 | 18,63 | 36,08 | 30,05 | 30,79 | 39,09 | 23,90 | 40,20 | 29,35 | 18,13 |
| 6 | 27,62 | 19,22 | 37,22 | 31,00 | 31,76 | 40,32 | 24,66 | 41,48 | 30,27 | 18,70 |
| 7 | 27,77 | 19,31 | 37,42 | 31,16 | 31,92 | 40,52 | 24,79 | 41,68 | 30,43 | 18,79 |
| 8 | 27,50 | 19,12 | 37,12 | 30,86 | 31,59 | 40,10 | 24,56 | 41,24 | 30,15 | 18,60 |
| 9 | 27,53 | 19,14 | 37,21 | 30,89 | 31,61 | 40,12 | 24,60 | 41,26 | 30,20 | 18,62 |
| 10 | 27,71 | 19,27 | 37,47 | 31,10 | 31,82 | 40,38 | 24,77 | 41,53 | 30,41 | 18,74 |
| 11 | 28,37 | 19,72 | 38,33 | 31,83 | 32,58 | 41,35 | 25,35 | 42,53 | 31,12 | 19,19 |
| 12 | 28,49 | 19,81 | 38,51 | 31,97 | 32,72 | 41,52 | 25,47 | 42,71 | 31,26 | 19,27 |
| 13 | 29,46 | 20,48 | 39,85 | 33,06 | 33,82 | 42,92 | 26,34 | 44,14 | 32,33 | 19,92 |
| 14 | 32,05 | 22,28 | 43,33 | 35,96 | 36,79 | 46,70 | 28,65 | 48,03 | 35,16 | 21,67 |
| 15 | 36,31 | 25,24 | 49,09 | 40,75 | 41,69 | 52,91 | 32,46 | 54,42 | 39,84 | 24,55 |
| 16 | 38,80 | 26,98 | 52,45 | 43,54 | 44,55 | 56,55 | 34,68 | 58,16 | 42,57 | 26,24 |
| 17 | 38,53 | 26,79 | 52,09 | 43,24 | 44,24 | 56,14 | 34,44 | 57,74 | 42,28 | 26,05 |
| 18 | 38,39 | 26,69 | 51,91 | 43,08 | 44,08 | 55,94 | 34,32 | 57,53 | 42,13 | 25,96 |
| 19 | 39,60 | 27,53 | 53,54 | 44,44 | 45,46 | 57,70 | 35,39 | 59,34 | 43,45 | 26,77 |
| 20 | 39,57 | 27,51 | 53,48 | 44,41 | 45,44 | 57,67 | 35,37 | 59,31 | 43,41 | 26,76 |
| 21 | 39,16 | 27,23 | 52,91 | 43,95 | 44,98 | 57,09 | 35,00 | 58,72 | 42,96 | 26,49 |
| 22 | 38,58 | 26,83 | 52,11 | 43,29 | 44,31 | 56,24 | 34,47 | 57,85 | 42,32 | 26,10 |
| 23 | 36,05 | 25,07 | 48,67 | 40,45 | 41,41 | 52,56 | 32,20 | 54,06 | 39,53 | 24,39 |
| 24 | 35,09 | 24,40 | 47,38 | 39,37 | 40,30 | 51,16 | 31,35 | 52,61 | 38,48 | 23,73 |

| Område | D6 | D11 | D16 | G3 | G9 | G11 | H7 | H15 | H14 | H2 | heter høyb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Antall leiliheter | 50 | 65 | 56 | 43 | 62 | 45 | 25 | 48 | 54 | 74 | 55 |
| Antall biler | 50 | 65 | 56 | 43 | 62 | 45 | 25 | 48 | 54 | 74 | 55 |
| Time | | | | | | | | | | | |
| 1 | 35,39 | 45,65 | 39,13 | 30,07 | 42,98 | 31,78 | 17,84 | 33,60 | 37,66 | 51,57 | 36,52 |
| 2 | 33,43 | 43,12 | 36,95 | 28,40 | 40,59 | 30,02 | 16,86 | 31,74 | 35,57 | 48,71 | 34,46 |
| 3 | 31,62 | 40,77 | 34,94 | 26,85 | 38,37 | 28,38 | 15,94 | 30,01 | 33,62 | 46,05 | 32,55 |
| 4 | 29,17 | 37,60 | 32,22 | 24,76 | 35,37 | 26,19 | 14,72 | 27,67 | 31,00 | 42,46 | 29,94 |
| 5 | 27,54 | 35,47 | 30,37 | 23,34 | 33,30 | 24,72 | 13,91 | 26,09 | 29,22 | 40,01 | 28,03 |
| 6 | 28,42 | 36,59 | 31,32 | 24,08 | 34,35 | 25,50 | 14,35 | 26,91 | 30,13 | 41,26 | 28,89 |
| 7 | 28,55 | 36,78 | 31,49 | 24,20 | 34,54 | 25,63 | 14,42 | 27,05 | 30,30 | 41,49 | 29,11 |
| 8 | 28,26 | 36,43 | 31,21 | 23,99 | 34,27 | 25,36 | 14,25 | 26,81 | 30,04 | 41,13 | 29,04 |
| 9 | 28,27 | 36,47 | 31,27 | 24,03 | 34,36 | 25,38 | 14,25 | 26,85 | 30,10 | 41,22 | 29,25 |
| 10 | 28,45 | 36,72 | 31,48 | 24,19 | 34,60 | 25,55 | 14,33 | 27,03 | 30,31 | 41,50 | 29,50 |
| 11 | 29,13 | 37,58 | 32,22 | 24,76 | 35,40 | 26,16 | 14,69 | 27,67 | 31,01 | 42,47 | 30,11 |
| 12 | 29,26 | 37,75 | 32,36 | 24,87 | 35,56 | 26,27 | 14,75 | 27,79 | 31,15 | 42,66 | 30,28 |
| 13 | 30,24 | 39,04 | 33,48 | 25,72 | 36,80 | 27,16 | 15,23 | 28,74 | 32,23 | 44,14 | 31,42 |
| 14 | 32,90 | 42,46 | 36,41 | 27,98 | 40,01 | 29,55 | 16,58 | 31,26 | 35,04 | 47,99 | 34,10 |
| 15 | 37,28 | 48,11 | 41,25 | 31,70 | 45,33 | 33,48 | 18,79 | 35,42 | 39,70 | 54,38 | 38,62 |
| 16 | 39,84 | 51,41 | 44,07 | 33,87 | 48,43 | 35,78 | 20,08 | 37,85 | 42,42 | 58,10 | 41,24 |
| 17 | 39,56 | 51,05 | 43,77 | 33,63 | 48,10 | 35,52 | 19,93 | 37,58 | 42,13 | 57,70 | 40,99 |
| 18 | 39,41 | 50,87 | 43,62 | 33,52 | 47,94 | 35,39 | 19,86 | 37,45 | 41,98 | 57,50 | 40,87 |
| 19 | 40,65 | 52,46 | 44,98 | 34,57 | 49,44 | 36,51 | 20,48 | 38,63 | 43,30 | 59,30 | 42,14 |
| 20 | 40,64 | 52,43 | 44,94 | 34,54 | 49,38 | 36,49 | 20,48 | 38,59 | 43,26 | 59,24 | 42,02 |
| 21 | 40,23 | 51,89 | 44,47 | 34,18 | 48,85 | 36,12 | 20,28 | 38,19 | 42,80 | 58,62 | 41,51 |
| 22 | 39,63 | 51,11 | 43,81 | 33,66 | 48,11 | 35,58 | 19,98 | 37,62 | 42,16 | 57,74 | 40,86 |
| 23 | 37,04 | 47,75 | 40,92 | 31,45 | 44,94 | 33,25 | 18,68 | 35,15 | 39,38 | 53,93 | 38,11 |
| 24 | 36,04 | 46,48 | 39,84 | 30,61 | 43,75 | 32,36 | 18,18 | 34,21 | 38,34 | 52,50 | 37,13 |

**Figure 11.7:** The daily demand profile when all of the residents drive EVs, input in eTransport

# Appendix B - production profiles

**Table 11.1:** The electricity prices used in eTransport based on hourly values form Nord Pool 2014-2018

| Hour | Base case | High price | Low price |
|---|---|---|---|
| **1** | 668 | 774 | 598 |
| **2** | 660 | 763 | 592 |
| **3** | 654 | 755 | 588 |
| **4** | 651 | 751 | 586 |
| **5** | 653 | 753 | 587 |
| **6** | 662 | 766 | 594 |
| **7** | 673 | 781 | 602 |
| **8** | 689 | 804 | 614 |
| **9** | 701 | 819 | 623 |
| **10** | 699 | 817 | 622 |
| **11** | 697 | 814 | 620 |
| **12** | 694 | 810 | 618 |
| **13** | 691 | 805 | 615 |
| **14** | 688 | 801 | 613 |
| **15** | 685 | 798 | 611 |
| **16** | 685 | 798 | 611 |
| **17** | 689 | 804 | 614 |
| **18** | 696 | 813 | 620 |
| **19** | 696 | 813 | 619 |
| **20** | 691 | 806 | 616 |
| **21** | 686 | 799 | 612 |
| **22** | 683 | 794 | 609 |
| **23** | 678 | 789 | 606 |
| **24** | 670 | 777 | 600 |

Table 11.2: Daily production profiles for the 100% solar PV system in [kWh]

| Hour | Spring | Winter | Autumn | Summer | Peak day |
|---|---|---|---|---|---|
| **1** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **2** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **3** | 1,06 | 0,00 | 0,00 | 13,33 | 0,00 |
| **4** | 16,13 | 0,00 | 0,00 | 63,49 | 0,00 |
| **5** | 74,57 | 0,00 | 0,29 | 196,17 | 0,00 |
| **6** | 202,25 | 0,00 | 17,15 | 418,64 | 0,00 |
| **7** | 402,22 | 0,13 | 82,15 | 684,13 | 0,00 |
| **8** | 647,07 | 15,37 | 211,90 | 942,17 | 97,75 |
| **9** | 864,81 | 64,97 | 374,19 | 1162,62 | 210,30 |
| **10** | 1023,15 | 149,52 | 528,31 | 1328,59 | 417,64 |
| **11** | 1118,73 | 232,42 | 643,47 | 1438,60 | 675,34 |
| **12** | 1145,39 | 263,75 | 675,63 | 1462,91 | 826,40 |
| **13** | 1099,32 | 221,62 | 605,94 | 1390,11 | 858,98 |
| **14** | 966,74 | 127,43 | 468,87 | 1241,08 | 462,07 |
| **15** | 759,62 | 47,33 | 302,87 | 1040,37 | 216,23 |
| **16** | 528,68 | 6,71 | 160,18 | 796,07 | 56,28 |
| **17** | 303,77 | 0,00 | 52,83 | 543,56 | 0,00 |
| **18** | 134,71 | 0,00 | 6,74 | 315,71 | 0,00 |
| **19** | 42,31 | 0,00 | 0,00 | 139,66 | 0,00 |
| **20** | 7,28 | 0,00 | 0,00 | 43,75 | 0,00 |
| **21** | 0,10 | 0,00 | 0,00 | 5,41 | 0,00 |
| **22** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **23** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **24** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

**Table 11.3:** Daily production profiles for the 50% solar PV system in [kWh]

| Hour | Spring | Winter | Autumn | Summer | Peak day |
|---|---|---|---|---|---|
| **1** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **2** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **3** | 0,53 | 0,00 | 0,00 | 6,66 | 0,00 |
| **4** | 8,07 | 0,00 | 0,00 | 31,74 | 0,00 |
| **5** | 37,28 | 0,00 | 0,15 | 98,08 | 0,00 |
| **6** | 101,13 | 0,00 | 8,58 | 209,32 | 0,00 |
| **7** | 201,11 | 0,07 | 41,08 | 342,06 | 0,00 |
| **8** | 323,53 | 7,77 | 105,95 | 471,09 | 48,87 |
| **9** | 432,40 | 32,85 | 187,09 | 581,31 | 105,15 |
| **10** | 511,57 | 75,60 | 264,16 | 664,29 | 208,82 |
| **11** | 559,37 | 117,51 | 321,74 | 719,30 | 337,67 |
| **12** | 572,70 | 133,36 | 337,81 | 731,45 | 413,20 |
| **13** | 549,66 | 112,06 | 302,97 | 695,06 | 429,49 |
| **14** | 483,37 | 64,43 | 234,44 | 620,54 | 231,04 |
| **15** | 379,81 | 23,93 | 151,44 | 520,19 | 108,11 |
| **16** | 264,34 | 3,39 | 80,09 | 398,03 | 28,14 |
| **17** | 151,88 | 0,00 | 26,41 | 271,78 | 0,00 |
| **18** | 67,35 | 0,00 | 3,37 | 157,86 | 0,00 |
| **19** | 21,15 | 0,00 | 0,00 | 69,83 | 0,00 |
| **20** | 3,64 | 0,00 | 0,00 | 21,88 | 0,00 |
| **21** | 0,05 | 0,00 | 0,00 | 2,70 | 0,00 |
| **22** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **23** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **24** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

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