Energy Cost Reduction in Residential Buildings Using Solar PV Panels, Battery Storage, and Time-Shifting of Flexible Loads

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Bachelor's thesis in Energy Technology
Bergen, Norway 2023

Høgskulen på Vestlandet

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IMM 2023-M75

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Norsk tittel:	Reduksjon av energikostnader i husholdninger ved bruk av solcellepanel, batterisystem og tidsstyring av fleksible laster.
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Study program:	Energy Technology
Date:	May 2023
Report number:	IMM 2023-M75
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Antall filer levert digitalt:	25

Preface

This bachelor thesis marks the end of a three-year education in the bachelor's degree Energy Technology at the Western Norway University of Applied Sciences, campus Bergen. The work of this thesis has been time-consuming, and demanding, and has provided a more comprehensive understanding of energy- and cost reduction in a household.

First of all, we would like to thank our internal supervisor Professor Richard J. Grant. Thank you for your invaluable guidance and feedback throughout the process, and for always being high-spirited. We appreciate your enthusiasm for our thesis and support for us as a group.

Furthermore, we would like to thank our external supervisor MSc Knut Ivar Gjerde from the company Pixii. Thank you for creating a captivating thesis in cooperation with your company and co-worker PhD Ole Jakob Sørdalen. Despite the distance, we immensely value your enthusiastic participation and follow-up throughout the whole project.

Abstract

Energy costs have skyrocketed in recent years, making the examination of where and how energy is utilized an important endeavor. Reducing energy costs in households is a growing concern as more and more households struggle to make ends meet.

This bachelor thesis will investigate the financial impact of implementing a hybrid energy system, consisting of solar panels and battery storage, in combination with a water heating tank. It will also examine the benefits of using a smart controller to shift the Time-of-Use of various flexible loads, such as heating tanks, and electric vehicle chargers. It will also provide an overview of household energy use and cost-reduction methods.

Through investigation of two cases, and examining several system size configurations, the results show that the use of a hybrid system will be viable in both cases. In the first case, a domestic dwelling at St. Olavs vei 170 in Bergen, Norway, the potential solar production is limited. The most viable system for this case will be to cover the roof with solar photovoltaic (PV) panels and combine them with a 3.3 kW, 20 kWh of battery storage. This system creates a 50.7% reduction in yearly energy costs. As the roof size is not ideal, the profitability is affected, making the lifetime and payback time align, resulting in an investment that only marginally breaks even.

The second case, a domestic dwelling at Rørvollveien 17 in Drammen, Norway, has better prerequisites, with a potential for extensive solar production. In this case, there are multiple viable systems, in all cases maximizing the installed effect of the solar panels will increase the cost savings. Therefore, one of the most profitable systems only uses solar production, resulting in a total reduction of 60.8%, and a payback time of 6.4 years. Another highly profitable system is combining 10 kW, 20 kWh battery storage with solar production, which reduces the cost by 73.4% and puts the payback time at 6.9 years. Both configurations have a potential total saving of 1.2 million NOK within the solar panels' lifespan of 25 years. When deciding which system to invest in, the decision is dependent on the unique needs and desires of the different scenarios.

Investing in a hybrid system, consisting of solar panels and battery storage, including a heating tank, creates flexibility for self-consumption. Which, based on the results, is shown to be a wise investment in these two cases. The results also indicate that the use of a hybrid system should be investigated for a dwelling and that the results will vary depending on the particular situations. A hybrid system and Time-of-Use shifting of flexible loads can substantially reduce energy costs in residential buildings.

Sammendrag

De siste årene har strømprisene økt betraktelig, noe som gjør det viktig å undersøke hvor og hvordan energi utnyttes. Det blir stadig viktigere å finne måter å redusere energikostnadene på ettersom flere husholdninger streber etter å få endene til å møtes.

Denne bacheloroppgaven undersøker den økonomiske effekten av å implementere et hybridsystem bestående av solcellepaneler og batterilagring, i kombinasjon med en varmtvannsbereder. Lønnsomheten ved å benytte seg av en smart kontroller for å regulere brukstiden til de fleksible lastene varmtvannsbereder og lading av elbil undersøkes også. Oppgaven vil også gi en oversikt over metoder for å redusere energiforbruk, og derav kostnader, i husholdninger.

Det er gjennomført to case-studier, og gjennom undersøkelser av flere konfigurasjoner av systemstørrelser, viser resultatene at bruken av et hybridsystem vil være lønnsomt i begge caser. I den første casen, St. Olavs vei 170, er den potensielle solproduksjonen begrenset. Det mest aktuelle systemet for denne casen vil være å dekke taket med solcellepaneler, og kombinere det med en 3,3 kW, 20 kWh batterilagring. Dette systemet vil redusere den årlige energikostanden med 50,7%. Ettersom forutsetningene ikke er ideelle og levetid og tilbakebetalingstid samsvarer, resulterer dette i en investering som knapt går i null.

Det andre case-studiet, Rørvollveien 17, har bedre forutsetninger med potensial for betraktelig mer solcelleproduksjon. I denne casen er det flere aktuelle systemer, der maksimering av installert effekt på solcellepanelene vil øke fortjenesten. Derfor er et av de mest lønnsomme systemene solenergiproduksjon alene, noe som fører til en reduksjon på 60,8% av energikostnaden, og en tilbakebetalingstid på 6,4 år. Ett annet svært lønnsomt system er en kombinasjon av 10 kW, 20 kWh batterilagring med solcelleproduksjon, som vil redusere energikostnaden med 73,4% og en tilbakebetalingstid på 6,9 år. Begge disse konfigurasjonene har en potensiell total besparelse på 1,2 millioner NOK innenfor solcellepanelenes levetid, som er 25 år. Ved bestemmelse av hvilket system det skal investeres i, vil beslutningen avhenge av behov og ønske i de ulike tilfellene.

Investering av et hybridsystem skape fleksibilitet for eget forbruk, og resultatene viser at det er en god investering i de respektive casene. Resultatene viser også at det er interessant å undersøke bruken av et hybridsystem for enhver husholdning, og at resultatene vil variere avhengig av forutsetninger. Avslutningsvis, et hybridsystem og regulering av brukstiden for fleksible laster vil kunne redusere energikostnadene i husholdninger vesentlig.

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Nomenclature

W	Watt
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt peak
ToU	Time-of-Use
PV	Photovoltaic
AC	Alternating Current
DC	Direct Current
Si	Silicon
Ge	Germanium
Li	Lithium
Hz	Hertz
V	Volt
BMS	Battery Management System
MPPT	Maximum Power Point Tracker
BESS	Battery Energy Storage System
DoD	Depth of Discharge
°K	Degree Kelvin
°C	Degree Celsius
kJ	Kilo Joule
Kg	Kilogram
PVGIS	Photovoltaic Geographical Information System
EV	Electric Vehicle
CSV	Comma-Separated Values
VAT	Value-Added Tax
NOK	Norwegian Krones
MILP	Mixed Integer Linear Programming
N/A	Not Applicable

1 Introduction

As the world strives for sustainable development, increasing the use of renewable energy and reducing its energy consumption are important measures to enact[1]. Energy costs have skyrocketed in recent years, making it important to examine how and where energy is utilized, and which conservation methods can be implemented to lower the cost of energy[2]. Reducing both the energy consumption and costs in households is a growing concern as energy costs rise and as more and more households struggle to make ends meet. By optimizing energy consumption and utilizing the energy in a household more cost-effectively, households can become much more efficient in their use of energy.

Through investigation and analysis of current and typical building stock, it may be possible to reduce energy costs through better regulation of its use. Regulating the energy use in the household can potentially reduce energy costs and contribute to the transition towards a more sustainable market. Renewable energy is under constant development and therefore it is getting progressively more reliable and thus more viable[3]. Other benefits include reducing greenhouse gas emissions and conserving natural resources. For the bill payer, the primary motivator is likely the monetary gain from reducing energy expenses[4].

This bachelor thesis was developed with this in mind and is a collaboration with the company Pixii and is combined with the two existing cases.

1.1 Company: Pixii AS

The company Pixii expressed interest in this bachelor thesis because of its basis in the utilization of a domestic hot water heating tank. In collaboration with Pixii, the scope of the project was formulated.

Their desire is to investigate the use of a water heating tank in combination with their new hybrid system for the domestic marketplace.

This new system is called Pixii Home and is an expansion of their business into the residential market. Previously, Pixii’s products were only available in the industrial market. Currently, the company’s home system consists of battery storage coupled with a smart home app. This is intended to be combined with new or existing solar energy production [5]. Pixii wants to investigate whether this smart app should include the control of a heating tank for the hot water supply as well, creating a system consisting of thermal- and electrical storage.

1.2 Case Studies

1.2.1 Case Study: St. Olavs vei 170

The first case study of this thesis is based on an old dwelling in St. Olavs vei and it examines the possibility of using a hybrid system in combination with their heating tank.

Figure 1-1: The case study house St. Olavs vei 170 viewed from west.

St. Olavs vei 170 is a dwelling built in 1927 in Bergen, Norway. The house has four floors with two bedrooms and houses four people in total; two adults and two children. It was most recently renovated in 1990 and has not been through any changes since then. Due to bad insulation and outdated solutions, the house requires a lot of heating, resulting in unnecessarily high energy consumption. High energy consumption in combination with the current electricity costs in Bergen results in a considerable potential for both energy- and money savings. Additionally, considering the climate crisis the world is currently facing, and the urgent need for a green change, the house in St. Olavs vei 170 makes for a great case study to investigate and explore possibilities for greener alternatives. The general objective of the case is to find a system which will provide a financially beneficial return. St. Olavs vei 170 is a shared case, where this thesis will explore methods of reducing energy costs by using a hybrid system, while civil engineering students from HVL will delve into the constructional aspects, with the aim of reducing the energy consumption in existing wooden houses.

1.2.2 Case Study: Rørvollveien 17

The second case study of this thesis is based on an old dwelling in Rørvollveien. It also examines the possibility of using a hybrid system in combination with their heating tank.

Figure 1-2: The case study house Rørvollveien 17 viewed from southeast.

This case is added as an additional case as it is better suited for solar production. It has a large southeast facing roof and tracked load data for the flexible loads, heating tank and electric vehicle charging. This makes this case more optimal when investigating this thesis.

Rørvollveien 17 is a dwelling built in 1961 in Drammen, Norway. The house has three floors with four bedrooms, and houses three adults. It was renovated in 1983 with major modifications, including new insulation. Additionally, a few years ago, the windows on the first floor were replaced.

1.3 Aim and Objectives

The aim of this thesis is: to investigate the effects of installing a hybrid energy system with the intention of optimizing usage and reducing annual running costs; including simulations of the potential savings from time shifting the flexible loads.

In order to achieve this aim, the thesis will have to complete a number of objectives.

1) Explain the theory of the initial investment cost, the potential cost savings, and general use of a hybrid system consisting of solar panels and battery storage, in combination with a water heating tank. The impact of the elements will be investigated as a total system, as well as separately.
2) Simulate the potential savings of using a smart controller to time shift the energy load in the heating tank and electric vehicle charger.
3) Analyze the energy requirements of the household.
4) Compare and contrast the cost of energy consumption in 2022, and cost savings in the household if the hybrid system is integrated.
5) Discuss which factors for solar panels are the most effective to optimize energy production for the cases’ location.
6) Examine the possible methods of reducing energy costs by utilizing battery storage, analyzing the impact of certain reduction strategies, such as increasing self-consumption.

1.4 Thesis Structure

This thesis consists of six main chapters. The first chapter is an introduction and includes the background for the thesis and presents the aim and objectives. These chapters are as follows.

Chapter 2 – Theory

Chapter 3 – Methodology

Chapter 4 – Results of calculations

Chapter 5 – Discussion

Chapter 6 – Conclusion

Chapter 2 explains the theory about energy cost, solar technology, residential battery storage, water heating tank, the hybrid system and investment analysis. Followed up by Chapter 3, which explains the methods used in the thesis, mainly the calculations in the programs Spyder (Python) and Excel. Chapter 4 presents the results of the calculations, and a discussion of the results is presented in Chapter 5. Rounding out with Chapter 6 which presents the conclusion of the thesis.

2 Theory

The basis of this bachelor thesis is using a hybrid system as a measure to reduce energy costs in a household. The hybrid system consists of three main components: solar panels, battery storage and a heating tank. It is essential to consider the cost of the system and the overall cost of energy consumption, therefore, this chapter will include an overview of the cost components. Additionally, it will include information about the three components, their characteristics, potential use, and how they work when combining them as a system.

2.1 Energy Cost

To calculate the cost of the energy used, it is necessary to examine what the energy price consists of and understand what factors effects the variation in the spot price. This section will also address various methods of reducing energy costs such as support arrangements and explain the Time-of-Use.

2.1.1 Calculating the Energy Cost

The price of energy in Norway varies on an hourly basis depending on multiple factors that will be explained further. The overall cost is dependent on the spot price and the regional grid tariff, which consists of the energy component and the capacity component. In general literature, the capacity component is also referred to as the peak component.

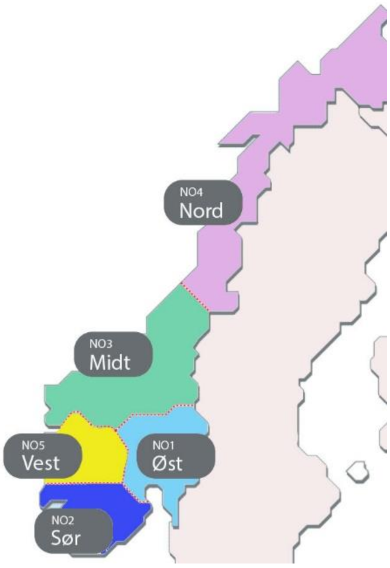


Figure 2-1: The electricity regions in Norway [6].

The spot price in Norway varies depending on the region, of which there are five[6]. As a result, the location of the dwelling decides which spot price rate to use. The spot price in Norway is fixed on an hourly basis and regulated through the day-ahead power exchange company Nord Pool. The energy producers offer the energy they plan to have available the next day, at a certain price, and the electricity suppliers buy the estimated electricity their customers will need. The agreed price between the seller and buyer at the power stock exchange is the spot hourly rate. This electricity is supplied to the consumers through the network providers' grid system[7]. Factors such as the weather and gas prices have an impact on the price; however, the energy demand has the most noticeable impact. The demand is dependent on the steadily increasing need for electricity in our society, but also on the time of day. Throughout the day, the highest demand is usually in the morning and in the afternoon[8]. To simplify, it is basic supply and demand, if there is a lot of electricity available, the price is lower, while when there is a lack of electricity, the price increases. The fact that the spot prices is released on a day-ahead basis makes it possible for customers to plan their energy use and regulate their use according to the fluctuating prices.

Grid tariffs is an additional cost that varies according to which network provider you purchase from. This is dependent on where the dwelling is located at, as the network provider has a monopoly over the network in a certain area. Here, the values from Bergenhalvøens Kommunale Kraftselskap (BKK) is used as an example.

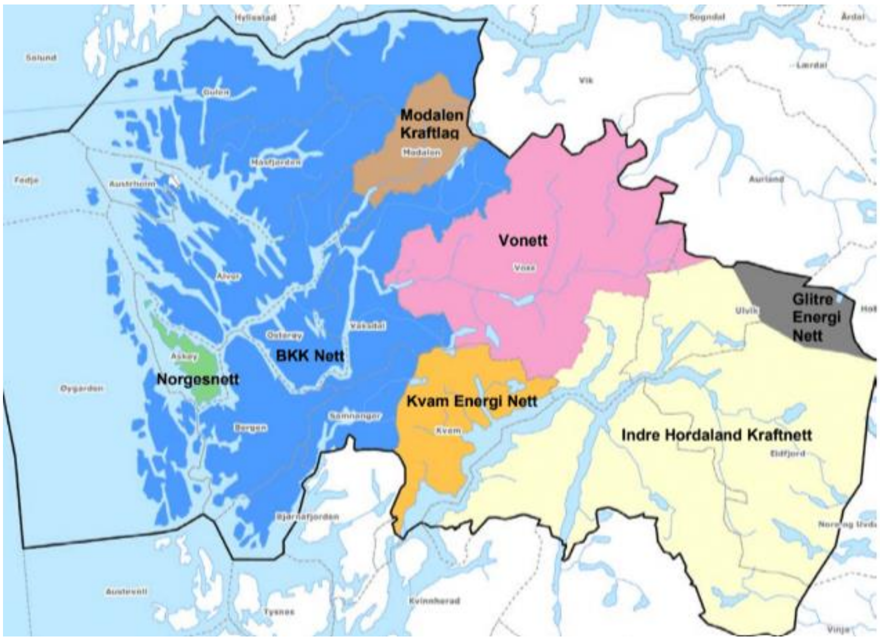


Figure 2-2: Overview of the distribution of network providers in parts of Vestland, Norway [9, p. 4].

The grid tariff is divided into two components: the capacity and energy component. The capacity component is dependent on the amount of energy you use continuously, and is a set additional cost each month[7]. To calculate this component Table 2-1 is used, where the calculated value each month assigns the months to corresponding tiers if it falls within a certain band of values. This value is calculated by finding the mean of three hours that have the largest energy use per month, where these hours need to be from separate days. In short, there is an additional cost that is assigned based on the average max energy used. It is a good idea to distribute the energy use throughout the day because this will result in a reduced capacity component.

Table 2-1: Capacity component values from BKK.

Capacity component	Average max use/month [kWh]	NOK/month	NOK/year
Tier 1	0-2	125	1500
Tier 2	2-5	206	2475
Tier 3	5-10	350	4200
Tier 4	10-15	494	5925
Tier 5	15-20	638	7650
Tier 6	20-25	781	9375

The energy component cost is dependent on the amount of energy used and when the electricity is used. This component typically varies depending on the month of the year (January-March or April-December), as well as the time of day, and whether it is a weekend or a national holiday. This cost includes all the necessary fees, such as the energy fund (Enova), electrical power fee (Elavgift), and Goods and Services Tax (GST) (25% VAT)[7].

Table 2-2: Energy component values from BKK.

Energy component øre/kWh	Daytime (06.00-22.00)	Night, weekends and holidays
January-March	42.09	32.09
April-December	50.44	40.44

Table 2-3: Fees included in the energy component for BKK.

Fees included in the energy component	Cost [øre/kWh]
Enova	1.00
Elavgift (Jan-Mar)	9.16
Elavgift (Apr-Dec)	15.84
Goods and Services Tax (GST)	25%

2.1.2 Electricity Support Arrangements

As the electricity costs are at a record high, at the time of writing this thesis, the government in Norway has introduced several temporary electricity support arrangements. There were multiple arrangements in 2022, such as support to households, reduced electricity taxes, and an electricity grant for students[10].

The arrangement for support to households is the most relevant and comes into effect when the monthly average market price in the given area exceeds 70 øre/kWh. In these cases, the government covers 90% of the cost exceeding this price. This arrangement lasted from September 2022 until March 2023 and from October 2023 until December 2023.

Considering that this is a temporary arrangement, it will not be included in the analyses in this thesis.

2.1.3 Time-of-Use

Shifting the Time-of-Use (ToU) of energy consumption refers to lowering the electricity use in times when the spot price is high and increasing it when the spot price is low.

Some measures that can be done is using smart devices connected to flexible loads, e.g, the heating tank, electrical vehicle (EV) charging, dishwashers, and washing machines[11]. This makes it possible to regulate when the devices should run, for instance when the spot price is low. Furthermore, the majority of electricity use in an ordinary household comes from heating. Therefore, simply lowering the temperature in rooms that are not in use makes it possible to save some money, and can be done when leaving the house or while sleeping[12].

Shifting Time-of-Use will be a central element in the cost analysis in Chapter 4 in order to reduce the energy cost.

2.2 Solar Technology

To assemble the hybrid system, an energy source needs to be implemented, which in this thesis includes solar technology. There are two main types of solar technology: solar thermal and photovoltaic (PV). In this section, which focuses on the latter, the theory of how solar cells work, the benefits of integrating PV panels into households, and how to estimate their energy outputs are explained.

Solar energy is currently one of the leading renewable energy sources in the world [13]. Solar technology involves the capture and utilization of the energy generated by the sun and converting it into usable forms of energy, such as electricity.

The most common solar technology used in the world today are PV solar panels[14]. Solar PV technology has been around since 1950 and its continuous development has led to a steady improvement in quality and efficiency[15]. Today, commercial PV panels have an efficiency varying between 20-25%, yet PV panels have been developed with efficiencies approaching up to 50% [16], [17]. These panels have a lifespan of approximately 25 years[18].

Although the efficiency of solar panels is improving, the generated electricity from the panels will still decline gradually over time. The degradation of high-quality solar panels is estimated to be around 0.5% each year. This means, by the end of the 25-years lifespan of the panels, it will generate around 12-15% less power than in the first year[19].

2.2.1 Photovoltaic Solar Cells

"The word photovoltaic implies the conversion of "photo" or light into "volts" or electricity"[20, p. 3].

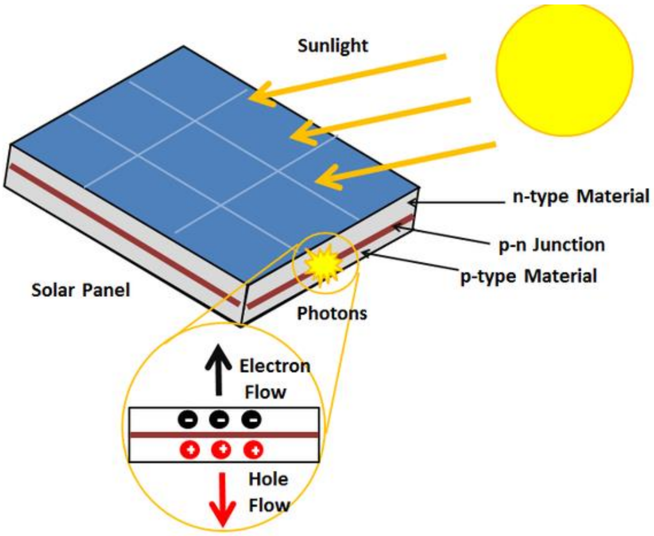


Figure 2-3: Illustration of how a PV cell works[21].

Photovoltaic technology converts sunlight directly into electricity in the form of direct current (DC). A photovoltaic cell contains two plates on top of each other with semiconducting materials, typically Silicon (Si) or Germanium (Ge)[20]. The top plate is N-type, which means that it contains extra electrons, and the bottom plate is P-type, meaning it has further spaces for electrons. This does not mean that the semiconducting atoms change into an ion, but some of them are replaced with atoms with an extra electron, typically phosphorus in the top plate, and some have one less electron, typically boron in the bottom plate. By connecting these plates, the surplus electrons from the top plate will naturally fill the empty spaces in the bottom plate, leading to a positively charged top plate and a negatively charged bottom plate. Due to the difference in charge, an electrical field appears in between the plates. When exposing the solar cell to the sun, the photons create a reaction which produces electricity. The disruption of the photon will separate one of the outer electrons in the atom in the electrical field, and these electrons will flow to the N-type plate to balance the charge difference. During this process, there is an occurrence of surplus electrons in the top plate. Due to the electrical field, the electrons cannot flow to the bottom plate. In order for the charge difference to equalize, an electrical wire is connected that allows the electrons to flow – this creates the electricity[22].

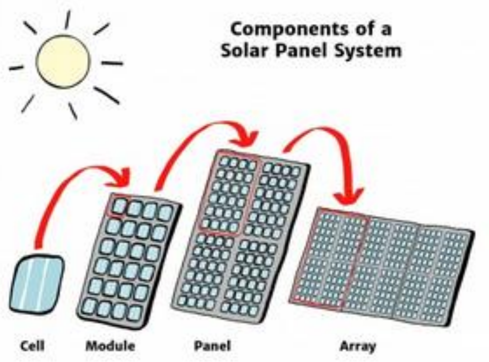


Figure 2-4: Illustration of large banks of solar cells [23].

When combining multiples of these PV cells, it creates a solar panel. When the sun shines on the solar panels, it activates them, and the system generates electrical energy which is the sum of what is produced by all these cells. For the household to use this produced electricity in most applications AC is required, and so the DC from the PV panels needs to go through an inverter [23].

When installing solar panels there are four important factors to take into consideration: the cardinal direction, azimuth, angle of the roof, and the angle of the solar panels. Both direction and angle of the panels are extremely important to optimize the production. Since the sun is constantly moving across the sky there is no general ideal angle, and it is dependent on where the house and the roof are located. For the two cases, which are in the south of Norway, angling the panels between 30 and 45 degrees is optimal. This is because positioning the panels facing true south and tilting them between 30 and 45 degrees is necessary as the panels produce the most electricity when positioned perpendicularly to the sun[24].

2.2.2 Integrated into Households

Solar panels are becoming an increasingly popular choice for supplying homes with energy. Considering that it is renewable energy, it would be a wise choice from an environmental perspective. Solar energy produces no air pollution when used, unlike other energy sources such as coal and gas[25]. Additionally, solar panels supply a household with a separate power source from the energy grid, meaning it is possible to provide a system that is no longer fully dependent on the grid. Although this is possible, most solar PV systems will be for premises that are grid tied. As the use of PV energy is more sustainable than the energy from the grid, it makes solar energy a fitting choice for people interested in reducing their carbon footprint or in reducing their energy cost. However, as 97% of the energy in the grid is produced from renewable energy, this means that this claim is not as relevant for Norwegians[26]. Contrastingly, in Poland, 83% of the energy in the grid is produced from fossil fuels, mainly coal[27]. This makes the claim relevant for countries where the electricity to the grid has a low share of renewable energy.

The investment cost of PV panels may seem expensive, but the savings over time make up for the initial investment[28]. To incentivize this, the government provides tax incentives and discounts to both companies and households who invest in renewable energy, as a measure to guide Norway to a low emissions society[29]. This investment support is done through Enova.

Another reason why PV panels are an attractive option is that they are relatively easy to install and maintain [30].

2.2.3 Energy Output

To be able to calculate and estimate the produced energy from solar panels, it is necessary to understand how the amount of generated energy is calculated.

The sun generates power and is known in two terms: solar radiation and solar irradiation. Solar radiation is the power emitted from the sun itself (W), while solar irradiation is the power received from the sun per unit area of the collector (W/m^2)[31].

Solar production is affected by the sun's path and varies depending on factors such as the time of year and location. Usually, the databases for solar radiation account for these factors[31]. The cosine effect is one aspect of the factors and will impact solar production as the angle of the solar rays on the panel will vary. This makes it necessary to include in the calculations of solar production[32].

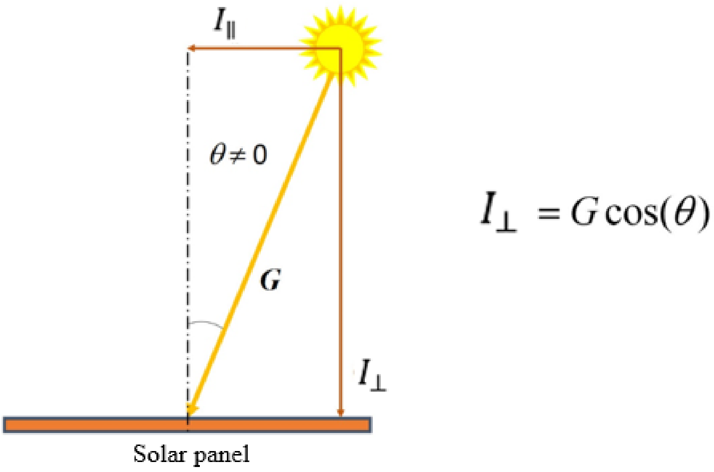


Figure 2-5: Illustration of the cosine effect[32].

Therefore, the relevant solar irradiation will be the solar irradiation perpendicular to the panel.

$$I_{\perp} = G \cos \theta \qquad \text{(Equation 2.1)}$$

The power available to be harnessed, for a solar panel, is therefore calculated using the power equation:

$$P_{\perp} = I_{\perp} \cdot A \quad [W] \qquad \text{(Equation 2.2)}$$

Where I, given in the unit W/m^2, is the irradiation from the sun, and A, given in the unit m^2, is the area of the solar panel.

The power output for a solar panel depends on the efficiency of the panel and needs to be included in the equations. Efficiency depends on different factors such as temperature, spectral response and solar shadings[33]. For example, the temperature affects the efficiency of the panels due to the natural characteristics of the semiconducting material built in the PV cells. When the temperature drops, the voltage in the panel increases, resulting in an increased efficiency[34].

The power equation, including efficiency, is:

$$P = I_{\perp} \cdot A \cdot \eta \quad [W] \qquad \text{(Equation 2.3)}$$

The albedo effect also impacts the power production of a solar panel. Albedo is a surfaces' ability to reflect sunlight, where light-colored surfaces have a high albedo due to a large reflection of sun rays, dark surfaces have a low albedo due to high light absorption[35]. Therefore, light surfaces, such as snow, will reflect sun rays back to the solar panels, increasing the production of power as it results in more irradiation [36]. However, it will not be included in the calculations, as this only affects the irradiation in some cases.

Further, the daily watt-hour is calculated by multiplying the power with average hours of direct sunlight, also known as the energy output[37].

$$E = P \cdot t \quad [Wh] \qquad \text{(Equation 2.4)}$$

2.3 Residential Battery Storage

The principles behind battery energy storage systems (BESS) are quite simple. When the panels produce more power than needed, the excess energy can be stored in the battery storage for later use. A BESS can also be used to shift the ToU, this is done by charging the battery during low spot prices and discharging the battery during spot price peaks[38].

The lifespan of a BESS depends on various factors such as the operating temperature of the battery, magnitudes of the charging and discharging currents (C-rate), depth of discharge (DoD), and number of cycles[39]. A battery’s lifespan is estimated to last from around 10 to 15 years, or 4000 cycles [40], [41].

The battery’s storage capacity limits the amount of energy that can be stored. The capacity of the battery decreases as the number of cycles increases; therefore, most companies have a cycle warranty, usually for 3-6000 cycles, where it is guaranteed that the capacity does not fall short of 80% [42]. When the capacity drops to a critical level, a while after passing the estimated lifetime, the battery elements can be replaced. This means that the whole battery storage does not need to be replaced and will only result in an added cost for the new batteries.

When choosing the optimal battery, it is dependent on different variables, this includes the lifespan, rated energy and power capacity, storage duration, state of charge, system life and round-trip efficiency. Lithium-ion batteries are the most popular form of solar batteries that can currently be found on the market. It has a high DoD, reliable lifespan, ability to hold a lot of energy for a long time, and a compact size [43]. This is, for reference, the same technology which is used for smartphones and other high-technology batteries such as certain electrical vehicles (EV). The use of lithium ion in EV charging is the main driver for battery technology development and the reduction in cost. This is due to a current spike in interest in electric vehicles, making more companies invest in making strides for the technological aspect of the EV batteries.

2.3.1 Hybrid System

When using a hybrid system, the batteries are charged during the day when the sun is shining, and power is stored and released for consumption when needed.

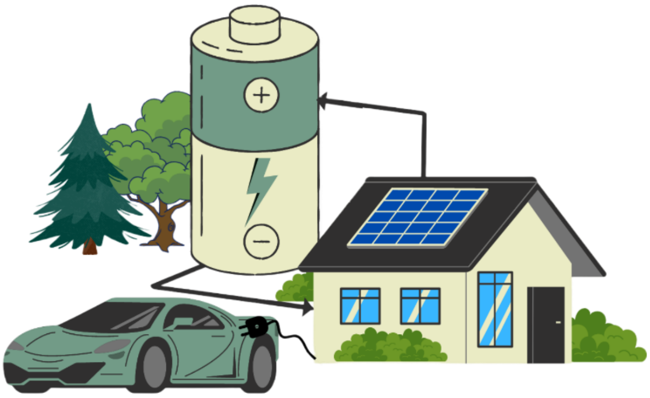


Figure 2-6: Illustration of a hybrid system with EV-charging.

Solar energy is not constant, as it fluctuates depending on the solar irradiation. The brighter the sun, the more voltage and current the solar panels produce. As Figure 2-7 illustrates, the voltage/current characteristics of a PV panel is complex, and to utilize the energy a maximum power point tracker (MPPT) is usually used [44]. MPPT is a charge controller that controls the flow and extracts the maximum power from the panels. The charge controller is an electronic converter, transforming a variable voltage from the AC panel to stable AC or DC voltage[45].

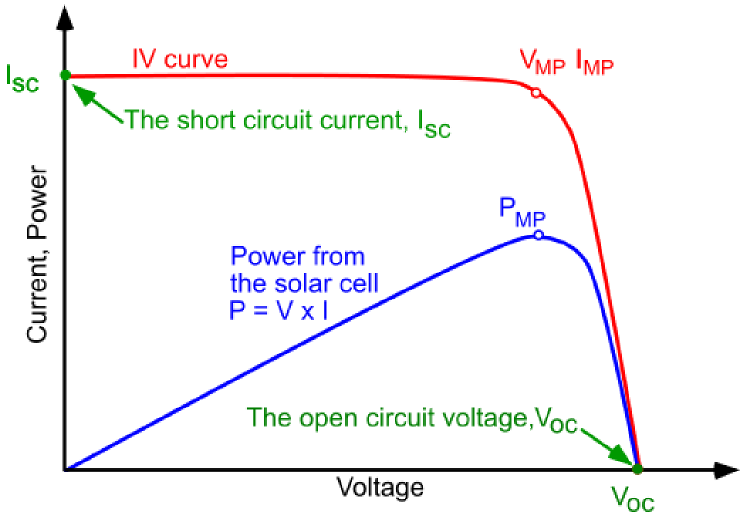


Figure 2-7: Graph of power curve for a solar panel with MPPT[46].

The most common way of connecting a hybrid system is an AC connected system and is illustrated in Figure 2-8. The PV panels are connected to a separate solar inverter, with MPPT, that converts the DC from the solar panels to AC used in the house. Connected to the same AC is a separate battery storage system with a bi-directional AC/DC converter. The benefit of this system is that components from different producers can easily be combined. However, this interferes with the system's ability to operate as a harmonious system [47].

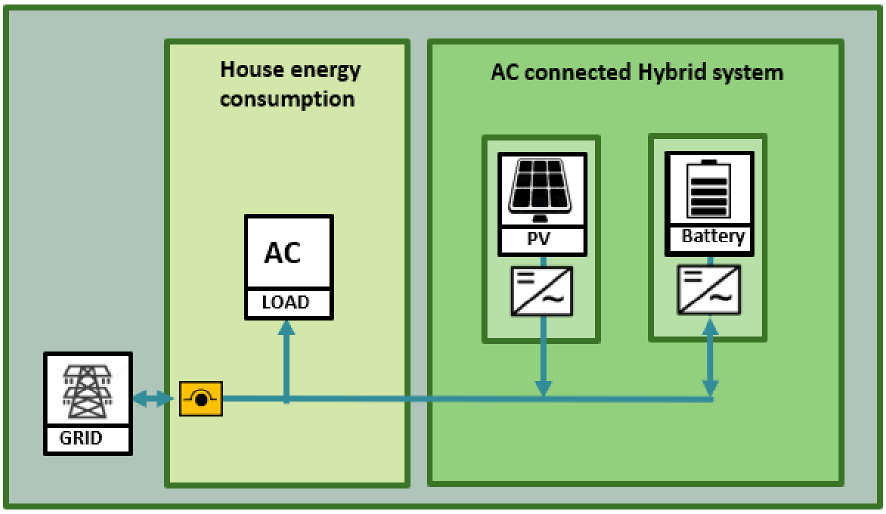


Figure 2-8: Illustration of an AC connected hybrid system[48].

2.3.2 Pixii Battery

The battery used in the hybrid system for this thesis is Pixii's new battery, Pixii Home. This is a DC coupled hybrid system, where the energy from the solar panels is converted directly through a DC/DC converter to the battery. The battery is then connected through bi-directional AC/DC converters to the grid, as illustrated in Figure 2-9.

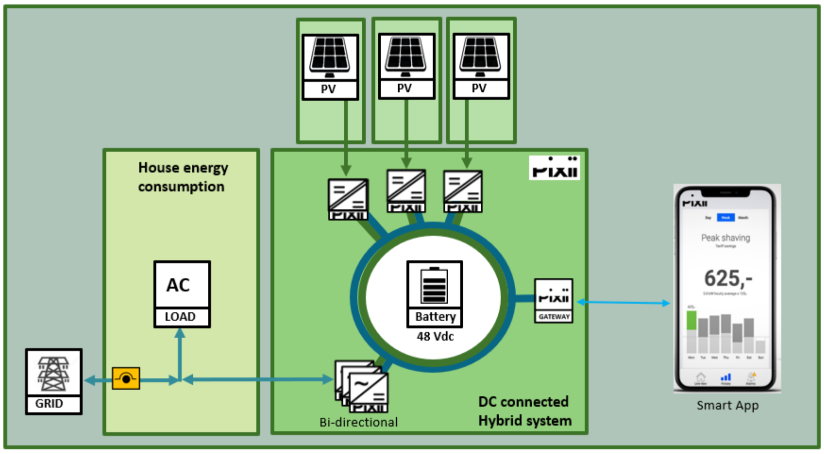


Figure 2-9: Illustration of an DC connected Pixii hybrid system[48].

This battery system is designed for residential energy storage, and has a scalable capacity of 5, 10, 15 and 20 kWh, and a continuous output capacity of 3.34, 6.67, and 10 kW[5]. Pixii Home is a lithium-ion battery with a nominal voltage of 48V and has integrated MPPT functionality in the solar DC/DC converter.

With this battery storage, the Pixii Smart Home Hub has integrated a smart home app functionality, making it a smart regulating battery. An expansion of the app is being considered, as they want to actively control additional loads. The focus is on investigating the effect of including the heating tank, as it has a huge potential for energy storage, demonstrated in Section 4.1.3.

The cost of this battery is not currently available to the public, as it is not on the market yet. Regardless, Knut Gjerde at Pixii estimated the battery with a capacity of 20 kWh, and a continuous output capacity of 10 kW to have a cost of 97 720 NOK[48].

2.4 Water Heating Tank

The water heating tank is an element in this thesis’s hybrid system, and to optimize its usage, it can be regulated. The following section will include the explanation of a heating tank, the thermodynamics of a heating tank, and control strategies.

A water heating tank is a tank that stores and heats up water, it contains a considerable amount of hot water, and therefore stores a lot of energy. In Norway this is usually achieved by an electrical element immersed in the water contained in the tank. In a household, a standard heating tank can typically hold a volume between 100-300 L, and will usually have a lifetime of 20 years[11], [49]. The installed effect of the elements is usually 2 kW for a 200 liter tank[50].

Usually, the water temperature is around 5-15°C when entering a household. As people often require the water temperature to be higher, the water needs to be heated. With an electric heating element, the cold water is heated to 65-95°C[51]. A thermostat is connected to ensure that the water is always at the preset temperature. If the temperature is below the preset value, the thermostat activates the electric element and heats the water until the desired temperature and then turns off the electric element when the temperature has reached the preset value[52].

The standard heating tank was commercialized in Norway in the 1930s[53]. In later years the technology has been developed further, with a focus on regulation of the heating tank, both regarding heat loss and ToU. A smart water heater is a technology that makes it easier to save money while also regulating energy use. This heater makes it possible to control and manage the temperature of the water in the tank through an automated built-in smart control system. The system will learn your household's water patterns and adjust accordingly. As habits change, the system's heating pattern adapts accordingly[54].

A problem that can occur in any heating tank is the growth of the bacteria Legionella. This can develop when the tank contains lukewarm (20-50°C) water for a period of time, usually more than a week [11]. The water heater keeps track of the water's temperature and will turn on regularly to keep the water hot, which kills these harmful bacteria[54].

2.4.1 Thermodynamics of a Heating Tank

As previously mentioned, a heating tank holds a considerable amount of energy in the form of heat. The heating tank supplies hot water during daily household tasks, such as showering and handwashing. Because of this use, the heated water is drained from the tank throughout the day. As the hot water is used, it is replaced by cold water that is supplied through the bottom of the heating tank. This results in a thermal gradient, with the remaining hot water at the top, and the newly supplied cold water at the bottom. To heat the water, the heating element in the tank is turned on. The element and the temperature sensor is typically at the bottom of the heating tank, where the water is the coldest.

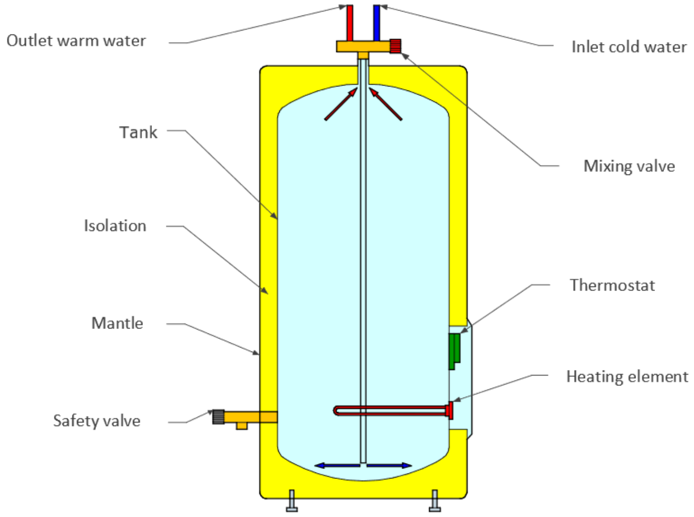


Figure 2-10: Cross section of an electric hot water heater[52].

The energy required in the heating elements to heat the water can be calculated by the given energy formula:

$$Q = m \cdot Cp \cdot \Delta T \; [kJ] \qquad \text{(Equation 2.5)}$$

Where:

$m = Mass\ of\ heated\ water\ [kg]$

$Cp = Heat\ capasity.\ For\ water{:}\ Cp = \ 4.18\ [\frac{kJ}{kg \cdot K}]$

$\Delta T = Temperature\ difference\ \ (T2 - T1)[K]$

$T2 = highest\ temperature$

$T1 = lowest\ temperature$

As energy often is given in the unit kWh, the correlation is:

$$kJ \leftrightarrow kWh \quad 1\ kJ = \frac{1}{3600} kWh \qquad \text{(Equation 2.6)}$$

The time it takes for a heating tank to be reheated can be calculated by using Equation 2.5. In addition, the power output of the specific heating tank needs to be in the equation for the output to be in hours [55].

$$\frac{kWh\ (energy\ required\ to\ heat\ water)}{kW\ (power\ output\ heating\ tank)} = h \qquad \text{(Equation 2.7)}$$

2.4.2 Control Strategies

The term flexibility, when talking about an energy load, describes the ability to adjust a load. This flexibility makes it possible to change the pattern of energy use by turning it off or by shifting the energy load. Shifting ToU is done as a response to fluctuating spot prices, making it possible to reduce overall energy cost[11]. When shifting ToU, two approaches are investigated, day-ahead and pre-set regulation.

Day-ahead regulation fetches the spot price data from Nord Pool, which is announced the day ahead, and sets the ToU for the heating tank based on these values. This means it is in line with the cheapest hour slots. As this method uses day-ahead spot prices that will vary daily, the ToU hours will vary somewhat from day-to-day.

Pre-set regulation also uses the spot prices, but in contrast to day-ahead, this regulation is based on the average data for a whole year, specifically on the average cheapest hours. As this method has pre-set hours corresponding to the predicted cheapest hours, it will not use the actual cheapest hours every day, as this will vary daily.

Usually, a heating tank has an installed effect of 2 kW. It is possible to increase the installed power of a heating tank, reducing the number of hours needed for reheating. A heating need of 16 kWh can be provided within the two cheapest hours, with a 9-kW element. While with a 2-kW element, the tank needs to be on for nine hour-slots to cover the need. A 9-kW hot water heater can be challenging for the dwelling's main inlet fuse. However, as most dwellings in Norway have a three-phase input, it is possible for electricians to divide the elements between the phases.

2.5 The Hybrid System Including Heating Tank

When approaching a configuration of a hybrid system and a heating tank, the theory covered in this chapter is highly relevant to understand the components' function. When striving to reduce the energy cost with a hybrid system, the optimal combination of the elements is the one where each component's potential is utilized. Solar panels provide an efficient method of energy production, while battery storage provides storage and a method of utilizing the produced energy. Including a heating tank in this hybrid system gives the option to store excess energy and provides the flexibility to regulate the ToU.

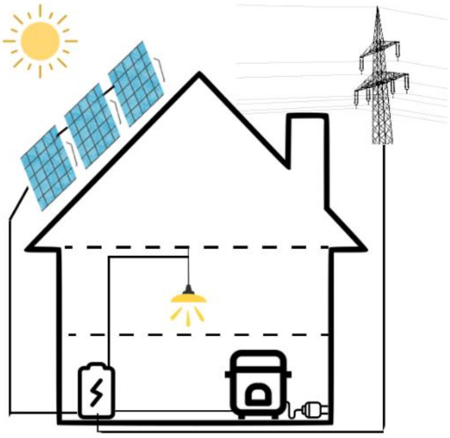


Figure 2-11: Illustration of the grid-connected hybrid system including the heating tank.

2.6 Investment Analysis

An investment analysis is used to analyze and predict future economic outcomes. Payback time is a method of investment analysis used to estimate the profitability of an investment. This method is known as the most simplified type of investment analysis, as the method disregards the time value of money and the interest rate. The payback period is the length of time it takes to recover the cost of the investment, meaning the shorter the payback time is, the better the investment will be. When the payback time has passed, the rest of the income from the investment will be the profit[56].

When calculating payback time, the investment cost is divided by the annual cash flow.

$$Payback\ time = \frac{Investment\ cost}{Yearly\ net\ cash\ flow} \qquad \text{(Equation 2.8)}$$

However, the method of calculating the investment cost will depend on what components the investment consists of. When investing in battery storage, the yearly energy savings is used as the annual cash flow. While for an investment in solar panels, the produced electricity is an important variable concerning the payback time. By multiplying the yearly produced electricity with the corresponding values of the spot prices, the yearly net cash flow is calculated.

$$Net\ cash\ flow = Produced\ electricity \cdot Mean\ electricity\ spot\ price \qquad \text{(Equation 2.9)}$$

3 Methodology

The aim of this thesis is: to investigate the effects of installing a hybrid energy system with the intention of optimizing usage and reducing annual running costs; including simulations of the potential savings from time shifting the flexible loads. Therefore, in this chapter, the tools used to collect and process data for this thesis, also known as method, are presented.

In the beginning of the bachelor thesis, an excursion to St. Olavs vei 170, Bergen, took place. The excursion gave documentation of the elements of the house, such as the model of the heating tank, cardinal direction, azimuth of the roof, and the size of the intended skylights. And it was also informed that the residents often use the fireplace to generate heat, which is important to consider when examining energy use. The energy consumption data from 2022 was obtained from the houseowner, through their electricity supplier. As this case lacks data of flexible loads, an additional case is has been considered.

For the additional case, Rørvollveien 17, Drammen, the load data for energy consumption is obtained as well. This includes the general energy consumption from 2022 obtained from the electricity supplier. Additionally, load data for the flexible loads were tracked in 2023, for EV charging and the heating tank. In addition, data for cardinal direction, azimuth of the roof, and the size of the roof is gathered from the houseowner.

Figure 3-1: Map showing the location of the two cases, excerpt from Homer Grid.

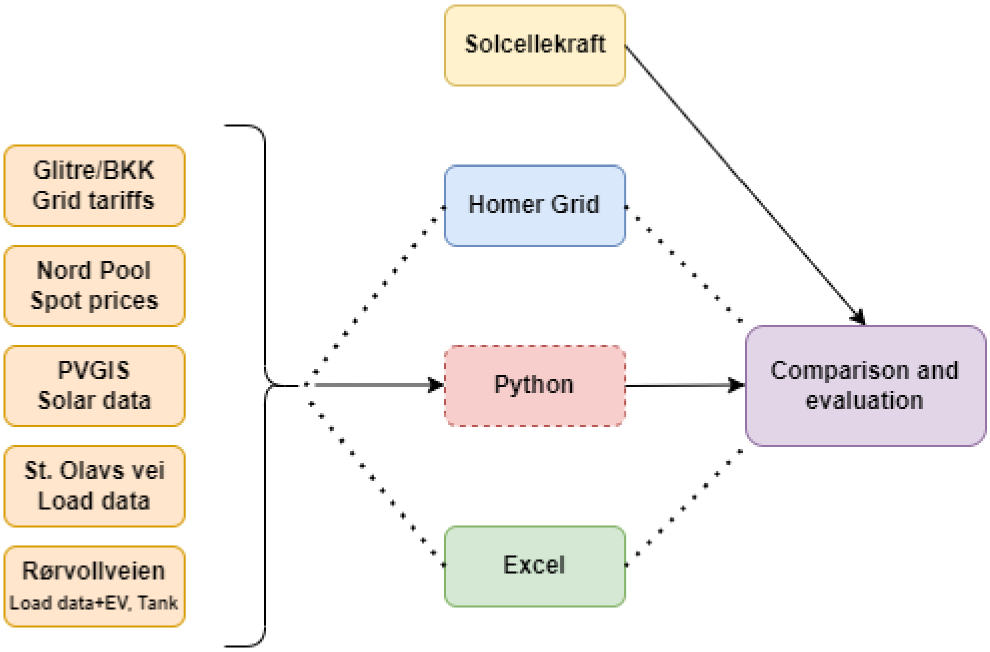


Figure 3-2: Illustration of the data and tool process in the thesis.

3.1 Python

For this thesis, it is necessary to investigate whether or not a hybrid system creates a significant impact on the energy cost. It is essential to contrast the actual cost of electricity for the implemented system with a heating tank, with the energy cost for the same year. These calculations were made using the programming language Python 3.9.12 and implemented in Spyder version 5, which is an integrated development environment. The calculations with Python are the main contributor to the data and calculations in this thesis.

A detailed description of the Python program is attached, see Appendix H. Additionally, the files for the Python code are attached in the thesis' zip file.

In short, the import files used in Python are a years' worth of hourly data for energy consumption, spot prices, and solar irradiation. The important factors used in the calculations are: total energy cost, grid tariffs, and solar production. To get an overview of the result, the data is aggregated for the year, as well as monthly.

Some main formulas used in the Python code are:

$$Cost_{total} = Energy_{component} + Capacity_{component}$$

$$Energy_{component} = \sum_{i=1}^{8760} ((spotprice[i] \cdot 1{,}25) + Gridtariff[day, night, holiday, summer, winter]) \cdot Energy_{consumption}[i]$$

$$Capacity_{component} = \sum_{l=1}^{12} \frac{peak_1[l] + peak_2[l] + peak_3[l]}{3}$$

3.1.1 Mean Hourly Values for Spot Prices

Additionally, to be able to demonstrate the concept of shifting ToU in later sections, it is necessary to calculate the mean price of each individual spot price hour-slot. This makes it possible to examine how the results of day-ahead and pre-set regulation will vary. Therefore, a calculation of the energy prices in 2022 is completed. A detailed description of this is attached in Appendix H.1.5.

3.1.2 Mixed Integer Linear Programming

To investigate the impact of the aforementioned elements, such as shifting ToU and the use of battery storage and installing solar panels, the mathematical modelling technique Mixed Integer Linear Programming (MILP) will be employed. MILP is a modeling technique in which a linear function is maximized or minimized when subjected to various constraints, such as the dwelling's energy demand, PV-production, EV charging and the heating tank[57]. Pixii has previously worked with Eskil Gjerde on a Bachelor thesis where MILP was utilized to create a model that minimizes the total electricity cost by optimally controlling a battery system[58]. This model was developed in collaboration with Professor Geert De Maere from the University of Nottingham, UK, where the main result was the development of a complex model of optimization. In their work, a model was developed to optimize the energy system, which will be used in the current work.

The MILP model is based on historical data, in other words, it is calculated with a perfect forecast. Therefore, if the system was implemented it would have a slightly lower result as the model simulates the most optimal result.

3.2 Other Tools

3.2.1 Excel

Excel is mainly used to collect and store data from different types of files, such as CSV. It is an important tool used to control and validate that the Python code is correct, in addition to sorting and presenting useful results. It is used to make graphs and tables, providing a clear and tidy overview of the extracted and collected data.

3.2.2 Homer Grid

Homer Grid is an application that combines engineering and economics to perform complex calculations easily and quickly. The application provides a powerful model which makes it possible to maximize savings as well as minimize costs, increase resilience, optimize EV charging stations, reduce carbon emissions, stack values to increase return investment, and explore combined heat and power [59]. Homer Grid was mainly intended to be used as a source to verify the results produced from the calculations from Python and Excel. However, the built-in Grid-tariffs are limited to the countries United States, Mexico, and Canada, which are not compatible with the Norwegian tariff system. There was a possibility of creating a custom complex tariff, however, this did not fit the tariff system used in this case study, as the method of calculation is not the same. Therefore, Homer Grid was not sufficiently flexible to meet this thesis' needs and demands.

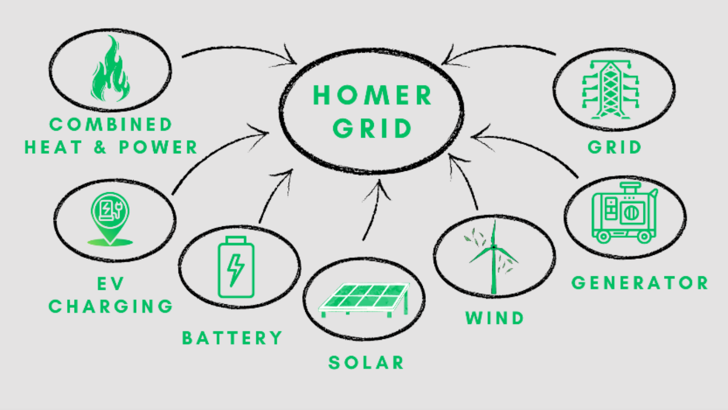


Figure 3-3: Illustration of various factors that can be inputs in Homer Grid

3.3 Choice of PV Panel

3.3.1 Solar Calculator - Solcellekraft

To decide which solar panel type to install, the website Solcellekraft is used. Solcellekraft is an online solar panel calculator which estimates energy production based on solar irradiation. In the calculator the location is entered, returning values about the area and angle of the roof. An estimation of the number of panels that would fit the roof is assumed and four different panel types are suggested. The program estimates the price of the panels, including the installation cost and Enova support[60]. To be able to choose the right panel type, an investment analysis is conducted for each type. Based on the payback time it is possible to determine which of the suggested panel types that is the most profitable for the given location.

3.3.2 Investment Analysis

To decide which panel to use, the payback time is calculated for each of the suggested panels from Solcellekraft. The data included in this analysis is spot prices and Solcellekraft's estimates of the investment cost and yearly produced electricity. The potential maintenance cost of the panels is not included. In these calculations, the mean of the spot prices from 2022 is used. As the spot price is simplified, the results give an estimate and are only used to determine the panel type. Therefore, an accurate analysis and calculation will be completed for the chosen panel in later calculations, where the actual hour-by-hour spot prices and solar irradiation from Photovoltaic Geographical Information System (PVGIS) will be used.

4 Results of Calculations

This chapter will present the calculated results of this thesis.

The result of the calculations is divided into three sections. First, a demonstration of the impact of using the theory of shifting the ToU of flexible loads is calculated. Including significant calculations and theory that are necessary for the reader to understand. The two following sections are analyses of this thesis' cases.

4.1 Flexible Loads

Investigating the impact of shifting the ToU in flexible loads is important when determining whether installing a smart controller is of value. The potential cost saving from shifting ToU of the heating tank is calculated and explained in the following section. In addition, the energy capacity in the heating tank is calculated.

4.1.1 Potential of Time-shifting

To estimate whether there is a potential for cost savings by shifting the energy load, in addition to demonstrating the concept of shifting ToU, a calculation of the energy prices in 2022 is conducted. As these values will be dependent on the spot prices in NO5/NO1 and local grid tariffs, they will be slightly different in St. Olavs vei 170, Bergen and Rørvollveien 17, Drammen.

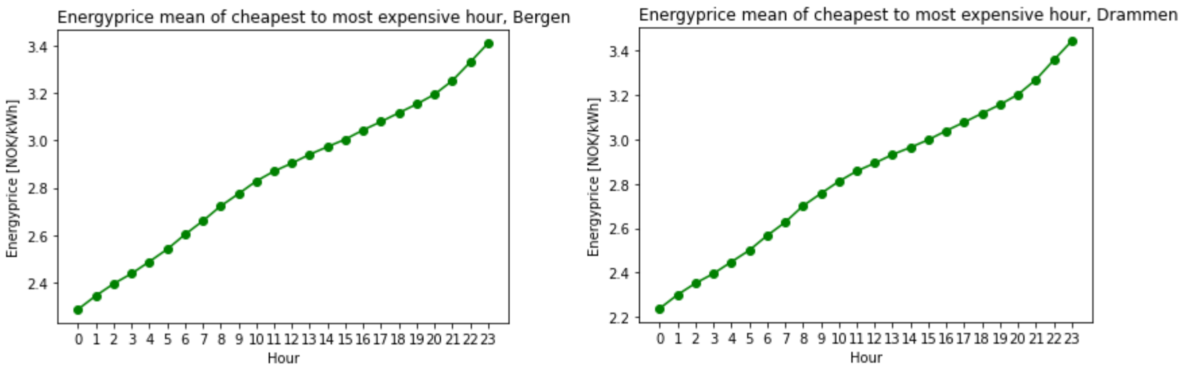


Figure 4-1: Graphs of the average price of the cheapest hour of every day.

Figure 4-1 shows the average distribution of the cheapest to most expensive hour slots, based on the hour-by-hour spot price for 2022. It is a calculation of what the energy price will be from cheapest to most expensive hour slot. With other words, the hours do not correspond with the hours of the day.

If a load continuously uses 1 kW for an hour, the cost of using this load for one hour will depend on what timeslot in which the use occurs. If the ToU in Bergen occurs in the most expensive hour slot, the cost would have been 3.41 NOK; however, if used in the cheapest hour slot, it would be reduced to 2.29 NOK. While in Drammen, the most expensive hour slot would have been 3.44 NOK and the cheapest 2.24 NOK.

To investigate the impact of time-shifting the heating tank, the energy data is tracked using a Shelly EM device in Rørvollveien 17. This will be used to calculate the potential savings from shifting ToU in Rørvollveien 17, Drammen. For the purposes of this comparison, it will be assumed that St. Olavs vei 170, has a similar hot water demand, as the data was not tracked at this location.

To demonstrate the cost savings from shifting the ToU, a daily average is used to estimate the daily and yearly savings. The data showed that the typical daily energy use of a heating tank is 16 kWh. Since the heating element is 2 kW, it would need to be on for 8 hours. This simplification is not used in later calculations for MILP, as the exact daily usage is covered.

The calculated cost savings from shifting ToU of the heating tank are therefore found by comparing the use drawing 2 kW in the eight most expensive hour slots to the eight cheapest hour slots. In Drammen, this theoretical maximum potential cost saving is 12.45 NOK every day. This results in a yearly saving of 4550 NOK. While in Bergen, the maximum potential daily savings is 11.65 NOK, resulting in yearly savings of 4300 NOK.

The promising result in this section makes it interesting to investigate some cases of controlling ToU further.

4.1.2 Analysis of Time-of-Use Control Methods

To determine if different control methods will have a significant financial impact, it is necessary to examine this further. For this reason, the energy load from the data tracking in Rørvollveien 17 will be used.

The following control methods for Rørvollveien 17 are.

1) A standard heating tank that turns on and off in line with the energy use and does not take the spot price into account, with 2 kW power.
2) Day-ahead, sets the ToU based on the cheapest hour slots using day-ahead spot prices.
    a. Tank with 2 kW power
    b. Tank with 9 kW power
3) Pre-set timer, with 2 kW power, based on the historical average cheapest hours and schedules the ToU in those hour slots.

To be able to control the ToU for the day-ahead and pre-set method, a controller is needed. This can be accomplished by either installing a smart water heating tank, or use a smart device to modify a standard heating tank. The resulting savings from the three cases, with an estimated 16 kWh load a day, is presented in Table 4-1.

Table 4-1: Overview of the cost savings from the time-shift methods, Rørvollveien 17.

Rørvollveien 17	**Original**	**Day-ahead**		**Pre-set**
Type of tank:	Original 2 kW	Smart tank 2kW	Smart tank 9kW	Smart tank 2kW
Time in use [h]:	8	8	1.77	8
Effect [kW]:	2	2	9	2
ToU:	Varied	Cheapest	Cheapest	Cheapest average
Sum avg cost per day [NOK]:	45.68	38.86	36.25	40.53
Savings per year [NOK]:	**Baseline**	**2489.30**	**3441.95**	**1879.75**

4.1.3 Energy Capacity in a Heating Tank

Using Equation 2.5, the potential energy stored in a water heating tank with 200 L can be calculated. The mass unit used in the energy equation is in kilograms, and the heating tank content is given in liters, since one liter of water approximately equals one kilogram in mass.

Assuming the temperature difference is 85°C, with the entering cold water T1=10°C and heated water T2=95°C.

$$Q = 200\ kg \cdot\ 4.18\ \left[\frac{kJ}{kg \cdot K}\right] \cdot\ 85\ K\ =\ 71\ 060\ kJ$$

$$71\ 060\ kJ\ = 19.74\ kWh\ \approx\ 20\ kWh$$

Through calculations, the estimated energy that can be stored in a 200 L water heating tank is approximately 20 kWh. Comparing this amount to a commercial battery storage with a capacity of 20 kWh, the heating tank has substantial storage potential for energy.

4.2 Case St. Olavs vei 170

In this section, the energy consumption and use of a hybrid system is investigated in the first case, St. Olavs vei 170, Bergen, Norway. The section is divided into five sub-sections. Firstly, analysis of energy consumption and costs. Then, solar panels for the given location are chosen and the energy production from these panels is calculated. Further, an analysis of the cardinal direction and MILP analyses is conducted.

4.2.1 Original Energy Use and Cost

First, it is interesting to analyze the energy use in St. Olavs vei 170 in 2022. The energy use is obtained from the houseowner’s electricity supplier and then analyzed using Python and Excel. Figure 4-2 shows an overview of the total monthly energy use. In total, the yearly energy use was 13 986 kWh.

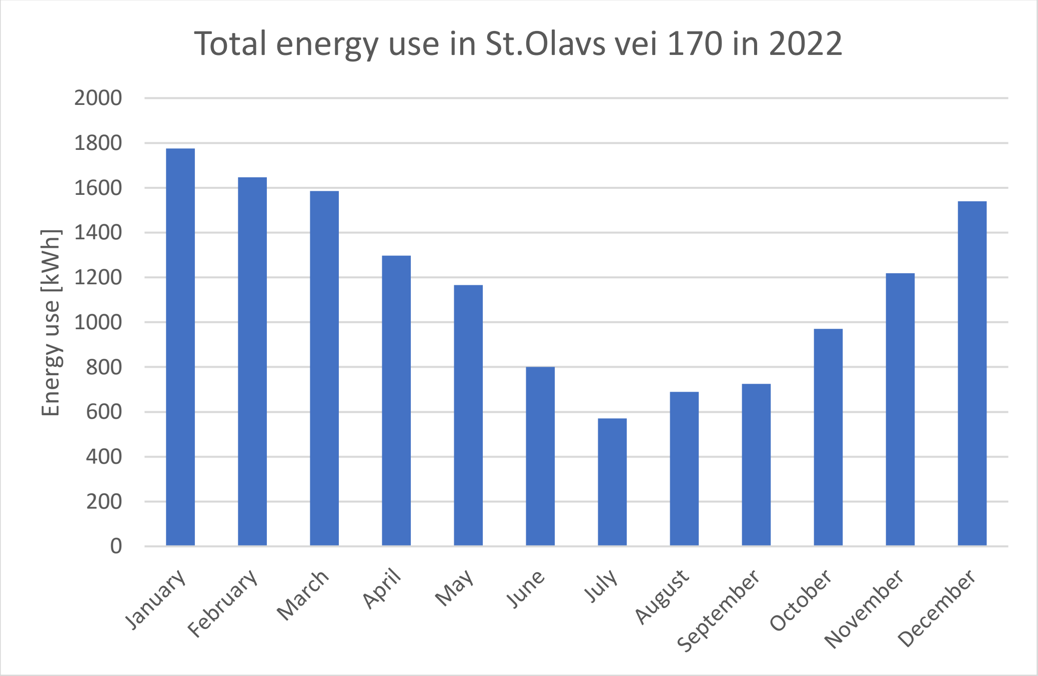


Figure 4-2: Bar graph of energy use per month, St. Olavs vei 170.

In Table 4-2, the total cost is separated into: monthly payments, with columns for the actual energy cost, the mean of the peaks, and the monthly peak cost.

Table 4-2: Total monthly energy payments, St. Olavs vei 170.

Month	Energy cost [NOK]	Mean of peaks [kW]	Peak cost [NOK]	Sum [NOK]
January	3718.71	5.47	350	4068.71
February	3104.12	5.67	350	3454.12
March	4380.77	4.82	206	4586.77
April	3423.61	5.68	350	3773.61
May	3001.77	4.33	206	3207.77
June	1858.95	3.74	206	2064.95
July	1437.06	3.42	206	1643.06
August	3217.98	3.51	206	3423.98
September	3625.81	3.20	206	3831.81
October	2085,35	3.95	206	2291.35
November	2421.16	4.58	206	2627.16
December	6579.20	5.30	350	6929.20
Total Sum	**38 854.51**		**3048**	**41 902.51**

Figure 4-3 shows the correlation between the energy use and the energy cost. It shows that although the energy use for two months might be the same, the energy cost can be significantly higher due to a variation in spot prices and grid tariffs.

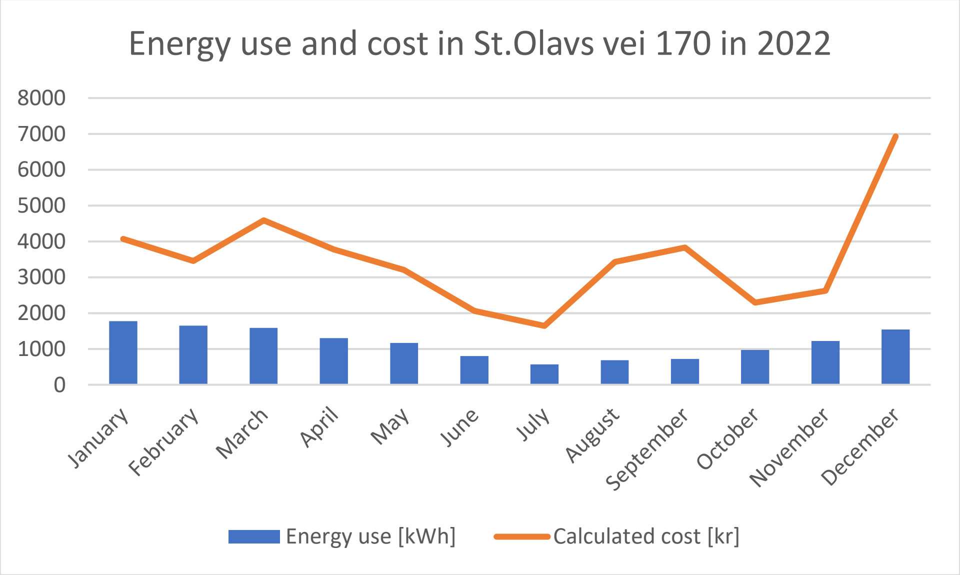


Figure 4-3: Graph showing the correlation between energy use and cost, St. Olavs vei 170.

4.2.2 Choice of Solar Panels

St. Olavs vei 170, intends to install skylights on the roof, and as a result, the estimated area of the roof from Solcellekraft will be somewhat inaccurate, it is therefore necessary to calculate the actual available area. The roof surfaces at St. Olavs vei 170 are 28.3 m^2 and 30.8 m^2 for Surface East and Surface West, respectively [61]. The intention is to install four skylights, two on each side of the roof, where the skylights' area is 0.94 m^2 per window. As a result, the area of the two roof surfaces will be smaller than the calculator estimates. The new calculated areas will be approximately 26.43 m^2 for Surface East and 28.93 m^2 for Surface West. These will be the areas used when considering the installation of the panels.

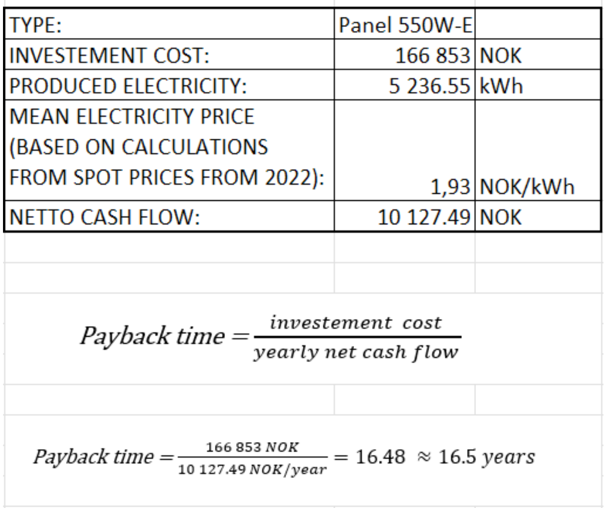
Table 4-3: Overview of the roof, St. Olavs vei 170

	Surface East	*Surface West*	*Surface East + Surface West*
Original area [m^2]	28.3	30.8	59.1
Window area [m^2]	0.94	0.94	
Number of windows	2	2	4
Total loss of area [m^2]	1.87	1.87	3.75
Available area for solar panels [m^2]	26.43	28.93	55.35
Azimuth direction	East	West	
Angle of the roof [°]	37.3	38.1	

Figure 4-4 shows the exterior of St. Olavs Vei 170 and is an excerpt from the engineer drawing of the house, see Appendix G.1.

Figure 4-4: Engineer drawing of the exterior, St. Olavs vei 170.

The estimated number of solar panels that will fit on the remaining area of the roof's surfaces is: 7 panels on Surface East and 8 panels on Surface West[61]. Investment analyses are completed, as Solcellekraft suggests four panel types. Investment Analysis 4, the 550W-E panel type, is chosen, as this panel resulted in the shortest payback time, see Appendix D. The total cost is 170 000 NOK, and the payback time is 16 ½ years. The complete investment analysis of the chosen panel is presented in Figure 4-5.



TYPE:	Panel 550W-E	
INVESTEMENT COST:	166 853	NOK
PRODUCED ELECTRICITY:	5 236.55	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,93	NOK/kWh
NETTO CASH FLOW:	10 127.49	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

$$Payback\ time = \frac{166\ 853\ NOK}{10\ 127.49\ NOK/year} = 16.48\ \approx 16.5\ years$$

Figure 4-5: Investment analysis 4, St. Olavs vei 170

To verify that these panels can fit on the surfaces, a suggestion for placement is illustrated in Figure 4-6. In the figure, the blue areas are solar panels, and the yellow areas are skylights. The measurement of the roof is extracted from the engineer drawing for St. Olavs vei 170, see Appendix G.1.

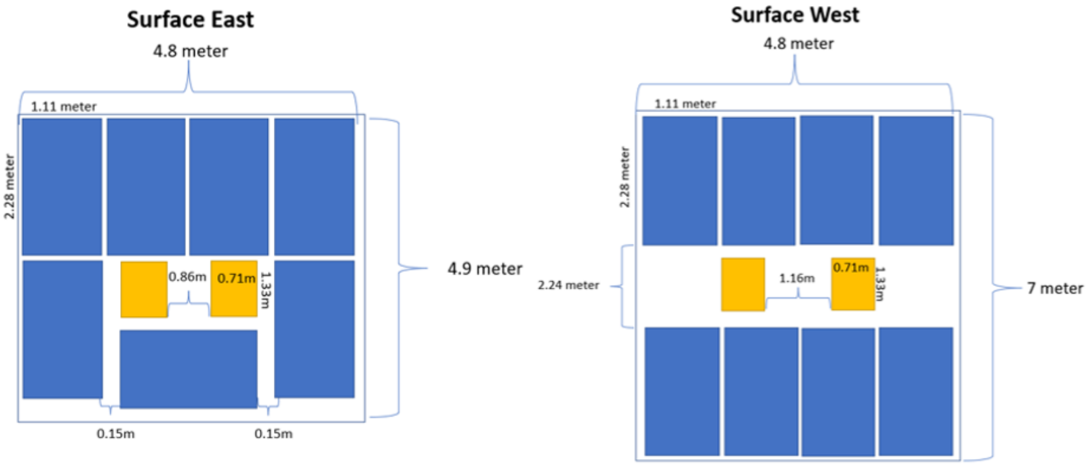


Figure 4-6: Illustration of suggested panel placement, St. Olavs vei 170.

4.2.3 Energy Production from the PV panels

Since Solcellekraft only provides the total yearly production, PVGIS is used to make it possible to analyze solar production in detail. The PVGIS data will be used for the calculation in the remainder of this section.

A calculation of the energy production was completed with Python to control the validity of Solcellekraft's estimate. The calculation is accomplished by multiplying solar radiation data for St. Olavs vei 170 from PVGIS with the installed power from the panel 550W-E. The installed power is 3.85 kWp on Surface East, and 4.4 kWp on Surface West. An 8% temperature loss and a 5% system loss in the panels are taken into consideration in the calculations. As the energy consumption and solar production data are calculated, it is useful to compare their monthly values to investigate the remaining energy needs. Figure 4-7 presents this in monthly data.

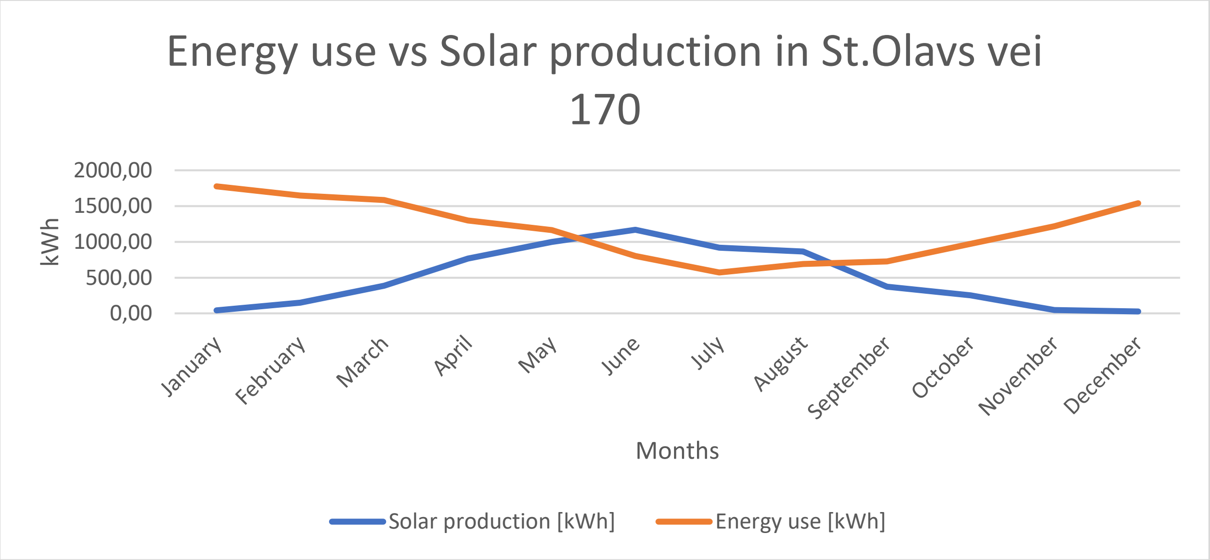


Figure 4-7: Graph of energy use and solar production, St. Olavs vei 170.

The data from Figure 4-7 results in a yearly production of 6000 kWh. The graphs show that the total amount of produced energy can sustain the energy consumption in the months of June, July, and August.

4.2.4 Analysis of Cardinal Direction

As stated in Section 2.2.1, the optimal direction of a solar panel is facing south. A panel facing south will receive the most direct solar radiation, thus producing the maximum amount of electricity. In Figure 4-8, the solar radiation for east, west, and south in St. Olavs vei 170 has been illustrated with curves in the graph. It is calculated using one kWp of installed power in the three directions, in order to compare the general energy production.

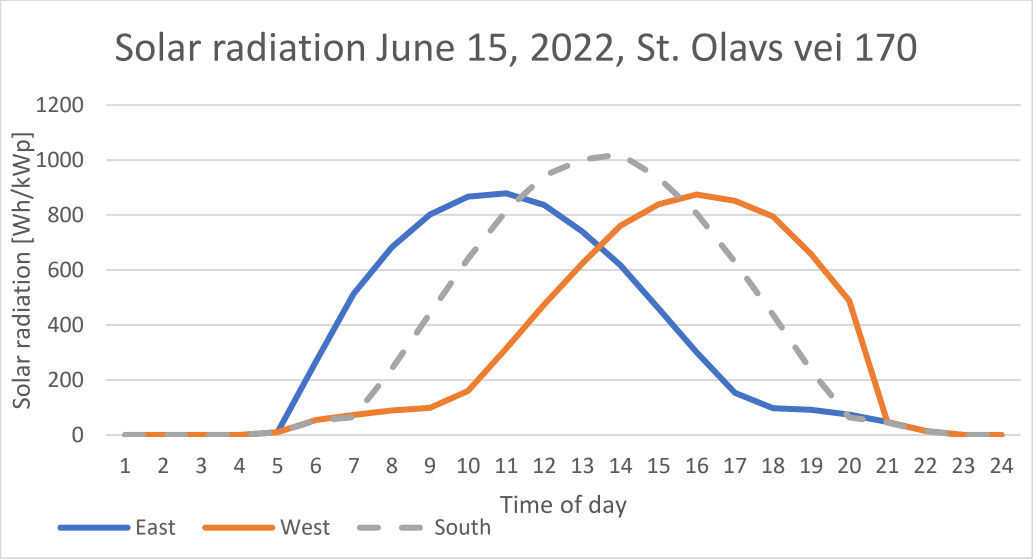


Figure 4-8: Graph of solar radiation June 15, 2022, St. Olavs vei 170.

As the surfaces of the roof in St. Olavs vei 170 only face east and west, their solar production is presented in correlation to the energy consumption in Figure 4-9. This figure is calculated using the suggested number of solar panels from Section 4.2.2, the installed power is 3.85 kWp towards east and 4.4 kWp towards west, making the amount of produced energy vary for the cardinal directions. The peak radiation for east is between 10:00-12:00, while for west it is between 15:00-17:00, while the energy consumption has multiple peaks throughout the day.

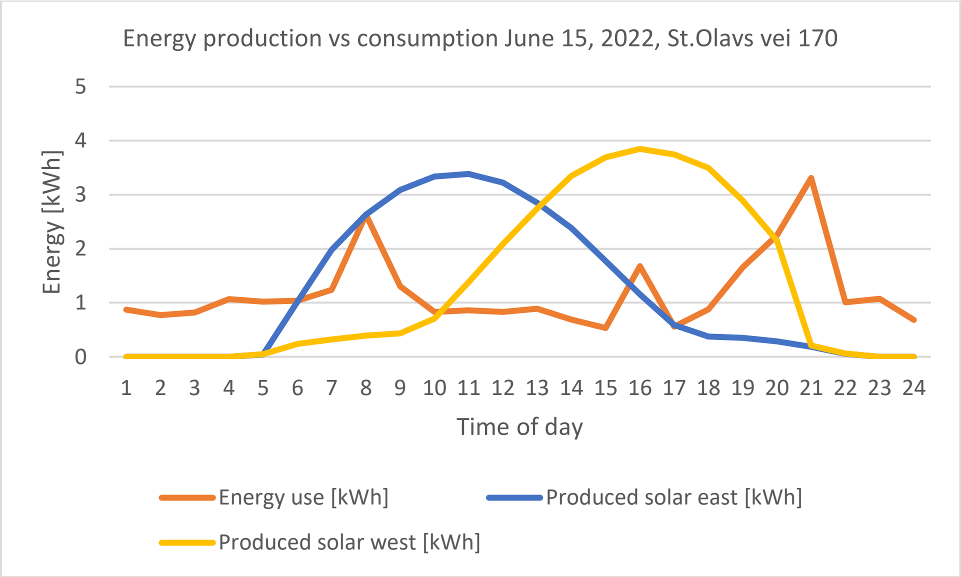


Figure 4-9: Graph of energy production and consumption June 15., 2022, St. Olavs vei 170.

4.2.5 MILP Analysis

To investigate whether the various investments are satisfactory, the MILP model is used to determine the components' economic contribution towards reducing the yearly energy cost for St. Olavs vei 170. This is found by comparing the actual energy cost in 2022, which was 42 000 NOK, with the yearly energy cost of using solar panels and batteries separately, as well as a hybrid system. Following the MILP analysis, an investment analysis is necessary to calculate the payback time. The analysis is completed in three separate parts, the solar panels, Pixii's battery storage, and finally, a combination of solar and storage. Since the data for the flexible loads is not tracked in St. Olavs vei 170, they are not applicable for the following tables.

The calculation for the analyses of the chosen solar panels is presented in Table 4-4. The installation consists of calculations for east and west separately, as well as together. The calculation of the combined yearly energy production resulted in 6000 kWh. Estimates with panels facing south are included to determine whether this hypothetical situation would be more economical than east and west. By using MILP, the most economical case was found to be combining west and east, which reduces the yearly energy cost to 27 000 NOK, meaning a reduction of 15 000 NOK. When accounting for the investment cost of 169 000 NOK, the resulting payback time is 11 years.

Table 4-4: MILP analysis for PV production, St. Olavs vei 170.

	Baseline	***West***	***East***	***South***	***East + West***	***Unit***
Installed PV	0	4.4	3.85	4.4	8.25	kWp
ToU Heating tank	N/A	N/A	N/A	N/A	N/A	kW
ToU EV charging	N/A	N/A	N/A	N/A	N/A	kW
Battery Power	0	0	0	0	0	kW
Battery Capacity	0	0	0	0	0	kWh
Yearly cost	**41 902**	**33 683**	**34 317**	**31 627**	**27 051**	**NOK**
Import	13 986	11 922	12 016	11 599	10 932	kWh
Export	N/A	1 124	834	1 623	2 939	kWh
PV production	N/A	3 189	2 805	4 010	5 994	kWh
Cycles	N/A	N/A	N/A	N/A	N/A	cycles
Cost, incl. Instal.	N/A	115 180	95 320	111 180	166 853	NOK
Savings	N/A	8219	7585	10 275	14 851	NOK
Payback time	**N/A**	**14**	**13**	**11.2**	**11**	**years**

The calculation for the analyses of the Pixii Home battery storage is presented in Table 4-5 and is conducted for several system size configurations. The configuration that is best suited is with a 10-kW continuous output capacity and 20 kWh capacity. Results from using MILP, show that the yearly energy cost could be reduced to 36 000 NOK, meaning that by using a battery storage alone, attaining a reduction of 6000 NOK a year is possible. When accounting for the investment cost of 98 000 NOK, the resulting payback time is 16.4 years.

Table 4-5: MILP analysis for battery storage, St. Olavs vei 170.

	Baseline	***Battery storage***	***Battery storage***	***Battery storage***	***Unit***
Installed PV	0	0	0	0	kWp
ToU Heating tank	N/A	N/A	N/A	N/A	kW
ToU EV charging	N/A	N/A	N/A	N/A	kW
Battery Power	0	10	3,3	3,3	kW
Battery Capacity	0	20	20	10	kWh
Yearly cost	**41 902**	**35 935**	**36 300**	**37613**	**NOK**
Import	13 986	14 585	14 201	14 080	kWh
Export	N/A	599	214	93	kWh
PV production	N/A	N/A	N/A	N/A	kWh
Cycles	N/A	417	385	592	cycles
Cost, incl. Instal.	N/A	97 720	82 498	52 498	NOK
Savings	N/A	5967	5602	4 289	NOK
Payback time	N/A	**16.4**	**14.7**	**12.2**	**years**

As the purpose of this thesis is largely based on the financial impact of using a complete hybrid system, a MILP analysis of the whole system is essential as the profitability and use of these elements will be affected by each other.

The calculation is done for several system size configurations, a select few is presented in Table 4-6. The configuration that is most valuable is with 8.25 kWp of installed solar panels, and a battery inverter system which is rated with a 10-kW continuous output and 20 kWh capacity. The heating tank and EV charger are not applicable as this case does not track flexible loads. The MILP model calculates that the yearly energy cost can be reduced to 20 000 NOK. This means that using a combination of solar production as well as a battery storage will result in a reduction of 22 000 NOK a year. When accounting for the investment cost of 265 000 NOK, the resulting payback time is 12.2 years.

Table 4-6: MILP analysis for total hybrid system, St. Olavs vei 170.

	Baseline	***Tot system***	***Tot system***	***Tot system***	***Unit***
Installed PV	0	8.25	8.25	8.25	kWp
ToU Heating tank	N/A	N/A	N/A	N/A	kW
ToU EV charging	N/A	N/A	N/A	N/A	kW
Battery Power	0	10	3.3	3.3	kW
Battery Capacity	0	20	20	10	kWh
Yearly cost	**41 902**	**20 262**	**20 652**	**21 988**	**NOK**
Import	13 986	10 103	9 715	9 832	kWh
Export	N/A	2 110	1 721	1 840	kWh
PV production	N/A	5 994	5 994	5 994	kWh
Cycles	N/A	391	364	562	cycles
Cost incl. Instal.	N/A	264 573	249 351	219 351	NOK
Savings	N/A	21 640	21 250	19 914	NOK
Payback time	**N/A**	**12.2**	**11.7**	**11.0**	**years**

4.3 Case Rørvollveien 17

In this section, the energy consumption and the use of a hybrid system is investigated for the second case, Rørvollveien 17, Drammen, Norway. At this location, the area of the roof is substantial. It also has tracked data for energy consumption, including separate data for EV charging and the heating tank. This creates a case where it is possible to analyze all the relevant elements in the thesis.

This section consists of six sub-sections. Firstly, analysis of energy consumption and costs examination. Then, solar panels for the given location are chosen and the energy production from these panels is calculated. Further, MILP analyses is completed for solar production, a BESS, and the flexible loads. Lastly, a MILP analysis of the whole hybrid system is presented.

4.3.1 Original Energy Use and Cost

First, as it is interesting to analyze the energy use in Rørvollveien 17, the data from 2022 is obtained from the houseowner. The data is analyzed with Python and Excel, finding that the energy use in 2022 was 31 500 kWh. Figure 4-10 shows an overview of the total monthly energy use for the household.

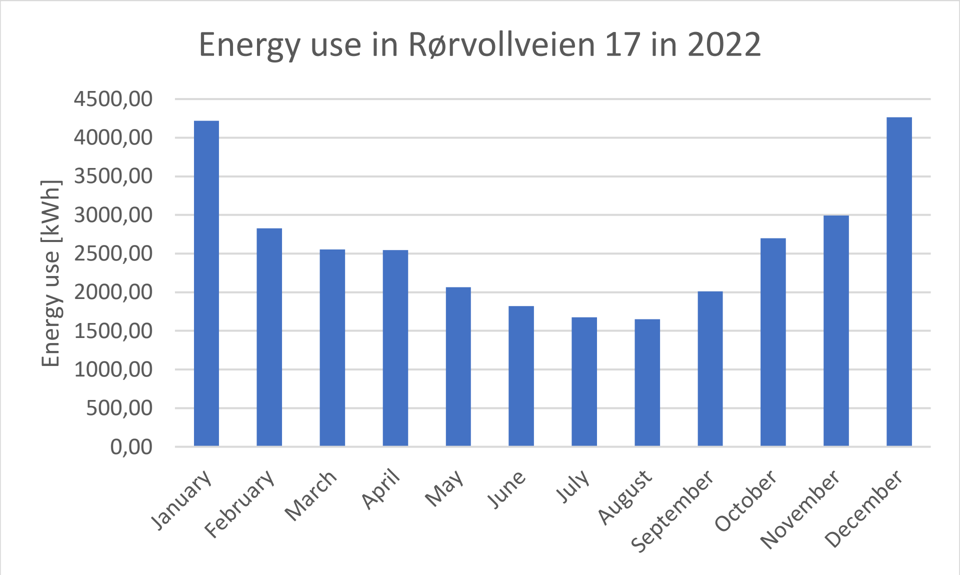


Figure 4-10: Bar graph of energy use per month, Rørvollveien 17

In Table 4-7, the total cost is separated into: monthly payments, with columns for the actual energy cost, the mean of the peaks, and the monthly peak cost.

Table 4-7: Total monthly energy payments, Rørvollveien 17.

Month	**Energy cost [NOK]**	**Mean of peaks [kW]**	**Peak cost [NOK]**	**Sum [NOK]**
January	8967.60	5.47	600	9567.60
February	5344.15	5.67	290	5634.15
March	6937.94	4.82	290	7227.94
April	6635.97	5.68	290	6925.97
May	5345.88	4.33	290	5635.88
June	4177.15	3.74	290	4467.15
July	4171.92	3.42	290	4461.92
August	8249.32	3.51	290	8539.32
September	9687.36	3.20	290	9977.36
October	5737.88	3.95	290	6027.88
November	5977.68	4.58	290	6267.68
December	16708.25	5.30	600	17308.25
Total Sum	**87941.09**		**4100**	**92 041.09**

Figure 4-11 shows the correlation between energy use and total energy cost. It shows that although the energy use two months might be the same, the energy cost can be slightly higher due to varying spot prices and grid tariffs.

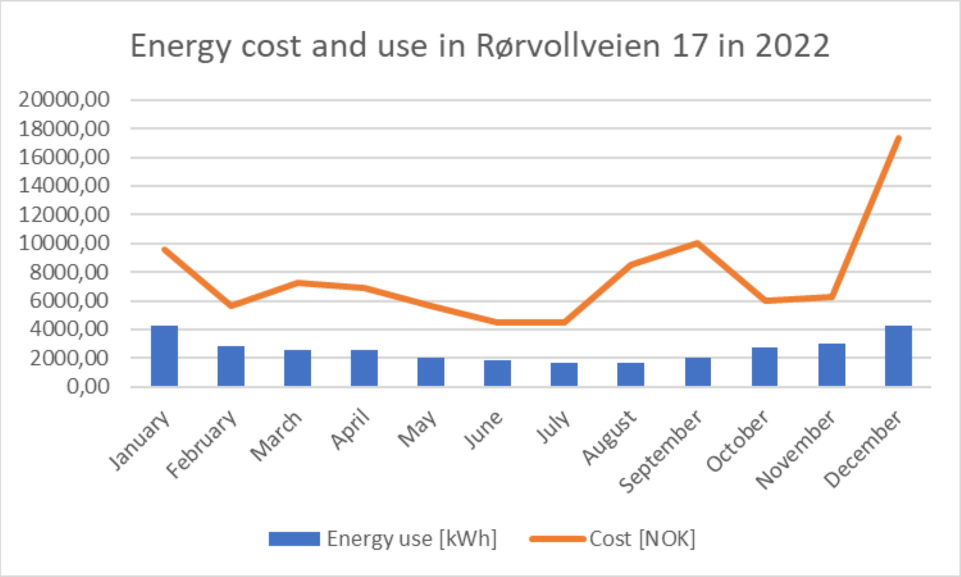


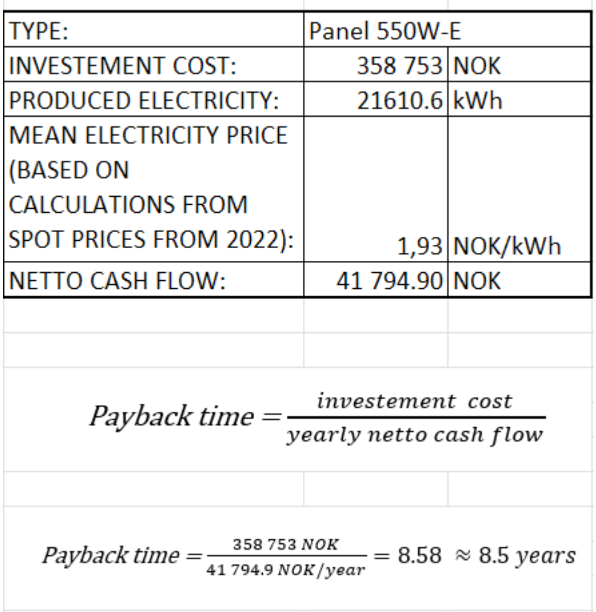
Figure 4-11: Graph showing the correlation between energy use and cost, Rørvollveien 17.

4.3.2 Choice of Solar Panels

As it is necessary to investigate the installation of solar panels, the optimal type of panel needs to be decided for Rørvollveien 17. An investment analysis is completed to determine which panel to choose for optimal utilization, see Appendix E. To decide which solar panel type to install, Solcellekraft is used.

The dwelling has a roof facing 150 degrees southeast with an area of 133.3 m^2. The estimated number of solar panels is 81 panels, covering both surfaces of the roof[62]. One of the roof's surfaces is facing north, and a brief analysis shows that the produced electricity is minimal. This results in a long payback time and will therefore not be further examined. The surface facing southeast is estimated to fit 38 panels. Investment analyses are completed, as Solcellekraft suggests four panel types. Investment Analysis 4, the 550W-E panel type, is chosen, as this panel resulted in the shortest payback time, see Appendix E. The total cost is 359 000 NOK, and the payback time is around 8 ½ years. The complete investment analysis of the chosen panel is presented in Figure 4-12.

To verify that these panels can fit on the surfaces, a suggestion for placement is illustrated in Figure 4-13. In the figure, the blue areas are solar panels, and the yellow areas are skylights. The measurement of the roof is extracted from Solcellekraft's calculation that suggests width and height, and placement and dimensions of the skylights is estimated by the houseowner.



TYPE:	Panel 550W-E	
INVESTEMENT COST:	358 753	NOK
PRODUCED ELECTRICITY:	21610.6	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,93	NOK/kWh
NETTO CASH FLOW:	41 794.90	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ netto\ cash\ flow}$$

$$Payback\ time = \frac{358\ 753\ NOK}{41\ 794.9\ NOK/year} = 8.58\ \approx 8.5\ years$$

Figure 4-12: Investment analysis 4, Rørvollveien 17.

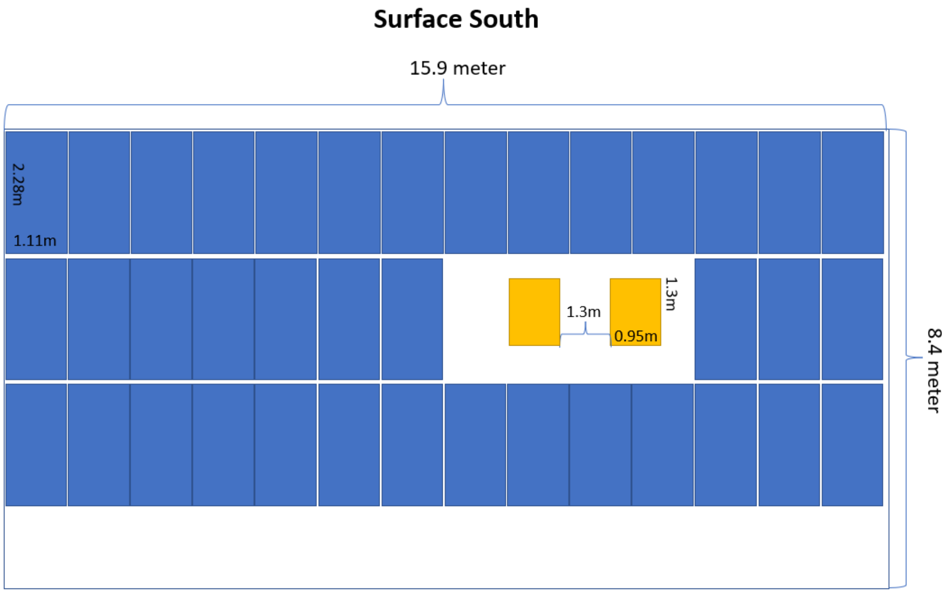


Figure 4-13: Illustration of suggested panel placement, Rørvollveien 17.

4.3.3 Energy Production from the PV Panels

Since Solcellekraft only provides the total yearly production, PVGIS is used to make it possible to analyze solar production. The PVGIS data will be used for the calculation in the remainder of the thesis.

A calculation of the energy production was completed with Python to control the validity of Solcellekraft’s estimate. The calculation is accomplished by multiplying solar radiation data for Rørvollveien 17 from PVGIS with the installed power from the panel 550W-E. A constant 8% temperature loss and a 5% system loss in the panels are accounted for in the calculations. As the energy consumption and solar production data are calculated, it is useful to compare their monthly values to investigate the remaining energy need. Figure 4-14 presents this in monthly data.

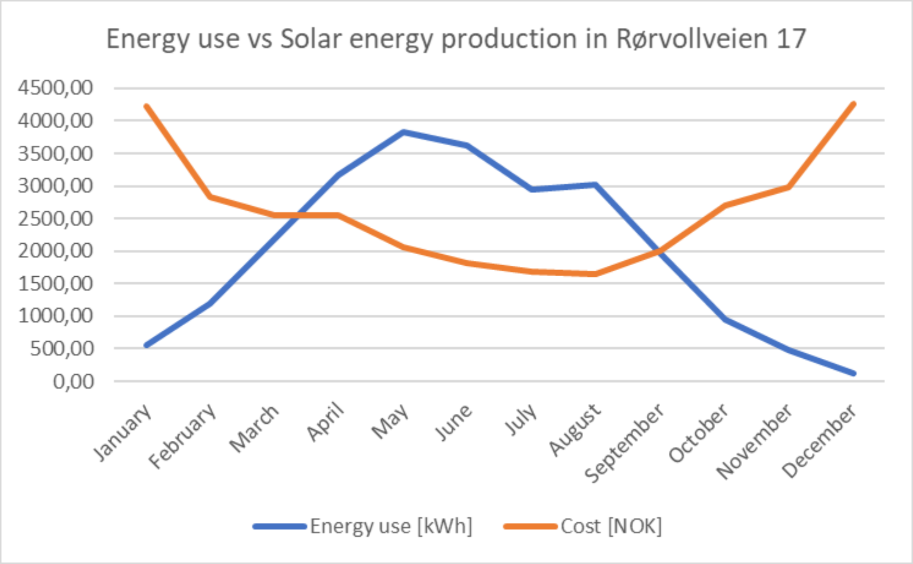


Figure 4-14: Graph of energy use and solar production, Rørvollveien 17.

The data from Figure 4-14 has a total yearly production of 24 000 kWh. The figure shows that the total amount of produced energy can sustain the energy consumption in the months of April to August.

4.3.4 MILP Analysis of Solar Panels and BESS

To investigate whether the various investments are cost-efficient, the MILP calculation is used to determine their economic contribution towards reducing the yearly energy cost. This is found by comparing the actual energy cost in 2022, which was 93 000 NOK, with the yearly energy cost of using the components separately, as well as a total hybrid system. Following the MILP analysis, an investment analysis is necessary to calculate the payback time of the investment. The analysis is completed separately for all four elements in the energy system.

The MILP model analyses of the chosen solar panels is presented in Table 4-8. The installation consists of 20.9 kWp of installed power, and the calculation of the yearly energy production resulted in 24 000 kWh. By using MILP, the yearly energy cost could be reduced to 36 000 NOK, meaning a reduction of 56 500 NOK. When accounting for the investment cost of 359 000 NOK, the resulting payback time is approximately 6 ½ years.

Table 4-8: MILP analysis for PV production, Rørvollveien 17.

	Baseline	**PV Production**	**Unit**
Installed PV	0	20.9	kWp
ToU Heating tank	0	0	kW
ToU EV charging	0	0	kW
Bat. Power	0	0	kW
Bat. Capacity	0	0	kWh
Yearly cost	**92 661**	**36 272**	**NOK**
Import	31 324	23 017	kWh
Export	N/A	15 720	kWh
PV production	N/A	24 026	kWh
Cycles	N/A	N/A	cycles
Cost, incl. Installation	N/A	358 753	NOK
Savings	N/A	56 389	NOK
Payback time	N/A	**6.36**	**years**

The calculation for the analyses of the Pixii Home battery storage is presented in Table 4-9 and is done for several system size configurations. The configuration with a fully equipped Pixii Home system, consisting of a battery with a 10-kW continuous output capacity and 20 kWh capacity, results in a yearly energy cost of 83 500 NOK. This means that by using a battery storage alone, a reduction of 9500 NOK a year is possible. When accounting for the investment cost of 98 000 NOK, the resulting payback time is 10 ½ years.

Table 4-9: MILP analysis for battery storage, Rørvollveien 17.

	Baseline	**Battery storage**	**Battery storage**	**Battery storage**	**Unit**
Installed PV	0	0	0	0	kWp
ToU Heating tank	0	0	0	0	kW
ToU EV charging	0	0	0	0	kW
Bat. Power	0	10	3.3	3.3	kW
Bat. Capacity	0	20	20	10	kWh
Yearly cost	**92 661**	**83 363**	**84 973**	**86 862**	**NOK**
Import	31 324	31 598	31 392	31 348	kWh
Export	N/A	275	68	25	kWh
PV production	N/A	N/A	N/A	N/A	kWh
Cycles	N/A	607	493	732	cycles
Cost, incl. Instal.	N/A	97 720	82 498	52 498	NOK
Savings	N/A	9298	7688	5 799	NOK
Payback time	N/A	**10.5**	**10.7**	**9.1**	**years**

As the profitability and use of these elements will be affected by each other, investigating them together as a whole system is essential to determine their effects together and any emergent behaviour. When investigating these elements separately, both results indicate that they will lead to cost savings; however, solar panels have a more significant impact.

4.3.5 MILP Analysis of Flexible Loads

When investigating the financial impact of shifting the ToU of flexible loads, it is essential to investigate both the existing appliance, as well as purchasing a new appliance with a higher effect. An appliance with a higher effect will alter the MILP positively but will negatively impact the investment analysis. Therefore, the result is dependent on the impact the increased effect has on the cost. To make it possible to shift ToU, a smart controller needs to be installed, further explained in Section 5.1.2, this will equate to an additional cost of 2000 NOK.

The MILP analysis of the heating tank is completed for two heating tanks with a varying power: 1.9 kW and 6 kW. The MILP analysis resulted in minimal savings, reducing the yearly energy cost with 2500 NOK and 3000 NOK, respectively. As the savings from the 1.9-kW tank is from the heating tank already installed in the household, there is no additional cost. With the cost of the controller, the payback time will be approximately 1 year. Although the savings from a new 6-kW tank is more substantial, the investment cost will have a bigger impact, see Appendix B.2. The total cost, including installation, will be 12 500 NOK, and the payback time will be approximately 4 years. These calculations are presented in Table 4-10.

Table 4-10: MILP analysis for the heating tank, Rørvollveien 17.

	Baseline	**1.9 kW Heating tank**	**6 kW Heating tank**	**Unit**
Installed PV	0	0	0	kWp
ToU Heating tank	0	1.9	6	kW
ToU EV charging	0	0	0	kW
Bat. Power	0	0	0	kW
Bat. Capacity	0	0	0	kWh
Yearly cost	**92 661**	**90 135**	**89 507**	**NOK**
Import	31 324	31 324	31 324	kWh
Export	N/A	N/A	N/A	kWh
PV production	N/A	N/A	N/A	kWh
Cycles	N/A	N/A	N/A	cycles
Cost	N/A	0	7 549	NOK
Smart controller, incl. Installation	N/A	2 000	5 000	NOK
Savings	N/A	2 526	3 154	NOK
Payback time	N/A	**0.79**	**3.98**	**years**

The MILP analysis of electric car charging was also completed for varying levels of energy use: a normal charger 2.3 kW charger and a 7.4 kW fast home charger. The MILP analysis resulted in minimal savings, reducing the yearly energy cost with 958 NOK and 1350 NOK, respectively, from shifting ToU. As the 2.3-kW charger is included when buying the electric car, there are no additional costs. When accounting for the cost of a smart controller, the payback time is 2 years. The savings from a new 7.4 kW fast home charger is marginally better, however, the investment cost will have a large impact, see Appendix C. The total cost including installation and a controller is 18 000 NOK, which results in a payback time of 13 ½ years. These calculations are presented in Table 4-11.

Table 4-11: MILP analysis for the EV charger, Rørvollveien 17.

	Baseline	***2.3 kW EV charger***	***7.4 kW EV charger***	***Unit***
Installed PV	0	0	0	kWp
ToU Heating tank	0	0	0	kW
ToU EV charging	0	2.3	7.4	kW
Bat. Power	0	0	0	kW
Bat. Capacity	0	0	0	kWh
Yearly cost	**92 661**	**91 703**	**91 326**	**NOK**
Import	31 324	31 324	31 324	kWh
Export	N/A	N/A	N/A	kWh
PV production	N/A	N/A	N/A	kWh
Cycles	N/A	N/A	N/A	cycles
Cost, incl. Instal.	N/A	0	15 990	NOK
Smart controller	N/A	2000	2000	NOK
Savings	N/A	958	1335	NOK
Payback time	N/A	**2.08**	**13.47**	**years**

4.3.6 BESS, Solar Production, and Load Control

As the purpose of this thesis is largely based on the financial impact of using a complete hybrid system, a MILP analysis of the whole system is essential. In this section a complete analysis of a system including all the aforementioned elements is conducted.

The calculation is done for several system size configurations, a select few are presented in Table 4-12. One of these configurations is with 20.9 kWp of installed solar panels, a heating tank with 1.9 kW of installed effect, a fast EV charger of 7.4 kW, and a battery with 10 kW continuous output capacity and 20 kWh capacity. Using this system, the yearly energy cost can be reduced to 25 000 NOK. When accounting for the investment cost of 472 500 NOK, the resulting payback time is 7 years.

Table 4-12: MILP analyses for total hybrid systems, Rørvollveien 17.

	Baseline	***Tot system***	***Tot system***	***Tot system***	***Unit***
Installed PV	0	20.9	20.9	20.9	kWp
ToU Heating tank	0	1.9	1.9	1.9	kW
ToU EV charging	0	7.4	7.4	7.4	kW
Bat. Power	0	0	3.3	10	kW
Bat. Capacity	0	0	10	20	kWh
Yearly cost	**92 661**	**32 177**	**26 303**	**22 416**	**NOK**
Import	31 324	21 259	19 408	18 558	kWh
Export	N/A	13 961	12 183	11 261	kWh
PV production	N/A	24 026	24 026	24 026	kWh
Cycles	N/A	N/A	693	579.5	cycles
Cost, incl. Instal.	N/A	378 743	431 241	476 463	NOK
Savings	N/A	60 484	66 358	70 245	NOK
Payback time	N/A	**6.26**	**6.49**	**6.8**	**years**

5 Discussion

This following chapter will discuss the results of the calculations.

5.1.1 Commercial Smart Water Heater

There are several models of smart water heating tanks on the market, e.g., the “OSO SAGA S 200” and “Høiax connected 200 smartbereder 2000W”. The heating tank from OSO is a standard water heating tank with a price of 7 190 NOK. To convert this tank to function as a smart tank, an OSO controller needs to be purchased separately. This increases the total cost for an OSO smart tank to 14 310 NOK. In contrast, the smart water heater from Høiax has a built-in controller and the total price is 13 990 NOK. Additionally, the installation cost for the tanks needs to be considered for both models as it is not included in the price. These smart tanks are a complete system, making them a great way to regulate the distribution of energy. However, as they are expensive, the profitability and payback time are impacted. Therefore, low-cost alternatives to a smart tank will be a better alternative.

5.1.2 Low-Cost Smart Tank

By installing a smart device to the heating tank, it can function as a smart water heater. A such smart device could be a Shelly device, which is a brand that has plenty of models to choose from. Shelly EM is a reasonable choice for a heating tank, due to its ability to control heavy loads and monitor energy consumption for the day, week, month, or year[63]. A smart device, such as the Shelly EM will cost around 600 NOK, and installation with an electrician is estimated to be 1500 NOK. Making the total investment cost of a smart controller around 2000 NOK[48], [63].

When the Shelly EM is connected to the Wi-Fi, the mobile application specified for the device can be used. In this application it is possible to track power output, daily usage, both hour for hour and momentarily, as well as being able to choose preset values and control the use of the heating tank. Shelly EM can start and turn off the devices it is connected to when needed, either through the website or application on the phone.

5.1.3 Flexible Loads

The calculated values in the analysis of ToU control methods are presented in Table 4-1. The calculation shows that regulating the ToU of a heating tank can lead to a reduction of the energy cost. When comparing the cost of using the original tank without any time-shifting and a smart tank with the same effect and day-ahead regulation, it results in a total saving of 2500 NOK.

When comparing the cost of using the original tank without any time-shifting and a smart tank with 9 kW and day-ahead regulation, it results in a total yearly saving of 3500 NOK.

Although the financial impact of regulating flexible loads might not be the most substantial, it should still be considered. As mentioned, the investment cost of a smart device will be 2000 NOK. By using day-ahead regulation on the preexisting heating tank the investment can be regained and surpassed within a year.

The calculation shows that given the same circumstances as with a 2-kW heater, a 9 kW could increase the savings by 25%. However, as it is necessary to buy new heating, this cost will affect the investment cost substantially. This will be discussed further in Section 5.3.4.

5.2 St. Olavs vei 170

5.2.1 Energy Use and Cost

As the cost of energy consumption is used in further calculations, it is necessary to verify the calculated cost. The calculated cost is dependent on several obtained files and data, leaving room for error. Therefore, it is compared with the house owner's electricity bill for all months except July, as this bill was missing. On average, the monthly deviation was 0.1%.

This deviation is relatively small but may be a result of varying tariff values as values from 2023 were used. The energy supplier BKK was contacted to obtain the tariffs from 2022, but they were not available to the public, therefore the 2023 tariff values are used, see Appendix A.1.

As the deviation is not substantial and shows a reasonable correlation, the calculated cost is verified.

5.2.2 Solar Panels

To decide what panel type to install, an investment analysis was completed for the four suggested panels from Solcellekraft. From the investment analysis, the most profitable panel, 550W-E, results in an estimated payback time of 16 ½ years.

Figure 4-6 is an illustration for a suggested placement of the chosen type and number of panels. Solcellekraft suggested an area of the surfaces, however, it did not correspond with the engineering drawing. The values from the drawing are accurate, while the area from Solcellekraft is an estimate, therefore, the engineering drawing's measurements are used. The design and placement of the panels is not heavily investigated but is calculated to control that the chosen panels can fit on the surfaces. The placement of the skylights should be investigated further, and the panels and design should be modified with this in mind. The chosen panel type, 550W, is a large panel with limited placement flexibility, to minimize this complication a smaller panel type can be used. Nevertheless, Figure 4-6 shows that it is possible to use the 550W panel at St. Olavs vei 170.

PVGIS is used to control the estimated PV production, and results in a total energy production of 6000 kWh, using the suggested number of panels and solar irradiation from Solcellekraft. The installed power is 3.85 kWp towards east and 4.4 kWp towards west. The graph in Figure 4-7 shows that the total amount of produced energy can sustain the energy consumption in the months of June, July, and August. However, considering that the energy production exceeds the consumption in these months, there is a lot of excess produced energy that gets sold to the grid. To reduce the export these months, an investment in a battery storage will be discussed in Section 5.2.4.

5.2.3 Analysis of Cardinal Direction

From the analysis of cardinal direction, presented in Figure 4-8, the graphs show that the peak radiation for east is between 10:00-12:00, while for west it is between 15:00-17:00. South’s peak radiation is between 13:00-15:00 and is the cardinal direction with the most solar radiation. The graph verifies the theory that south-facing panels are most optimal in terms of total energy production. However, as east and west’s production peaks simultaneously with the consumption, it can be an effective utilization of increasing self-consumption without the need of battery storage.

In Figure 4-9, the graphs show that the energy consumption for the household is coordinated with the actual energy production for the east and west cardinal direction. This means the produced electricity from the solar panels can be used directly for self-consumption during the consumption peaks. Since production is greater than consumption, the excess energy is sold to the grid. As the value of using self-produced energy is substantial, as less energy needs to be exported to the grid, it is interesting to investigate using battery storage to limit the export of energy. This investigation is done through the MILP analysis.

5.2.4 MILP Analysis

When investigating the profitability of the total system, several factors need to be considered. Some of these factors are the capacity of the components, type of panels, combination of components, number of cycles, the yearly savings, and the resulting payback time. Depending on the desired outcome, the recommended system size and components will change. In principle, a low payback time equals a good investment, however, in many cases a low payback time is accompanied by a low investment cost, and therefore a low profit. When the payback time is higher, it can be a result of a larger investment cost and can still be a sensible investment. This is because the yearly savings after the payback time will have a greater impact and will generate more savings over time than an investment with a lower payback time.

Table 4-4 presents the investment analysis of the solar panels. The combination of east and west, with 8.25 kWp, will have the largest impact in reducing the yearly energy cost, as well as being the investment with the shortest payback time, with 11 years. This might initially seem like a long payback time; however, the investment cost will be paid off within the panels lifespan and contribute to reducing the energy cost. There is 14 years left of the panels’ lifetime after the payback time, where the remaining years will reduce the energy cost by 204 000 NOK, considering the yearly cost reduction of 15 000 NOK and the investment cost.

Table 4-4 also includes values for a hypothetical roof facing south with 4.4 kWp. When compared to combining east and west, the latter is more profitable and has a shorter payback time. However, if the same amount of kWp is to be installed facing south, it would result in a slightly lower payback time. It would have the same investment cost, but a slightly higher energy production. Further validating that south is the most optimal cardinal direction. However, as there is no roof facing south, the combination of east and west is the suggested combination to install in St. Olavs vei 170.

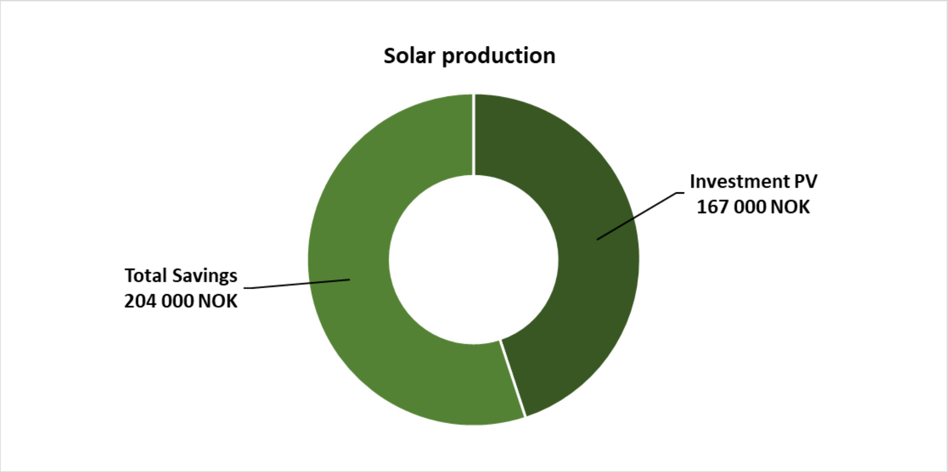


Figure 5-1: Diagram of the cost for the solar configuration, through the panels' lifespan.

When investigating the significance of battery storage alone, it will, on average, reduce the energy cost with 5000 NOK a year. Table 4-5 shows that the payback time will vary between 12.2-16.4 years depending on its modular combination. As this is a somewhat long payback time considering the battery's lifetime, the use of a battery storage alone is not advisable.

As the purpose of this thesis is largely based on the financial impact of using a complete system, a MILP analysis of the whole system is essential as the profitability and use of these elements will be affected by each other.

In Table 4-6, several system configurations are presented. As the variation in payback time is small, and a similar saving of around 20 000 NOK per year, choosing which combination to invest in is intricate. Considering the same PV production, similar savings and payback time, the critical factors to decide the optimal system are investment cost and amount of battery cycles. The system with the largest investment cost has the longest payback time and the largest yearly savings. This makes it hard to use the investment cost as a deciding factor. However, after investigating the number of cycles in a year, the 3.3 kW and 10 kWh system was found to have 562 cycles, while the 3.3 kW and 20 kWh had 364, and the 10 kW and 20 kWh had 391 cycles. 562 cycles is somewhat high, and as the remaining system's cycles are very similar, deciding one system over the other is not a straightforward decision. Despite this, considering that there is a lower investment cost and less cycles for the 3.3 kW and 20 kWh system, it could be preferable to invest in this system.

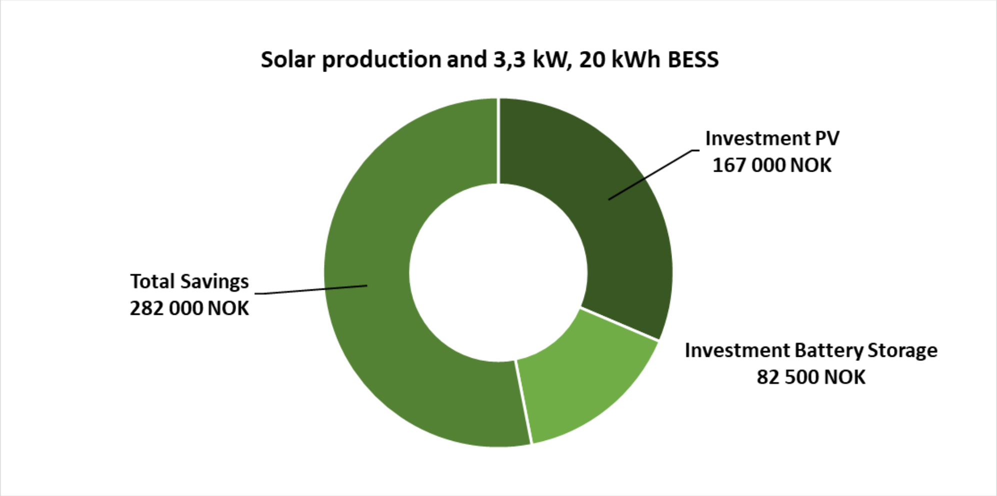


Figure 5-2: Diagram of the cost for the solar and BESS configuration, through the panels' lifespan.

The result of using the 3.3 kW and 20 kWh storage system in combination with solar production results in a reduction of 21 250 NOK a year. When accounting for the investment cost of 250 000 NOK, the resulting payback time is 11.7 years. If the system included shifting ToU of flexible loads there would be additional savings, but as the data for the flexible loads are not available it is not included in the final results. A benefit of choosing a system with battery storage is being able to increase self-consumption and to reduce the amount of imported energy by from 13 986 kWh to 9717 kWh, a reduction of more than 30%.

5.3 Rørvollveien 17

5.3.1 Energy Use and Cost

As the cost of energy consumption is used in further calculations, it is necessary to verify the calculated cost. The calculated cost is dependent on several obtained files and data, leaving room for error. Therefore, it is compared to the houseowner's electricity bills from May to December 2022, as the bills from January to March were unavailable, see Appendix F. On average, the monthly deviation from May to December was 0.04 %.

This deviation is relatively small but may be a result of varying tariff values, as values from 2023 were used. The energy supplier used by the Drammen property, Glitre, utilized another tariff model, but as the total cost is similar, the 2023 values are used, see Appendix A.2.

As the deviation is not substantial, and is reasonably representative, the calculated cost is verified.

5.3.2 Solar Panels

To decide what panel type to install, an investment analysis was completed for the four suggested panels from Solcellekraft. From the investment analysis, the most profitable panel, 550W-E, results in a payback time of 8 ½ years. This result makes installing solar panels in Rørvollveien 17 have a potential of large cost savings.

Figure 4-13 is an illustration of a suggested placement for the chosen panel type and number of panels. In contrast to St. Olavs vei 170, Rørvollveien 17 does not have the engineering drawing of the house available. Therefore, Solcellekraft's estimation of the width and height of the roof is used for the illustration. The design and placement of the panels is not heavily investigated but is calculated to control that the chosen panels can fit on the surface. The placement and dimensions of the skylights is estimated by the houseowner in Drammen. The chosen panel type, 550W, is a large panel with limited placement flexibility, to minimize this complication a smaller panel type can be used. Nevertheless, Figure 4-13 shows that it is possible to use the 550W panel in Rørvollveien 17.

Controlling the estimated PV production, the suggested number of panels and solar irradiation from PVGIS is used, and results in a total energy production of 24 000 kWh when installing 20.9 kWp facing southeast. Figure 4-14 shows that the total amount of produced energy can sustain the energy consumption from April to August. However, considering that the energy production exceeds the consumption in these months, there is a lot of excess produced energy that gets sold to the grid. To reduce the energy export these months, an investment into battery storage will be discussed.

5.3.3 MILP Analysis of Solar Panels and BESS

Table 4-8 presents the investment analysis of the solar panels in Rørvollveien 17. With 20.9 kWp installed, the resulting energy cost reduction is 56 389 NOK per year. When considering the investment cost of 359 000 NOK, the payback time is 6.36 years. In the panels' remaining lifetime of about 18 ½ years, based on the yearly cost reduction, the estimated total saving of 1 036 000 NOK. As the use of the chosen solar panels is profitable, more panels equate more savings. This is desirable and the following systems will only consider the use of 20.9 kWp panels, utilizing most of the roof's available area.

The calculation for the analysis of the Pixii Home battery storage alone is presented in Table 4-9 and is done for several system size configurations. When investigating the significance of battery storage alone, it will on average reduce the energy cost by 7600 NOK in a year. Table 4-9 shows that the payback time will vary between 9.1-10.7 years depending on its modular combination. Like the battery storage case in St. Olavs vei 170, the payback time is too high when taking the battery's lifetime into consideration, therefore, using battery storage alone is not advisable.

5.3.4 MILP Analysis of Flexible Loads

Table 4-10 shows the result of shifting the ToU of a heating tank. For the preexisting tank with 1.9 kW, the payback time is about a year, due to the investment cost from the smart controller. If investing in a new tank with 6 kW, the payback time would be about 4 years. The yearly cost savings are 2500 NOK and 3000 NOK, respectively, meaning a yearly difference of 500 NOK, which makes the difference miniscule when compared to the total cost. The impact of shifting ToU is relevant, but whether to invest in a new 6 kW tank or use the preexisting unit has an insignificant impact. Therefore, the 1.9-kW tank is used in further calculation.

As a side note, if a new heating tank is installed either way, it would be preferable to install the 6-kW tank. The payback time is reduced to 1.77 years when accounting for the cost of 5000 NOK for a new Høiax 1.9 kW tank.

Table 4-11 shows the result of shifting ToU for two EV chargers: an emergency charger (2.3 kW) included when buying the car, and a new fast home charger (7.4 kW). The calculation shows that the impact is small, as the 2.3-kW charger reduces the energy cost by 1000 NOK and the 7.4-kW fast home charger reduces it by 1300 NOK. The payback times are 2 years and

13.47 years, respectively, due to the investment cost and the cost of a smart controller. As the results from shifting the ToU for EV charging is so miniscule, it is not relevant to consider unless a smart controller is installed to control other loads as well.

Another factor to consider is the flexibility the fast home charger provides. Many EV owners value faster charging time more than a marginally larger cost. Additionally, regulations for charging of EVs have recently been implemented, resulting in it being necessary to invest and install a 7.4 kW charger[64]. Therefore, the 7.4-kW charger will be used in further calculations, but from a cost saving standpoint it is not a good investment.

5.3.5 BESS, Solar Production, and Load Control

In Table 4-12, several system configurations are presented. As the variation in payback time is small, and a similar saving of 60-70 000 NOK per year, choosing what combination to invest in is difficult. When comparing the 10 kW, 20 kWh system and the 3.3 kW, 10kWh system, the payback time and savings are similar. The payback time is 6.8 years and 6.5 years, respectively, while the savings have a 4000 NOK difference. However, the investment cost of the smaller system is less by 45 000 NOK. As the systems are similar in cost and savings, the deciding factor is the flexibility a bigger battery storage can provide when considering the PV production. Therefore, the 10 kW, 20 kWh system is the preferred investment.

To investigate if battery storage is necessary, a system configuration of only solar panels and shifting the ToU is calculated. The yearly cost reduction is significant, and the system with only solar panels and time shifting will be the system in Rørvollveien 17 with the shortest payback time, with 6.26 years. When deciding between the two systems the yearly savings are significant, as the system including battery storage has an additional saving of 10 000 NOK. When calculating the total cost savings after 25 years, the configuration with a battery will have a saving of 1 197 000 NOK, this includes the cost of replacing the battery’s elements after 12 years. The configuration without a battery will have a total saving of 1 133 000 NOK. This makes it challenging to suggest which system to invest in, as the system with a slightly larger saving requires maintenance of the battery storage and more uncertainty. A benefit of choosing the system with battery storage is being able to increase self-consumption and to reduce the amount of imported energy.

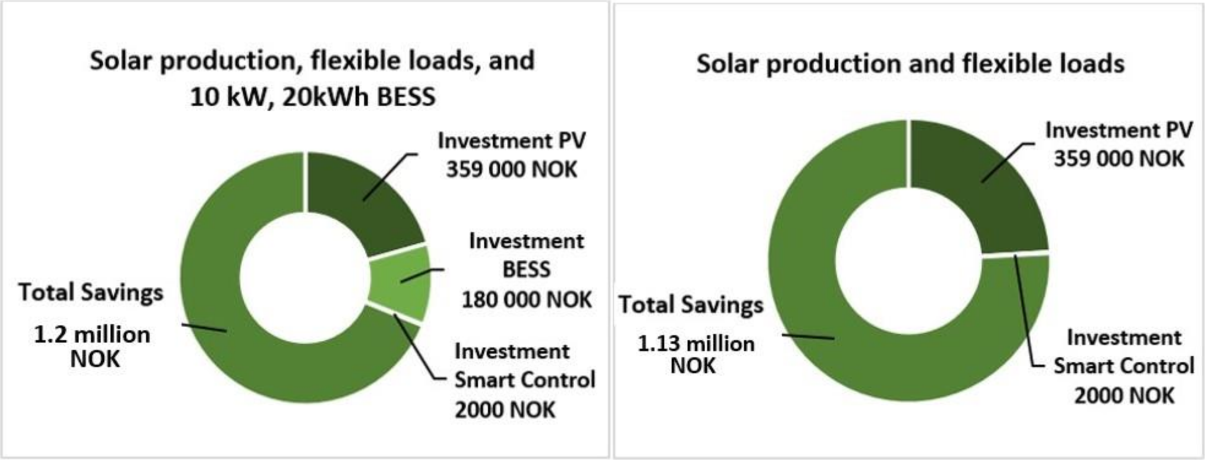


Figure 5-3: Diagram of the cost for different system configurations, through the panels' lifespan

The savings from investing in battery storage are usually marginal, due to a high investment cost as well as a short lifespan. When deciding which system to invest in, the decision will depend on the needs and desires for each individual instance. In this case, either of the systems would be a good choice in reducing the yearly energy cost. However, it is important to consider that using battery storage will increase self-consumption and reduce energy import. This is an important factor as many value the possibility of being mainly self-sufficient which will be attainable if battery storage is used, where the proportion of self-consumption will increase with larger battery sizes. Compared to the baseline, it is reduced from 31 324 kWh to 18 558 kWh, which is a reduction of more than 40% in imported energy.

5.4 Comparison

Comparing the two locations in this thesis, Rørvollveien 17 has been found to be significantly better suited for installing either just solar panels or a whole energy system. St. Olavs vei 170 has neither a big roof area, optimal cardinal direction of the roof, or an optimal location. Therefore, the roof will not be able to utilize the solar radiation to its full potential. Installing solar panels in St. Olavs vei 170 has been shown to be beneficial; however, the payback time is somewhat long. Installing solar panels in Rørvollveien 17, on the other hand, will have half the payback time, and a significantly larger production. This makes the installation of solar panels considerably more attractive due to more optimal conditions.

When comparing the two cases of investing in a hybrid system, both have viable results. In general, the use of battery storage is an investment that barely breaks even. This is applicable in St. Olavs vei 170, as the lifetime and payback time somewhat align. However, in Rørvollveien 17, the extensive PV production positively affects the system, making it have a short payback time. In short, investing in a hybrid system creates flexibility for self-consumption, and the results show it is a wise investment.

The results from Rørvollveien 17 show that shifting ToU of flexible loads is a simple yet effective method of controlling energy use, resulting in reducing the energy cost. The method can be replicated in any household, e.g., St. Olavs vei 170, and is applicable to any household's energy use pattern.

5.5 Cycling Grid Bought Energy Through the Battery

Investigating the electricity support arrangement and the use of a battery storage, revealed that it is possible to use the electricity support to one's advantage. As explained in Section 2.1.2, when the spot price exceeds 70 øre/kWh, the government will pay 90% of the exceeded price. When selling energy to the grid, the price will be set by the spot price, and will not be affected by the electricity support. Therefore, it is possible to earn profit by buying the energy from the grid when the energy price is high and then selling it back to the grid. Hence, this will result in a profit of 90% of the cost exceeding 70 øre/kWh and will increase the larger the spot price is in the time slot the energy is sold.

Cycling energy is a possible method of making an investment in a battery and energy production more attractive. Considering that the investment cost of a battery storage system is significant, this can result in earning back the investment cost in a shorter time frame, and possibly generate profit. Currently, there are no regulations on doing this, but it would not be wise to assume that this method can be used in the foreseeable future. Considering that regulations and restrictions can be set in motion to stop the use of battery storage in this way. In addition, the moral implications of exploiting this arrangement would need to be considered.

5.6 Sources of Error

This is a thesis consisting of complex calculations using several collected datafiles and multiple sources to compare and verify results. There may be some inconsistencies or errors in either calculations or datafiles. The errors can occur because of human errors or randomly, such as faulty programs or imported files. Analyses and estimates may have some inconsistencies due to inconsistent data files.

5.6.1 High Spot Prices

The spot prices in 2022 were abnormally high, and the estimates made for the cost savings are positively affected, as the value of using self-consumption has increased. Considering that the spot price is unpredictable, it might stabilize or escalate further, which will ultimately affect the estimated costs. Therefore, the estimates of the savings are not as reliable in coming years and will be affected by the change in spot prices.

5.6.2 Electrical Support

This case is interested in the total cost of energy use, and the reduction the energy system can make on the total cost. Considering that the government's energy support is a temporary arrangement, it is not included in this thesis, as it is not certain that it will apply for the following years.

5.6.3 Solar Irradiation Data

The estimated solar production from Solcellekraft and the calculated PV production in Python deviate somewhat from one another. The calculated solar production uses data from the solar weather model PVGIS, which considers an 8% loss due to temperature, in addition to added 5% system loss in the solar panels' inverters[65]. As the solar database in PVGIS is only available up to 2020 for solar irradiation for the set cases, the year 2020 is used. This means that the data does not correspond with the year that is being examined. However, it is used as an estimate of the solar radiation data in this thesis for 2022.

Solcellekraft on the other hand, uses data from the closest weather station, where the data is used to calculate the estimated production from the solar cells. The estimation is an average of solar radiation from 2012 to 2023. The calculator considers the angle of the roof, terrain around the house, as well as loss in the inverter and wires. Solcellekraft states that the customer needs to allow for a 5% margin, as the actual year of production can have irregularly good or bad weather. This might explain the difference in solar production between the Python calculation and the estimate from the calculator.

5.6.4 Degradation and Maintenance of the Solar Panels

As mentioned in Section 2.2, solar panels will degrade over time, leading to a reduction in efficiency. However, this is not considered in the calculations concerning solar production throughout the thesis. If this was included, it would result in slightly lower PV production, and less potential savings for the two cases presented.

Additionally, based on the location where the panels are placed, the need for maintenance, in the form of cleaning, may vary. Dust, water, and leaves are some factors that can decrease the power generated from the PV panels as it may reduce the amount of absorbed solar rays. This is, however, not investigated further in this thesis as it is highly individual how often the panels should be cleaned[66].

5.6.5 Degradation and Loss in the Battery Storage

Another source of error is neglecting the system loss in the battery storage, resulting in an increasing number of cycles in the MILP model calculation. If the loss was included, the number of cycles would be somewhat reduced and would only slightly affect the yearly cost savings. This is a result of the MILP deciding that the battery uses peak shaving in instances of very low savings. The savings and system loss offset each other, making the battery run unnecessary cycles. In addition, the loss itself will slightly reduce the savings.

Additionally, as mentioned in Section 2.3, the battery's capacity will degrade over time. They are continuously degrading from the moment they are first used, due to the fundamental chemistry of a battery. For this reason, the result with MILP is slightly better than if the storage is actually implemented[67].

5.6.6 Interest- and Inflation Rate

Several estimates have been used throughout this thesis to be able to calculate multiple elements, e.g., the energy cost, choosing what appliances to use, their cost, and installation fee. Often a 5% interest rate is considered when calculating payoff time. However, as the resulting values in the investment analysis and payback time are based on estimates, it sets an unsteady basis for including an interest rate.

Regarding the inflation rate, the cost of energy will likely increase over time. The cost of the equipment will likely be stable or decrease, due to a higher production volume and developing technology.

Therefore, these fluctuations in interest and inflation rate are difficult to predict, and as they may further impact the discrepancy in the calculation, they are not included. For this reason, the calculation of payback time is used as a method of assessing the investments.

5.6.7 Generated Heat from Fireplace

During the excursion in St. Olavs vei 170, the house owner informed that their household often uses their fireplace to generate heat. This means that a large amount of the heating energy is fulfilled from using the fireplace, instead of electrical energy. This will undoubtedly affect the energy requirements, as the only data for the energy consumption is their electricity bill. This is observed in their bill, as it has a relatively low energy need. Therefore, the energy consumption obtained from the house owner does not represent the actual energy consumed in the house. Thereby affecting the accuracy of the results presented in this thesis, as the heating from the fireplace is not considered in the calculations.

5.6.8 Tracking and Estimation of Energy Consumption

The data tracking of the heating tank and EV charging in Rørvollveien 17, is a source of error due to the short time frame of data tracking. Due to limited time, the data was only tracked in a two-month period in 2023, from March to April. The data was duplicated to provide an annual data sample, although it was realized that this had some shortcomings and might not be representative. These values are tracked because of the interest in time-shifting these loads. To be able to calculate this throughout the year, it was necessary to use the recorded values, and replicate it throughout the year to have continuous values.

In addition, there is some inaccuracy in the consumption data, as there will be variation in consumption due to members of the household traveling or variations in habits. This leads to some fluctuating periods with either less or more consumption than usual. However, as this variation is normal, the use offsets each other to some extent.

6 Conclusion

6.1 Conclusion

The purpose of this thesis was to investigate the effect of installing a hybrid energy system with the intention of optimizing usage and reducing annual running costs; including simulations of the potential savings from time shifting the flexible loads.

The first case, St. Olavs vei 170, Bergen, Norway, has a small roof area that face east and west, creating poor prerequisites for an energy production system. A solar energy system that utilizes all the roofs available area, with an installed effect of 8.25 kWp, will have a payback time of 11 years. Calculations show that installing battery storage alone will not be economically beneficial. Combining solar photovoltaic panels with battery storage provides flexibility, and will break even, despite excluding time shifting of the flexible loads. This system results in a significant 30% reduction in imported energy from the grid.

The second case, Rørvollveien 17, Drammen, Norway, has a large southeast facing roof creating optimal prerequisites for an energy production system. A solar energy system that utilizes all the roofs available area, with an installed effect of 20.9 kWp, will have a payback time of only 6 ½ years. This system will a generate saving of 1.2 million NOK through the panels' lifespan. Calculations show that implementing a smart control device to time-shift a standard heating tank is a wise investment and is preferable to a smart tank. Both will lead to cost savings; however, the payback time is 1 year and 4 years, respectively. Controlling the load of an electric vehicle would be wise as well, as the savings can finance a fast home charger. Most electric vehicle owners prefer making this investment, regardless of its payback time of 14 years, as it creates flexibility in charging time. Calculations show that a hybrid system, including shifting Time-of-Use of flexible loads, is a wise investment, with a payback time of 6-7 years. Like the solar system, this system saves a total of 1.2 million NOK. This shows that the battery does not generate additional savings, however, the main benefit of the battery storage is the 40% reduction in imported energy.

It is necessary to acknowledge that the result of the hybrid system being profitable is heavily skewed by the abnormally high spot prices in 2022. Therefore, this result will not necessarily be replicable for other periods of time. The system can still be profitable, but this is impossible to predict accurately at this time.

6.2 Further Work

Recommendations for further work will be to investigate using spot prices from other years, as this will presumably make the hybrid system unprofitable. To validate the results further, multiple, and various cases should be investigated. To improve results, the electricity support arrangement should be included in the calculations, as this was neglected for this thesis. Additionally, the other sources of error mentioned should be taken into account, as these will also impact the results.

7 References

[1] "Bærekraftig utvikling," Oct. 28, 2021. https://www.fn.no/tema/fattigdom/baerekraftig-utvikling (accessed Apr. 25, 2023).

[2] "Om strømpriser," *Statnett*, Apr. 18, 2023. https://www.statnett.no/om-statnett/bli-bedre-kjent-med-statnett/om-strompriser/ (accessed Apr. 25, 2023).

[3] "What is battery energy storage system and how it works," *Enel X*. https://corporate.enelx.com/en/question-and-answers/what-is-battery-energy-storage (accessed Jan. 23, 2023).

[4] E. R. Frederiks, K. Stenner, and E. V. Hobman, "Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 1385–1394, Jan. 2015, doi: 10.1016/j.rser.2014.09.026.

[5] "Pixii Home – Q2, 2023." https://www.pixii.com/pixii-home/ (accessed Feb. 03, 2023).

[6] "Strømregioner | Dagbladet Strømsjekk." https://www.dagbladet.no/tjeneste/strom/regioner (accessed May 19, 2023).

[7] "Nettleie for privatkunder | BKK." https://nett.bkk.no/produktdetaljer?productId=49cedfc9-82b1-4d3b-be45-904704e3b9c7 (accessed Feb. 21, 2023).

[8] "Hva skjer med strømprisen? | Lyse." https://www.lyse.no/kundeservice/omstrom (accessed Feb. 23, 2023).

[9] BKK, "Regional Kraftsystemutredning for Midtre Vestland 2022 - 2042," Jun. 2022.

[10] O. energidepartementet, "Regjeringens strømtiltak," *Regjeringen.no*, Feb. 16, 2023. https://www.regjeringen.no/no/tema/energi/regjeringens-stromtiltak/id2900232/ (accessed Mar. 06, 2023).

[11] T. U. Øverli, "Forbrukerfleksibilitet som en ressurs i fremtidens kraftsystem," p. 85, Jun. 2018.

[12] M. Matic, "Verdt å vite om dag- og nattsenking av varme." https://blogg.micromatic.no/verdt-aa-vite-om-dag--og-nattsenking-av-varme (accessed Feb. 21, 2023).

[13] H. Ritchie, M. Roser, and P. Rosado, "Energy," *Our World in Data*, Oct. 2022, Accessed: Jan. 25, 2023. [Online]. Available: https://ourworldindata.org/renewable-energy

[14] "Renewable Energy Market Update - May 2022 – Analysis," *IEA*. https://www.iea.org/reports/renewable-energy-market-update-may-2022 (accessed Jan. 25, 2023).

[15] "History and the Development of Photovoltaics," *AE Solar*, Oct. 08, 2021. https://ae-solar.com/history-of-solar-module/ (accessed Jan. 25, 2023).

[16] "Solcellers effektivitet | UngEnergi." https://ungenergi.no/energikilder/solenergi/solcellers-effektivitet-2/ (accessed Apr. 29, 2023).

[17] "Photovoltaic Energy Factsheet," *Center for Sustainable Systems*. https://css.umich.edu/publications/factsheets/energy/photovoltaic-energy-factsheet (accessed Feb. 01, 2023).

[18] Sunrun, "How Long do Solar Panels Really Last?," *Sunrun*, Jan. 10, 2018. https://www.sunrun.com/go-solar-center/solar-articles/how-long-do-solar-panels-really-last (accessed May 05, 2023).

[19] "Why and how do solar panels degrade? — RatedPower." https://ratedpower.com/blog/solar-panels-degradation/ (accessed May 20, 2023).

[20] Y. Abou Jieb and E. Hossain, *Photovoltaic Systems: Fundamentals and Applications*. Cham: Springer International Publishing, 2022. doi: 10.1007/978-3-030-89780-2.

[21] "Photovoltaic cell - Energy Education." https://energyeducation.ca/encyclopedia/Photovoltaic_cell (accessed Apr. 18, 2023).

[22] "Solceller – e-forelesning - Natural science (EL) - NDLA," *ndla.no*. https://ndla.no/en/subject:1:7a0cbbc6-f213-4545-a6e3-44d3043ddaae/topic:2:e8b69704-fef6-

4689-8d46-92edb4332831/resource:0641e50a-5564-48d2-9c90-d1fca3a66ac8 (accessed Jan. 23, 2023).

[23] “How a PV Cell Works - Knowledge Bank - Solar Schools.” https://www.solarschools.net/knowledge-bank/renewable-energy/solar/how-a-pv-cell-works (accessed Feb. 22, 2023).

[24] J. Marsh, “Solar Panel Direction And Angle: Does It Matter? | EnergySage,” *EnergySage Blog*, Sep. 25, 2022. https://news.energysage.com/solar-panel-performance-orientation-angle/ (accessed Mar. 09, 2023).

[25] “Hva er solenergi | UngEnergi.” https://ungenergi.no/energikilder/solenergi/hva-er-solenergi/ (accessed Jan. 25, 2023).

[26] “Hvor kommer strømmen fra? - NVE.” https://www.nve.no/energi/energisystem/kraftproduksjon/hvor-kommer-stroemmen-fra/?fbclid=IwAR3U4Spgr8KRlOVXC1xSEJUddxAyU3mRqbtyfREiGFTYFWH1PB834jeOGZE (accessed May 18, 2023).

[27] K. Elster, “EU fikk for første gang mer strøm fra fornybart enn fossilt i fjor,” *NRK*, Feb. 03, 2021. https://www.nrk.no/urix/eu-fikk-for-forste-gang-mer-strom-fra-fornybart-enn-fossilt-i-fjor-1.15353582 (accessed May 18, 2023).

[28] “Fordeler med solceller – Hvorfor solenergi?,” *Fjordkraft*. https://www.fjordkraft.no/solcellepanel/fordeler-med-solceller/ (accessed Jan. 25, 2023).

[29] “Solcelleanlegg | Energitiltak | Solenergi,” *Enova*. https://www.enova.no/privat/alle-energitiltak/solenergi/solcelleanlegg/ (accessed Jan. 25, 2023).

[30] “Solar Panel Maintenance : Everything You Need to Know Archives,” *Solar.com*. https://www.solar.com/learn/solar-panel-maintenance/ (accessed Jan. 25, 2023).

[31] “The importance of solar irradiance and meteorological data for PV design — RatedPower.” https://ratedpower.com/blog/solar-irradiance-meteorological-data/ (accessed Apr. 18, 2023).

[32] “3.3. Cosine Effect | EME 812: Utility Solar Power and Concentration.” https://www.e-education.psu.edu/eme812/node/896 (accessed May 19, 2023).

[33] Rossana, “Which are the factors that affect solar panels’ efficiency?,” *Trace Software*, May 25, 2020. https://www.trace-software.com/which-are-the-factors-that-affect-solar-panels-efficiency/ (accessed May 19, 2023).

[34] Rossana, “Which are the factors that affect solar panels’ efficiency?,” *Trace Software*, May 25, 2020. https://www.trace-software.com/which-are-the-factors-that-affect-solar-panels-efficiency/ (accessed Apr. 29, 2023).

[35] “Albedo effect.” https://www.npolar.no/en/fact/albedo/ (accessed Apr. 29, 2023).

[36] “Dette skal du vite om solceller og solenergi,” *Viivilla NO*, Mar. 09, 2022. https://viivilla.no/ovrig/energi/solceller-alt-du-skal-vite-om-solenergi-til-boligen/ (accessed Apr. 29, 2023).

[37] sami, “A Guide on How to Calculate Solar Panels Output,” *Dynamic SLR*, Dec. 01, 2020. https://www.dynamicslr.com/a-guide-on-how-to-calculate-solar-panels-output/ (accessed Apr. 29, 2023).

[38] “Peak Shaving: Optimize Power Consumption with Battery Energy Storage Systems.” https://www.exro.com/industry-insights/peak-shaving (accessed Mar. 28, 2023).

[39] G. He, Q. Chen, C. Kang, P. Pinson, and Q. Xia, “Optimal Bidding Strategy of Battery Storage in Power Markets Considering Performance-Based Regulation and Battery Cycle Life,” *IEEE Transactions on Smart Grid*, vol. 7, no. 5, pp. 2359–2367, Sep. 2016, doi: 10.1109/TSG.2015.2424314.

[40] “David, “What’s the lifetime of a home battery?,” *Electric Car Home Ltd*. https://electriccarhome.co.uk/battery-storage/whats-the-lifetime-of-a-home-battery/ (accessed May 08, 2023).

[41] “NeoVolta Increases Battery Life from 10.95 Years to 16.5 Years,” *NeoVolta*, Jun. 02, 2021. https://www.neovolta.com/neovolta-increases-battery-life-from-10-95-years-to-16-5-years/ (accessed May 08, 2023).

[42] "Electric Car Battery Life | Electric Life | MG MOTOR UK." https://www.mg.co.uk/electric-life/guide-electric-car-battery-life (accessed Apr. 29, 2023).

[43] Palmetto, "How Does A Solar Battery Work? | Energy Storage Explained." https://palmetto.com/learning-center/blog/how-does-a-solar-battery-work (accessed Feb. 24, 2023).

[44] M. Pathare, V. Shetty, D. Datta, R. Valunjkar, A. Sawant, and S. Pai, "Designing and implementation of maximum power point tracking(MPPT) solar charge controller," in *2017 International Conference on Nascent Technologies in Engineering (ICNTE)*, Jan. 2017, pp. 1–5. doi: 10.1109/ICNTE.2017.7947928.

[45] "What is Maximum Power Point Tracking (MPPT)," *NAZ Solar Electric*. https://www.solar-electric.com/learning-center/mppt-solar-charge-controllers.html/ (accessed Apr. 28, 2023).

[46] Lindholm, J. G. Fossum, and E. L. Burgess, "Application of the superposition principle to solar-cell analysis," *IEEE Transactions on Electron Devices*, vol. 26, pp. 165–171, 1979.

[47] "Solar battery system types - AC Vs DC coupled," *CLEAN ENERGY REVIEWS*, Oct. 30, 2020. https://www.cleanenergyreviews.info/blog/ac-coupling-vs-dc-coupling-solar-battery-storage (accessed May 20, 2023).

[48] K.-I. Gjerde, "Pixii, Knut Gjerde," May 2023.

[49] "Når bør du bytte varmtvannsbereder?," *Høiax Netthandel*, Feb. 24, 2023. https://www.hoiax.no/om-hoiax/articles/nar-bor-du-bytte-varmtvannsbereder (accessed May 11, 2023).

[50] "(+) Dimensjonering av varmtvannsberedere," Jul. 16, 2019. https://sanitar.nemitek.no/kapittel-75-sanitaerteknikk-prosjektering-og-utforelse-av-sanitaerinstallasjoner-i-bygg-vannvarmere/dimensjonering-av-varmtvannsberedere/156330 (accessed May 15, 2023).

[51] "(+) Beredertemperatur og varmetap," Aug. 23, 2019. https://vannbaserte.nemitek.no/kapittel-833-vannbaserte-oppvarmings-og-kjolesystemer-2014-vannvarmere/beredertemperatur-og-varmetap/163668 (accessed May 19, 2023).

[52] "Varmtvannsbereder - Praktisk yrkesutøvelse (BA-BAT vg1) - NDLA," *ndla.no*. https://ndla.no/nb/subject:1:0d67724e-d9fa-4365-9839-4cc91c012855/topic:1:eaf487bb-a2ad-4725-8e57-fd709dd4cade/topic:2:152327/resource:3c3b5049-9a24-40ba-a3c2-de9b822634bb (accessed Feb. 01, 2023).

[53] "(+) Historisk tilbakeblikk," Jul. 16, 2019. https://sanitar.nemitek.no/kapittel-71-sanitaerteknikk-prosjektering-og-utforelse-av-sanitaerinstallasjoner-i-bygg-vannvarmere/historisk-tilbakeblikk/156439 (accessed May 19, 2023).

[54] "What Is a Smart Water Heater?," Feb. 17, 2021. https://www.homeserve.com/en-us/blog/home-improvement/smart-water-heater/ (accessed Feb. 07, 2023).

[55] Y. A. Cengel, M. A. Boles, and M. Kanoglu, *Thermodynamics: An Engineering Approach*, 9th ed. 2019.

[56] "Hagland Finans - Investeringsanalyse," *Hagland Finans*. https://haglandfinans.no/tjenester/okonomiske-analyser/investeringsanalyse/ (accessed May 19, 2023).

[57] "Mixed Integer Linear Programing - an overview | ScienceDirect Topics." https://www.sciencedirect.com/topics/engineering/mixed-integer-linear-programing (accessed May 18, 2023).

[58] E. Gjerde, "Novel Approaches for Optimal Control of Battery Energy Storage Systems," University of Nottingham, 2021.

[59] "HOMER Grid | Design and Optimization Software for Solar, Energy Storage and Microgrids." https://www.homerenergy.com/products/grid/index.html?utm_source=DSIRE&utm_medium=website&utm_campaign=HOMER_Grid&utm_id=98384&utm_source=DSIRE&utm_medium=website&utm_campaign=HOMER_Grid (accessed Mar. 08, 2023).

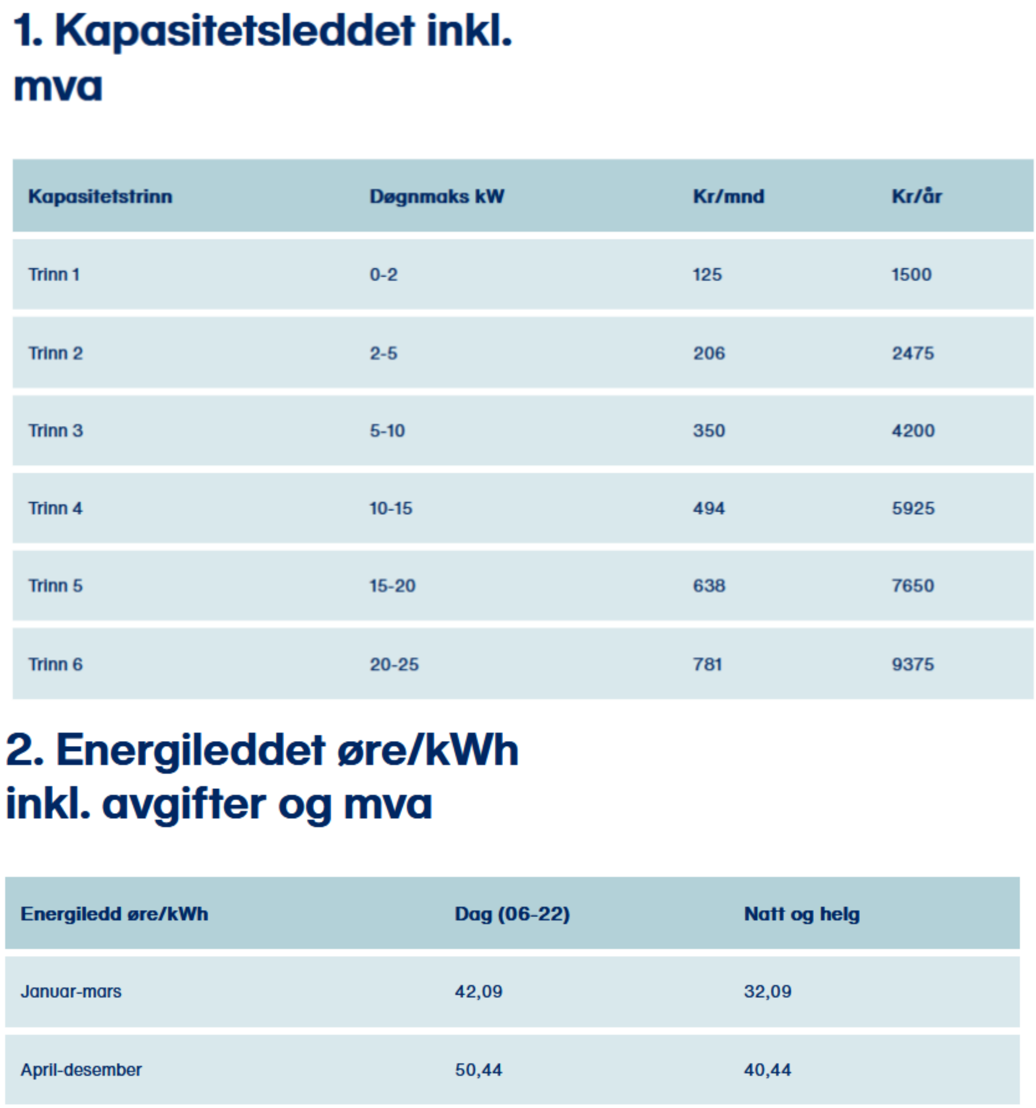
[60] "Forsiden | Solcellekraft." https://www.solcellekraft.no/ (accessed May 01, 2023).

[61] "Beregning | Solcellekraft." https://www.solcellekraft.no/quote/5886f8a5-5583-4968-8cd6-21e7d58a85be (accessed May 11, 2023).
[62] "Beregning | Solcellekraft." https://www.solcellekraft.no/quote/08823aac-0998-4261-9ab3-f156ad3bf815 (accessed May 11, 2023).
[63] "Shelly EM + 120A Clamp," *Shelly Cloud*. https://www.shelly.cloud/en/products/shop/em-120a (accessed Mar. 15, 2023).
[64] "Nye regler for lading av el- og hybridbiler," *gjensidige.no/godtforberedt*. https://www.gjensidige.no/godtforberedt/content/forbudt-med-stikkontaktlading (accessed May 07, 2023).
[65] "PVGIS Online Tool." https://joint-research-centre.ec.europa.eu/pvgis-online-tool_en (accessed May 20, 2023).
[66] E. Matters, "Cleaning Solar Panels: Why, When, and How You Should Do It," *Energy Matters*, Aug. 15, 2022. https://www.energymatters.com.au/renewable-news/solar-panels-cleaning/ (accessed May 20, 2023).
[67] B. Browning, "Why do lithium-ion batteries degrade over time?," *AirQualityNews*, Jan. 12, 2021. https://airqualitynews.com/fuels/why-do-lithium-ion-batteries-degrade-over-time/ (accessed May 20, 2023).

Appendix

A. Grid tariffs

A.1 BKK Tariffs from 2023, Bergen



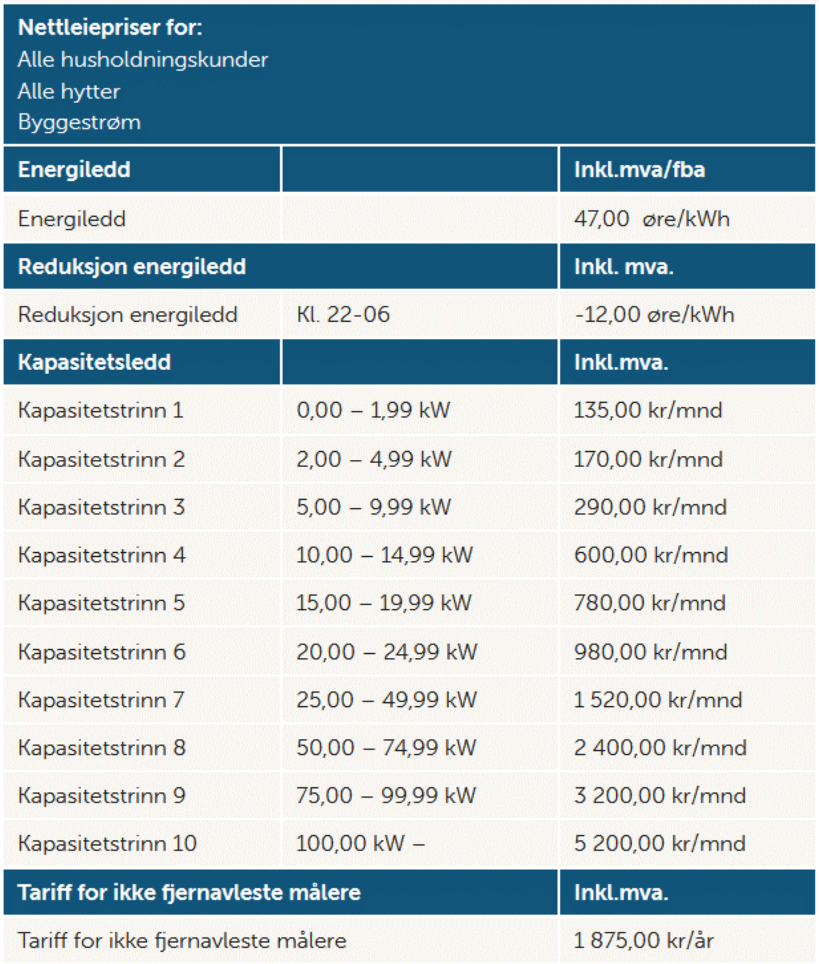
1. Kapasitetsleddet inkl. mva

Kapasitetstrinn	Døgnmaks kW	Kr/mnd	Kr/år
Trinn 1	0-2	125	1500
Trinn 2	2-5	206	2475
Trinn 3	5-10	350	4200
Trinn 4	10-15	494	5925
Trinn 5	15-20	638	7650
Trinn 6	20-25	781	9375

2. Energileddet øre/kWh inkl. avgifter og mva

Energiledd øre/kWh	Dag (06-22)	Natt og helg
Januar-mars	42,09	32,09
April-desember	50,44	40,44

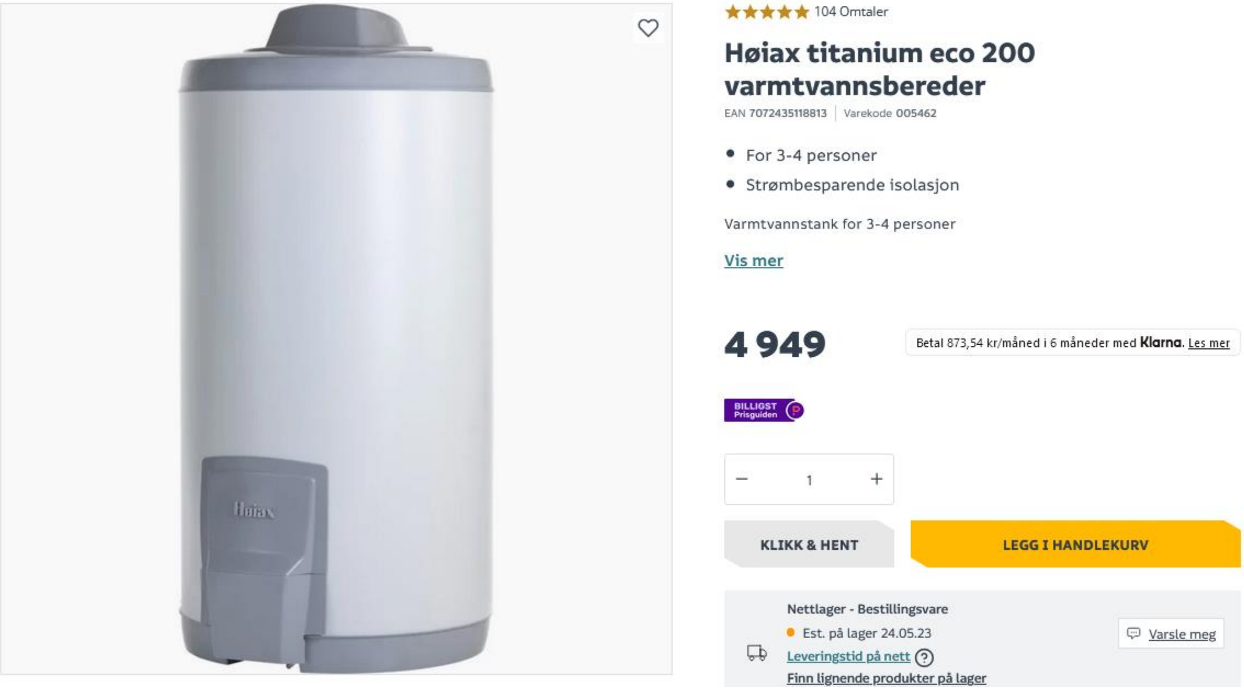
A.2 Glitre Tariff from 2023, Drammen



Nettleiepriser for: Alle husholdningskunder Alle hytter Byggestrøm		
Energiledd		**Inkl.mva/fba**
Energiledd		47,00 øre/kWh
Reduksjon energiledd		**Inkl. mva.**
Reduksjon energiledd	Kl. 22-06	-12,00 øre/kWh
Kapasitetsledd		**Inkl.mva.**
Kapasitetstrinn 1	0,00 – 1,99 kW	135,00 kr/mnd
Kapasitetstrinn 2	2,00 – 4,99 kW	170,00 kr/mnd
Kapasitetstrinn 3	5,00 – 9,99 kW	290,00 kr/mnd
Kapasitetstrinn 4	10,00 – 14,99 kW	600,00 kr/mnd
Kapasitetstrinn 5	15,00 – 19,99 kW	780,00 kr/mnd
Kapasitetstrinn 6	20,00 – 24,99 kW	980,00 kr/mnd
Kapasitetstrinn 7	25,00 – 49,99 kW	1 520,00 kr/mnd
Kapasitetstrinn 8	50,00 – 74,99 kW	2 400,00 kr/mnd
Kapasitetstrinn 9	75,00 – 99,99 kW	3 200,00 kr/mnd
Kapasitetstrinn 10	100,00 kW –	5 200,00 kr/mnd
Tariff for ikke fjernavleste målere		**Inkl.mva.**
Tariff for ikke fjernavleste målere		1 875,00 kr/år

B. Specifications Water Heating Tanks

B.1 Standard Water Heater, Høiax 2 kW



★★★★★ 104 Omtaler

Høiax titanium eco 200 varmtvannsbereder

EAN 7072435118813 | Varekode 005462

- For 3-4 personer
- Strømbesparende isolasjon

Varmtvannstank for 3-4 personer

4 949

Betal 873,54 kr/måned i 6 måneder med Klarna.

Nettlager - Bestillingsvare

● Est. på lager 24.05.23

Detaljer

Varmtvannstank for 3-4 personer

Produktinformasjon

Varmtvannsberederen er designet og utviklet for å møte morgendagens krav til kvalitet og funksjonalitet. Ved å benytte det ypperste innen materialer og ved utvikling av nye produksjonsteknikker, har vi kommet frem til varmtvannsberederen som er ledende når det gjelder levetid, isolasjonsevne og driftssikkerhet.

Varmtvannsberederen har et varmetap på ca 70 Watt *) og sparer ca 15 % strøm sammenlignet med andre skumisolerte beredere. Dette er dermed markedets desidert best isolerte bereder. Alle ventiler er skjulte og isolerte for å forhindre varmetap. Toppen er vridbar i 360° for enkel montering.

Tekniske spesifikasjoner:

- Strømbesparende isolasjon
- El-boksen er godkjent for IP klasse 44
- Enkel montasje
- Vridbar topp 360°
- Design: Bård Eker
- Passer for: 3-4 personer
- Mål: H: 1229xØ585 mm
- Watt: 1950
- Vekt: 34 kg
- M3: 4,21
- Tappeklasse: XL
- Energiklasse: D

B.2 Standard Water Heater, Høiax 6 kW

Høiax titanium express eco 200 varmtvannsbereder

EAN **7072435119001** | Varekode **020263**

Express bereder til 5-7 personer

Vis mer

7 549

Betal 1 332,45 kr/måned i 6 måneder med **Klarna**. Les mer

1. BESKRIVELSE AV PRODUKTET

1.1 TEKNISKE DATA

NRF-nr.	Modell	Logistikk (M^3)	Nettovekt (kg)	Effekt (kW)	Tank-volum (L)
8025221	Titanium Express Eco 200	0,443	33	3+3	188
8025222	Titanium Express Eco 300	0,616	46	3+3	283

Trykkområde for produktene er 1MPa / 10 Bar.
Se punkt 3.1 «Produktets dimensjoner og eskens innhold» for produktmål.

B.3 Smart Water Heating Tank, Høiax

Valgt modell:

Høiax CONNECTED 200 - 8025262

Veiledende pris: 13 990,-

Skal du først bytte ut den gamle varmtvannsberederen med en ny, bør du gå for en smart varmtvannsbereder som gir deg full kontroll på strømforbruket, samtidig som den hjelper deg å redusere strømregningen.

Du kan få inntil 5.000 kroner i støtte fra Enova når du installerer Høiax CONNECTED.

Den smarte varmtvannsberederen Høiax CONNECTED er tilkoblet en skyløsning og du kan enten styre den via en egen app på mobilen din, eller via et brukervennlig display på varmtvannsberederen. I tillegg kan den pr. i dag kobles opp mot flere smarthusløsninger, slik at du kan kontrollere og optimalisere strømforbruket i hele boligen din.
I appen myUplink kan du for eksempel sette opp en tidsplan for når Høiax Connected skal varme opp vannet. Du har tilgang til dagens spotpris fra Nord Pool, slik at du enkelt kan styre unna de dyreste strømprisene og la berederen varme opp vannet kun når strømmen er på sitt billigste. Du kan også følge med på varmtvannsberederens strømforbruk i sanntid, fyllingsgraden og historikk i appen.

NYHET - Gjør din gamle bereder Smart med Høiax RetroFit-løsninger!

Du kan få full CONNECTED-funksjonalitet på din gamle skumisolerte Høiax varmtvannsbereder ved å oppgradere med en RetroFit-løsning.

- RetroFit-løsning nå tilgjengelig. For Høiax standard og eco-beredere (200/250) uten utvendig temperatur-ratt og for 300 modellen produsert etter 2013.
- Høiax kvalifiserer til **Enova-støtte**, **Sjekk ENOVA støtten**
- Nord Pools spotpriser er tilgjengelig i appen myUplink
- Med myUplink app har du smart styring av varmtvannsberederen fra smarttelefonen
- Mulighet for å styre varmtvannsberederen på hytta fra app (krever wifi)
- Flere nyttige funksjoner og driftsmodus, samt automatisk legionella-program
- Integrert med smarthusløsningene: FutureHome, Athom Homey, Google Home, Google assistenten, Alexa og IFTTT

Passer for:	2-4
Mål:	Ø 585 x 1191
Watt:	2000
Vekt:	31
M^3:	0,44
NRF-nummer:	8025262
Tappeklasse:	XL
Volum, liter:	190
Energiklasse:	C

4934-Energylabel_Fiche_8025262

5068-Brukermanual_Høiax_CONNECTED_med_TD_V1.6.6

B.4 Smart Water Heating Tank, OSO

B.4.1.1 Heating Tank

Inneklima > Varmtvannsbereder > Oso saga s 200 8000554

OSO SAGA S 200

Produktnummer: 8000554

Varmtvannsbereder i moderne design med heldekkende, isolert, avtagbar topp. Saga er en varmtvannsbereder i særklasse når det gjelder livsløpsøkonomi og ressursbesparelse. I tidløst design og med smarte tekniske løsninger er berederen designet for å gi varmtvann i flere tiår. Berederen er på 200 liter, noe som passer for 3-4 personer. Den har en høy beredertemperatur på 75 grader for best mulig ytelse, og en UX-blandeventil justerer temperaturen ned til der vannet skal tappes i boligen. Det tilkommer miljøgebyr på beredere.

Mer info om produktet

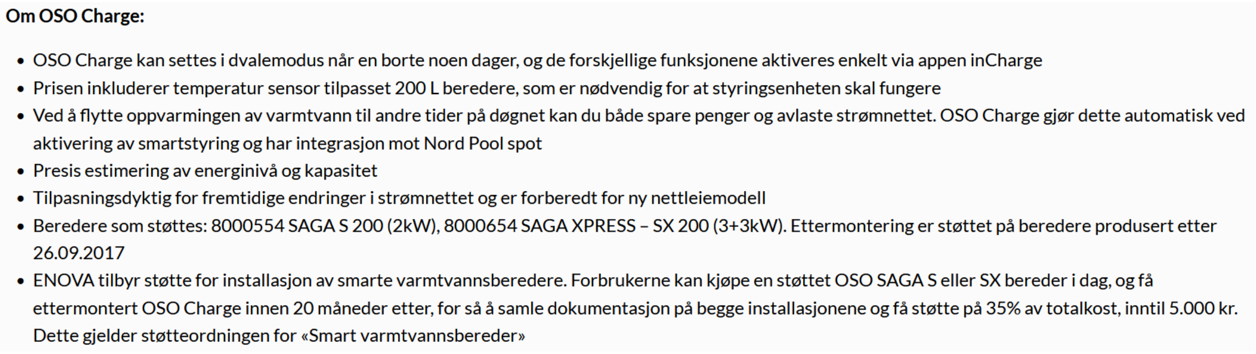
7 120 kr

LEGG I HANDLEKURV

LEGG I ØNSKELISTE

Spar energi!

Det kan være flere grunner til hvorfor du burde bytte varmtvannsbereder – økonomi er en av dem. Bedre energieffektivitet kan gjøre det til en lønnsom investering.



Om OSO Charge:

- OSO Charge kan settes i dvalemodus når en borte noen dager, og de forskjellige funksjonene aktiveres enkelt via appen inCharge
- Prisen inkluderer temperatur sensor tilpasset 200 L beredere, som er nødvendig for at styringsenheten skal fungere
- Ved å flytte oppvarmingen av varmtvann til andre tider på døgnet kan du både spare penger og avlaste strømnettet. OSO Charge gjør dette automatisk ved aktivering av smartstyring og har integrasjon mot Nord Pool spot
- Presis estimering av energinivå og kapasitet
- Tilpasningsdyktig for fremtidige endringer i strømnettet og er forberedt for ny nettleiemodell
- Beredere som støttes: 8000554 SAGA S 200 (2kW), 8000654 SAGA XPRESS – SX 200 (3+3kW). Ettermontering er støttet på beredere produsert etter 26.09.2017
- ENOVA tilbyr støtte for installasjon av smarte varmtvannsberedere. Forbrukerne kan kjøpe en støttet OSO SAGA S eller SX bereder i dag, og få ettermontert OSO Charge innen 20 måneder etter, for så å samle dokumentasjon på begge installasjonene og få støtte på 35% av totalkost, inntil 5.000 kr. Dette gjelder støtteordningen for «Smart varmtvannsbereder»

B.4.1.2 Smart Controller

OSO CHARGE R2

Produktnummer: PK20064

Smart styringsenhet for varmtvannsberedere, som gir deg muligheten til å styre oppvarmingen av varmtvann når strømprisen er lavest. Automatisk prisoptimalisering. Passer til utvalgte OSO beredere, se under for mer beskrivelse. Inkludert sensor for 200L. NB! Grunnet stor etterspørsel på produktet kan leveringstid oppstå. Lagerbeholdning kan variere fra butikk til butikk.

Mer info om produktet

7 190 kr

Smart styring!

Endelig kommer den, en ny og smartere måte å varme opp vannet. OSO kommer nå med egen smartstyring til varmtvannsbereder, og ja den kan ettermonteres om du bestiller ny eller har en nyere varmvannsbereder fra OSO. Installer OSO Charge Smart styring og få inntil 5000 kroner i ENOVA-støtte!

Varmtvannsbereder i moderne design med heldekkende, isolert, avtagbar topp. Saga er en varmtvannsbereder i særklasse når det gjelder livsløpsøkonomi og ressursbesparelse. I tidløst design og med smarte tekniske løsninger er berederen designet for å gi varmtvann i flere tiår. Berederen er på 200 liter, noe som passer for 3-4 personer. Den har en høy berederttemperatur på 75 grader for best mulig ytelse, og en UX-blandeventil justerer temperaturen ned til der vannet skal tappes i boligen. Det tilkommer miljøgebyr på beredere.

- Dimensjon: Ø580x1260 mm
- Vekt: 39 kg
- Kapasitet: 3-4 personer
- Temperatursetting: 75 grader
- Energiklasse: C
- 10 års garanti på den rustfrie trykktanken

C. Specifications EV Fast Home Charger 7.4 kW

Elektroimportøren Partner Ladestasjon • 52629

Ferdig montert elbillader - Easee 32A 230V

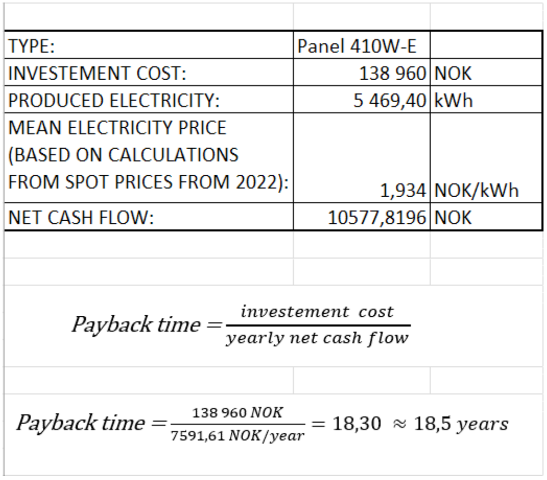
fra Elektroimportør... Easee Home Omtaler (50) ★★★★☆ 4.5 (190)

Denne varen og/eller tjenesten leveres av **Elektroimportøren Partner**

15 990,- 12 792,- eks. mva. Pris per 1 Pakke

D. Investment Analyses and Specifications Solar Panels, St. Olavs vei 170

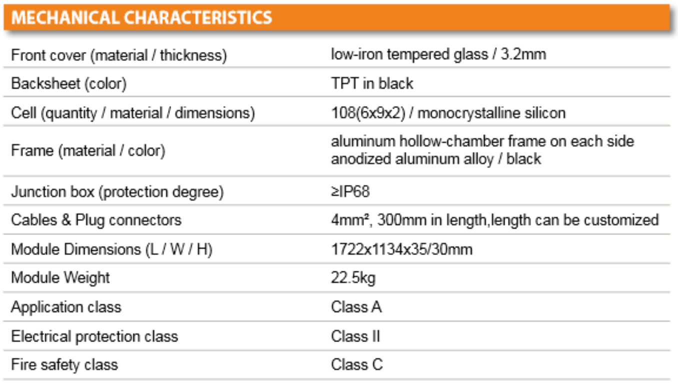
D.1 Investment Analysis 1



TYPE:	Panel 410W-E	
INVESTEMENT COST:	138 960	NOK
PRODUCED ELECTRICITY:	5 469,40	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NET CASH FLOW:	10577,8196	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

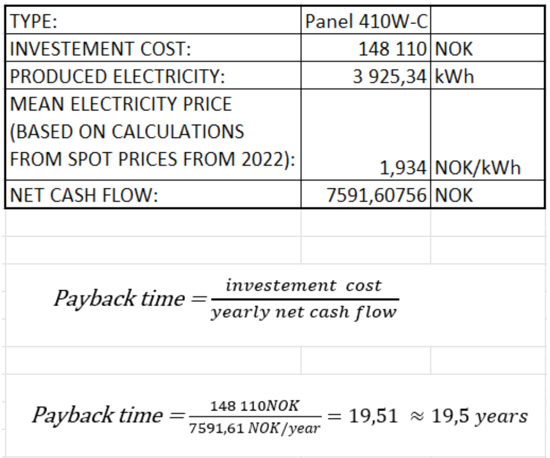
$$Payback\ time = \frac{138\,960\ NOK}{7591{,}61\ NOK/year} = 18{,}30\ \approx 18{,}5\ years$$



MECHANICAL CHARACTERISTICS

Front cover (material / thickness)	low-iron tempered glass / 3.2mm
Backsheet (color)	TPT in black
Cell (quantity / material / dimensions)	108(6x9x2) / monocrystalline silicon
Frame (material / color)	aluminum hollow-chamber frame on each side anodized aluminum alloy / black
Junction box (protection degree)	≥IP68
Cables & Plug connectors	4mm², 300mm in length,length can be customized
Module Dimensions (L / W / H)	1722x1134x35/30mm
Module Weight	22.5kg
Application class	Class A
Electrical protection class	Class II
Fire safety class	Class C

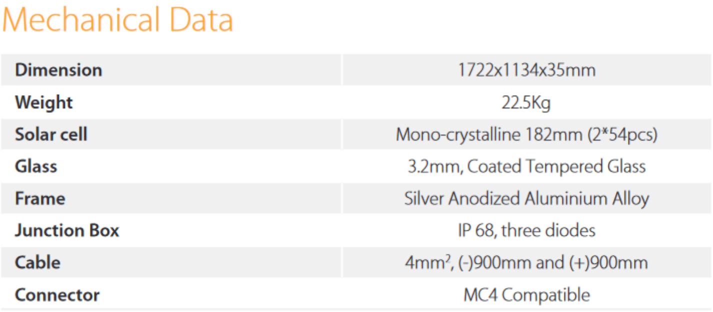
D.2 Investment Analysis 2



TYPE:	Panel 410W-C	
INVESTEMENT COST:	148 110	NOK
PRODUCED ELECTRICITY:	3 925,34	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NET CASH FLOW:	7591,60756	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

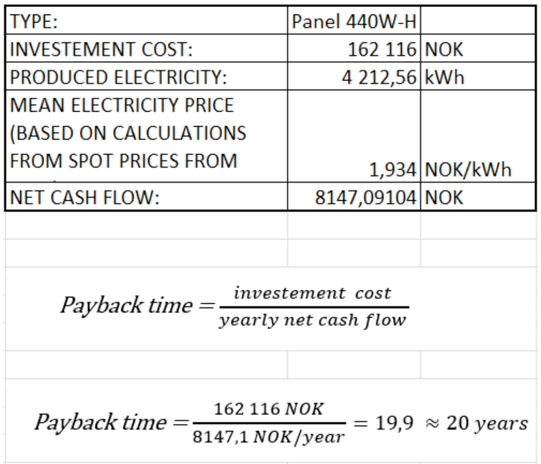
$$Payback\ time = \frac{148\ 110 NOK}{7591{,}61\ NOK/year} = 19{,}51\ \approx 19{,}5\ years$$



Mechanical Data

Dimension	1722x1134x35mm
Weight	22.5Kg
Solar cell	Mono-crystalline 182mm (2*54pcs)
Glass	3.2mm, Coated Tempered Glass
Frame	Silver Anodized Aluminium Alloy
Junction Box	IP 68, three diodes
Cable	4mm², (-)900mm and (+)900mm
Connector	MC4 Compatible

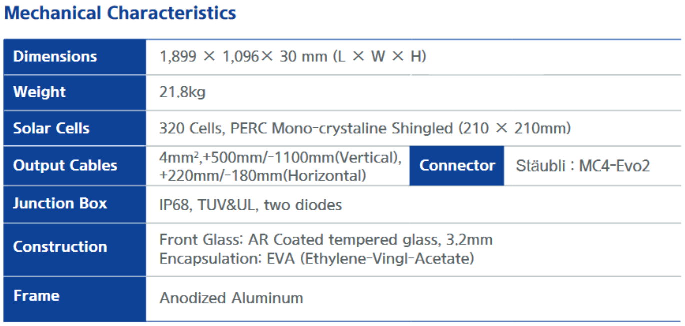
D.3 Investment Analysis 3



TYPE:	Panel 440W-H	
INVESTEMENT COST:	162 116	NOK
PRODUCED ELECTRICITY:	4 212,56	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM	1,934	NOK/kWh
NET CASH FLOW:	8147,09104	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

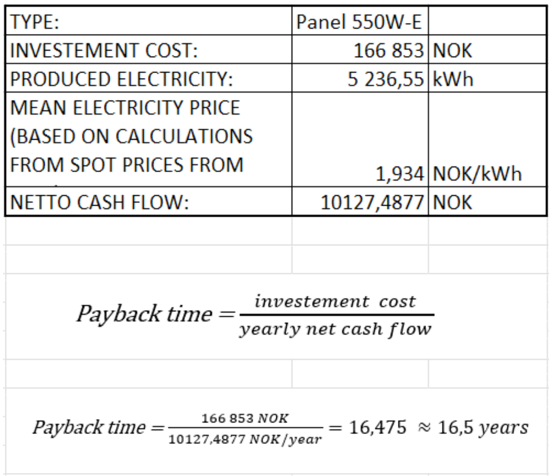
$$Payback\ time = \frac{162\ 116\ NOK}{8147{,}1\ NOK/year} = 19{,}9\ \approx 20\ years$$



Mechanical Characteristics

Dimensions	1,899 × 1,096× 30 mm (L × W × H)		
Weight	21.8kg		
Solar Cells	320 Cells, PERC Mono-crystaline Shingled (210 × 210mm)		
Output Cables	4mm²,+500mm/-1100mm(Vertical), +220mm/-180mm(Horizontal)	**Connector**	Stäubli : MC4-Evo2
Junction Box	IP68, TUV&UL, two diodes		
Construction	Front Glass: AR Coated tempered glass, 3.2mm Encapsulation: EVA (Ethylene-Vingl-Acetate)		
Frame	Anodized Aluminum		

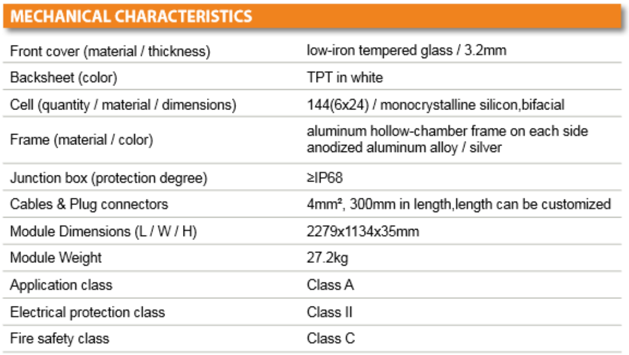
D.4 Investment Analysis 4



TYPE:	Panel 550W-E	
INVESTEMENT COST:	166 853	NOK
PRODUCED ELECTRICITY:	5 236,55	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM	1,934	NOK/kWh
NETTO CASH FLOW:	10127,4877	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

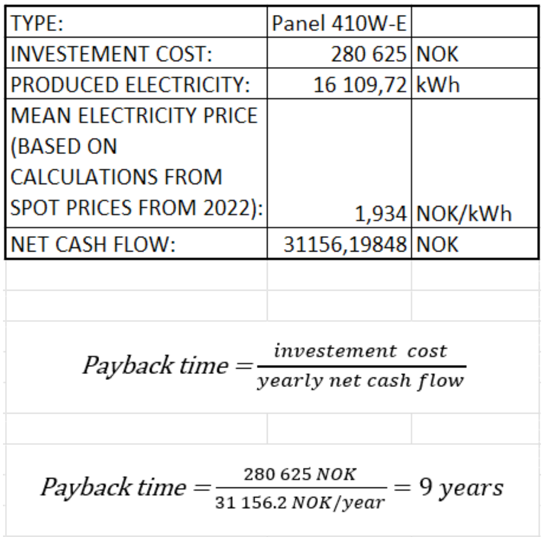
$$Payback\ time = \frac{166\ 853\ NOK}{10127{,}4877\ NOK/year} = 16{,}475\ \ \approx 16{,}5\ years$$



MECHANICAL CHARACTERISTICS	
Front cover (material / thickness)	low-iron tempered glass / 3.2mm
Backsheet (color)	TPT in white
Cell (quantity / material / dimensions)	144(6x24) / monocrystalline silicon,bifacial
Frame (material / color)	aluminum hollow-chamber frame on each side anodized aluminum alloy / silver
Junction box (protection degree)	≥IP68
Cables & Plug connectors	4mm², 300mm in length,length can be customized
Module Dimensions (L / W / H)	2279x1134x35mm
Module Weight	27.2kg
Application class	Class A
Electrical protection class	Class II
Fire safety class	Class C

E. Investment Analyses and Specifications Solar Panels, Rørvollveien 17

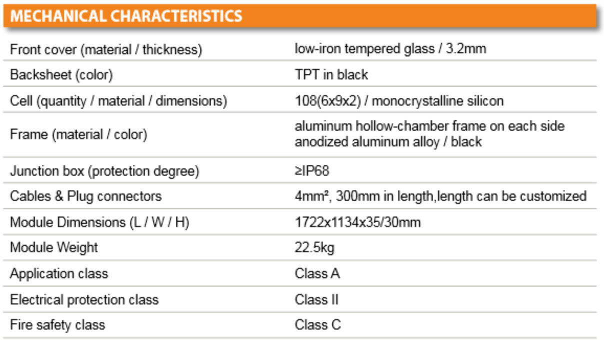
E.1 Investment Analysis 1



TYPE:	Panel 410W-E	
INVESTEMENT COST:	280 625	NOK
PRODUCED ELECTRICITY:	16 109,72	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NET CASH FLOW:	31156,19848	NOK

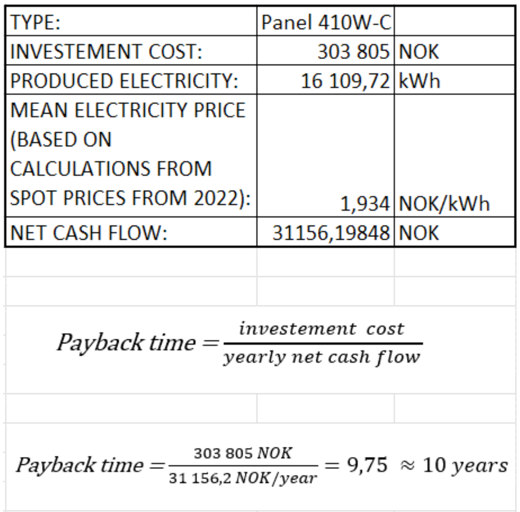
$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

$$Payback\ time = \frac{280\ 625\ NOK}{31\ 156.2\ NOK/year} = 9\ years$$



MECHANICAL CHARACTERISTICS	
Front cover (material / thickness)	low-iron tempered glass / 3.2mm
Backsheet (color)	TPT in black
Cell (quantity / material / dimensions)	108(6x9x2) / monocrystalline silicon
Frame (material / color)	aluminum hollow-chamber frame on each side anodized aluminum alloy / black
Junction box (protection degree)	≥IP68
Cables & Plug connectors	4mm^2, 300mm in length,length can be customized
Module Dimensions (L / W / H)	1722x1134x35/30mm
Module Weight	22.5kg
Application class	Class A
Electrical protection class	Class II
Fire safety class	Class C

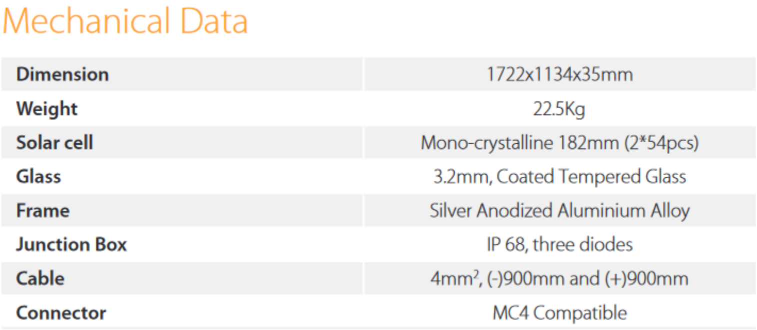
E.2 Investment Analysis 2



TYPE:	Panel 410W-C	
INVESTEMENT COST:	303 805	NOK
PRODUCED ELECTRICITY:	16 109,72	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NET CASH FLOW:	31156,19848	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

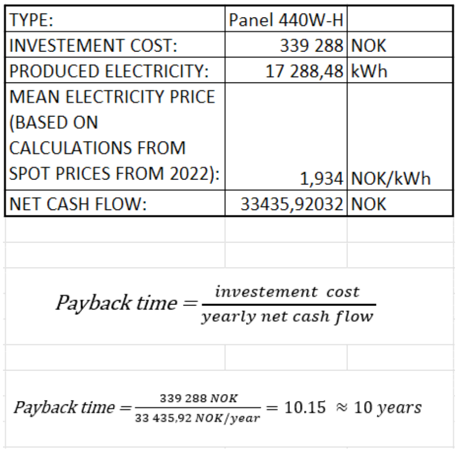
$$Payback\ time = \frac{303\ 805\ NOK}{31\ 156{,}2\ NOK/year} = 9{,}75\ \approx 10\ years$$



Mechanical Data

Dimension	1722x1134x35mm
Weight	22.5Kg
Solar cell	Mono-crystalline 182mm (2*54pcs)
Glass	3.2mm, Coated Tempered Glass
Frame	Silver Anodized Aluminium Alloy
Junction Box	IP 68, three diodes
Cable	4mm^2, (-)900mm and (+)900mm
Connector	MC4 Compatible

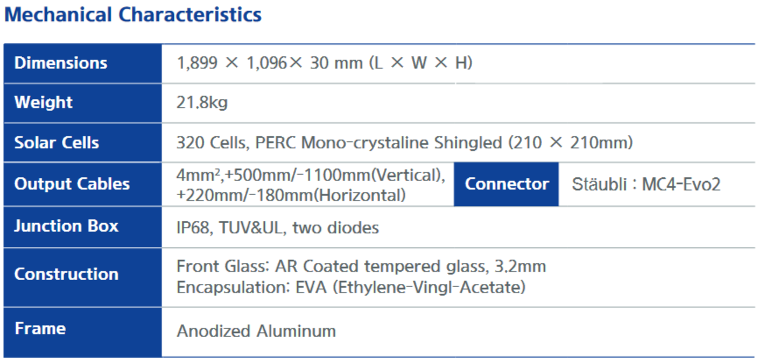
E.3 Investment Analysis 3



TYPE:	Panel 440W-H	
INVESTEMENT COST:	339 288	NOK
PRODUCED ELECTRICITY:	17 288,48	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NET CASH FLOW:	33435,92032	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ net\ cash\ flow}$$

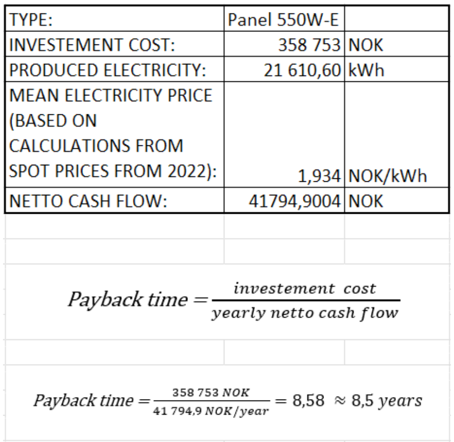
$$Payback\ time = \frac{339\ 288\ NOK}{33\ 435{,}92\ NOK/year} = 10.15\ \approx 10\ years$$



Mechanical Characteristics

Dimensions	1,899 × 1,096× 30 mm (L × W × H)		
Weight	21.8kg		
Solar Cells	320 Cells, PERC Mono-crystaline Shingled (210 × 210mm)		
Output Cables	4mm²,+500mm/-1100mm(Vertical), +220mm/-180mm(Horizontal)	**Connector**	Stäubli : MC4-Evo2
Junction Box	IP68, TUV&UL, two diodes		
Construction	Front Glass: AR Coated tempered glass, 3.2mm Encapsulation: EVA (Ethylene-Vingl-Acetate)		
Frame	Anodized Aluminum		

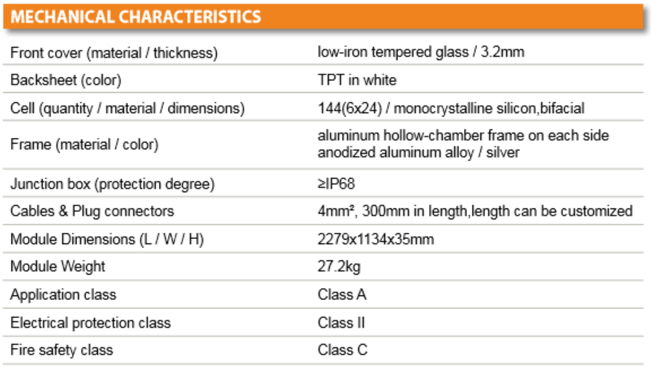
E.4 Investment Analysis 4



TYPE:	Panel 550W-E	
INVESTEMENT COST:	358 753	NOK
PRODUCED ELECTRICITY:	21 610,60	kWh
MEAN ELECTRICITY PRICE (BASED ON CALCULATIONS FROM SPOT PRICES FROM 2022):	1,934	NOK/kWh
NETTO CASH FLOW:	41794,9004	NOK

$$Payback\ time = \frac{investement\ \ cost}{yearly\ netto\ cash\ flow}$$

$$Payback\ time = \frac{358\ 753\ NOK}{41\ 794{,}9\ NOK/year} = 8{,}58\ \approx 8{,}5\ years$$

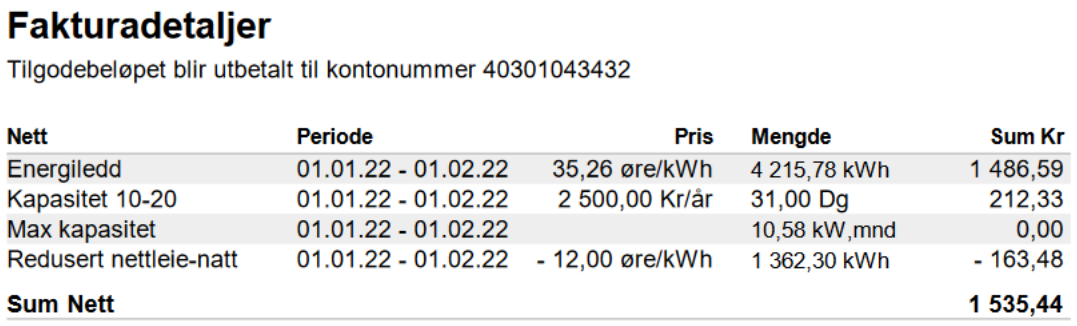


MECHANICAL CHARACTERISTICS

Front cover (material / thickness)	low-iron tempered glass / 3.2mm
Backsheet (color)	TPT in white
Cell (quantity / material / dimensions)	144(6x24) / monocrystalline silicon,bifacial
Frame (material / color)	aluminum hollow-chamber frame on each side anodized aluminum alloy / silver
Junction box (protection degree)	≥IP68
Cables & Plug connectors	4mm², 300mm in length,length can be customized
Module Dimensions (L / W / H)	2279x1134x35mm
Module Weight	27.2kg
Application class	Class A
Electrical protection class	Class II
Fire safety class	Class C

F. Electricity Bills and Grid Tariffs from WATTN AS, Rørvollveien 17

F.1 Grid Tariff January 2022

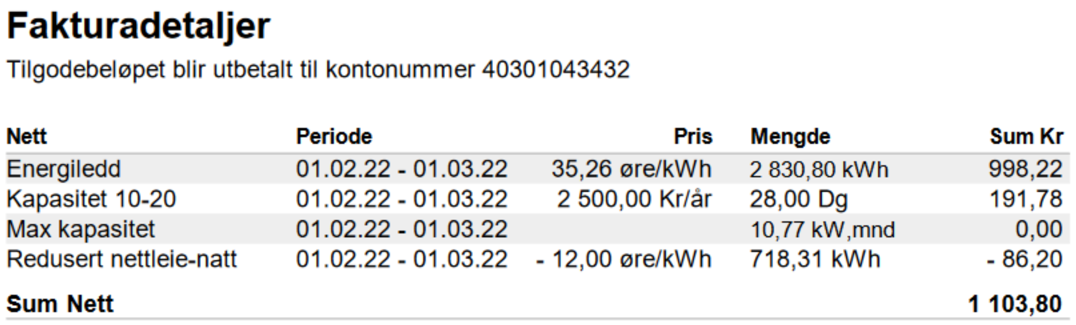


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.01.22 - 01.02.22	35,26 øre/kWh	4 215,78 kWh	1 486,59
Kapasitet 10-20	01.01.22 - 01.02.22	2 500,00 Kr/år	31,00 Dg	212,33
Max kapasitet	01.01.22 - 01.02.22		10,58 kW,mnd	0,00
Redusert nettleie-natt	01.01.22 - 01.02.22	- 12,00 øre/kWh	1 362,30 kWh	- 163,48
Sum Nett				**1 535,44**

F.2 Grid Tariff February 2022

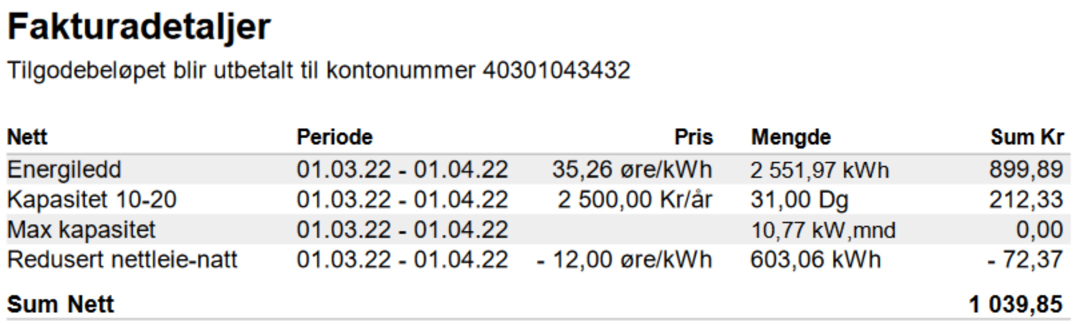


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.02.22 - 01.03.22	35,26 øre/kWh	2 830,80 kWh	998,22
Kapasitet 10-20	01.02.22 - 01.03.22	2 500,00 Kr/år	28,00 Dg	191,78
Max kapasitet	01.02.22 - 01.03.22		10,77 kW,mnd	0,00
Redusert nettleie-natt	01.02.22 - 01.03.22	- 12,00 øre/kWh	718,31 kWh	- 86,20
Sum Nett				**1 103,80**

F.3 Grid Tariff March 2022

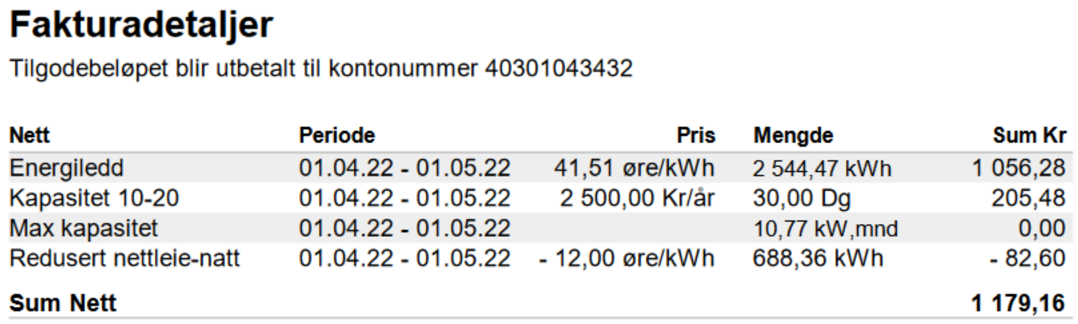


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.03.22 - 01.04.22	35,26 øre/kWh	2 551,97 kWh	899,89
Kapasitet 10-20	01.03.22 - 01.04.22	2 500,00 Kr/år	31,00 Dg	212,33
Max kapasitet	01.03.22 - 01.04.22		10,77 kW,mnd	0,00
Redusert nettleie-natt	01.03.22 - 01.04.22	- 12,00 øre/kWh	603,06 kWh	- 72,37
Sum Nett				**1 039,85**

F.4 Grid Tariff April 2022

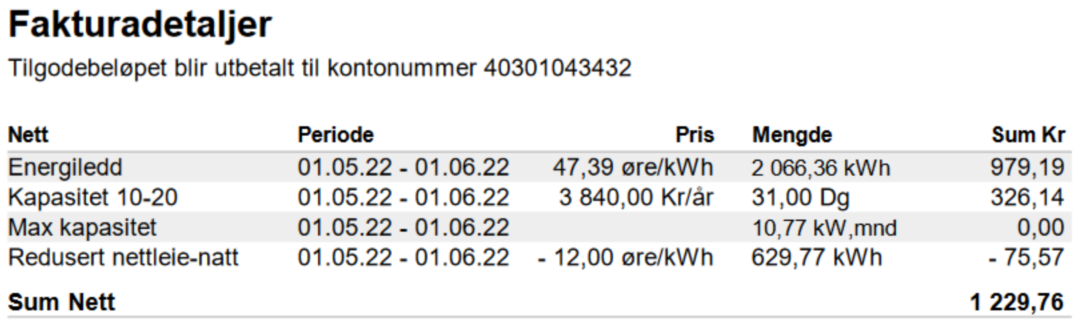


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.04.22 - 01.05.22	41,51 øre/kWh	2 544,47 kWh	1 056,28
Kapasitet 10-20	01.04.22 - 01.05.22	2 500,00 Kr/år	30,00 Dg	205,48
Max kapasitet	01.04.22 - 01.05.22		10,77 kW,mnd	0,00
Redusert nettleie-natt	01.04.22 - 01.05.22	- 12,00 øre/kWh	688,36 kWh	- 82,60
Sum Nett				**1 179,16**

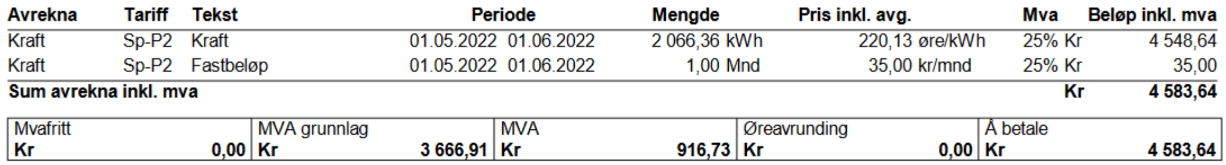
F.5 Grid Tariff and Electricity Bill May 2022



Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

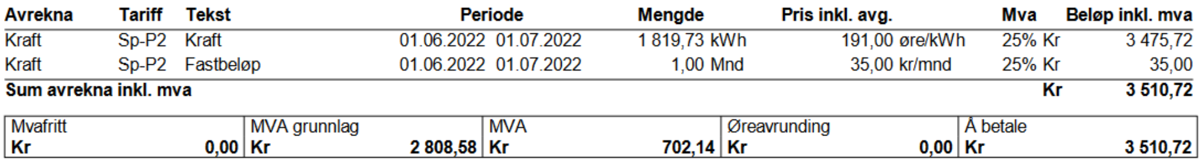
Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.05.22 - 01.06.22	47,39 øre/kWh	2 066,36 kWh	979,19
Kapasitet 10-20	01.05.22 - 01.06.22	3 840,00 Kr/år	31,00 Dg	326,14
Max kapasitet	01.05.22 - 01.06.22		10,77 kW,mnd	0,00
Redusert nettleie-natt	01.05.22 - 01.06.22	- 12,00 øre/kWh	629,77 kWh	- 75,57
Sum Nett				**1 229,76**



Avrekna	Tariff	Tekst	Periode	Mengde	Pris inkl. avg.	Mva	Beløp inkl. mva
Kraft	Sp-P2	Kraft	01.05.2022 01.06.2022	2 066,36 kWh	220,13 øre/kWh	25% Kr	4 548,64
Kraft	Sp-P2	Fastbeløp	01.05.2022 01.06.2022	1,00 Mnd	35,00 kr/mnd	25% Kr	35,00
Sum avrekna inkl. mva						**Kr**	**4 583,64**

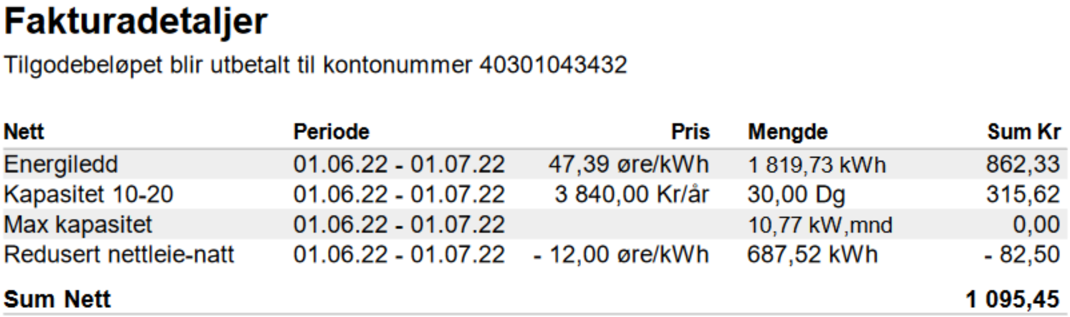
Mvafritt	MVA grunnlag	MVA	Øreavrunding	Å betale
Kr 0,00	**Kr 3 666,91**	**Kr 916,73**	**Kr 0,00**	**Kr 4 583,64**

F.6 Grid Tariff and Electricity Bill June 2022



Avrekna	Tariff	Tekst	Periode	Mengde	Pris inkl. avg.	Mva	Beløp inkl. mva
Kraft	Sp-P2	Kraft	01.06.2022 01.07.2022	1 819,73 kWh	191,00 øre/kWh	25% Kr	3 475,72
Kraft	Sp-P2	Fastbeløp	01.06.2022 01.07.2022	1,00 Mnd	35,00 kr/mnd	25% Kr	35,00
Sum avrekna inkl. mva						**Kr**	**3 510,72**

Mvafritt	MVA grunnlag	MVA	Øreavrunding	Å betale
Kr 0,00	**Kr 2 808,58**	**Kr 702,14**	**Kr 0,00**	**Kr 3 510,72**

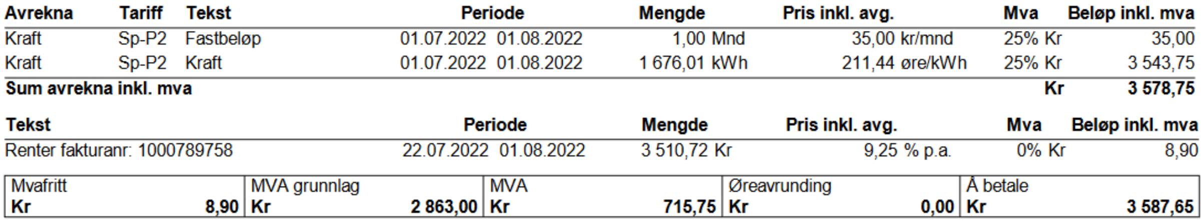


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.06.22 - 01.07.22	47,39 øre/kWh	1 819,73 kWh	862,33
Kapasitet 10-20	01.06.22 - 01.07.22	3 840,00 Kr/år	30,00 Dg	315,62
Max kapasitet	01.06.22 - 01.07.22		10,77 kW,mnd	0,00
Redusert nettleie-natt	01.06.22 - 01.07.22	- 12,00 øre/kWh	687,52 kWh	- 82,50
Sum Nett				**1 095,45**

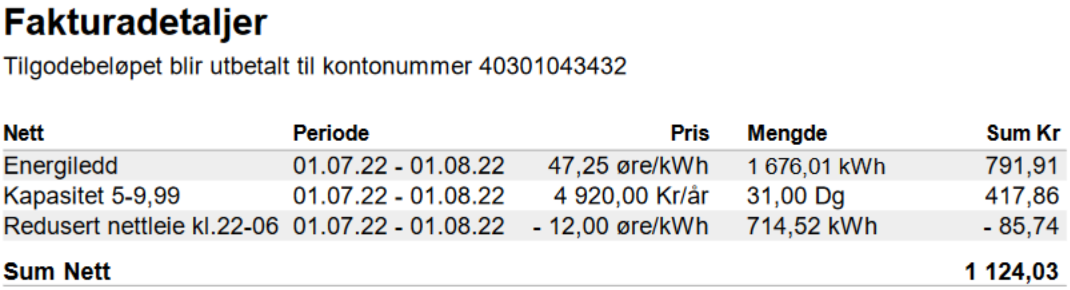
F.7 Grid Tariff and Electricity Bill July 2022



Avrekna	Tariff	Tekst	Periode	Mengde	Pris inkl. avg.	Mva	Beløp inkl. mva
Kraft	Sp-P2	Fastbeløp	01.07.2022 01.08.2022	1,00 Mnd	35,00 kr/mnd	25% Kr	35,00
Kraft	Sp-P2	Kraft	01.07.2022 01.08.2022	1 676,01 kWh	211,44 øre/kWh	25% Kr	3 543,75
Sum avrekna inkl. mva						**Kr**	**3 578,75**

Tekst	Periode	Mengde	Pris inkl. avg.	Mva	Beløp inkl. mva
Renter fakturanr: 1000789758	22.07.2022 01.08.2022	3 510,72 Kr	9,25 % p.a.	0% Kr	8,90

Mvafritt	MVA grunnlag	MVA	Øreavrunding	Å betale
Kr 8,90	**Kr 2 863,00**	**Kr 715,75**	**Kr 0,00**	**Kr 3 587,65**

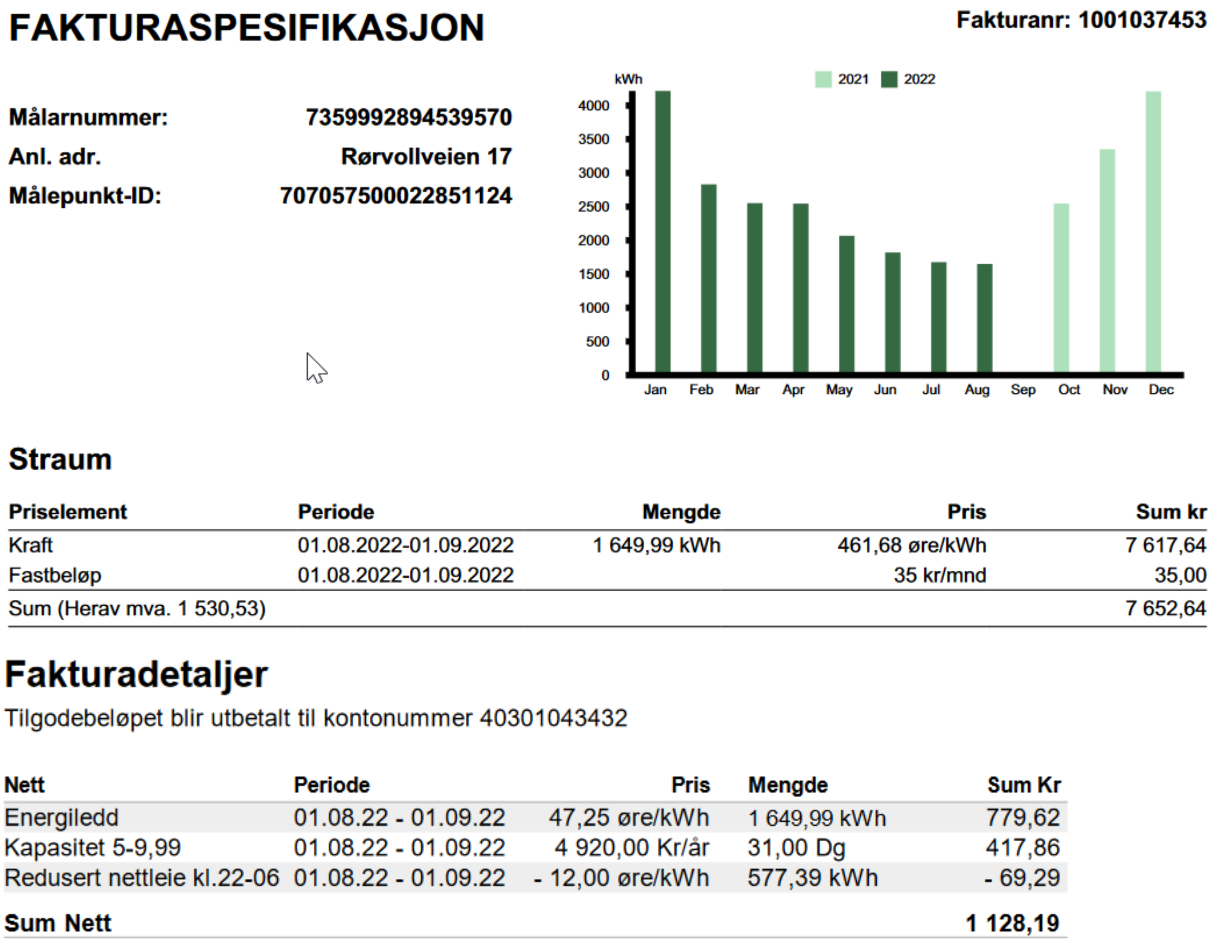


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.07.22 - 01.08.22	47,25 øre/kWh	1 676,01 kWh	791,91
Kapasitet 5-9,99	01.07.22 - 01.08.22	4 920,00 Kr/år	31,00 Dg	417,86
Redusert nettleie kl.22-06	01.07.22 - 01.08.22	- 12,00 øre/kWh	714,52 kWh	- 85,74
Sum Nett				**1 124,03**

F.8 Grid Tariff and Electricity Bill August 2022



FAKTURASPESIFIKASJON

Fakturanr: 1001037453

Målarnummer:	**7359992894539570**
Anl. adr.	**Rørvollveien 17**
Målepunkt-ID:	**707057500022851124**

Straum

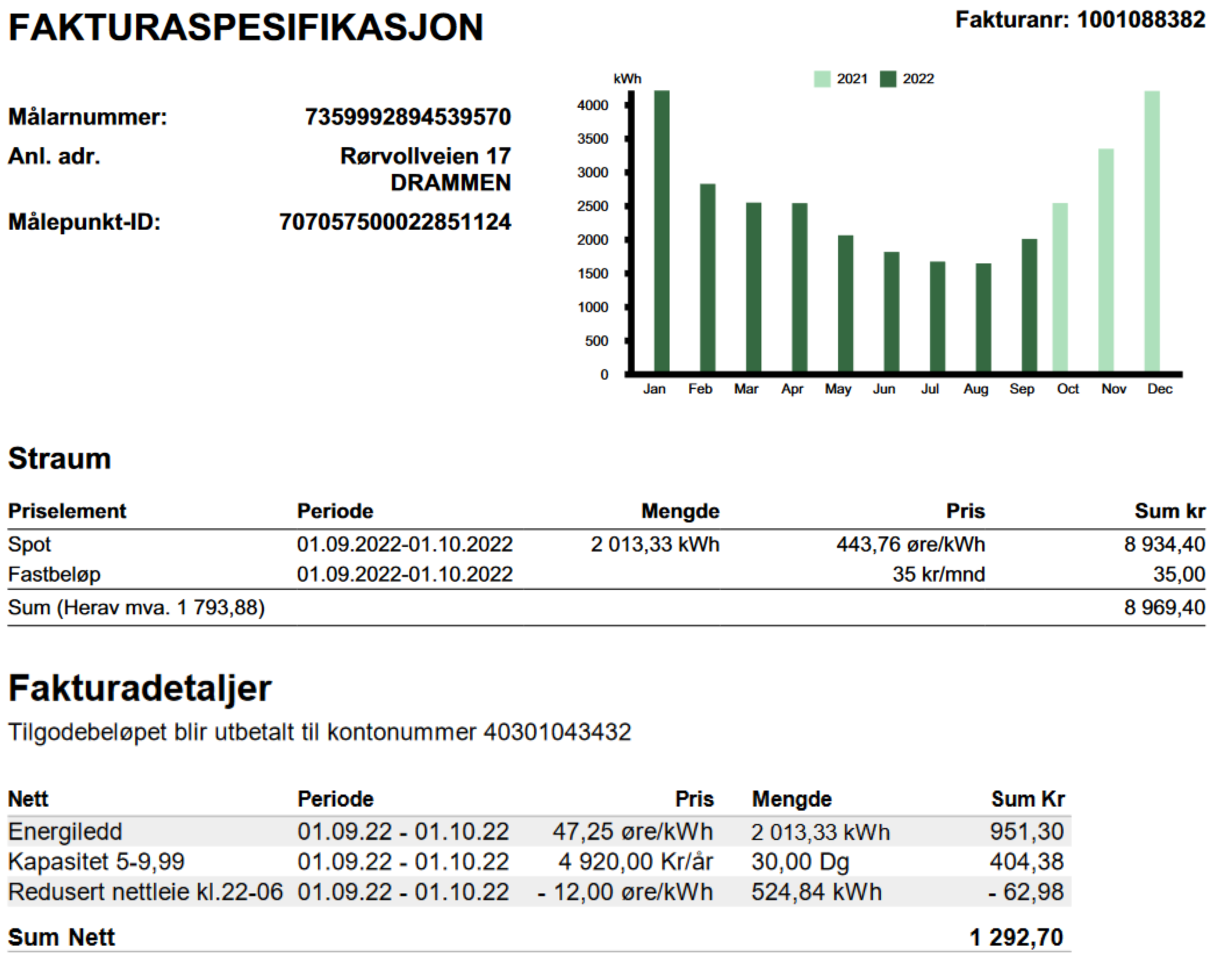
Priselement	**Periode**	**Mengde**	**Pris**	**Sum kr**
Kraft	01.08.2022-01.09.2022	1 649,99 kWh	461,68 øre/kWh	7 617,64
Fastbeløp	01.08.2022-01.09.2022		35 kr/mnd	35,00
Sum (Herav mva. 1 530,53)				7 652,64

Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	**Periode**	**Pris**	**Mengde**	**Sum Kr**
Energiledd	01.08.22 - 01.09.22	47,25 øre/kWh	1 649,99 kWh	779,62
Kapasitet 5-9,99	01.08.22 - 01.09.22	4 920,00 Kr/år	31,00 Dg	417,86
Redusert nettleie kl.22-06	01.08.22 - 01.09.22	- 12,00 øre/kWh	577,39 kWh	- 69,29
Sum Nett				**1 128,19**

F.9 Grid Tariff and Electricity Bill September 2022



FAKTURASPESIFIKASJON

Fakturanr: 1001088382

Målarnummer:	**7359992894539570**
Anl. adr.	**Rørvollveien 17 DRAMMEN**
Målepunkt-ID:	**707057500022851124**

Straum

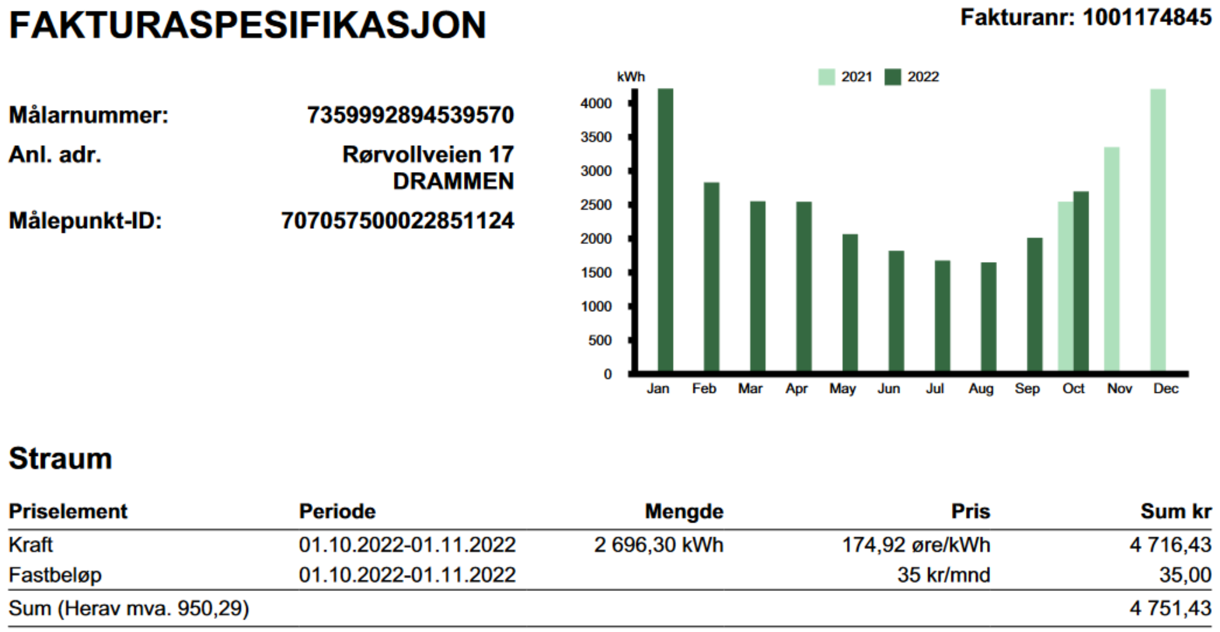
Priselement	Periode	Mengde	Pris	Sum kr
Spot	01.09.2022-01.10.2022	2 013,33 kWh	443,76 øre/kWh	8 934,40
Fastbeløp	01.09.2022-01.10.2022		35 kr/mnd	35,00
Sum (Herav mva. 1 793,88)				8 969,40

Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.09.22 - 01.10.22	47,25 øre/kWh	2 013,33 kWh	951,30
Kapasitet 5-9,99	01.09.22 - 01.10.22	4 920,00 Kr/år	30,00 Dg	404,38
Redusert nettleie kl.22-06	01.09.22 - 01.10.22	- 12,00 øre/kWh	524,84 kWh	- 62,98
Sum Nett				**1 292,70**

F.10 Grid Tariff and Electricity Bill October 2022



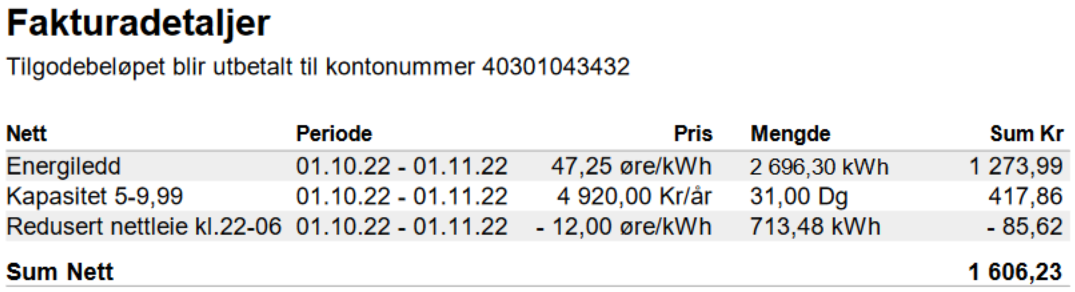
FAKTURASPESIFIKASJON

Fakturanr: 1001174845

Målarnummer:	**7359992894539570**
Anl. adr.	**Rørvollveien 17** **DRAMMEN**
Målepunkt-ID:	**707057500022851124**

Straum

Priselement	**Periode**	**Mengde**	**Pris**	**Sum kr**
Kraft	01.10.2022-01.11.2022	2 696,30 kWh	174,92 øre/kWh	4 716,43
Fastbeløp	01.10.2022-01.11.2022		35 kr/mnd	35,00
Sum (Herav mva. 950,29)				4 751,43

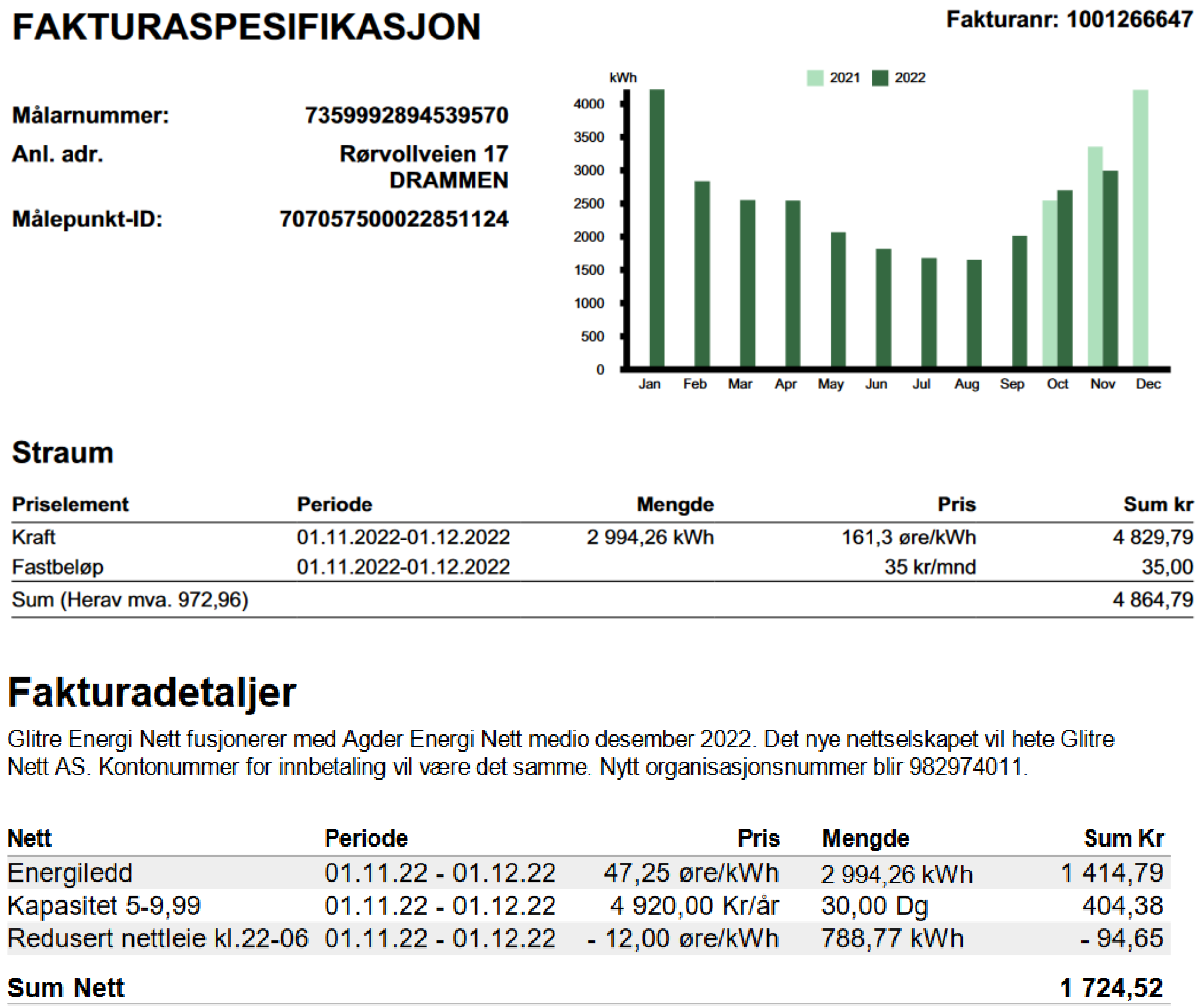


Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Nett	**Periode**	**Pris**	**Mengde**	**Sum Kr**
Energiledd	01.10.22 - 01.11.22	47,25 øre/kWh	2 696,30 kWh	1 273,99
Kapasitet 5-9,99	01.10.22 - 01.11.22	4 920,00 Kr/år	31,00 Dg	417,86
Redusert nettleie kl.22-06	01.10.22 - 01.11.22	- 12,00 øre/kWh	713,48 kWh	- 85,62
Sum Nett				**1 606,23**

F.11 Grid Tariff and Electricity Bill November 2022



FAKTURASPESIFIKASJON

Fakturanr: 1001266647

Målarnummer:	**7359992894539570**
Anl. adr.	**Rørvollveien 17 DRAMMEN**
Målepunkt-ID:	**707057500022851124**

Straum

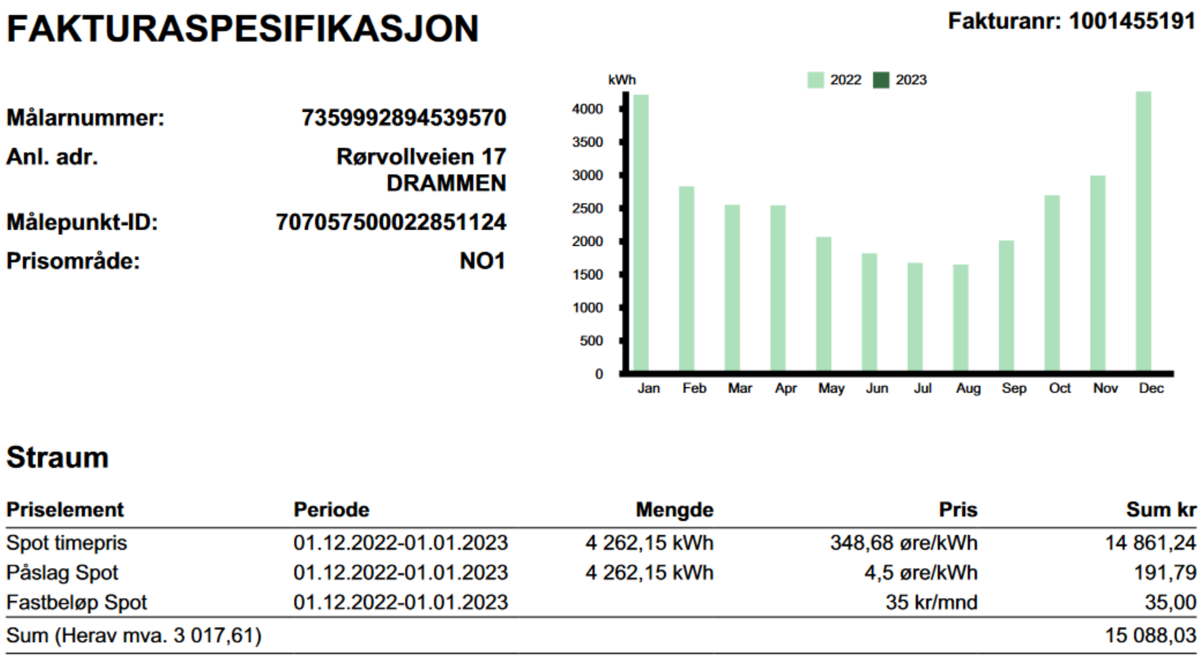
Priselement	Periode	Mengde	Pris	Sum kr
Kraft	01.11.2022-01.12.2022	2 994,26 kWh	161,3 øre/kWh	4 829,79
Fastbeløp	01.11.2022-01.12.2022		35 kr/mnd	35,00
Sum (Herav mva. 972,96)				4 864,79

Fakturadetaljer

Glitre Energi Nett fusjonerer med Agder Energi Nett medio desember 2022. Det nye nettselskapet vil hete Glitre Nett AS. Kontonummer for innbetaling vil være det samme. Nytt organisasjonsnummer blir 982974011.

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.11.22 - 01.12.22	47,25 øre/kWh	2 994,26 kWh	1 414,79
Kapasitet 5-9,99	01.11.22 - 01.12.22	4 920,00 Kr/år	30,00 Dg	404,38
Redusert nettleie kl.22-06	01.11.22 - 01.12.22	- 12,00 øre/kWh	788,77 kWh	- 94,65
Sum Nett				**1 724,52**

F.12 Grid Tariff and Electricity Bill December 2022



FAKTURASPESIFIKASJON

Fakturanr: 1001455191

Målarnummer:	**7359992894539570**
Anl. adr.	**Rørvollveien 17** **DRAMMEN**
Målepunkt-ID:	**707057500022851124**
Prisområde:	**NO1**

Straum

Priselement	Periode	Mengde	Pris	Sum kr
Spot timepris	01.12.2022-01.01.2023	4 262,15 kWh	348,68 øre/kWh	14 861,24
Påslag Spot	01.12.2022-01.01.2023	4 262,15 kWh	4,5 øre/kWh	191,79
Fastbeløp Spot	01.12.2022-01.01.2023		35 kr/mnd	35,00
Sum (Herav mva. 3 017,61)				15 088,03

Fakturadetaljer

Tilgodebeløpet blir utbetalt til kontonummer 40301043432

Målepunktet med målernummer 7359992894539570 ligger i prisområdet .

Nett	Periode	Pris	Mengde	Sum Kr
Energiledd	01.12.22 - 01.01.23	47,25 øre/kWh	4 262,15 kWh	2 013,87
Kapasitet 10-14,99	01.12.22 - 01.01.23	8 820,00 Kr/år	31,00 Dg	749,10
Redusert nettleie kl.22-06	01.12.22 - 01.01.23	- 12,00 øre/kWh	1 272,64 kWh	- 152,72
Sum Nett				**2 610,25**

G. Engineering Drawing

G.1 St.Olavs vei 170

H. Detailed Description of Python Calculations

H.1 Main Calculations in Python

For this thesis, it is necessary to investigate if using a hybrid system significantly impacts the energy cost. It is essential to investigate the actual cost of electricity, of the implemented system with a heating tank against the energy cost for the same year. These calculations are made using the program Spyder, using the programming language Python.

The following sections contain explanations of how the calculations are done, including some programming language. These sections can be read to get a deeper understanding of the calculations. However, it is not necessary to understand the calculations in Chapter 4.

There are two separate Python files that essentially are the same, one is for St. Olavs vei 170, and the other is for Rørvollveien 17, due to a difference in import files and data. In St. Olavs vei 170 the input data was only the energy use and solar irradiation from south, west, and east. While in Rørvollveien 17 the input data consisted of energy use, including specific data for the heating tank and electric car charging, and solar irradiation for only southeast. This created a difference in needed solar variables and import files, making it more efficient to have separate files for the different cases.

When referring to the Python code in the coming explanation, the line references match the St. Olavs vei 170 Python file, see Attachment xxx.

H.1.1 General Information

To calculate the cost of the energy use, the data for the energy consumption, spot price, energy- and capacity components is needed. The values for these three components are obtained from the houseowner, Nord Pool, NO5/NO1 and BKK/Glitre. The hour-by-hour values are saved as CSV datafiles, and imported into the coding program Spyder, and the three CSV files consist of the energy consumption, spot prices, and solar irradiation. The data is sorted in Data Frames, like a table, into rows and columns, with 8760 rows, one for every hour of 2022. The data frames are edited, where unnecessary columns are deleted and columns with impractical names are renamed. The columns needed for further calculations, spot price and solar production, are copied into the main data frame called ‘df’. From the timestamp in the energy consumption file, information about the time is separated and added into ‘df’ in separate columns, making it possible to sort data for time of day, day of year and months in later calculations.

The cost of the energy use and preparation for further calculations is programmed in the Python file in lines 16 to 65.

H.1.2 Total Energy Cost

To calculate the total cost, it is necessary to calculate the cost of the energy use hour-by-hour, this will consist of the spot price multiplied by 25 % (VAT) added with the energy component and multiplying the total with the energy use of the corresponding hour. The total cost will have the added monthly cost from the capacity component. The main formulas used are:

$$Cost_{total} = Energy_{component} + Capacity_{component}$$

$$Energy_{component} = \sum_{i=1}^{8760} ((spotprice[i] \cdot 1{,}25) + Gridtariff[day, night, holiday, summer, winter]) \cdot Energy_{consumption}[i]$$

$$Capacity_{component} = \sum_{l=1}^{12} \frac{peak_1[l] + peak_2[l] + peak_3[l]}{3}$$

First, the energy component of the grid tariff needs to be calculated. This will vary depending on the energy supplier. The hour-by-hour values is affected by which month it is, the time of day, and whether it is a holiday or weekend. In this case, the holidays are specified in a variable, as well as a variable for daytime and night-time. As these values are dependent on the month, the daytime and night-time variables are defined with an *if statement*, used to specify which value to use. This makes it possible to calculate the price of the energy component by using the timestamp column in ‘df’ and use another *if statement* to set the energy component to the correct price corresponding with the various factors that will vary hour-by-hour. This is programmed in the Python file in lines 71 to 89.

In the main data frame ‘df’, the columns needed to calculate the hourly cost is the three columns: the energy use, spot price, and energy component. Most of the columns does not need to be modified further, as the necessary information is already set. The only column in need of modification is the spot price, as the 25% VAT needs to be accounted for. Therefore, a new column, ‘Import Spot’ is created in ’df’, which is a copy of the values from the spot price but multiplied with 1.25 (line 39-41). The hour-by-hour sum is then calculated by adding the columns for ‘Energy component, grid tariff' with 'Import Spot' and multiplying this with 'Energy use', programmed in the lines 85-88.

When looking at the total monthly or yearly energy cost, the capacity component of the grid tariff must be included. Considering this is a fixed additional fee every month it is done in a semi separate calculation. As explained previously in Section 2.1.1 xxx, it is necessary to find the mean of the three hours with the highest energy use from every month. This is done by making a new data frame 'df_aggregated' from 'df', where the function *groupby()* in Python is used, keeping the columns 'Month' and 'Day of Year', and modifies the data frame into having only one row for each day. The *groupby* function specifies that the value representing each day, will be the maximum value in the 'Energy use' column. To find the mean of the three highest values and the corresponding tier and additional cost, three empty lists are created so this information can be accessed easily. A *for-loop* is used to separate the data into a new data frame for each month, where the values from 'df_aggregated' is sorted in ascending order, and the mean of the three highest values are appended into the 'peaks' list. Resulting in a list with the mean of the three highest energy use values for every month. To find the tier and additional fee, a *for-loop* is used to investigate each value in 'peaks' and appends the corresponding tier and fee into the lists. This is programmed in lines 177-215.

By finding these values it is now possible to find the total energy use for each month and the whole year. To summarise, this cost is calculated hour-by-hour, adding the energy component of the grid tariff use with the import price, then multiplying with the energy use.

H.1.3 Overview of the Cost, Energy Use and Production

To get an overview of the result of several important factors, the data is summarized monthly. To view this data later, empty lists are created, where the monthly data can be saved. Lists were created for the energy need, the energy cost, the energy cost without the capacity component fee, and solar production from west, east and south. To be able to calculate the yearly sum for this data, variables were defined, to be used later. To separate the data, a *for-loop* is used to isolate each month by reading the data in sections from the 'Month' column in 'df', calculating January first, then February and so on. The sum of the different factors' value for every hour in that month is calculated and is added into the corresponding list. So, for every loop the lists will get a new summarized value, one for the energy need, one for the energy cost and so on. When the *for-loop* is done, a list with 12 values is created for every factor mentioned earlier. To find the total use, cost, and production for the year, another *for-loop* is created, which goes through every value in the lists and adds them together and saves them in the corresponding premade variable. This is programmed in the Python file in lines 221 to 263.

H.1.4 Mixed Integer Linear Programming

To investigate the impact of the aforementioned elements, such as shifting ToU and the use of a battery system and installing solar panels, the mathematical modelling technique Mixed Integer Linear Programming (MILP) will be employed. MILP is a modeling technique in which a linear function is maximized or minimized when subjected to various constraints, such as the dwelling's energy demand, PV-production, EV charging and the heating tank[55]. Pixii has previously worked with Eskil Gjerde on a Bachelor thesis where MILP is used to make a program that minimizes the total electricity cost by optimally controlling a battery system[56]. This Python program was developed in collaboration with Professor Geert De Maere of University of Nottingham, UK, where the main result was the development of a complex model of an optimalization. In this work a model was developed to optimize the energy system, which will be used in the current work. As this model is complex and difficult to program, the basic functionality around linear programming is acquainted with, and the necessary data and formulas are prepared.

The model is based on historical data, with other words it is calculated with perfect forecast. It is a simplification, where everything is optimized, if one were to use the system, it would have a slightly lower result.

H.1.5 Calculating and Plotting Mean Hourly Values for Spot Prices

To estimate if there is a potential for cost savings by shifting the energy load, a calculation of the energy prices in 2022 was completed. As one time-shift method is set to the average cheapest hour slots (Set 1: corresponds with the clock), while the other is not tied to the time of day and is set from the cheapest hours from day-ahead spot prices (Set 2: not tied to time of day). It is essential to calculate both sets of values as these will not be the same. The same method of calculation and plotting is used for both sets. However, when calculating the average mean of the cheapest to most expensive hours (Set 2) there is an additional step.

The imported dataset consists of hourly spot prices for a whole year. Using Python, the values are separated into a data frame, consisting of 365 columns, one for every day, and 24 rows, one for every hour. This data frame is duplicated, so one can be used for each set of calculations. The following is done only for Set 2: the columns are sorted in ascending order, meaning for every day the value of the cheapest price is in row 1, while the most expensive hour is in row 24. Following this, the mean of every row is calculated, creating a single column with 24 rows consisting of the mean of the 24 values each day. This result is then plotted in Python by specifying plot title, axis labels and the graph type. The results of the calculations are presented in Figure 3-5 xxx (Set 1) and Figure 3-6 xxx (Set 2).

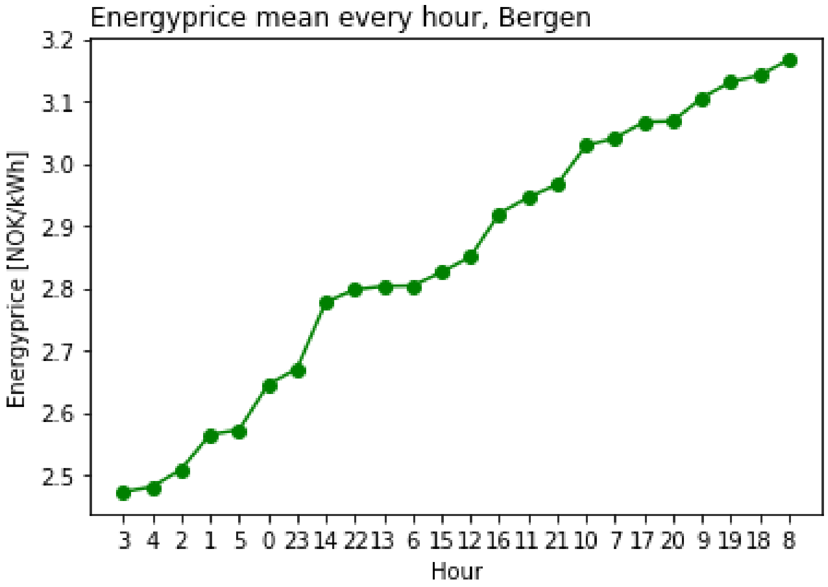


Figure H-1: Graph of the mean of the spot price hourly in 2022, Bergen.

The Figure 3-5 xxx shows the mean value of the spot price every hour in 2022. By reading the graph, this shows that on average the time 03:00 was the average cheapest hour in 2022, with a cost of 2.47 NOK/kWh. While the average most expensive hour is 08:00, with a cost of 3.16 NOK/kWh.

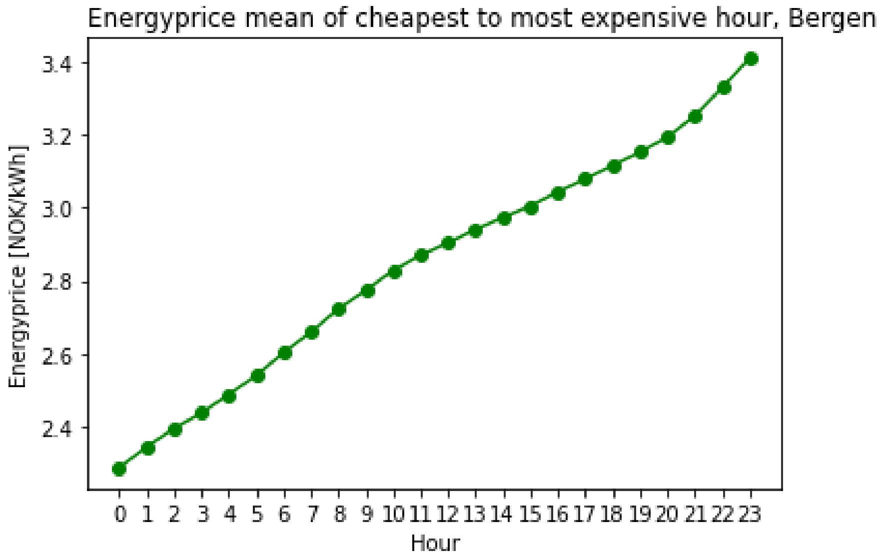


Figure H-2: Graph of the mean of the energy price, sorted in ascending order, Bergen.

Figure 3-6 xxx shows a graph with an estimate of what the energy price will be from cheapest to most expensive hour slot. With other words, the hours do not correspond with the hours of the day. The cheapest hour slot had an average cost of 2.28 NOK/kWh. While the most expensive hour slot has an average cost of 3.41 NOK/kWh.

This calculation is done in the Python file in between the lines 95 and 171. The numbers are calculated from line 95 to 121 and are plotted from line 123 to 171.