Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

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Economic value of peak shaving using charging container on construction sites

Bachelor's thesis in Renewable Energy
Supervisor: Mihir M. Hazarika
Co-supervisor: Siri Førsund Bjerland and Anna Dorthea Willassen
May 2023

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Bacheloroppgave

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Preface

This bachelor's thesis is produced by students of the Norwegian University of Science and Technology in Trondheim in their third and final year in the Renewable Energy Study Program. The group consists of three students specializing in energy storage. The title of the thesis is *Economic value of peak shaving using charging containers on construction sites* and is presented by Aneo Build.

Throughout the spring semester of 2023, this thesis has been produced. The thesis is the base for the evaluation of the subject FENT2900. In January of the spring semester of 2023, a pre-project was executed to initiate the work for the thesis. In March, a poster that included the framework and goals for the thesis was produced. An oral presentation was given in April, where aspects like the progress and further work were presented. These milestones have ensured a stable line of progress in the project.

Aneo Build provided the problem for the thesis, which initially was to make a model for economic value of peak shaving and battery efficiency. As all group members are specialized in energy storage, this was intriguing for the entire group. After realizing the scope of this initial problem, it was decided to mainly look into the economic value of peak shaving and change the name of the thesis. Working with the model has been challenging, as none of the authors have much experience with models or programming in general, but the learning curve has been steep.

The thesis consists of an analysis of the economic value of using charging containers for peak shaving. The target is construction sites using the charging containers to charge electrical construction machines. To calculate the values, a model has been developed. The model takes the necessary inputs in account to get an economic estimate of peak shaving for different kinds of construction sites.

The objective has been produced by the three group members, as well as Aneo Build's Siri Førsund Bjerland and Anna Dorthea Willassen. A thank you is directed towards Bjerland and Willassen for providing valuable data and supervision. Additionally, gratitude is directed towards Anders Dahl from Aneo Build for an educational and interesting tour around one of Aneo build's ongoing projects. A thank you is directed to professor Steven Boles for providing clarifications regarding charging and discharging batteries. Course leader Jacob Lamb deserves recognition and a big thank you for the time, flexibility and helpfulness he has provided regarding the project. Lastly, a great thank you is directed towards internal supervisor Mihir M. Hazarika for feedback, assistance and follow-up.

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Abstract

In 2021, a declaration was signed by seven of the largest cities in Norway - Oslo, Trondheim, Bergen, Kristiansand, Stavanger, Tromsø and Drammen. The declaration states that the construction industry in these cities will be emission free by 2030. To meet the goal of emission free construction sites, an electrification of the construction industry is a necessity.

A consequence of the increasing electricity demand is a larger load on the electrical grid. The grid is not dimensioned for this increased load. To limit the amount of power drawn from the electric grid simultaneously, power peaks, the government has implemented measures to encourage the population to distribute their power use.

In July 2022, a new grid tariff model was implemented. The new system makes high power peaks more costly. This can be a challenge for construction sites with electrical machines. The model produced in this thesis as well as communication with Aneo build reveals that electric machines normally need charging around lunch time. Power prices are generally higher during the day, and a high degree of contemporaneous charging leads to high grid tariffs.

Peak shaving is a strategy that can be enforced to reduce the total cost for electricity and grid tariffs. Peak shaving is a term that describes distributing the power drawn from the grid more evenly throughout the day, rather than using large amounts simultaneously and creating high power peaks. One method to achieve peak shaving is using energy storage solutions. Using an energy storage system to charge machines on a construction site can be cost-efficient, as the high power prices and high power peaks that lead to costly grid tariffs are avoided.

Throughout the development of this thesis, a model in Python has been developed. The model is based on the most regular charging patterns. The intention of the model is that Aneo Build can use it when planning a project with a customer. The inputs of the model include information regarding the location and duration of the project, as well as the construction machines, charging solution and network company. Using the information provided by Aneo as well as functions and preset values for power prices and grid tariffs, the model calculates the economic value for peak shaving. The model estimates the cost of electricity and grid tariffs with and without a charging solution from Aneo. Then, the total cost with a charging solution is subtracted from the total cost without a charging solution. The difference is an estimate of the customer's economic savings due to peak shaving.

With the finished model, three fictitious cases have been simulated to determine which input has the largest impact on the total economic value of peak shaving. The results revealed the that a bigger sized machine park has the most economic value of peak shaving using charging containers, as long as the total power peaks is not higher than the highest price level for grid tariffs. Additionally the price area the project is located in, as well as grid operator, has a large impact on economical savings. This is due to the large difference in grid tariff prices between grid owners.

Samandrag

I 2021 blei ei erklæring signert av dei 7 største byane i Noreg - Oslo, Trondheim, Bergen, Kristiansand, Tromsø og Drammen. Erklæringa seier at innan 2030 skal alle anleggsarbeid i byane vera utsleppsfrie. For at dette målet skal vera oppnåeleg må anleggsarbeida elektrifiserast.

Ein konsekvens av det aukande elekrisitetsbehovet er ei større last på kraftnettet, noko det ikkje er dimensjonert for. For å avgrensa effektoppar, har myndigheitene iverksatt tiltak for å oppfordra folk til å fordele kraftforbruket sitt betre.

I juli 2022 blei ein ny nettleige modell innført. Den nye modellen gjer det dyrare å trekke store mengder kraft på ei gong. Dette kan vera utfordrande for anleggsplassar som nyttar elektriske maskiner. Modellen som har vorte utarbeida i denne oppgåva samt kommunikasjon med Aneo build har vist at elektriske anleggsmaskinar vanlegvis krever lading rundt lunsj tider. På dagtid kan kraftprisane vera høge, og med dei kraftkrevande maskinane blir det høge nettleiger.

Peak shaving er ein metode som kan redusera dei totale kostnadane for kraft og nettleige. Begrepet peak shaving beskriver tiltak for å utjamne høge effektoppar. Ein måte å gjere dette på er ved bruk av energilagringsløysingar. Ved å trekke kraft frå denne til å lade anleggsmaskinane kan ein auke kostnadseffektiviteten, ved å unngå dei høge kraftpristoppane og effekttoppane som fører til høge nettleige kostnadar.

I arbeidet med denne oppgåva, har ein modell vorte utvikla i Python. Modellen er basert på dei mest gjentakande lademønsterene. Formålet med modellen er at Aneo Build skal bruka denne i konsultasjon med kundar. Inndataen til modellen inkluderer informasjon om lokasjonen og lengda til prosjektet, samt anleggsmaskinene som er brukt, ladeløysing og nettselskap. Med den gitte informasjonen frå Aneo Build, saman med funksjonar og førehandssatte verdiar for kraftprisar og nettleige, reknar modellen ut den økonomiske verdien av peak shaving. Modellen estimerer kostnadane for kraft og nettleige med og utan ladeløysing frå Aneo. Sidan vert total kostnaden med ladeløysing trekt frå den totale kostnaden utan ladeløysing. Differansen er eit estimat av kundens økonomiske sparing med peak shaving.

Med den ferdige modellen har tre fiksjonelle caser vorte simulert for å finne ut kva inndata som har størst påverknad på den totale økonomiske verdien av peak shaving. Resultatet viste at ein større maskinpark har størst økonomisk lønsemd av å peak-shave ved å bruke ladecontainer, så lenge den totale effekttoppen for maskinparken ikkje er høgare enn det høgaste prisklassenivået for nettleieprisar. I tillegg viser det seg at prisområdet prosjektet føregår i og ka for eit nettselskap som er brukt vil ha ein stor innflytelse på dei økonomiske besparelsane. Dette på grunn av store skilnadar mellom nettselskapane sine prisar.

Contents

List of Figures

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List of Abbreviations

Abbreviation	**Definition**
AC	Alternating Current
ATES	Aquifer Thermal Energy Storage
CC	Constant-Current
CCS	Combined Charging System
CENS	Costs of Energy Not Supplied
CV	Constant Voltage
DC	Direct Current
DoD	Depth of Discharge
ESS	Energy Storage System
EST	Energy Storage Technology
HES	Hydrogen Energy Storage
HLH	Heavy Load Hours
LIB	Lithium-ion Battery
NSL	North Sea Link
PHES	Pumped Hydroelectric Energy Storage
SEI	Solid Electrolyte Interphase
SoC	State of Charge
SOH	State of Health
TES	Thermal energy storage

List of symbols

I	Current, [A]
I_{line}	Line current, [A]
P	Power, [W]
Q	Reactive Power, [VAr]
R	Resistance, [Ω]
S	Apparent Power, [VA]
U	Voltage, [V]

Greek Symbols:

η	Efficiency, [%]
ρ	Phase Angle, [deg]
τ	Time Constant, [-]

1 Introduction

This chapter provides the introduction for this thesis. First, the background and motivation for the thesis are introduced. Then, the objective is presented. Limitations for the projects are explained further, and finally, the structure of the thesis is presented.

1.1 Background and Motivation

The building and construction industry in Norway accounted for more than two million tons of climate gas emissions in the country in 2021 [1]. Ninety five percent of the emissions from this industry comes from transportation and operation of construction machines. Oslo and six other large cities in Norway have committed to making all building and construction activities in the cities emission free by 2030 [2]. To achieve the goal of emission free construction sites, using electric construction machines rather than construction machines powered by fossil fuels is necessary [3]. Aneo Build owns and distributes several charging solutions to construction sites [4].

The electric grid faces multiple challenges today, especially concerning grid capacity. In some areas of Norway, the grid is unable to supply enough electricity to meet the demands [5]. This is in spite of the existence of multiple laws and regulations that are intended to ensure a stable energy supply [6, 7, 8]. With the ongoing electrification in Norway, the power grid must be developed to provide electricity all over the country [9]. However, grid upgrades can be costly. Therefore, a new grid tariff model was implemented in Norway in 2022. Making high power peaks more costly, the new grid tariff system is intended to motivate people to shift their power usage [10].

The new grid tariff model makes it costly to use large amounts of electricity from the power grid simultaneously [10]. Therefore, charging multiple construction machines on a construction site at the same time can come at a great cost. In addition the power prices are higher during the day, which might contribute to an even higher cost of charging [11].

To counteract the potential for high costs, power peak shaving is a possible approach. Peak shaving refers to the act of reducing high power peaks on the electric grid by distributing the electricity that is drawn from the grid evenly over the course of the day [12]. Using a charging container with batteries for charging electric machines on a construction site is a method to achieve peak shaving [13]. This leads to lower grid tariffs, as well as lower power costs. Through this thesis, the economic value of peak shaving on a construction site will be researched, and a model that estimates the value is produced. A charging solution from Aneo Build will be the basis for the model.

1.2 Objective

Aneo Build owns and rents out charging solutions to construction companies [4]. They are interested in estimating the economic value for peak shaving that is achieved using these solutions. By analyzing data from former Aneo projects, relevant values will be found and used to construct a model that estimates the value of peak shaving with Aneo Build's products. The inputs for the model include information regarding the capacity of the charging container and the grid, number of construction machines and information about each machine, as well as inputs related to area and project duration. The output of is a table showing the costs of grid tariff, power price and total cost for the project.

1.3 Limitations

This thesis is limited by data provided by Aneo Build. The model is based on data provided regarding former projects. Using charger containers for this purpose is still a rather new practice, which limits the amount of data available and therefore restricts the accuracy of the model.

No specific data from the construction machines has been provided, only which machines have been used. Without this information, the exact amount of consumed power from operation is not known. Instead, this has been assumed from looking at the power provided from the container to the machine combined with the known characteristics of the machine's battery. This causes for some uncertainties as there is no information on the state of health of the battery, which influences the battery's performance [14].

Another limitation is the limited knowledge the authors of this thesis possess about construction sites. Many assumptions have been made due to this, and the degree of accuracy is uncertain. However, close communication with the external supervisors from Aneo Build and a field trip to one of their construction sites has provided clarity and justification around many of the assumptions. All assumptions are presented and explained in Section 4.4.

Power prices are difficult to predict as they are associated with many uncertainties [15]. Changing the power prices used in the model will make the model output more precise. This could end with results different from the thesis, if the high cost periods are drastically different from the ones used for the model. It has been proved difficult to find power prices for every hour further back in time than 2021. The used price data is also from years that are not characteristic compared to other years. This can result in calculations which are not representative for longer time periods.

1.4 Structure of thesis

The thesis begins with providing the theoretical background which the thesis is based on in Chapter 2. The chapter covers relevant theory concerning the Norwegian construction industry and the electrical grid. It presents different energy technology storage systems, like chemical batteries, which used by Aneo's products. Additionally, chemical batteries might be the most suitable for energy storage purposes on a construction site. Theoretical background for power production and future power prices is also introduced in this chapter.

Further, in Chapter 3, a description of the project is provided. This includes a presentation of the industry partner for this thesis, as well as their products to provide a sufficient understanding of the thesis and model. A field trip that took place on Trondheim Cathedral School on May 10^{th} is also presented in this chapter.

After describing the project, the methodology is presented in Chapter 4. Firstly, the data and software used in the thesis is presented. Secondly, there is a summary on the two projects that were analyzed to produce the model. Further, the methodology for building the model is explained, including a description of the electric circuit system for one of Aneo Build's products. Then, the background for the chosen charging patterns as well as power prices are presented. Additionally all assumptions made throughout the project are explained.

Next, the cases which are used for simulations in the model are described. Then, the results from the simulations are presented in Chapter 5 and then later discussed in Chapter 6. Lastly, the conclusion for the thesis is presented in Chapter 7.

2 Theory

When gaining insight into a project, it is important to acquire the necessary understanding of the systems involved. Therefore, this chapter contains the theoretical background relevant for this thesis, as well as the model that has been produced in the project period. The chapter covers relevant theory concerning the Norwegian construction industry, the structure of the electrical grid, including laws and regulating, technical challenges, and the new grid tariff model that was implemented in 2022 [10]. Different methods for peak shaving will be explained further. Then, different energy storage technologies are presented and a separate section for chemical batteries as this is the technology used in the model. Lastly, theoretical background for current and future power production and power prices is provided. The objective of this section is to provide an insight and comprehension of how the elements are interconnected.

2.1 The Norwegian construction industry

In 2009, 95% of the emissions from the building and construction industry in Norway came from the transportation and operation of construction machines. In the same year, this industry accounted for 1.2% of the total amount of climate gas emissions [2]. According to newer data from SSB, all industries and households in Norway had a combined amount of climate gas emission of 64.5 million tons CO_2 equivalents in 2021. In the same year, the building and construction industry accounted for 2.2 million tons CO_2 equivalents [1]. This makes up approximately 3.4% of the total amount of climate gas emission from Norwegian industries and households.

In 2021, multiple of the largest cities in Norway committed to making the building and construction industry emission free [16]. Trondheim, Bergen, Oslo, Drammen, Tromsø, Stavanger and Kristiansand signed a declaration which states that the municipal section of the building and construction industry in these cities will become zero-emission by 2025. Further, the declaration specifies that the entire building and construction industry in the committed cities will be emission free by 2030 [2].

According to statistics from SSB, around 229 500 Norwegians were employed in the building and construction sector in 2021. The combined amount of people employed in this industry for the committed cities are around 71 500. This makes up approximately 31.2% of the employees in the building and construction industry in the country for the year 2021 [17]. This could mean that if all emissions in these areas were cut, it might have a great effect on the total amount of emission in the construction sector of Norway.

In 2020, the Norwegian Environment Agency released a report called *Klimakur 2030*, which can be translated to *Climate Cure 2030.* In summary, the report deals with measures that must be implemented to significantly decrease emissions in Norway by 2030. This report states that non-road mobile machines and other transport have the potential for reducing emissions with 4 million tons CO_2 equivalents from 2021 to 2030. Non-road mobile machines include construction machines, tractors and other machinery used in sectors like building and construction, agriculture and industry [9].

2.2 The power grid

The power grid in Norway is divided into three levels: the transmission grid, the regional grid, and the distribution grid. The transmission grid, which is owned and managed by Statnett, is a high voltage grid, normally with 300-420 kV lines. It connects big power producers and consumers in the entire country and enables power exchange between them. The total line length of the transmission grid is 11 000 km [18]. The transmission grid makes up the main power lines nationwide and is also connected to electric grids in foreign countries, enabling power export and import [19]. Figure 2.1 shows the transmission grid in 2020.

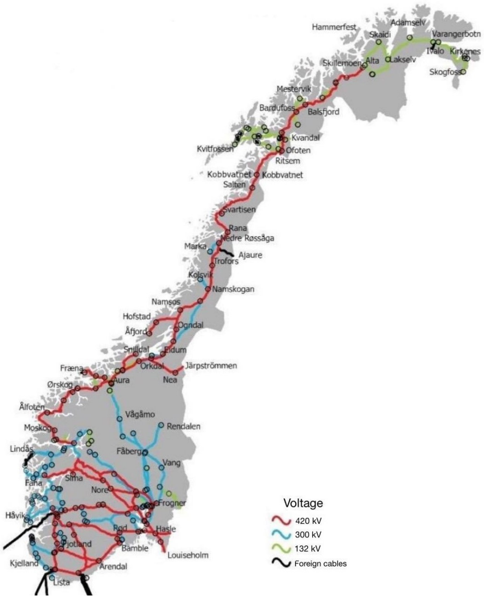


Figure 2.1: An illustration of the Norwegian transmission grid in 2020 [20].

The regional grid works as a connection between the transmission grid and the distribution grid and can also connect power producers and consumers with a high voltage level as it normally contains lines with a voltage of 33-132 kV. The regional grid has a total line length of 19 000 km and is owned and managed by local network companies. In Norway, there are approximately 100 different network companies [21]. Further in this thesis, such companies will be referred to as grid owners, grid operators or network companies interchangeably [19, 18].

The distribution grid distributes electricity to the consumers, such as households or industry buildings. The distribution grid consists of lines with a voltage of 0.23-22 kV, and has a total line length of 100 000 km. Like the regional grid, the distribution grid is owned by local grid owners [19, 18].

Building and investing in the power grid can be costly. Therefore, there is no competition between the grid operators in each area. If two companies invested in building or expanding the grid in the same area, there would not be enough profit from the operation to cover the cost of building the grid. For this reason, each section is monopolized by one company who owns the electric grid on the regional or distribution level. To prevent the grid owners from exploiting the customers, the Norwegian authorities have established extensive regulations. Some central regulations will be presented in Chapter 2.2.2 [19].

Norway is also divided into five main price areas. Power prices vary between these areas because of differences in power production and consumption. Also, electricity is not able to flow freely through the country due to insufficient grid capacity. The price areas are intended to ensure efficient utilization of power resources, quick communication to the market regarding deficiency and surplus in power production as well as proper operation of the system. Figure 2.2 shows a map over the different price areas in Norway [22].

Figure 2.2: Map of the different price areas in Norway [22].

2.2.1 Different types of transmission lines

The distribution grid in Norway mainly consists of TN- and IT- grid. The IT-grid is dominating in the Norwegian distribution grid, but new facilities are built as TN-grid. The IT-grid has a line voltage of 230 V and is constructed with a delta connection. While the TN- grid has a line voltage of 400 V and has a wye connection [23].

There are two types of current; Alternating Current, AC, and Direct Current, DC. AC supplies Norwegian homes with electricity, while DC technology can be found in batteries. When the current flow is only one way, direct, the current can be referred to as DC. When the current flows in both direction, it is referred to as AC. Due to AC's ability to change voltage, this is the preferred current form in most countries. Changing voltage leads to less power loss when transporting the electricity. The power is transported with high voltage through the power lines, before the voltage is transformed to low voltage and transported to the customer. AC can be transformed into DC when needed, and vice versa [24].

Electric AC circuits can either be described as resistive, inductive, or capacitive, depending on the load connected to the AC voltage source. In a resistive AC circuit, the sinusoidal waves for current and voltage are in phase with each other, meaning that the current and voltage peak appears at the same time unit. When there is a time difference between the current and the voltage, the circuit is inductive if the current *lags* the voltage. The circuit is capacitive if the current *leads* the voltage. Current lagging voltage means that the peak appears later than the voltage peak, and current leading voltage means that it appears before the voltage peak. Figure 2.3 illustrates how the sinusoidal voltage and current waves look like in a resistive, inductive, and capacitive circuit [25, 26].

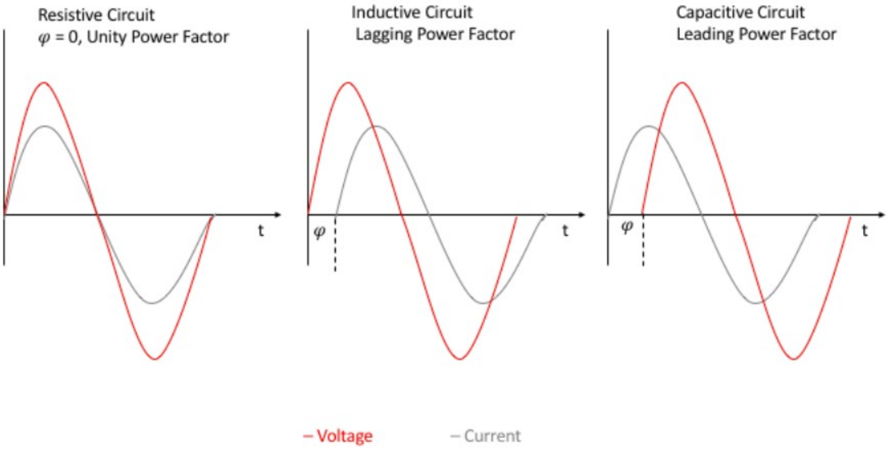


Figure 2.3: Voltage VS current, sinusoidal waves in AC circuits [26].

The time difference between the current and voltage peak in inductive and capacitive circuits can be referred to as the *phase angle* φ. For resistive circuits, the phase angle is always zero because there is no time difference between the voltage and current sinusoidal waves. When the phase angle does not equal zero, the AC circuit has an active power, reactive power, and an apparent power. Apparent power is the total amount of power produced by the voltage source, and can be calculated using Equation 2.1 [25, 26].

$$|S| = \sqrt{P^2 + Q^2} \tag{2.1}$$

where:

- S is the apparent power in kVA
- P is the active power in kW
- Q is the reactive power in kVAr

Active power is the power that delivers the actual work to the load in the AC circuit, while reactive power is often described as the waste power. The apparent power is the total amount that must be produced to deliver the needed active power to the load. The efficiency of a power system can be defined as the ratio of active power to total apparent power required. In other words, it measures how much of the input power is used to perform useful work, and how much is lost as non-productive energy. The active power delivered to the load can be calculated with Equation 2.2 for single phase AC circuits [25].

$$P = U \cdot I_{line} \cdot cos(\varphi) \tag{2.2}$$

where:

- U is the voltage between phases in V
- I_{line} is the line current in A
- φ is the phase angle between vectors I and U

For three-phase line to line AC circuits, the active power is calculated with Equation 2.3 [25].

$$P = \sqrt{3} \cdot U \cdot I \cdot cos(\varphi) \tag{2.3}$$

AC circuits can be improved to be more efficient and resistive. For inductive circuits, adding a capacitor can minimize the phase angle and improve the efficiency of the circuit. For capacitive circuits, the efficiency can be improved by adding an inductor. The phase angle will then be close to zero. The active power delivered for a three-phase line to line circuit can be calculated with Equation 2.4 [25].

$$P = \sqrt{3} \cdot U \cdot I \cdot \tag{2.4}$$

2.2.2 Laws and regulations

A stable, reliable power supply is essential for a modern society. A balance between the amount of energy produced and energy consumed is required to ensure a secure and dependable power supply in Norway. Therefore, numerous laws and regulations are implemented. Additionally, laws are enforced to prevent grid owners from capitalizing on their customers, although the different areas are monopolized. Another purpose is to ensure that enough capital is invested in the electric grid, to make sure the capacity and quality of the grid is adequate [19].

One significant law regarding the electric grid is the *Act relating to the Generation, Conversion, Transmission, Trading, Distribution and Use of Energy etc.* [27]. This is often referred to as the *Energy Act*. The purpose of the Energy Act is to ensure that the energy supply chain is conducted efficiently and in a manner that promotes the interests of the Norwegian society, including public and private interests [6].

A significant section of the Energy Act is paragraph 3-3. Paragraph 3-3 deals with mandatory delivery and states that the grid operator is obligated to provide electric energy to all customers within the geographical boundaries of their concession. Further, it is specified in the Energy Act paragraph 3-3 that the network company is obliged to invest in expanding or developing the power grid if needed, for instance in the event of increased consumption [28].

In areas where the electrical grid is unable to meet the energy demand, the network company is responsible for finding a solution. This is the case in Lierne municipality in Trøndelag, which experience a deficiency of power in the industry. Tensio, which is the grid operator in most municipalities in Trøndelag, has rented a large battery from Eidsiva to meet the demand when the access to electricity is too low [5].

The grid tariff price is constructed by the grid owners and regulated with authority in the Energy Act [29]. Norway's new grid tariff model will be presented and described in Section 2.2.4. The Regulation Authority for Energy, RAE, sets an annual revenue limit for each grid operator. The revenue limit is the base for determining the cost of the grid tariff for the grid operator's customers. The revenue limit is decided by two factors: cost basis and cost standard. The cost basis is based on the actual revenue of the grid operating company, and accounts for 40% of the revenue limit. Cost standard is based on what the company's revenue would be if the operation, development, and utilization of the grid was according to the standard. In other words, the fictional revenue of an average grid operating company that performs neither better nor worse than a set of standards is the basis of the cost standard. This factor accounts for 60% of the revenue limit. The grid owners who operate the grid more cost efficiently than the average, gain a higher cost standard than cost basis. The yield for such companies is therefore higher than grid operators with a cost basis that is higher than the cost standard. This is an incentive for grid owners to operate, develop and utilize the grid efficiently [21].

The Norwegian Regulation of Quality of Supply is a significant regulation for the Norwegian power system. All parties connected to the electric grid have a degree of influence of the quality of the electricity supplied through the grid. Therefore, this regulation applies to owners, operators, and users of the Norwegian power grid. The Regulation of Quality Supply includes requirements related to continuity of supply, voltage quality and commercial quality. It is stated that in the case of interruptions or a reduced degree of quality, the network company is obligated to fully restore the power supply as quickly as possible. Network companies must report deviations in frequency and voltage quality, and customer complaints regarding power quality must be investigated appropriately [7].

When a power outage occurs, or if energy is not supplied to the customers for other reasons, Costs of Energy Not Supplied, CENS, are deducted from the network company's allowed revenues. CENS is a system that calculates the value of the customers' lost load. This system works as an incentive for grid operators ensure sufficient maintenance of the power grid. Additionally, the CENS arrangement is a motivation for the network companies to make the necessary investments in the grid to prevent power outages and ensure a satisfactory development of the grid [8].

2.2.3 Technical challenges with today's power grid and production

Due to the global threat of climate change, there is an increasing focus on electrification in Norway. Substituting fossil fuels with renewable energy sources is one of the main requirements for diminishing the effects of climate change. To accomplish this, industry, transportation, and other power consuming sectors need to transition to electricity or other low-emission sources as the main power source [9]. This section will cover some important technical challenges concerning the electric grid, both now and in the future.

Because of the electrification, large amounts of electrical appliances draw power simultaneously in some time periods. This creates high power peaks, or Heavy Load Hours, HLH. A result of HLH is grid loss. Grid loss is the loss of electrical energy in the grid which always occurs during transport of electricity. The issue with HLH is that the grid loss increases with the squared value of the current, as shown in Equation 2.5. If the amount of current is increased, so are the losses. By increasing the voltage, the same amount of power is transported, but with less current and lower loss. This is why the transmission grid, which includes the longest and most important cables, operates with a high voltage [30].

$$P_{load} = R \cdot I^2 \tag{2.5}$$

where

- P_{load} is the power of the load
- R is the resistance of the cable
- I is the current

One of the biggest technical challenges with the power grid in Norway is the capacity. In the future, both power production and power consumption are expected to increase. The grid must distribute this power, but in many of the areas where new industry and electrification of industry is anticipated, the grid capacity is limited. To accommodate this issue, developing the grid is a necessity [9]. For grid operators to extend the grid, they must have a concession from the authorities. Getting a concession granted can be a slow process because the authorities must consider the trade-off between the benefits of the case to the cost for the community. One measure made from the government is the arrangement of a public committee who suggests actions to reduce the time to evaluate concessions to develop the grid [31, 32].

Another challenge for the power grid is optimal power flow regarding its capacity. It is expected that power production from costumers and power plants will increase in the future [32]. This forces the grid to manage a bigger energy production, but also to deliver more energy to where it is needed. When there is a power surplus in one region and a large amount of electricity is sent to a region with a power deficiency, a phenomenon called *electronic bottleneck* may occur. Limitations in the amount of electricity which a power line can receive simultaneously can prevent the transport of power. Figure 2.4 shows a map over the areas where electronic bottlenecks occur in Norway, as well as the different price areas that were presented in Section 2.2. The green squares mark the areas that are prone to electronic bottlenecks [33].

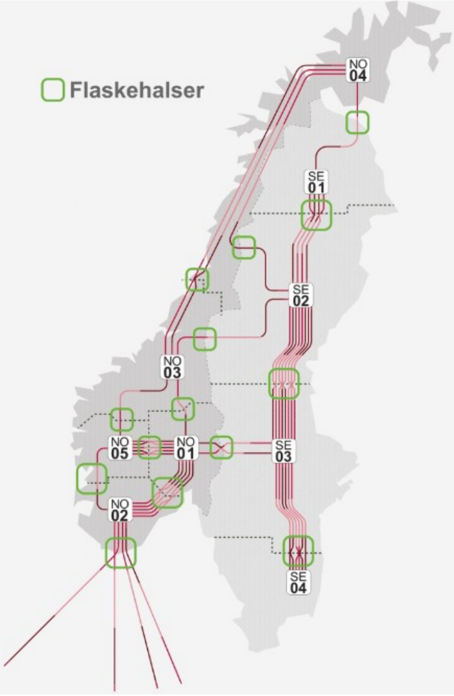


Figure 2.4: Price areas and electronic bottlenecks in Norway [33].

While electronic bottlenecks are challenging some places, some areas in Norway lack the infrastructure to provide electricity to industry and commercial activities. An example is Lierne, which was mentioned in Section 2.2.2. The existing power grid in Lierne, as well as multiple other municipalities, does not have the capacity to support the energy demand of new establishments and industry. An upgrade of the electric grid can cost hundreds of millions of kroner, so other options are considered [5].

The electrical power grid is dependent on having a balance between power production and power consumption. At all times, the amount of energy produced must be the same as the amount of energy consumed and exported. This is because electricity is produced the moment it is consumed. The balance is measurable by frequency, which indicates the rotational speed of the aggregates in the Nordic electrical system. When there is a balance between production and consumption, the frequency of the electric grid operates according to the standard. In the Nordic electrical system, a grid frequency of 50 Hz, with a range of ± 0.10 Hz is defined as normal operation. If the electrical frequency is lower or higher, the grid operates with a frequency deviation. Figure 2.5 is retrieved from Statnett and shows a fragment of the Nordic power balance, illustrated with frequency, from April 26th, 2023, 11:01-11:15. Although the figure only illustrates the frequency over 15 minutes, frequent observations have shown that the graph generally is rather consistent [11].

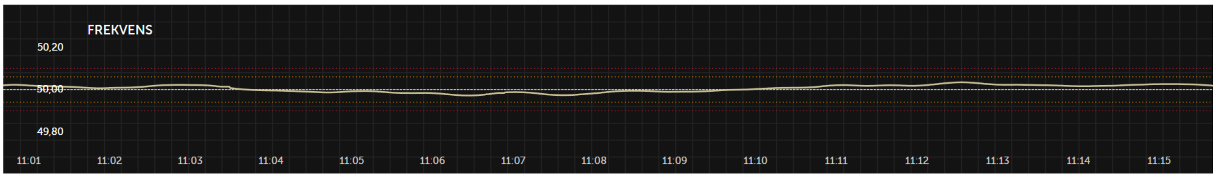


Figure 2.5: The grid frequency on April 26th, 2023, 11:01-11:15 [11].

Frequency deviations occur when there is an imbalance between power production and consumption. If the load of the electric grid increases without an increase in the production, the grid frequency decreases. Similarly, if the energy generation increases without an increase in demand, the grid frequency increases. If the frequency exceeds the range of normal grid operation, the power system's reliability, security, efficiency, and operation are affected. Additionally, the system's load performance can be diminished, and transmission lines can experience an overload. If the frequency deviation remains for a longer time, a total blackout of the entire power system can occur. Traditionally, frequency regulation is performed by increasing or decreasing power production in power plants. However, energy storage systems can regulate the power system's frequency and provide balance by reacting to changes nearly instantly [13, 34, 11].

2.2.4 The new grid tariff model

One possible solution to issues related to grid capacity could be to expand and upgrade the electric grid nationwide, to accommodate the increase in power production and consumption. However, expanding the power grid would lead to great economic expenses and getting concessions granted can take a long time. It would also be an extensive intervention in the surrounding nature, perhaps causing critical disturbance in the affected ecosystems [35, 31].

In 2021, the Norwegian government decided that a new model for grid tariff would be implemented in 2022. This new model was designed to facilitate more efficient usage of the electric grid. Additionally, the new model aims to reflect the actual costs of investing in, operating and maintaining the grid, making the tariff distribution fairer [36].

The Norwegian grid tariff model is based on both fixed and variable costs. The main difference between the new and the previous model is that the new version has fixed costs at different price levels. The price level at which the customer belongs to is decided by the average of the three hours each month where the customer's power peaks are the highest. The three hours that the fixed cost is based on must be distributed between three different days. The variable cost is calculated with a non-fluctuating price for power used. There is also a consumption fee of 0.1541 kr/kWh, and Enova tax of 67 kr/year. Table 2.1 shows an overview over the different price groups and how the grid tariff is calculated for costumers with an expected yearly consumption below 100 000 kWh. In Appendix C, prices for the biggest network companies in Norway can be found. The prices are provided by Aneo Build. The overview consists of prices for the network company Tensio. Grid tariff prices vary between network companies, and Tensio was selected to present in the thesis because Tensio is the grid operator in most of Trøndelag [5]. After researching the grid tariffs for specific network companies, it has become evident that the prices change over time [10].

Table 2.1: Grid tariff prices for Tensio, expected yearly consumption below 100 000 kWh (data provided by Aneo Build)

Expected yearly consumption below 100 000 kWh			
Fixed cost		**Variable cost**	
Average of three highest monthly power peaks, (kW)	**Monthly cost (kr)**	**Day price (kr/kWh)**	**Night/weekend price (kr/kWh)**
25-50	729,00	0,13	0,06
50-75	1 144,00	0,13	0,06
75-100	1 560,00	0,13	0,06
100-150	2 253,00	0,13	0,06
150-200	3 084,00	0,13	0,06
200-300	4 469,00	0,13	0,06

Table 2.2 shows an overview over the grid tariff prices for costumers with an expected yearly consumption above 100 000 kWh. As seen in the table, there is an additional cost for customers with an expected yearly consumption above 100 000 kWh. The prices are provided by Aneo Build.

Table 2.2: Grid tariff prices for Tensio, expected yearly consumption below 100 000 kWh (data provided by Aneo Build)

Expected yearly consumption above 100 000 kWh			
Season	**Fixed cost (kr/kWh/month)**	**Variable cost (kr/kWh)**	**Additional cost (kr/month)**
Winter (Nov-Apr)	46,00	0,04	257,50
Summer (May-Oct)	30,00	0,04	257,50

The new grid tariff model might be a challenge for the construction industry, as this industry aims to be emission free by 2030 in multiple Norwegian cities [2]. Using electric machines rather than fossil fueled machines requires charging during the workday, due to the machine's battery capacity. For instance, a Zeron ZE210 construction machine can operate for two to six hours without charging [37]. As the power prices vary through the day, it could be strategic to charge the machines when power prices are low. However, there are some times that are more beneficial for charging, for instance during lunch time on a construction site. Charging multiple appliances or machines from the electric grid simultaneously creates high power peaks, leading to a high grid tariff. In other words, using large amounts of electricity when it is at its most inexpensive, might not lead to the lowest total cost. The new grid tariff model can cause high costs, even when most of the power has been drawn from the grid during cheap hours [10].

2.2.5 Peak shaving

Peak shaving is a strategy that can be used to reduce costs regarding electricity during peak periods when energy demand is high. Peak-shaving means distributing the electricity that is drawn from the power grid evenly throughout the day, instead of drawing large amounts of power simultaneously. Figure 2.6 shows a graph for power consumption over time. The consumption from the grid during the highest peaks are redistributed, so the load after shaving has a much lower peak than the load before shaving. The same amount of power is used, but drawn from the grid at a different time [12].

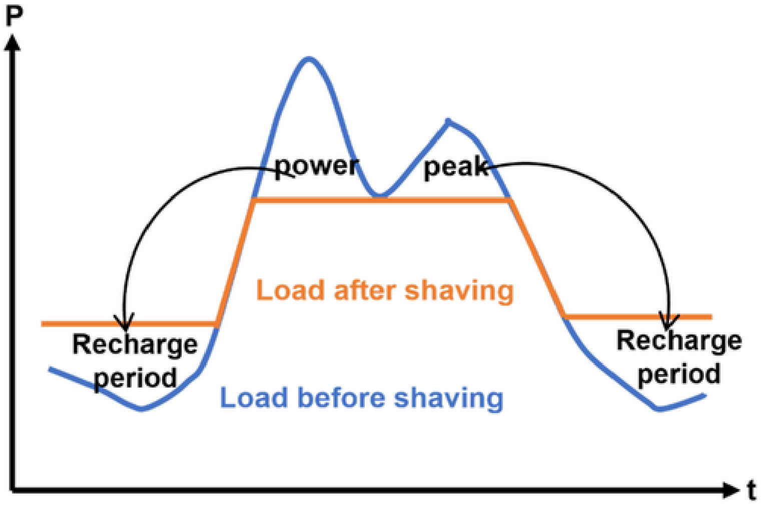


Figure 2.6: Peak shaving [38].

Peak shaving can be cost-saving, both concerning the new grid tariff model, as well as the fluctuating power prices. Regarding power prices, peak shaving can reduce the costs by redistributing the power usage to time periods where power prices are low. To reduce costs related to the new grid tariff model, peak shaving can be implemented to reduce the contemporaneousness of electricity usage to reduce high power peaks [12].

One of the methods that can be used to achieve peak shaving is lowering the total energy usage by implementing energy saving methods, such as energy-efficient technologies. Technology that demands less energy will decrease the energy demand, which lowers the power peaks. Additionally, using renewable energy for self-produced energy reduces the amount of electricity drawn from the power grid. This leads to lower power peaks and lower power load supplied by the grid. As explained in Section 2.2.4, lower power peaks can be cost reducing regarding the new grid tariff model. Lowering the total power consumption can also reduce the grid tariff because the variable cost is based on total consumption. Peak shaving and reducing the power consumption can also be cost reducing regarding power prices [12, 39].

Another method to achieve peak shaving is by shifting non-critical energy usage to hours with a lower energy demand when the strain on the power grid is low. The aim of Norway's new grid tariff model is to accomplish this, by incentivizing efficient usage of the electric grid. In private households, distributing the electricity usage throughout the day can be done by, for instance, charging any electric cars at night or running the dishwasher after the clothing dryer has finished its cycle [10].

While peak shaving can significantly reduce the grid tariff and power costs, the approach has other benefits. As described in Section 2.2.3, the electrical system is dependent on having a balance between power production and consumption. An unpredictable and fluctuating pattern of production or consumption can cause complications in the power system. Because of Norway being supplied mainly from renewable, weather dependent energy sources, the production can be rather unpredictable [32]. Implementing peak shaving strategies, especially in areas with high demand for electricity and a high degree of contemporaneousness, enables a more stable and predictable consumption pattern that might be advantageous for the power balance and grid frequency [34, 13].

Using an energy storage system, ESS, is also a possibility for peak shaving. On a construction site, an ESS can be used to charge the electric construction machines. By charging the energy storage system evenly throughout the day and then using it to rapid charge the machines when needed, high power peaks are prevented. Connecting the ESS with a rapid charger to the construction machine, lowers the power peaks from the grid. Instead of having a surge of power drawn from the grid, the power is supplied from the ESS. This leads to lower total cost because the power peaks are considerably smaller with the system. By implementing peak shaving strategies, facilities can help reducing the strain on the power grid and promote more sustainable energy use, while simultaneously reducing costs [12].

2.3 Energy Storage Technologies

One way to achieve peak shaving is by storing energy in periods with low demand, and using the stored energy when demand is high. There are many different technologies which have this ability. Several energy storage technologies will be presented in this section. Although some of them are not directly relevant for this thesis, as batteries are the focal point, it is significant to gain a basic understanding of different energy storage technologies and to gain a broad perspective of this sector. Chemical battery technology is the most relevant technology for this thesis, as a chemical battery is used in Aneo Build's charging containers. In this section, some energy system technologies will be presented and compared. In Section 6, which energy storage technology is the most applicable for peak shaving on a construction site.

2.3.1 Hydrogen energy storage

A technology that has experienced a rapid development in the last decades is hydrogen energy storage systems, HES. Hydrogen is widely used in different industries and sectors, such as metal refining and the food industry. Hydrogen can be produced using various methods, such as extraction from fossil fuels, by reacting steam with methane, or by electrolysis. Renewable energy, non-renewable energy, nuclear power, and biomass are the main energy sources used in hydrogen production. This thesis will not go further into detail about the different methods or feedstock used in hydrogen production and storage [40, 15].

Electricity can be generated using hydrogen by using, among others, fuel cell technology. A fuel cell converts chemical potential energy into electrical energy by conducting electrochemical reactions. There are several fuel cell technologies on the market, but these will not be presented in this thesis. [40].

Using hydrogen for energy storage has both benefits and disadvantages. Different feedstock and methods for production have both positive and negative sides. For instance, hydrogen production from biomass cuts the cost of municipal solid waste disposal, it is more sustainable, and has less CO_2 emissions than non-renewable sources. However, the availability of biomass might vary throughout the year and over the seasons, making biomass an unreliable source [40].

Using renewable energy to produce hydrogen for energy storage has no emissions of neither greenhouse gases nor gases that are harmful to human health. Additionally, renewable energy power plants can be located far away from the demand site. Therefore, it can be beneficial to use renewable energy to decrease the need for transportation of renewable energy from the power plant to the consumer. On the other side, renewable power is rather unpredictable, as it is highly dependent on weather conditions [15]. Also, hydrogen is less energy efficient than using electricity directly as an energy carrier. Energy loss and reduced efficiency are results of having multiple steps in the energy chain. There are also few hydrogen stations in Norway today, which can be a challenge for vehicles and machines powered by hydrogen. Figure 2.7 shows a simplified illustration of a chain where hydrogen is produced using renewable energy and then used to power a vehicle [40, 41].

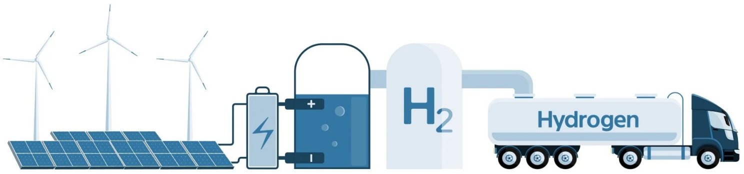


Figure 2.7: A simplified illustration of hydrogen produced with renewable energy, used to power a vehicle [42].

2.3.2 Pumped hydroelectric energy storage

Pumped hydroelectric energy storage, PHES, is another method used to store energy. In a PHES system, two water reservoirs are located at different heights. Water is pumped from the lower to the upper reservoir when the system is in charging mode. When the power plant is in discharging mode, the water flows from the upper reservoir, through the turbines that generate electricity and into the lower reservoir. A PHES power plant provides flexibility to the Norwegian power system, as it can be turned on or off when it is beneficial. Figure 2.8 illustrates a PHES power plant [15].

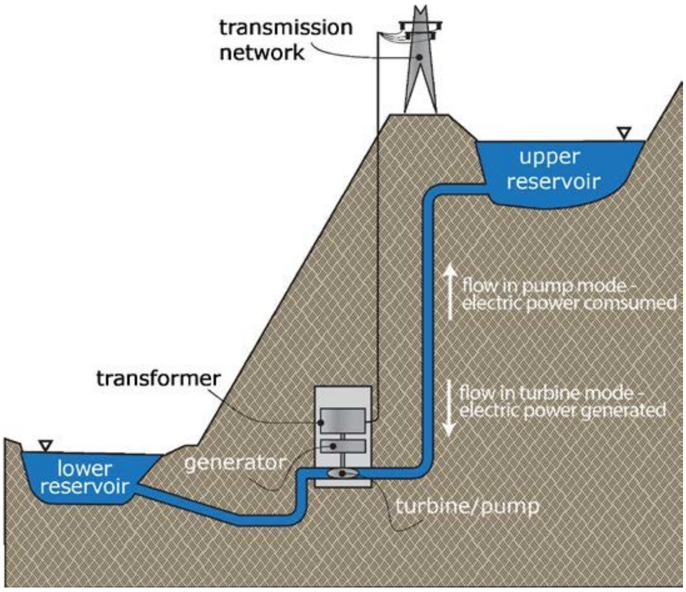


Figure 2.8: A pumped hydroelectric system [43].

A negative side to a PHES system is its dependence on the weather conditions. The amount of rainfall is a significant factor for the power production and energy storage in a PHES power plant. The effects and impact rainfall and other weather circumstances have on the Norwegian power system will be further presented in Section 2.5 [15].

2.3.3 Flywheels

A flywheel can be used as an energy storage system. The flywheel charges by accelerating and therefore creating kinetic energy. When discharging, the flywheel decelerates, and kinetic energy is withdrawn and used as electricity. The two different types of flywheels are called low-speed and high-speed. The low-speed version is low-cost but has a short discharge time. This means that the low-speed flywheel can only supply energy for a short time, only up to a few minutes. The high-speed flywheel, however, can provide energy for a longer time, up to an hour. On the other side, the high-speed version is costly and can cost around 100 times more than the low-speed type [15].

An illustration of a cylindrical flywheel is provided in Figure 2.9. Energy is stored by the flywheel rotating around its center axis. The cylinder is stored inside an evacuated container to eliminate friction . Energy is generated in the generator [44].

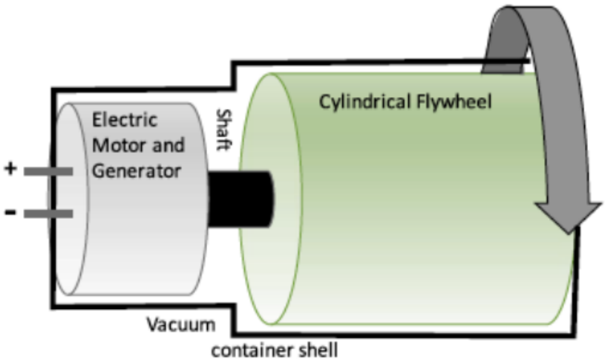


Figure 2.9: A cylindrical flywheel [45].

Although the energy storage capacity is limited for a low-speed flywheel and the high-speed flywheel is costly, there are several advantages to this technology. It has a satisfactory power rating, as well as charging and discharging speed. The flywheel's modularity is also beneficial. Lastly, this technology is durable as it does not deteriorate after many cycles [15].

2.3.4 Thermal energy storage

Thermal energy storage, TES, is based on either the heat capacity of a storage medium, or the phase change of a storage medium. Electricity is stored as heat, low or high, in a medium. Different materials can be used as heat storage medium, such as water. Heat engines convert the stored heat into electricity when needed, or the temperature in the storage medium can be used directly as heating or cooling [15, 46].

Water tank storage is the most common method for TES. This is a cost-effective medium and energy storage technique. Water tanks used in TES can have a volume of several thousand cubic metres. Underground thermal energy storage is another technology that is widely used. Underground TES has a high degree of flexibility in regards to choosing the medium. Energy in the form of heat is transported through pipes in the ground [46]. Aquifer Thermal Energy Storage, ATES, is a form of underground TES where groundwater is extracted from a well and heated with the available heat source. Then, the heated groundwater is injected back into the aquifer in another well. Figure 2.10 shows an ATES system [47].

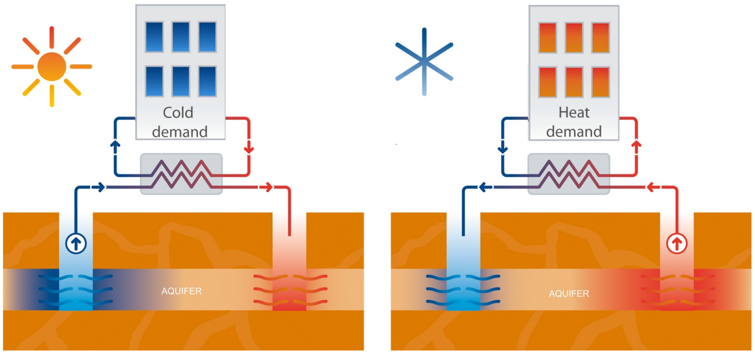


Figure 2.10: An illustration of an Aquifer Thermal Energy Storage system [48].

TES technology is used in fossil or biomass thermal power plants, to increase the efficiency of the plant. Thermal energy is stored in periods with low demand and used when the demand is higher or during a peak. Buildings and industry processes also often use TES. It is also possible to combine a heat pump with a TES system to accomplish peak shaving [49, 15, 46].

Thermal capacity is an essential aspect of TES technology and is one of the deciding factors for which medium is chosen. Different mediums and methods have advantages and disadvantages. Water is the only medium that will be presented in this thesis, because using water as a storage medium is the oldest and most developed method in a TES system. However, this technology requires multiple specific properties in terms of storage vessel. To ensure a satisfactory performance of the system, the water tank should be tall and thin, and the insulation should be optimized. The velocity of the water flow should be low as well. To avoid mixing the water and producing a uniform flow, the water inlet and outlet must be installed in a specific manner. Another requirement is that the storage water should be as little in contact with the surface of the storage vessel as possible. Additionally, internal access into large tanks is necessary to enable maintenance [49].

2.3.5 Chemical batteries

A chemical battery is a device that stores chemical energy and converts it into electrical energy. Further in this thesis, chemical batteries will be referred to as batteries, as this is the only type of battery that is presented. A battery is a type of electrochemical cell that contains two or more electrodes separated by an electrolyte, which works as an electrical conductor. When the electrodes are connected to an external circuit, a chemical reaction takes place within the cell, producing a flow of electrons that can be used to power different devices [50, 14].

A battery can be made from nearly any kind of substance, if electrons are exchanged between the substance and an electrical conductor. In the electrochemical cell, the two electrodes are submerged in the electrolyte and connected with an external wire which transports the electrons from one electrode to the other. During operation, a half-cell reaction occurs at each of the electrodes. The driving force of the reaction is the difference in electrode potentials of the two half-cell reactions, called the electromotive force [51]. One of the electrodes are oxidized, meaning it releases electrons, while the other is reduced by receiving electrons. These reactions occur during discharging [50, 14].

The electrode at which the oxidation takes place is called the anode, which is termed the negative electrode. The reduced electrode is called the cathode and is termed the positive electrode. During charging, the induced voltage forces the reaction to change direction. The anode will then become the positive electrode, while the cathode becomes the negative electrode. The cell also needs a separator to separate the two electrodes. This is to prevent the electrodes from coming in contact with each other and cause a short circuit. If a short circuit occurs, the current will flow directly between the electrodes and there will be no external flow, meaning no power can be produced. In addition, it can cause a fire from overheating from the overload current [50, 14].

The Daniell Cell shown in Figure 2.11 is an example of a simple battery cell. It consists of a zinc anode and a copper cathode submerged in metal salt solutions. The salt bridge provides the solutions with ions to keep the reaction going. Without this, the reaction would stop due to the build up of positive and negative charge around the electrodes [52, 50].

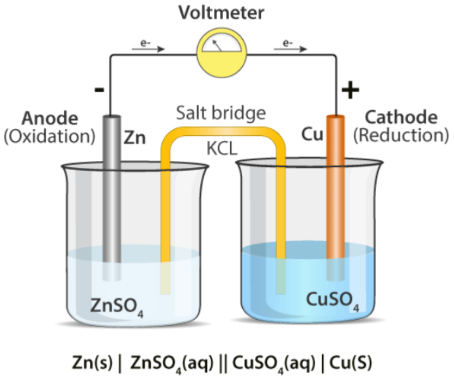


Figure 2.11: Setup of a Daniell Cell [53].

Some advantages of using batteries for energy storage are the wide range of sizes, their ability to supply electrical power instantly, their portability, and the option of single-use or multiple-use. For this thesis and for construction sites, a battery with large capacity is necessary due to the construction machines' battery capacity. Therefore, some commonly used batteries for large scale will be further investigated in Chapter 2.4 [14].

2.4 Different types of batteries

Batteries and other energy storage technologies can be used to achieve peak shaving, as described in Section 2.2.5. However, this technology can also be used to cover the energy demand in areas where the capacity of the electric grid is limited. In Lierne, where the power grid is unable to fully supply electricity to new establishments and industry buildings, a battery has been placed. With a capacity of approximately 1 MW, the battery can supply Lierne with energy when the grid supply is low, and charge with excess energy from time periods where the demand is low [5].

2.4.1 Lead-Acid Battery

The lead-acid battery is traditionally the most common battery used for storing energy. It consists of a lead anode and a lead oxide cathode divided by a separator, typically of a porous polymer, with a sulfuric acid electrolyte. An advantage with this battery is that the key component, lead, is always in a solid state. Therefore, the loss of lead will be very small. The temperature rise is not as high as lithium-ion batteries, which lowers the chance of thermal runway. This is the phenomenon of positive temperature feedback of a system with higher heat generation than cooling through the battery walls, which can lead to fire and rupture of the battery [54]. It has a sufficient power density, but a rather low energy density. Lead is heavy, making it less convenient for mobile purposes [55]. The chemical reaction for a Lead-Acid battery is provided below.

$$Pb + PbO_2 + 2H_2SO_4 \xrightleftharpoons[Charge]{Discharge} 2PbSO_4 + 2H_2O$$

2.4.2 Nickel Cadmium Battery

The nickel cadmium, NiCd, battery consists of a cadmium anode and a nickel oxide hydroxide cathode. The electrolyte is potassium hydroxide, KOH, which is filled between the two electrodes. The nickel-cadmium battery was previously widely used in industrial applications. It has a higher energy density and longer cycle life than lead acid batteries. It also performs well at low temperatures. One issue with the battery is the memory effect. This means that if the battery is only subjected to light discharges, followed by a recharge, it will lose the ability to deep discharge. The Ni-Cd battery is little used today because batteries with higher energy density are available for a lower price. The battery also contributes to environmental concerns associated with disposal due to the toxicity of cadmium which is hazardous to biological systems. The total chemical reaction of the battery is presented below [50].

$$Cd + 2NiOOH + 2H_2O \xLeftrightarrow[Charge]{Discharge} Cd(OH)_2 + 2Ni(OH)_2$$

2.4.3 Sodium Sulfur Battery

The Sodium Sulfur Battery consists of a cathode covered in molten sulfur and an anode covered in molten sodium. The electrolyte is a ceramic alumina called beta alumina. This is a highly sophisticated ceramic with a high ionic conductivity for sodium ions above 300°C. Different from other batteries in a sodium sulfur battery, the electrodes are liquid, while the electrolyte is in solid state. During discharging, the sodium metal releases electrons, which pass through the beta alumina, to the positive sulfur electrode. The total chemical reaction of the battery is divided into two steps. Both steps to the chemical reaction are provided below, chronologically [14]. In step one, Na_2S_5 is in equilibrium with sulfur, when all sulfur is converted to Na_2S_5 step 2 begins, where lower polysulfides are produced. The battery has a high efficiency, high power density, a long lifetime, and a high discharge depth. Materials for the battery are inexpensive, making it more attractive. Some downsides are the high temperature requirements and thermal management which is necessary to maintain the integrity of the ceramic separator [56, 57].

$$2Na + 5S \xLeftrightarrow[Charge]{Discharge} Na_2S_5$$

$$2xNa + (5-x)Na_2S_5 \xLeftrightarrow[Charge]{Discharge} 5Na_2S_{5-x}$$

2.4.4 Lithium-Ion Battery

Lithium-ion batteries, LIB, have a wide branch of battery chemistry variations. The common structure of the battery is a Li-metal oxide cathode, a separator, an electrolyte made of conductive salts, and a lithium-carbon anode. Both electrodes are coated on a metal current collector which collects electrons and supports the electrode. After the first few charging cycles of the battery, a solid electrolyte interphase, SEI, is generated on the anode. It provides a passivation layer which inhibits further electrolyte decomposition [58]. The advantages of lithium-ion batteries are the high energy density and long cycle life. Downsides are the safety challenges of thermal runway, no system for recycling and the temperature dependency of performance. The chemical reaction for a $LiCoO_2$ or LCO battery is presented below [59, 50].

$$LiC_6 + CoO_2 \underset{Charge}{\overset{Discharge}{\Longleftrightarrow}} LiCoO_2 + C_6$$

Figure 2.12 shows a schematic illustration of a lithium-ion battery during discharging. In this figure, the battery has a $LiMO_2$ cathode. The illustration shows the flow of electrons from the anode to the cathode, and the Li^+ passing through the electrolyte from the anode to the cathode during discharging.

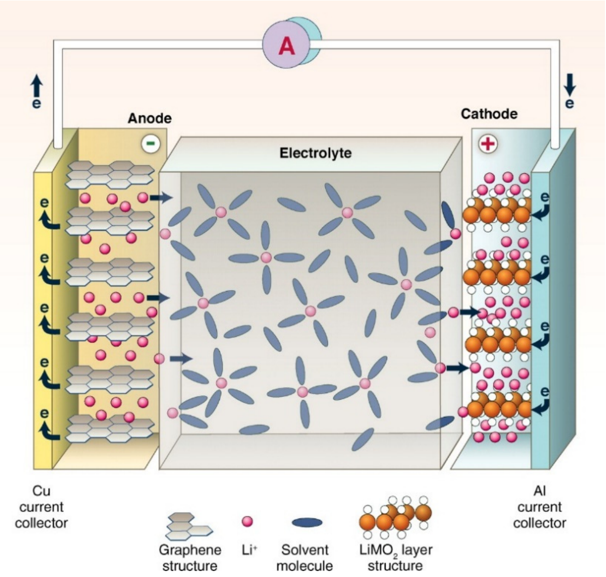


Figure 2.12: A schematic figure of a lithium-ion battery with a $LiMO_2$ cathode [60].

2.4.5 Comparison

The choice of battery type for the purpose of a large-scale energy storage system is important. To explore which type has the most desirable abilities, a comparison is necessary. In Table 2.3, the different battery types are listed with their associated capacity factors. Lithium-ion has the best results in all categories. The sodium sulfur is close to the lithium-ion in energy density and has a long cycle life but has the lowest score of all the batteries on power density. Lead Acid has a high power density, but both energy density and cycle life are lower than the others. For NiCd, the power density is high, and it has a higher energy density than lead acid, but the efficiency and cycle life is quite poor. Lithium-ion batteries have the best overall performance for capacity factors of all the considered batteries.

Table 2.3: Capacity factors for different battery technologies [50].

Capacity factor	**Lead Acid**	**NiCd**	**Sodium Sulfur**	**Li-ion**
Energy [Wh/kg]	20-40	4-60	110	150-250
Power density [W/kg]	5-200	10-150	50	100-500
Energy efficiency [%]	60-90	80	85	90-98
Cycles/1000	1-5	1-3	4-5	1-20

2.4.6 Charging and discharging

When describing the charge and discharge of batteries, there are some terms which need to be introduced. To describe the capacity withdrawn compared with the total amount which is available at the same discharge rate the term depth-of-discharge, DoD, is used. This ratio is usually described as a percentage. The term state-of-charge, SoC, describes the fraction of the full capacity that is still available for further discharge. The relation is shown in Equation 2.6 [14].

$$SoC = 100\% - DoD \tag{2.6}$$

When discharging a battery, the voltage decreases. This happens because the cell resistance increases due to accumulation of discharge products, activation and concentration, polarization, and related factors [61]. If the voltage is lower than the cut-off voltage, or the battery's SoC is below 20%, it discharges. The cut-off voltage is the voltage which the manufacturer of the charger has set as the point where the charging process will be cut off to avoid overdischarging [62]. At this point, the battery needs to be recharged. Overdischarging and overcharging can affect the condition of the battery considerably because it accelerates the battery degradation process [63]. Charging the battery reverses the process and increases the voltage. There are several techniques to charge a battery. Three regimes in which a battery can be charged are: constant-current, constant-voltage and constant-current-constant-voltage[14].

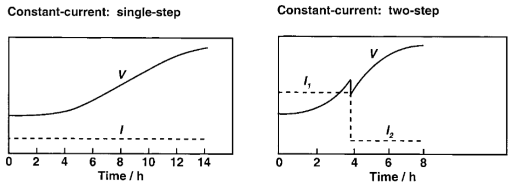
For constant-current, CC, charging, a constant current will be applied throughout the charging process, as illustrated in Figure 2.13a. This charging regime can be slow at a low current, but if the current is too high, it can cause gassing. Gas buildup causes swelling, it worsens the contact between the electrode particles elevating resistance, and increases the pressure, which leads to cell failure and risk of rupture [64, 14]. Ideally, the battery should be charged at a high current in at least the first half of the process, and then be charged at a lower current later in the charging process. This is the two-step constant-current charge illustrated in Figure 2.13b.

Another regime for charging is the Constant-voltage, CV, charging. In this regime, the level of current is determined by the voltage difference between the charger and the battery. The current will begin at a high value and then roughly exponentially decrease as the charging proceeds, as shown in Figure 2.13c. For this reason, reaching a full charge takes a long time. If the battery is deeply discharged, the starting current can be very high, which necessitates the use of a large, expensive charger and can cause unacceptable internal heating of the battery [14].

Constant-current-Constant-voltage charging is a combination of the two above. It begins with CC until a set voltage is reached, where gassing is likely to occur. Then, the battery will charge at CV, making the current decline exponentially. In Figure 2.13, this charging regime is illustrated, and it shows the efficiency compared to the CC and CV charging [14].

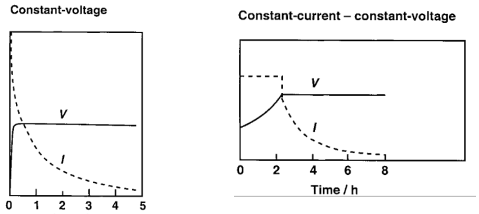
When calculating the power consumed during charging, it is necessary to know the charging curve. The challenge is knowing the power during the CV stage. During the CC stage, the voltage will increase linearly, as can be seen from Equation 2.7 called the Ohm's law [61].

$$U = R \cdot I \tag{2.7}$$



(a) One-Step Constant-current charging.

(b) Two-Step Constant-current charging.



(c) Constant-voltage charging.

(d) Constant-current-constant-voltage charging.

Figure 2.13: Voltage and Current over time for different charging regimes [65].

When the charging has reached the pre-set voltage, the CV charging stage will begin. In this stage, the current will decrease. This section of the charging curve is not linear, like the CC charging stage, but it exponentially decreases. Equation 2.8 expresses the current during the CV stage [66].

$$I_L(t) = Ae^{-\tau t} + B \tag{2.8}$$

where:

- I is the load current
- τ is the CV current time constant
- t is the sampling time
- A and B are model parameters

The time constant τ describes the rate of decay of the CV current. As time t approaches infinity, the current converges to its limiting value.

2.4.7 Lithium-ion charging and capacity

Lithium-ion batteries should be charged by CC-CV charging. It provides a high efficiency and sufficient protection of the cell [65]. If the battery is exposed to overcharge, it can result in metallic lithium build up on the anode, which can lead to thermal runway [67, 68]. Therefore, Li-ion batteries must have a system for stopping the charging process when the desired voltage is reached [65].

In Figure 2.14, the CC-CV charging cycle for a Li-ion battery is graphed. In the constant-current phase, the voltage increases exponentially until the pre-set voltage is reached. Then, it changes to constant-voltage charging and the current decreases. The charge process stops when the current drops below cut-off level, which is typically less than 3% of the rated current [65].

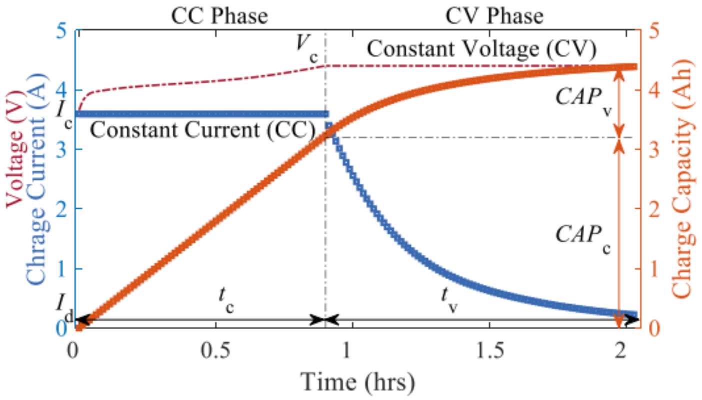


Figure 2.14: Charge cycle of Li-ion battery with CC-CV charging [65].

Batteries experience degradation from aging, which is dissociated as cycle aging and calendar aging. The first refers to aging due to the charge and discharge of the battery, while calendar aging occurs when the battery is stored [69].

For LIBs, calendar aging depends on temperature and SoC as a function of time. Additionally, factors like cycle aging depends on current rate, charge and discharge cut-off voltages. In any case, the battery capacity decreases and/or the internal resistance increases. The mechanism's effect on the battery varies with different kinds of lithium-ion battery chemistry technologies [69].

High temperature and a high SoC lead to additional and accelerated SEI formation, reducing capacity. Low temperatures cause lithium plating which is the deposition of metallic lithium on the anode graphite surface. This increases the internal resistance, decreases energy density, and limits the fast-charging capability. In severe cases, lithium plating forms lithium dendrite, which penetrates the separator and causes an internal short circuit. Low SoC levels cause increased aging because of corrosion of the materials. Generally, the acceptable temperature region for LIBs is between -20 °C and 60 °C. The optimal temperature range is 15 °C to 35 °C. In Norway, temperatures can reach below -20 °C, but it rarely occurs [70, 71].

The increased resistance caused from these aging mechanisms increases the CV charge time. In Figure 2.15, the CC-CV charging curves for 632 cycles are plotted. By observing the plots, there is a clear relation between number of cycles and decrease in CC charge time [65].

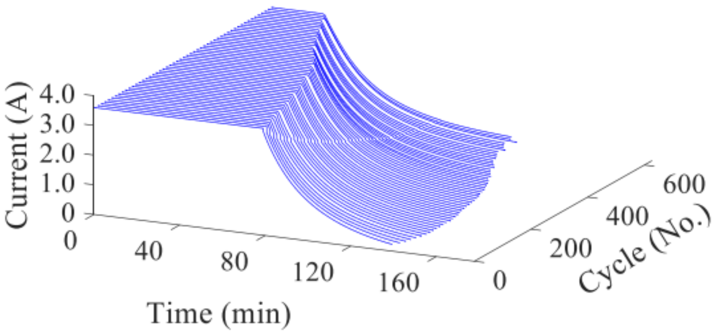


Figure 2.15: Capacity of Li-ion battery [65].

The switch from the CC to CV stage often occurs when the SoC of the battery is about 80-90% for Li-ion batteries. However this wont always be the case as it will depend on the battery chemistry and age [72]. The time the battery uses to charge from its SoC to the switching point from CC to CV charging at for example 80%, can be calculated by Equation 2.9 [73].

$$t_{cc} = \frac{Q_{battery} \cdot DoD \cdot 0.8}{P \cdot \eta} \tag{2.9}$$

where:

- t_{cc} is the charging time under CC stage (h)
- $Q_{battery}$ is the batterycapacity (kWh)
- DoD is the depth of discharge (%)
- P is the charging rate (kW)
- η is the efficiency to the battery

2.5 Power production and distribution

Norwegian power production mainly comes from hydro, wind, and thermal sources. In Figure 2.16, the ratio of power from the different sources is presented. Hydro power is the largest contributor and makes up almost 90% of the total production in Norway. In recent years, there has been a growth in wind power, and this has made the production less dependent on water levels in the reservoirs. Some thermal power production also exists but represents less than 2% of the total power production [74].

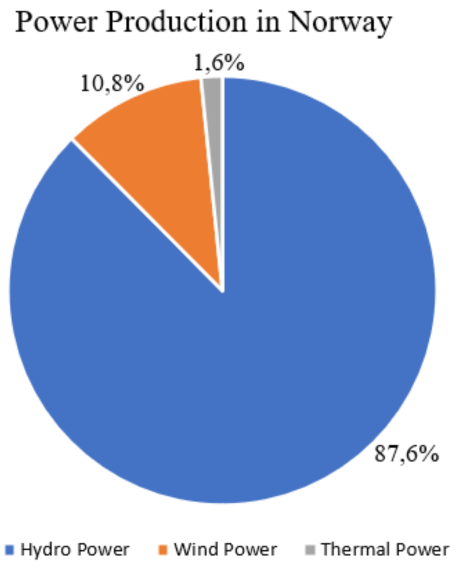


Figure 2.16: Pie chart of the Norwegian power production [74].

In a normal production year, the total power production in Norway is around 156 TWh. The average yearly consumption from 2010-2023 was about 131 TWh. This gives a positive energy balance and makes Norway a net exporter of power [11].

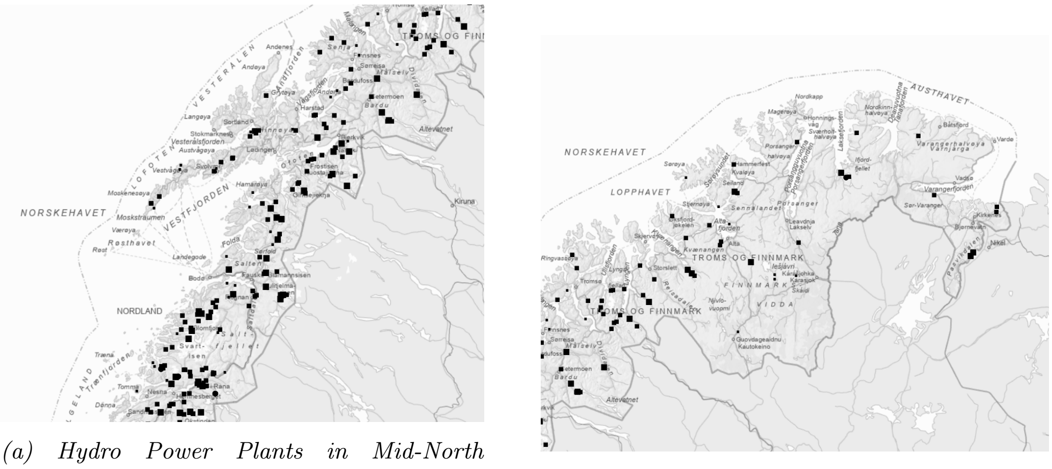
2.5.1 Hydro Power

Hydro Power has a 90% efficiency, making it a high efficiency power source. The large amount of hydro power makes the Norwegian production unique. It is a flexible source which quickly can be switched on and off. To optimize the hydroelectric power plants, they are shut down during the night when power demand and prices are low. Instead, power is imported during the night, saving water for time periods when high power peaks occur. This ensures a steady power supply and that large fluctuations in power price are avoided [11].

A Disadvantage to hydro power is the dependency on weather making it prone to drought. In Norway, power prices are therefore dependent on the weather conditions. The amount of rainfall varies through the seasons and differs greatly between the different regions in Norway, the western part being the rainiest. In comparison, Bergen had 2447.5 mm of rain in 2022, while Oslo had 703.1 mm [75, 32].

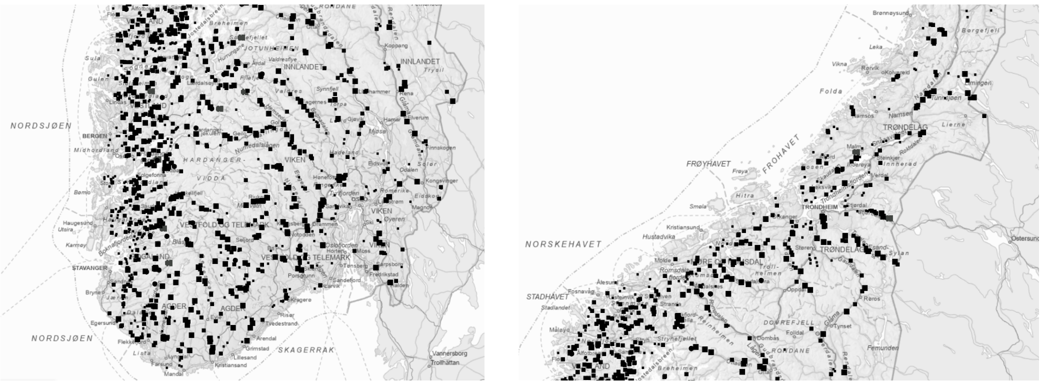
With the large portion of hydro power, there is a strong correlation between hydro power production and power prices. The prices also vary in the different price areas because prices depend on the production in each area. When water levels are high in the reservoirs, the power prices decrease in the corresponding region. If the power production is large enough to create a surplus, power can be transported to other areas with higher demand. Due to limitations in the power grid, it may not be possible to transport all the excess power. This causes inefficiency and electronic bottlenecks, as explained in Section 2.2.3 [32].

There are a currently 1768 Hydro Power Plants in Norway [76]. Figure 2.17 displays a map showing the location of all operating hydro plants in Norway. The west of Norway has steep terrain in addition to the large amounts of rainfall which make up suitable nature conditions for hydro power [77]. This is where most of the hydro plants in Norway are located [78].



(a) Hydro Power Plants in Mid-North Norway.

(b) Hydro Power Plants in North Norway.



(c) Hydro Power Plants in South Norway.

(d) Hydro Power Plants in Mid-South Norway.

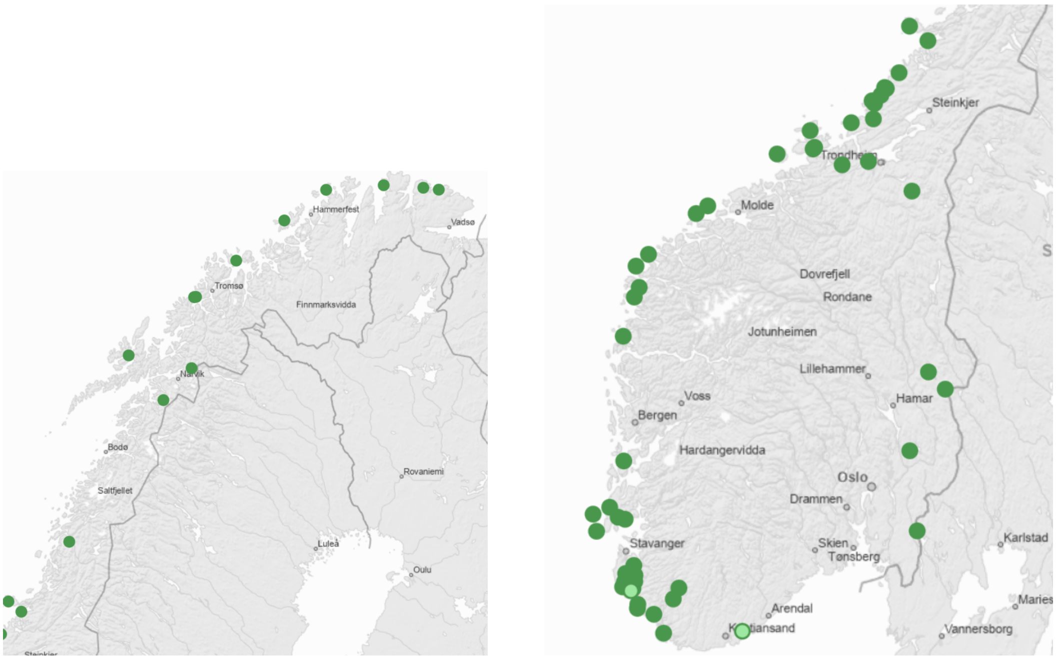
Figure 2.17: Hydro Plants in Norway [79].

2.5.2 Wind Power

Hydro Power is the main source of power production in Norway, but in recent years there has been a growth in wind power production. Figure 2.18 provides an overview of all operating wind power plants in Norway. An seen in the figure, most of these plants are placed along the south and mid coast of Norway. Strong and stable winds combined with the large coast areas make Norway one of the best suited countries in Europe for production of wind power [80].

There has been resistance and discussions concerning onshore wind power production in Norway. One recent example is the wind power plant built in Fosen. There was a conflict between the power company and the indigenous people using the areas for reindeer husbandry. Months after the turbines had started operating, the supreme court ruled that the power company had broken the human rights of the indigenous people. The supreme court did not state what was going to happen to the wind power plant, and in mid-May of 2023, they are still operating [81].

With the large resistance for wind power plants onshore, it is expected that most of the wind production will be offshore in the future. This technology is still being developed and is more costly than onshore turbines [32].



(a) Wind Power Plants in North Norway. *(b) Wind Power Plants in South Norway.*

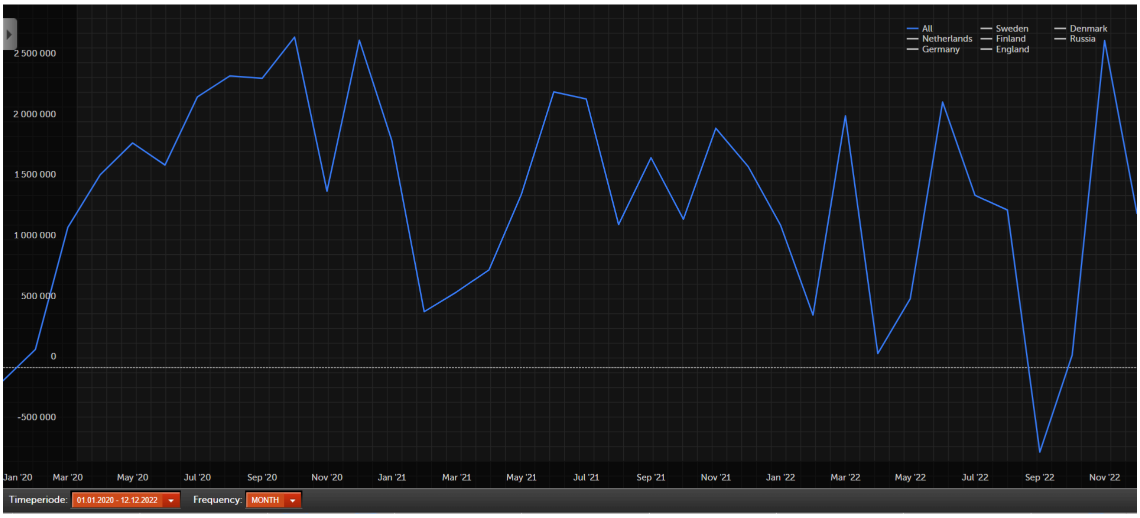
Figure 2.18: Wind Power Plants in Norway.

2.5.3 Thermal Power

A small amount of power is produced from thermal energy in Norway. Municipal waste, industrial waste, waste heat, oil, natural gas, and coal are the resources used for this production. The thermal power plants in Norway are usually attached to larger industrial companies. Therefore, the production is associated with the power demand in the industry [82].

2.5.4 Import and Export

In general, the net exchange of power in Norway is positive, meaning there is more export than import. In Figure 2.19, the net exchange of power in Norway between 2020 and 2023 is illustrated. There are variations throughout the year with some reoccurring patterns. Generally, in January there is a large degree of import and in November there is a spike of export [11].



Timeperiode: 01.01.2020 - 12.12.2022 Frequency: MONTH

Figure 2.19: Net exchange of power in Norway from 2020-2023 [83].

When trading power between the price areas in Norway, Statnett receives bottleneck income. If power is sold from NO5 to NO1, the customer in NO1 pays the cost applicable in this area. The producer in NO5 gets paid the cost applicable in their area. Generally, the price is the highest in the area buying power, meaning NO1 in this example. The cost difference, the profit, is allocated to Statnett. Statnett then uses the income to operate and maintain the grid and belonging infrastructure. When Statnett profits from the bottleneck income, it results in a lower grid tariff for consumers as it is used to lower the tariff of the grid [33].

In international power trade, the two companies who own the power cable receive half of the profit each. For instance, if Norway sells excess power to Sweden, Statnett, who owns the Norwegian transmission grid, receives one half of the profit, while the owner of the Swedish part of the cable receives the other half [33].

New power connections between Norway and Germany started operating in 2021. The North Sea Link, NSL, which is an interconnector between England and Norway, started test operations the same year. With these international connections, more power trade was enabled and resulted in the largest power revenue in Norwegian history [84, 85].

2.6 Power prices

The Norwegian power prices fluctuate from year to year and from season to season because of the high dependency on weather conditions. Other factors such as political climate, conflicts or other unforeseen events may also have significant impact [32].

Figure 2.20 shows the average yearly power price, power price subsidies, fees, and grid tariff in Norway from 2012-2022. The subsidies are a measure implemented by the government to make the extreme increase in power prices in the period from September 2022 to March 2023 more manageable for the Norwegian population [86]. The graph shows how the prices vary from year to year. It seems that the price gradually increased until 2020 when there was a sudden drop in prices. Then, from 2021-2022, a drastic increase occurred [87].

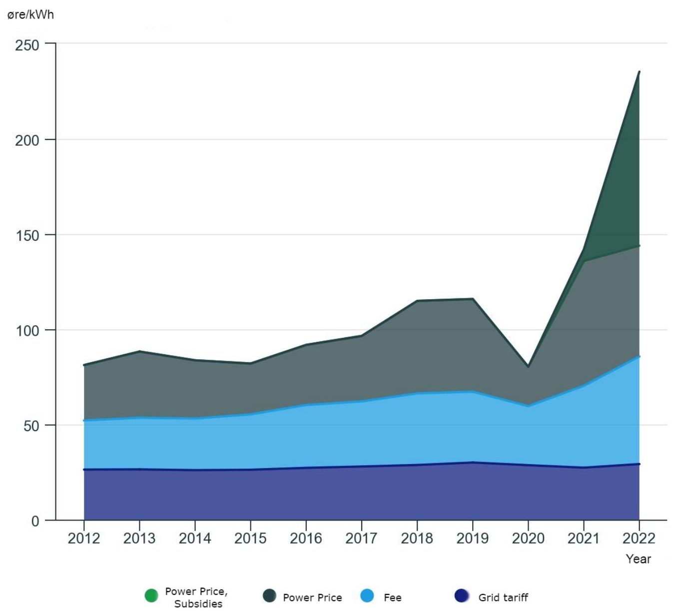


Figure 2.20: Average yearly power price, power price subsidies, fees, and grid tariff from 2012-2022 [87].

2020 was a year with large amounts of rain causing high filling levels in the hydro reservoirs. The power prices that year were very low. 2021 started with record high power production, cold weather, record high power consumption, and record high import of power during an hour. In the second half of 2021, the power prices reached the highest value ever recorded in Norway. Simultaneously, the price difference between the regions in Norway reached new heights. These exceptional prices were a result of historically high gas and coal prices, in addition to the CO_2 quota prices from the EU Emissions Trading System doubling [88, 84].

Early in 2022, water levels were low in the reservoirs in the south of Norway, while the situation in the north was far better. In February, the war in Ukraine broke out, causing an immense need for power in Europe. Both power consumption and production were lower in the south of Norway than in 2021. In September and October, the south of Norway was a net importer of power. In comparison, the north had a high power production, low prices, and considerable export to the north of Sweden and south of Norway throughout substantial parts of the year. During the winter, prices increased in the north as well [89].

In Figure 2.21, the average electricity prices for households in Norway from 2020 through 2022 are presented. These show the drastic change over these 3 years. In the first quarter of 2020, the power price was 32.7 øre/kWh, and in the last quarter of 2022, it was 207.0 øre/kWh [90].

2.7 Future Power Production and Prices

The power consumption is expected to increase in the future. Improvements in energy efficiency for households and commercial buildings will lower the power demand for this sector. However, the electrification of the Norwegian oil sector combined with the electrification of industry and transport will contribute to an increase in the total power consumption. In addition, it is expected that new power demanding industry like computer centers and hydrogen production will emerge, and further increase the power demand [32].

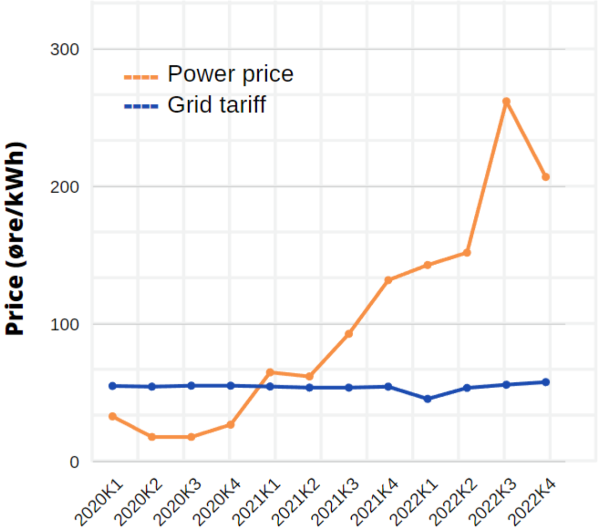


Figure 2.21: Power prices and grid tariffs for households from 2020-2023, including taxes (values retrieved from [90])

To accommodate the increased power consumption, the production must expand while the fossil production is substituted with renewable energy production. This will be challenging and cause the power balance to decrease until 2030. Towards 2040, it is expected that there will be a more rapid growth in power production. Due to the technological advances, solar panels and offshore wind turbines are expected to become cheaper and more efficient, making them more attractive as power sources. By this time, it is expected that the turbines in many Norwegian hydro power plants need to be changed due to aging. Advances in technology give hydroelectric turbines a higher efficiency, contributing to a higher power production. Some new hydro power plants and expansions of already existing plants are also anticipated [32].

The expected load increase of the electrical grid can be problematic as it demands a certain capacity. Some areas of Norway already experience problems related to low capacity. A development and reinforcement of the grid will be necessary in these areas. Developing the grid takes time and even small measures can have high investment costs [91].

Having a large share of renewable power production will contribute to larger fluctuations in the production and thereby also the power prices. Norway is likely to import more power in the future, both during periods when production is low, but also when other countries have a large power surplus and can offer lower prices. A possible occurrence is a common low production period all over Europe, where no countries are able to export due to weather conditions. To avoid this, flexibility options like batteries and hydrogen for energy storage will be necessary [32].

The advance in technology will be a key contributor to the energy transition. Advances in power source technology is one area that can be improved, and another will be energy storage solutions. Further development in battery technology and hydrogen storage is anticipated as well. These are important to provide a flexible solution, which is a major challenge with renewable energy. By offering a solution to store energy from renewable sources in large scale will provide a steadier power supply and less fluctuations in prices [32].

In the coming years, the power prices are expected to increase because of the CO_2 quota price set by EU. This quota price is meant to accelerate the development of renewable power, to reduce the climate gas emissions. When fossil sources are replaced to a higher degree, the quota price gradually diminishes as it only needs to be paid for sources releasing CO_2. Correspondingly, the power prices also decrease [32].

Further, the difference in power price between the north and south of Norway is expected to decline. New industry and the electrification of transportation will rise the power prices in the north. Most of the new renewable sources will be implemented in the south, causing a decrease in power prices. Another factor which will contribute to making the prices more equal between the different areas of Norway is the upgrade of the power grid between the north and south of Sweden. The upgrade will contribute to a better transmission capacity because the capacity limits in the grid between the north and south of Sweden is a central bottleneck in the Nordic power distribution network. With a higher amount of power exchange between these regions, the power prices will become more balanced [32].

In summary, power prices will continue to increase with the increase in power consumption and CO_2 quota price. Cutting emissions by replacing fossil energy sources with renewable energy is challenging because of the low flexibility in production and ability for storage. When the renewable technology is mature and there is sufficient production to cover the demand, the prices will stop increasing. Until there are well implemented methods to distribute the energy over longer periods of time, large fluctuations in power prices will occur because of the weather dependency of renewable energy production [32].

3 Project description

To ensure a structured and conclusive thesis, it is important to define the framework, goals, background, and a clear description of the report. In this chapter, a project description will be presented. The project description includes the goal and scope of the thesis, as well as a section about the thesis' industry partner.

3.1 Goal and scope

In the thesis, the goal is to create a model that estimates the economic value of peak shaving. Throughout the thesis, theoretical background is used to produce the model and discuss the relevant concepts and technologies. The goal is to give the reader an in-depth understanding of the aspects that are involved in the model and thesis, and how the different factors are interconnected.

Ultimately, the goal is to produce a model that can be used by Aneo Build in their contributions to making the Norwegian building and construction industry emission free. The model uses inputs from the user as well as a great deal of pre-set data and functions to give an estimate of the customer's savings due to peak shaving.

Hopefully, this model can contribute to enabling companies investing in using charging solutions, instead of using fossil fuels to power construction machines. Substantiating the claim of charging containers leading to peak shaving and economic savings might motivate construction companies to electrify their projects, resulting in reduced climate gas emissions.

Two projects where Aneo Build's products were used have been analyzed, both to create the basis for the model and to estimate the economic value that was a result of peak shaving. The model is not only intended to estimate and illustrate the effects of peak shaving directly, but also to demonstrate the differences between the price areas in Norway, machine parks and which time of year the project is executed.

To illustrate the effects of different factors for a construction project, different fictitious cases will be analyzed. To establish the significance of geographic location, three cases that are identical, except price area and network operator will be analyzed in the model. Then, three cases in the same location and same duration but different electrical equipment will be analyzed to verify the effects of having different machine parks. Lastly, three cases with different work periods will be analyzed to show the effects of seasonal price differences. The parameters for these cases are provided in Section 4.5.

3.2 Industry partner

The industry partner for this thesis is Aneo. Aneo is a Nordic renewable energy-focused company that started as a collaboration between TrønderEnergi and HitecVision. Aneo aims to contribute to the development of renewable energy, electrification and increasing energy efficiency to make the energy shift beneficial to their owners, their customers, and to society. [92]

Aneo combines years of experience from the energy industry with new, innovating energy services and solutions. They have several sections with different service areas, including Mobility, Retail, Industry, Real Estate, Energy Management and Build. Aneo Mobility has expertise in charging systems for electric cars, while Aneo Retail focuses on sustainable energy solutions for grocery stores. Aneo Industry aims to make the process industry more energy efficient and making this industry zero-emission. Further, Aneo Real Estate has expertise in solar power solutions for commercial properties [93]. Aneo Energy Management works with monitoring production facilities, as well as dealing with trading of power production and consumption [94, 92].

Lastly, Aneo Build's focus area is electrification of construction sites. They aim to help their consumers reach the requirement for zero-emission construction sites before 2030. Aneo Build owns and rents out different charging solutions to construction companies with different projects and enables charging of the electric construction machines when needed. Aneo Build representatives are the external supervisors for this thesis [92, 4].

3.2.1 Aneo Build's products

Aneo Build has four different products for renting out to construction sites. In the following section, some products will be presented and described, and their relevance for this thesis will be discussed. Additionally, which type of project that would benefit from renting the different charging solutions will be discussed. All figures of the products are provided by Aneo Build, in addition to some information about the different products that is not found on their website.

The *BoostCharger* is Aneo Build's largest charging solution and contains lithium-ion batteries and rapid chargers. The battery capacity is between 390 kWh and 580 kWh, depending on the customer's preference. The BoostCharger has two rapid charging outlets that can deliver 150 kW from both outlets, or one outlet with 300 kW and one with 150 kW. The BoostCharger has regular AC outlets for slow charging machines and other electrical gear as well. If the SoC of the BoostCharger reaches 12%, it will begin trickle charge, reducing the power delivered to the outlets. If it is further discharged to 6% SoC, it will stop supplying power to the outlets to increase the SoC. When it is sufficiently recharged, charging from the outlets will proceed. BoostChargers are suited for projects where the electric grid capacity is low, or where large amounts of power is required, or both. Figure 3.1 shows an illustration of the BoostCharger. As the figure shows, this product is large and not placed on a trailer. Therefore, it is less mobile than the other solutions Aneo Build offers. It is, however, a possibility to move the BoostCharger during the project [4].

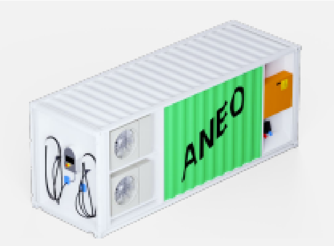


Figure 3.1: An illustration of the charging solution BoostCharger [4].

The *Hummingbird* is another charging solution by Aneo Build with lithium-ion batteries and rapid charging. This product has a battery capacity of 190 kWh and one rapid charging outlet of 150 kW. The Hummingbird is mobile, as it is placed on a trailer and can easily be moved by a vehicle on the construction site. Moving electric construction machines from its working area to the charger, also called belting, is energy demanding. The Hummingbird can help diminish the amount of belting, thus saving energy and expenses. An illustration of the Hummingbird is provided in Figure 3.2 [4].

Figure 3.2: An illustration of the charging solution Hummingbird [4].

Aneo Build offers two more products: The BoostPoint, which is a rapid charger, and the AutoPower, which is an energy storage device. They both have a high degree of mobility, which reduces unnecessary energy use and economic expenses caused by belting. The BoostPoint and AutoPower do not contribute directly to peak shaving because each of them do not offer both rapid chargers and energy storage. Also, as of May 2023, the BoostPoint and AutoPower have not yet been put into use. Therefore, these two products will not be included in the model or considered further in this thesis.

The aspects that differentiate the BoostCharger from the Hummingbird is the degree of mobility, battery capacity and amount of charging outlets. Mobility can be a cost- and energy saving feature, as machine belting is highly energy demanding. However, the required amount of machine transportation to and from the charger depends greatly on the project. The construction site size, number of electric machines used, and charging habits and patterns are variables that determine the necessity of mobility in a charging solution. Mobility is often an advantage, but not necessarily the deciding factor.

The battery capacity of the Hummingbird and BoostCharger varies between 128 kWh and 580 kWh. The battery capacity required for a construction project depends on the energy demand, as well as the grid capacity. For instance, a large project with a multitude of electric machines requires a charging container with more capacity than a small project with fewer electric machines. A charging solution with more than one charging outlet might also be beneficial for big projects. This enables the electric construction machines to be able to charge when needed. However, on projects with fewer construction machines, multiple outlets might not be necessary and a smaller battery capacity in the container might be sufficient

A comparison of the charging solutions Aneo Build rents out to construction sites makes it evident that which product is the most beneficial, is different for each specific project and construction site. Aspects such as project size and duration, power grid capacity, and usage pattern of electric machines and charging container decide which product is the most advantageous for each specific project. Ideally, a model that accounts for all of Aneo's products would be made. However, due to time limitations and the lack of data concerning previous projects using a Hummingbird, this has not been done.

3.2.2 Field trip

On May 10th, the authors of this thesis were invited to visit a construction project where a BoostCharger from Aneo was used. Betonmast is building a new school next to Trondheim Cathedral School. All machines and vehicles on the site are electric, and therefore there is a need for a charging solution. Multiple people on the construction site stated that the electric grid in Trondheim does not have the capacity to meet the current power demands. Without the possibility to use an energy storage system, the construction machines would have to charge directly from the grid. The power grid does not have the capacity to support rapid charging from multiple construction machines simultaneously. Therefore, the main intention of using a BoostCharger is not specifically peak shaving in this project.

One challenge experienced on this construction site is that the battery cells in the charging solution do not charge quickly enough. Although the charging container enables energy storage and rapid charging, the capacity of the power grid limits the utilization of the container. This can again lead to ineffective work on the site. One specific situation that was mentioned by Aneo during the visit was that an electric truck was fully charged from the container one day. Due to the truck charging, the battery in the container was around 15% during lunch. This resulted in the main electric machine getting an insufficient amount of power when it was charged during the lunch break. Most likely, this would not be a problem if the power grid was adequately dimensioned because the container would be able to recharge quickly enough.

During the visit, it became evident that the power grid in the Trondheim city center is rather old and therefore severely under dimensioned for the demand of the ongoing electrification. As the electric grid in this location is dimensioned for smaller loads, the construction company are considering acquiring a provisional electrical substation to gain access to the power that is needed to support the project. Such investments can be extremely costly.

Although Betonmast uses the BoostCharger for other purposes than peak shaving, the field trip provided valuable insight in the construction industry, charging solution technology and the power grid in Trondheim. Figure 3.3 shows some pictures that were taken by the authors during the field trip.

(a) Battery cells inside the container. *(b) The electric construction machine.*

(c) The outside of the container.

Figure 3.3: Highlights from the field trip. The photos were taken by the authors of this thesis.

4 Methodology

This chapter will provide an overview over the different methods, approaches and assumptions that have been used and made concerning this thesis, including the analyses and the model.

4.1 Data and Software

Aneo Build provided the raw data from two previous cases which created the basis of this thesis. The raw data contains information of charging patterns for each day during the project period, as well as a brief description of which construction machines that have used the container for charging. Aneo Build has also provided access to the instruction manuals of the BoostCharger and the Hummingbird with relevant information of the different components in the charging containers, how the components are connected in an electrical circuit system, and how the charging containers operate during different scenarios when charging and discharging. Aneo Build has also provided the grid tariff price data that has been used in the model. In addition to this, data of electricity prices for the different price areas in Norway have been retrieved from Nord Pool.

The software used for both analyses and building the economic model is Python. Python is a programming language with many applications across a wide range of fields and is often used for scientific and numeric computing as well as data analysis, developing algorithms, and creating models. Python provides several model building methods and libraries for various domains and gives the user the possibility of creating functions and self-made models. It also contains several libraries that can be used for interacting with other software, such as Microsoft Office Excel, which gives the opportunity to effectively analyze and modify big data collections. For this project, the data collection was mainly imported from Excel and processed in Python with the Pandas library. Microsoft Excel is a spreadsheet software developed by Microsoft that allows users to organize, analyze, and visualize data in a tabular format. Excel offers a range of built-in functions and tools for data analysis, such as formulas, functions, charts, and graphs [95, 96].

Additionally, GeoGebra was used to do some approches graphically. GeoGebra is a dynamic mathemathics software and includes tools that combines various mathemathical consepts, and allows the user to graph functions, explore mathematical relationships in real-time, and perform calculations and visualizations [97].

Geogebra allows users to create dynamic mathematical models by defining and manipulating geometric shapes, equations, functions, and data sets. It supports a wide range of mathematical operations and visualizations, enabling users to graph functions, perform calculations, create animations, and explore mathematical relationships in real-time.

4.1.1 Power Prices

Power prices are fundamental aspects of the model because the fluctuations in power prices are partially why peak shaving can lead to economic savings. To produce a model that is as precise as possible, using accurate power prices would be optimal. However, this would require precise predictions of the future power prices for each hour of the duration of a future project. Unfortunately, this is impossible due to the power prices being dependent on many external factors, such as weather conditions, political circumstances, and other unforeseen situations.

Initially, the ambition was to find power prices from further back in time and use this to calculate an average power price for each hour of the year for the model. The Nord Pool database was used to find this data. When trying to find historical data, the oldest prices available were from 2021. Because of this, it was decided that the prices for 2021 only would be used. This is further explained in Section 4.4. It is important to note that 2021 was an uncharacteristic year concerning power prices, which is further described in Section 2.6. Both years had abnormally high power prices but 2021 was chosen because the average monthly prices for this year were closer to former years than 2022, as shown in Figure 2.20.

The data from Nord Pool was not possible to download, meaning all data needed to be copied from the database. To find an average price for every hour of the year therefore became a very time-consuming task, especially considering that this would have been done for all five price areas. This led to the decision of using one average day of each month to represent the hourly power prices for that month. This was executed by first finding the average price for each month in 2021 from Nord Pool data [98]. Then, the average power price for each day in all five price areas was inspected. Using the average monthly prices, the day of each month closest to the monthly average was chosen to represent the hourly power prices for that month.

The power prices used in the model for the calculations for this thesis could be more accurate, and more data could have been included. To limit the workload and due to limited available data, this has not been performed. The model is created in a manner that makes it easy for the user to replace date if desired, which is one of the reasons why it was deemed unnecessary to spend a long time on including more data.

After finding the day with the daily power price closest to the corresponding month's average, the hourly prices for that day were retrieved and put into the model and analyses. The specific day that was chosen, represents the entire month in the model and analyses. Therefore, the power prices for one day per month are repeated in the model every day of the specific month. This process was repeated for all months and all price areas in Norway.

When using the model to investigate different aspects of peak shaving, price areas NO1, NO3 and NO4 have been used as location. In Figure 4.1, the hourly power prices from each month for each of these price areas through one year are graphed. These values are used in the analyses and model. All values are retrieved from 2021.

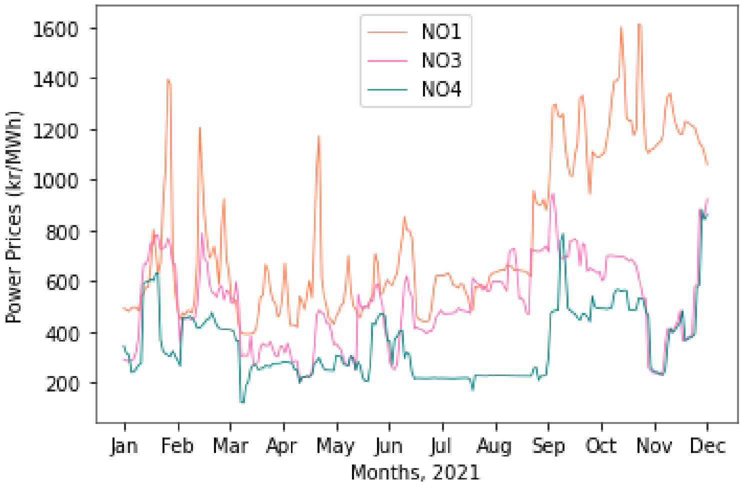


Figure 4.1: Hourly Power prices for each month for NO1, NO3 and NO4 from 2021 [99].

4.2 Analyses of previous projects

Before starting to build the model, two previous projects Aneo Build have been involved in were examined. Both Nidarvoll School and Valle Hovin Stadium used a BoostCharger to charge different construction machines, electric vehicles, and other smaller electric gear during the project period. The data collection from these projects contains charging values of power delivered from both the CCS outlets and the AC outlet, in addition to measurements of power consumed by the BoostCharger from the connected grid.

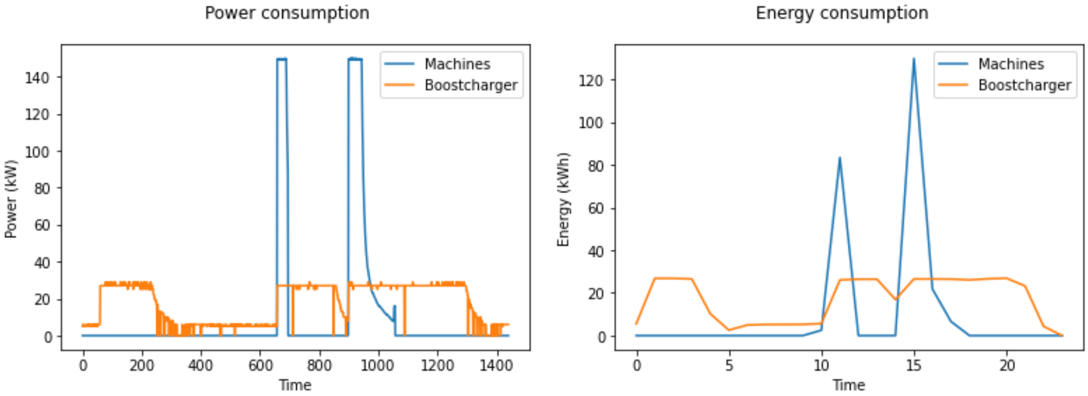
4.2.1 Nidarvoll School project

The first case analyzed was the project of building Nidarvoll School in Trondheim. The duration of the project was from November 22^{nd}, 2021, to June 30^{th}, 2022. The BoostCharger was used to supply a Pon Cat 320 construction machine with power. The Pon Cat 320 has a capacity of 300 kWh and can operate for 5-6 hours during heavy excavation work and 6-8 hours during light excavation work. The Pon Cat 320's battery is capable of rapid charging at a maximum rate of 190 kW [100]. However, due to the maximum output of the CCS outlets of the BoostCharger, the construction machine was charged at a rate of 150 kW during the project.

BoostCharger data
Appendix D In[1]-In[2]:
The data provided by Aneo contains measurements of the power delivered from the grid to the BoostCharger, and power drawn from the CCS and AC outlets. The relevant data is defined with their respective Cloudtags used in Aneo's Excel workbook. Further, for each month during the project period, nine of the working days were chosen to represent the whole month, and uploaded with the built in python function *pd.read_csv*. Its assumed that there are 20 working days in total each month.

Appendix D In[2]-In[4]:
The power consumption profiles for the CCS and AC outlets as well as the power drawn from the grid to the BoostCharger were obtained by using the self made function *fn.databehandling*, which is shown in Appendix E. *fn.databehandling* contains the functions *combined_function* and *forbruk_ved_klokketimer*, which take in the considered measurement and the relevant nine days representing the month. The function returned three matrices that would be used to make the charging patterns. The three returned matrices from the function are a timestamp (hh:mm), a power consumption (kW) matrix representing each minute during the relevant nine days, and an energy consumption (kWh) matrix for each hour during the relevant nine days.

The analysis resulted in a plot for the power consumption for each day of the duration of the project, as shown in Appendix A. Figure 4.2 shows the plots for one day, and illustrates the peak shaving. Subfigure 4.2a illustrates the power consumption for each minute of the day, and Subfigure 4.2b shows the energy consumption each hour of the same day. The blue lines represent the consumption of the construction machines from the charging container, while the orange lines represent the consumption for the BoostCharger from the electrical grid. The day that is represented in the figure was chosen arbitrarily, as which specific day was chosen for demonstration in this section is rather irrelevant. This figure is intended to emphasize the effects of the charging container in general, and not to demonstrate specific values.



(a) Power consumption each minute. *(b) Energy consumption each hour.*

Figure 4.2: Peak shaving during a selected day at the Nidarvoll project.

Appendix A shows the charging pattern for the two CCS outlets and the AC box every month of the Nidarvoll project. Additionally, the pattern for the BoostCharger's consumption from the grid is provided.

Calculations of costs

Appendix D In[5]-In[6]:
The power price data extracted from Nord Pool for NO3 for the relevant months and the grid tariff prices provided by Aneo were imported. The self made functions *fn.Nettleiepriser* and *fn.strompris_prosjekt*, shown in appendix E, were used to calculate the total costs of energy consumption and grid tariff for the whole project period. In these functions, it is assumed that the nine power consumption patterns representing each month are repeated 20/9 times, as is is assumed that there are 20 working days each month. The function *fn.Nettleiepriser* also asks what grid operator is used, and for this analysis, Tensio was chosen because this is the grid operator for most of Trøndelag.

The output from this analysis is shown in Table 4.1. The table shows an overview of the grid tariff and the power costs with and without the BoostCharger, as well as the economic savings due to peak shaving when using the BoostCharger.

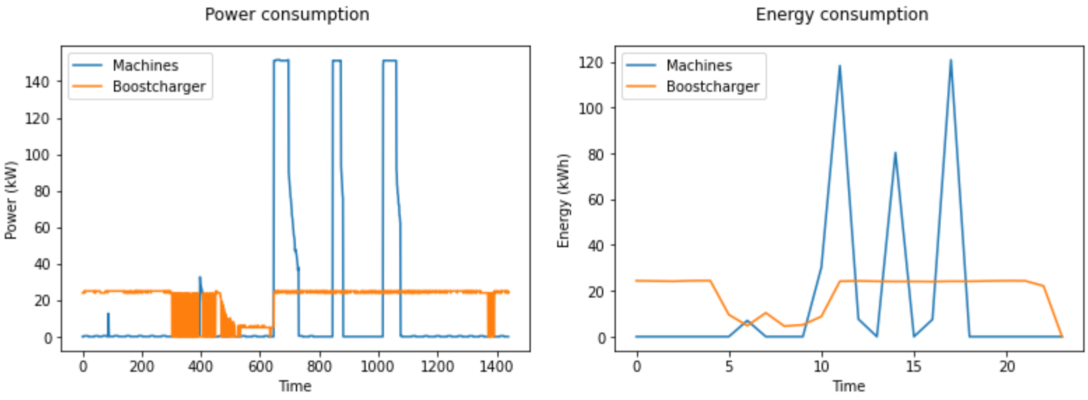
Table 4.1: Economic calculations for Nidarvoll project

	Grid tariffs (kr)	**Power costs (kr)**	**Total (kr)**
Without charging container	21 000	17 000	38 000
With charging container	10 000	20 000	30 000
Economic savings	11 000	-3000	8000

4.2.2 Valle Hovin Stadium project

The second project that was analyzed was building an ice-skating stadium in Valle Hovin in Oslo. This project lasted from February 18th to June 30th, 2022. Like the Nidarvoll project, Valle Hovin used a BoostCharger with a battery capacity of 390 kWh and two CCS rapid charging outlets of 150 kW each. The AC box was also used, mainly for charging smaller electric machines. A Hitachi Zeron ZE210 construction machine was rapid charged, as well as electric cars and trucks. The Zeron ZE210 has a battery capacity of 300 kWh. This construction machine can operate for 2.5-3 hours during heavy excavation work and 4.5-6 hours during light [37]. It rapid charges at 150 kW due to the CCS charging capacity.

The analysis of the Valle Hovin project was performed in the same steps and with the same functions as the Nidarvoll project, which is described in Section 4.2.1. Appendix B shows the charging patterns in the Valle Hovin project, both the charging from the container to the machines and the charging container's consumption from the electric grid. Charging data from every month of the duration of the project is included in the appendix. Figure 4.3 shows a plot for one of the days in the project. Like the Nidarvoll project, a day has been selected arbitrarily as the intention is to illustrate the peak shaving achieved through the charging container in general, instead of specific values.



(a) Power consumption each minute. *(b) Energy consumption each hour.*

Figure 4.3: Peak shaving during one day at the Valle Hovin project.

With the same functions and approach used in the Nidarvoll analysis, the total cost of energy consumption and grid tariff for the Valle Hovin project was calculated. With this project taking place in Oslo, the grid tariff from Elvia was used. The output of the analysis is shown in Table 4.2.

Table 4.2: Economic savings for Valle Hovin Project.

	Grid Tariffs (kr)	**Power Costs (kr)**	**Total (kr)**
Without charging container	33 000	7000	40 000
With charging container	12 000	9000	21 000
Economic savings	21 000	-2000	19 000

4.2.3 Error in the analyzed data

For both analyzed projects, some errors in the data provided by Aneo were found. Some of the data for power consumption for the CCS and AC outlets showed clear outliers. Figure 4.4 shows an example of an outlier found when analyzing the Valle Hovin project. According to the plot, the electric machine is charged at $2{\cdot}10^6$, kW which is impossible.

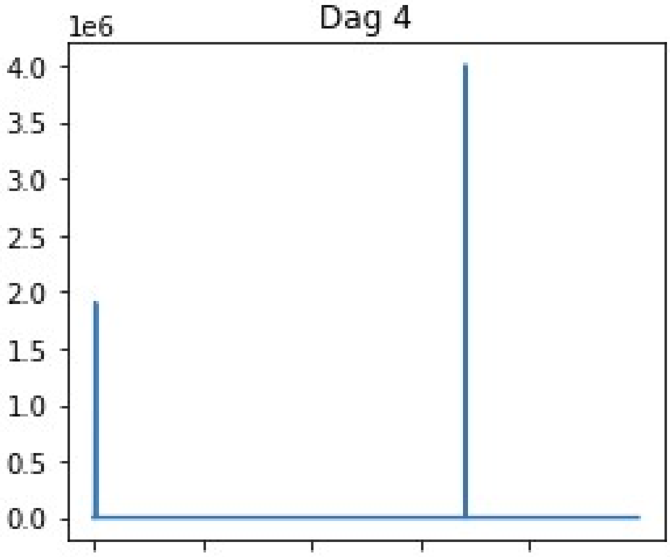
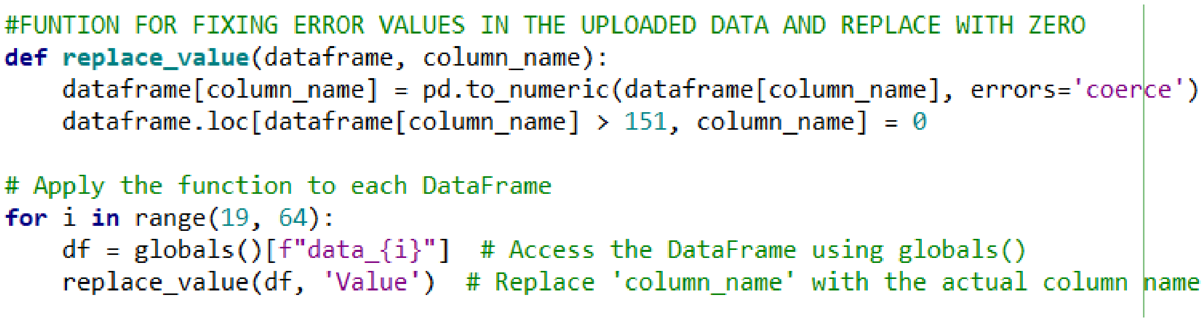


Figure 4.4: Example of an outlier in the Valle Hovin project.

As the BoostCharger used in both the Nidarvoll and Valle Hovin projects had a maximum charging rate at 150 kW, a code was made to replace any numbers above 150 kW with 0 to remove all outliers. Figure 4.5 shows the code that was made to remove outliers in the data.



```
#FUNTION FOR FIXING ERROR VALUES IN THE UPLOADED DATA AND REPLACE WITH ZERO
def replace_value(dataframe, column_name):
    dataframe[column_name] = pd.to_numeric(dataframe[column_name], errors='coerce')
    dataframe.loc[dataframe[column_name] > 151, column_name] = 0

# Apply the function to each DataFrame
for i in range(19, 64):
    df = globals()[f"data_{i}"]  # Access the DataFrame using globals()
    replace_value(df, 'Value')  # Replace 'column_name' with the actual column name
```

Figure 4.5: Function for removing outliers in the provided data.

4.3 Building the model

This chapter will explain the methodology behind building the model for estimating economic savings by using Aneo Build's products for different scenarios. To limit the size of the model and due to lack of data, it was decided that only the BoostCharger will be considered in the model. However, this model may be a basis of developing an more advanced model in the future that considers the other charging solutions of Aneo.

4.3.1 Electric circuit system of BoostCharger

To get a better understanding of the function for the different components of the BoostCharger and how they interact, the charging container's instruction manual and its electric circuit system was studied. Figure 4.6 is retrieved from the instruction manual of the BoostCharger and shows how the electric circuit is built up of different components.

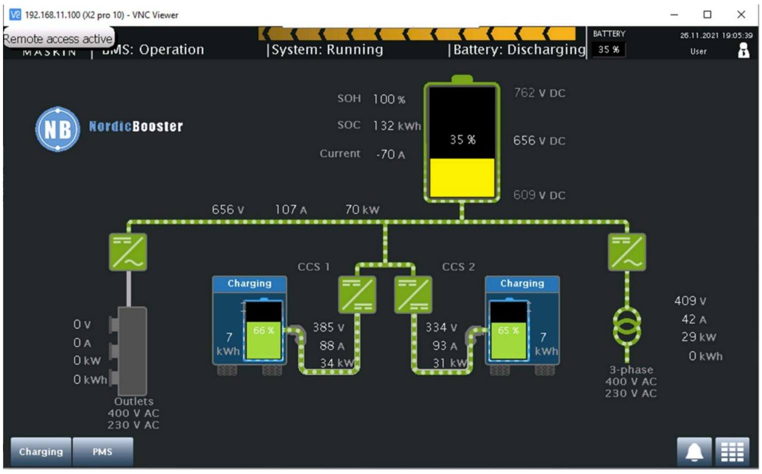


Figure 4.6: BoostCharger circuit system.

On the bottom right, the transformer is connected to the power grid at either 400V AC and 230V AC 3 phase, depending on both the power demand for the relevant construction site and the power available from the grid. The current load can be regulated up to 125A, also depending on the power demand and the power available from the grid. The power delivered to the BoostCharger can then be calculated using Equation 2.3 for 3 phase active power line to line. The transformer is then connected to an AC/DC converter. The power output from this converter is approximately the same as the power input, but in DC instead of AC.

When using the CCS outlets and the AC outlet for charging electric machines, the total power supplied is the sum of the power delivered from the grid and from the battery in the BoostCharger. By the principle of power in and out from a node and neglecting losses and power delivered to the air conditioners in the BoostCharger, the power drawn from the battery can be calculated with Equation 4.1 [101].

$$P_{battery} = P_{CCS1} + P_{CCS2} + P_{AC} - P_{grid} \tag{4.1}$$

When the SoC of the battery in the BoostCharger reaches 12%, the charging rate of the electric machines will decrease. When the SoC reaches 6%, power will not be provided to the CCS and AC outlets. Instead, the power delivered from the grid will only be used to charge the BoostCharger's battery. When the SoC of the container battery increases again, the BoostCharger will continue to charge the electric machines. How fast the BoostCharger is charged and discharged depends on how much power is delivered from the grid.

To limit the size of the algorithm in the model, it was not taken into account that the BoostCharger stops delivering power to the outlets when the SoC reaches 6%. It is assumed that the effect of this is negligible on the estimated economic savings, considering that the BoostCharger will continue delivering power when the SoC increases again and the total energy consumption drawn from the BoostCharger is expected to be unchanged.

4.3.2 Charging Pattern

As this thesis and the model revolves around the economic value of peak shaving on a construction site, the charging patterns of the construction machines and charging container are among the most significant aspects. In the light of the new grid tariff model making high power peaks more costly than before, the charging pattern is a determining factor for economic value. Therefore, it is necessary to establish a general charging pattern.

As only two previous Aneo projects were studied, scope of this pattern is limited. However, after close communication with the industry partner, Aneo Build, it has become evident that the approximation of the pattern should be adequately representative for construction sites. When examining these cases, it was decided that a solution could be to make three different patterns with similarities to the analyzed projects.

Instead of analyzing all individual days from the project, nine days from each month of the duration of the project were selected to perform the analysis. The goal of the analysis was to establish a general charging pattern, and therefore it was decided that it was rather unnecessary to analyze each day individually. Aneo Build communicated that in their experience, the construction machines are regularly rapid charged during the lunch break around 11 o'clock, and then slow charged with the AC outlet overnight after the end of the workday. This pattern is only applicable to projects with the BoostCharger, not the Hummingbird, as the Hummingbird does not contain any AC outlets. Additionally, Aneo stated that smaller machines and vehicles, such as electric vans used for transportation, were charged when the container was available or in other locations such as gas stations.

The nine days each month that were used for the analyses were selected arbitrarily, but with three to four days between to ensure an adequate representation. These days from each month would lay the foundation for the model, as the charging pattern is one of the most significant aspects of the model. Data provided by Aneo Build was retrieved from the nine selected days in each month, and the power consumption was plotted against time. Firstly, the graph for power from the charging container to the construction machine was plotted. This represents the consumption *without* a charging container because the plot shows how the load profile for the grid would look without the container. Therefore, the power price and grid tariff would be based on this plot if the charging container was not used, if the grid capacity was sufficient. Secondly, the power from the grid to the charging container was plotted. This plot represents the charging *with* a charging container because this is what the cost of power and grid tariff is based on.

After analyzing the graphs from the nine days each month, the three most repetitive patterns were selected to represent the load profiles used in the model. Although Aneo Build suggested one specific charging pattern, it was decided that choosing three patterns was the most realistic. If the pattern that was suggested by Aneo was repeated every day, the charging container would not be able to recharge enough to supply the construction machines every day. It was assumed that these three patterns were sufficiently representative and realistic, and the model therefore varies between them when calculating the cost of electricity and grid tariff. The three charging patterns and the order that was decided are illustrated in Figure 4.7. The plot called *Day 6* can be neglected. All assumptions that were made concerning the charging patterns are described and explained in Section 4.4.

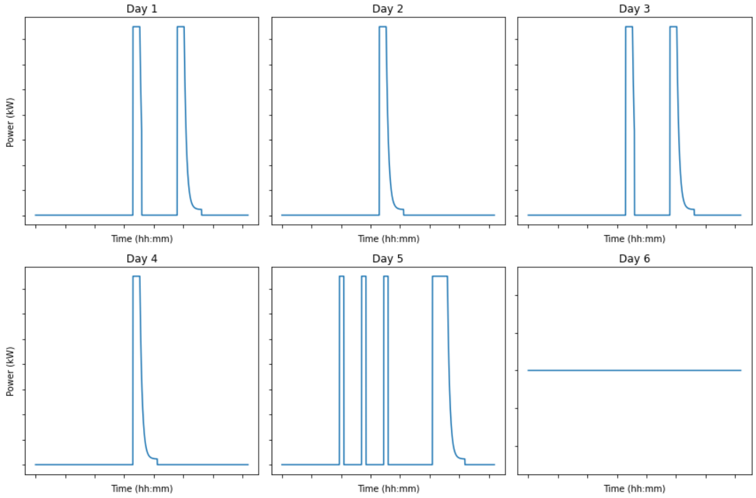


Figure 4.7: The three charging patterns and their order of appearance throughout a work week.

The model is based on a five-day work week. In the model, this sequence of three patterns over five days is repeated every week over the course of the project. The pattern used in day 1 and 3 is referred to as pattern 1, while the pattern in day 2 and 4 is called pattern 2. Day 5 represents pattern 3. It is desirable that patterns 1 and 3 do not appear on two consecutive days. Due to the overnight construction machine charging in patterns 1 and 3, the container is at risk of not being charged 100% the next day when it is time to charge. A possible consequence of this is the charging container not having the capacity to supply power to the construction machines the following day.

Pattern 2 has been placed deliberately between pattern 1 and 3, giving the charging container some extra hours to recharge overnight. As pattern 1 and 3 supply more energy to the machines than pattern 2, they appear often enough to ensure that the machines have sufficient power. After day 5, the weekend gives the charging container enough charging time to be fully charged when the next week begins.

Observations that substantiate the assumptions regarding the frequency of the occurrence of the three patterns have been made. In the two projects that have been analyzed, it appears like charging pattern 1 occurs the most frequently. Additionally, Aneo Build has stated that this is the most common pattern. The second most common pattern, according to the analyses, is pattern 2. Although pattern 1 seems to appear more frequently, it is decided that pattern 1 and 2 will occur two times each week in the model, to give the charging container the possibility to recharge overnight.

4.3.3 Estimating CC-CV pattern

Section 2.4.7 states that lithium-ion batteries are charged with CC-CV charging. As lithium-ion battery technology is the most common battery technology, this charging regime was assumed for all construction machines. Additionally, CC-CV charging was observed while analyzing the Nidarvoll and Valle Hovin projects.

As described in Section 2.4.7, the CC stage occurs when the battery reaches 80-90% SoC. The remaining 20-10% is then charged with CV charging until the current reaches its cut-off level at approximately 3% of its rated current. The CC-CV charging pattern for a specific machine is dependent om the battery components and chemistry. For the model to consider an exact discharging curve for all construction machines, a great deal of data which has not been provided would be required. Therefore, it was decided that the CC charging stage will be set to 85% SoC, and CV stage for the remaining 15% SoC for all machines. The cutoff current is set to 3% of its charging current at the CC stage.

The charging current is an input for each machine considered in the model. The machine will then continue to charge at its preset charging rate until 85% SoC is reached.

To calculate the CV charging curve for the remaining 15% SoC, Equation 2.8 was used. The model parameters A and B depend on the current input for each machine. The initial condition $I_L(0)$ equals the charging rate at the CC stage, while $I_L(t \rightarrow \infty)$ equals the cut-off current B, 3% of $I_L(0)$. By these conditions, parameter A can be calculated to:

$$A = I_L(0) - I_L(0) \cdot 0.03$$

As explained in Section 2.4.6, the speed at which the CV current decreases is dependent on the condition and chemistry of the battery. Therefore, the pattern of the PonCat 320 was used as a basis for determining the time constant τ during CV charging. It is assumed that the estimated time constant for the PonCat 320 can be sufficiently representative for all machines.

The PonCat 320's charging rate, $I_L(0)$, is observed to be approximately 235 A from the data provided by Aneo. The model parameters A and B are then calculated to be respectively 227 and 7.05 A. It is also observed that the time it takes the curve to decrease from $I_L(0)$ to 7.05 is approximately 124 minutes. The exponential equation describing the CV current curve for the Pon Cat320 can then be written as:

$$I_L(124) = 227 \cdot e^{-\tau \cdot 124} + 7.05$$

The equation was plotted in GeoGebra, as shown in Figure 4.8. Line g represents the calculated cut-off current, and the exponential graph f represent the CV current.

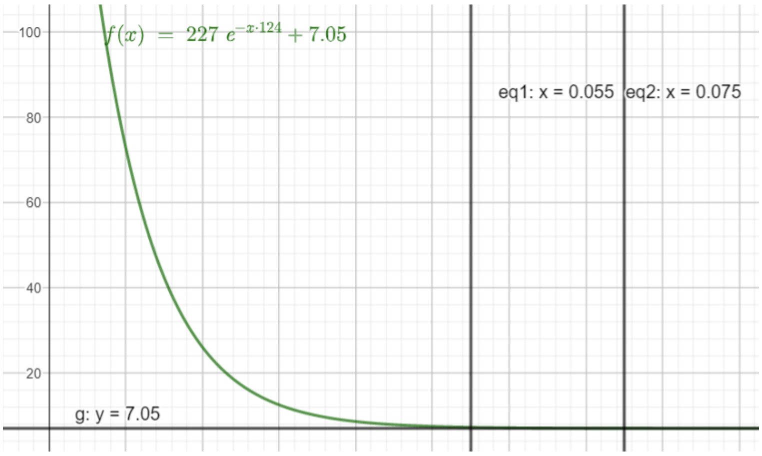


Figure 4.8: Approach used to find the CV charging curve.

From the plot, it is observed that the time constant τ lies somewhere between 0.055 and 0.075 s^{-1}. A trial and error approach of different time constants between the observed interval was used to find a similar curve to the observed CV curve.

The estimated CV charging curves were plotted against the measured CV curve to evaluate the accuracy of the estimation. Time constant equal to 0.065 gave an estimated curve best fitted to the measured curve for the Pon Cat320. Figure 4.9 shows the two graphs plotted together.

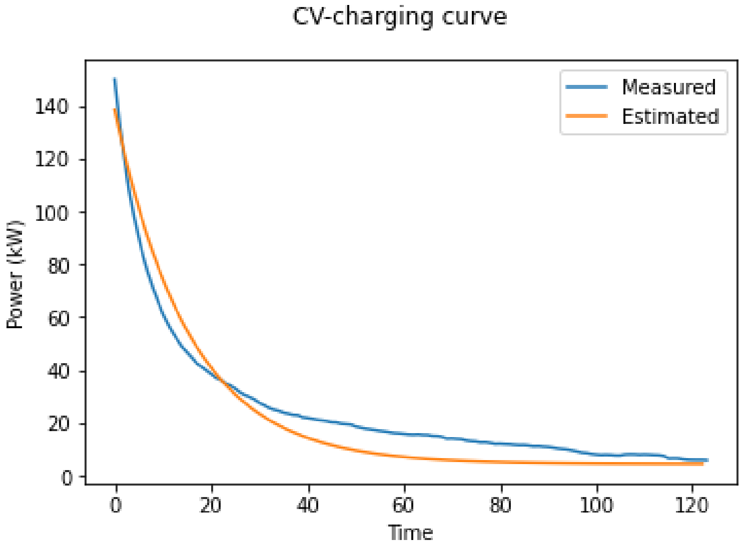


Figure 4.9: Comparison of estimated and measured CV charging.

As a result, equation 4.2 was used in the model to estimate the CV charging curve for different machines. Here, τ is changed to 0.065 due to this being the time constant that resulted in the most fitting estimated curve.

$$I(t) = A \cdot e^{-0.065 \cdot t} + B \tag{4.2}$$

4.3.4 Model setup

The model built for calculating the economic savings by using Aneo's charging containers for peak shaving, needs the following inputs from the user to do the calculations:

- Numbers of machines used
- Machine characteristics
    -Batterycapacity (kWh)
    -Charging power (kW)
    -Charging current (A)
    -Max working hours before discharged (h)
- BoostCharger characteristics
    -Batterycapacity (kWh)
    -Connected voltage to grid (V AC)
    -Connected current load (A)

- Project characteristics

  -Start month

  -End month

  -Network company

  -Price area

The resulting setup of the model is illustrated by the flow chart shown in Figure 4.10. The blue nodes in the flow chart illustrate the process of estimating the total power consumption pattern for the amount n of machines for the considered project. The total power consumption during the three different charging patterns, ends in a power consumption pattern for one week with five working days where charging pattern 1 and 2 are repeated twice and pattern 3 once, as described in Section 4.3.2. Appendix F In[1]-In[2] shows how this process is done in the Python code for the model by using the self made function *fm.Forbruksmønster_CCS()*.

The charging pattern for a week is assumed to repeat each week during the given project period. In[2]-In[3] in Appendix F shows the code where power and grid tariff costs are calculated for the scenario when the electric machines are charged from rapid chargers directly connected to the grid for the chosen price area and grid operator. The self made function *fm.strompris* takes in the estimated total energy consumption for the machines and returns the power costs for the project period. The function *fm.Nettleiepriser* estimates the total grid tariff costs.

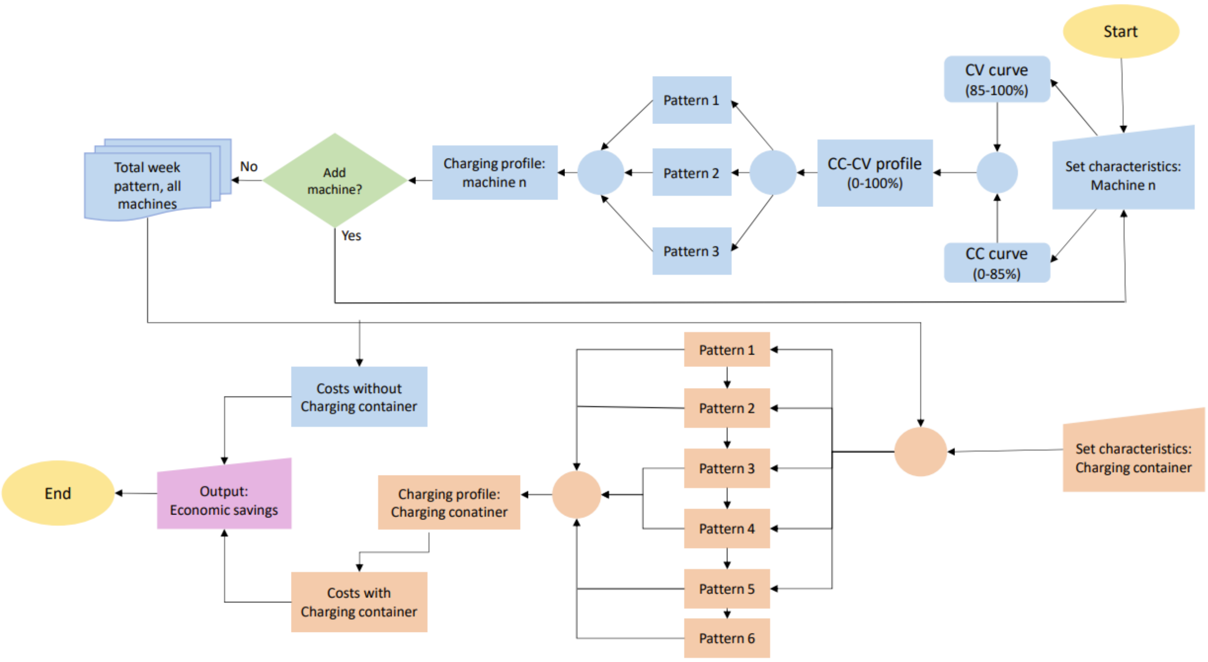


Figure 4.10: Flow chart: Overview of the model setup.

The orange nodes of the flow chart illustrate the process of estimating the total power consumption pattern for the charging container. The consumption of the charging container is both dependent on the power supplied to the electric machines, but also the characteristics of the charging container. As mentioned in Section 4.3.1, the BoostCharger starts to draw power from the grid when power is drawn from the container. When the construction machines stop charging from the BoostCharger, the container still continues drawing power from the grid until the battery SoC is 100%. It has been observed that 5 kW is constantly being drawn from the grid even if the SoC of the battery is 100%, because of other system components in the charging container. This observation was taken into account in the model as well.

In Appendix F, In[3]-In[4] shows the Python code for estimating the power consumption of the BoostCharger for each five working days. For the BoostCharger, a sixth day is also added in case a big power consuming machine park is simulated and the BoostCharger needs more time to reach 100% SoC. The resulting energy consumption pattern is used to calculate the power and grid tariff costs with function *fm.strompris* and *fm.Nettleiepriser* for the scenario when the electric machines are charging from the BoostCharger.

The output of the model is a comparison of the grid tariff and power costs with and without using the BoostCharger for the simulated construction project, as well as the economic savings. The output does also plot the power consumption patterns for the machine park, as well as the BoostCharger's to illustrate the peak shaving.

4.3.5 Model calculations and functions

The self made functions used in the model are shown in Appendix F. The most fundamental function used in the model is the function *Forbruksmønster_CCS*. This function was built up by several other self made functions for different calculations, and in total contains all the calculations concerning the power consumption for a given machine for each charging session in the three charging patterns.

Section 4.3.3 explains the method for finding the CC-CV charging curve for a given machine with Equation 4.2, which is used in the function *CV_P_estimat* to calculate the power consumption during the CV charging stage. The function includes a *while loop* that continues to calculate the next charging rate I(t+1) until the total energy charged equals the remaining 15% of the battery capacity until fully charged for the CV stage.

Considering a constant charging power during the CC stage, the power consumption pattern during the CC stage was found by calculating the time it takes for the machine to charge from the current SoC to 85% using Equation 2.9. The total charging curve for each minute during CC-CV charging for the considered machine was then found. This charging curve was used when estimating the curve for each charging session for the three different patterns.

When estimating the charging curve for each charging session in the function *Forbruksmønster_CCS*, the SoC before starting the charging session also had to be considered. Assuming that each day, the machines start working at 8 o'clock in the morning with a SoC of 100% and work every hour during the work day, except under charging sessions, the SoC can be calculated before each charging session. SoC was calculated with Equation 2.6 by dividing the remaining energy after working with the total battery capacity. The remaining energy after a working session depends on the discharging rate. How fast the battery discharges per working hour was estimated by dividing the total battery capacity with the hours the specific machine uses to fully discharge. The SoC after a charging session is estimated by adding the remaining energy before the charging session, to the total amount of energy charged during the session. The output of the function *Forbruksmønster_CCS* is the power consumption each minute during the day for the three different charging patterns for the specific machine considered.

The *forbruk_klokketime* function processes the estimated power consumption list in kW for each minute during the day, and estimates the total energy consumption in kWh for each hour. The function *Nettleiepriser* then estimates the grid tariff costs based on the estimated energy consumption, the highest power peak for the machine park and the chosen grid operator for the project period. Although the fixed cost for grid tariff is based on the average of the three highest peak hours during the month, the model does not calculate the average. This is because the model is constructed in such a way that the highest peak occurs every day during the lunch charging, and the highest peak is the same each day.

When running the function, the user is asked which network company will be used in the upcoming project. The function then uses an *if-sentence* to estimate the grid tariff costs based on the relevant prices for the chosen company. The highest power peak expected for the machine park decides which price range must be taken into account when the fixed price cost is calculated. The variable costs for day and night is estimated by looking at the total energy consumption of the Machine/BoostCharger during the day and night for the whole project. The Enova tax is multiplied with the number of months in the considered project period, while the consumption fee is multiplied by the total energy consumption for the project. The total grid tariff price for the project is then returned from the function. Functions *strompris_dag* and *strompris* are used for estimating the total power costs for the considered project.

After calculating the total grid tariff and power costs, the output from the model is a table of economic values for power and grid tariff, with and without the charging container. The grid tariff costs with the charging container are lower than the same cost without the charging container as a direct result of peak shaving. In the table, the total savings are calculated by subtracting costs without the container from the costs with the container.

4.4 Assumptions

During this project period, a multitude of assumptions have been made. Some of the assumptions are based on communication with internal and external supervisors, while some are based on patterns seen in the analysis. Some of the assumptions are also made based on convenience and for the sake of making limitations for the model and thesis to ensure a reasonable and manageable workload.

One assumption that was made is that there are no more than three construction machines used simultaneously in a project. This assumption was made because it was stated by Aneo Build that using more than three rarely occurs. In the two projects that were provided for the analysis, only one machine was used. Finding a pattern that includes more machines than outputs was a challenge as there was no data from such cases, and it was therefore concluded that the model would not take into account more than three machines. Additionally, this was seen as necessary to avoid making the model unreasonably complicated.

Many assumptions were made when deciding the three charging patterns. Mainly, this is because the producers of this thesis and model have limited knowledge regarding construction sites and electric construction machines. One assumption that was made for all the patterns is that all construction machines are charged during the lunch break every day. This assumption is both based on information from Aneo Build and frequent observation of repeated charging from around 11 o'clock - 12 o'clock. Lunch break is therefore assumed to take place in this time period.

The work week is assumed to be five days long, followed by the weekend. Further, it is also assumed that no one on the construction site works during the weekend. Therefore, 20 workdays each month are assumed. It is also assumed that the construction workers are somewhat intentional with their charging habits. It cannot be expected that the construction workers have the possibility to follow a strict charging plan every day. However, communication with Aneo Build, the field trip to the construction site on Trondheim Cathedral School, and results from the analysis have shown that it is reasonable to assume intentional charging to a certain degree.

Additionally, it is assumed that on days with charging pattern 2, the construction machines are used for three hours after the lunch charging session. Then, the machines are left overnight without charging. Further, the construction workers are assumed to start the excavation work at 8 o'clock each morning. This assumption was necessary to make to calculate the state of charge by the first charging session. A simplifying assumption was made, that on day 5, where charging pattern 3 is used, at least one construction worker arrives on the site at 7 o'clock to charge the construction machines because they did not charge the night before. Power losses from the machines and charging container are not taken into consideration to limit the scope of the project.

It is plausible to believe that the construction workers want to use their work time efficiently. Therefore, it is assumed that the rapid chargers are preferred over the AC outlets when charging during the workday. The more quickly a construction machine is charged, the more quickly it can be used. This, combined with all machines being charged during lunch break, means that the highest power peak for each day is situated between 11 o'clock - 12 o'clock. If there are three construction machines, the third machine is slow charged with the AC outlet.

Further, electric vehicles are assumed to not use the charging container at night. This is because they can be transported to other charging stations more easily and energy efficiently than the construction machines. Additionally, overnight charging might not always be necessary for the vehicles. If less than three construction machines are used, the parameters for smaller electric vehicles or appliances can be set as inputs. However, it will then be assumed that these appliances use the same charging pattern as the construction machine. If three construction machines are used, it is not possible to include smaller appliances due to limitations in the model.

Another simplifying assumption that has been made is that the charging container charges at a constant power rate. This means that no CV charging has been put into the model for the charging container. Although this is not necessarily accurate in reality, it was decided to neglect the CV charging for the container due to time pressure. However, as the charging container charges over a much longer time than the machines due to its low charging power rate, a lower percentage of the total CC-CV charging will occur at the CV stage, resulting in a minimal impact on the charging curve outcome.

It is also assumed that the state of charge has a linear curve. This means that at 50% SoC, it is assumed that 50% of the maximum working time for the construction machine is remaining. Although this is most likely not the reality, this was deemed a necessary assumption. For the model to take non-linear SoC graphs into account, much more data would be required for each individual construction machine and battery.

Due to the lack of data, the maximum outcharging power for the AC box is set to 50 kW. This is the highest value from the AC outlet that has been observed when analyzing the Nidarvoll and Valle Hovin projects, except for some clear outliers. These outliers can be seen in, for instance, Appendix A, in Figure A.4.

The hourly power prices for the selected day each month is assumed to represent the entire month. Although this is not the reality of power prices, it was assumed that this strategy was sufficiently representative. The assumption of one average for each month seems appropriate because the day-to-day power prices generally do not vary to a large extent. The power prices for 2021 were assumed to be more representative than 2022, because the power prices of 2021 were more like the power prices in former years.

This approach for finding power prices was used in both the analyses and the model. Although retrieving the actual power prices for every individual hour of the two analyzed projects might lead to more precise results, it was deemed unnecessary. The analyses, like the model, are intended to give an estimate of economic value, instead of an exact number.

4.5 Analyzed cases

To investigate the effects of peak shaving and which inputs have the most influence on economic value, various fictitious cases have been analyzed. The influence of geographic location, difference in machine parks, and time of year have been explored. The analyses where geographic location is investigates is called Case 1. Case 2 is referred to as the analyses where the machine park is explored. The analyses where the duration and time of year have been explored are referred to as Case 3.

Firstly, a base case was established. It was decided that all analyses should have the same conditions, except the factors that would be investigated. The connected power from the electric grid to the charging container is 50 kW for all cases. The voltage is 230 V AC and the current is 125 A. Further, the charging container has a battery capacity of 580 kWh and two CCS outlets of 150 kW each. It was decided that these factors should be the same for all simulations, to ensure an identical base. This way, the different aspects that were investigated, would demonstrate the difference.

4.5.1 Case 1

In Case 1, the influence geographic location has on peak shaving was explored. Three analyses with identical inputs as described in Section 4.5, except price area and network company were performed. All three cases had the inputs mentioned above, as well as one construction machine similar to the machine used in the Nidarvoll project. The duration for all three cases was set from January through December. In Subcase 1a, the price area NO1, and the network company Elvia were selected. Then, price area NO3 and grid operator Tensio were chosen as inputs for Subcase 1b. NO1 and NO3 were chosen to analyze because many of Aneo Build's projects are located in these price areas. Lastly, NO4 was chosen as the price area, and Arva was the selected grid owner. This is referred to as Subcase 1c. NO4 was chosen due to their generally low power prices, to show the impact more clearly. Figure 4.11 shows the location of the price areas used for the subcases. In each price area that was selected, the main grid operator for the corresponding area was chosen. The results from Case 1 are presented in Section 5.1.

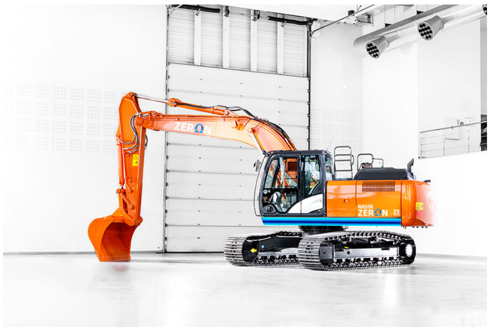
Figure 4.11: The price areas picked out for Subcase 1a, 1b and 1c

4.5.2 Case 2

The influence that the machine park has on economic value of peak shaving was explored in Case 2. Photos of the different machines used for the simulation in Case 2 are shown in Figure 4.12. Like the first round of simulations, the inputs described in Section 4.5 were set in the model. Each of the three simulations had NO3 and Tensio as inputs. All analyses had a duration from January to December. The difference made by using a different machine park was investigated by first analyzing a project with one machine in Subcase 2a. Values for the first machine were put into the model. The battery capacity was set to 300 kWh and the maximum of expected work hours to 7 hours with no charging. Then, the maximum charging rate was set to 190 kW. 235 A was set as the current drawn. These are values identical to the construction machine used in the Nidarvoll project.

Then, a project with two construction machines was analyzed in Subcase 2b. Values for the Pon Cat 320 as well as the construction machine used in the Valle Hovin project, a Hitachi Zeron ZE210, were given as inputs in the model. The Zeron ZE210 has a battery capacity of 300 kWh. 4 hours was set to the maximum expected work time with no charging. It can rapid charge at 15 kW and the current drawn is 125 A. Lastly, Subcase 3 was analyzed and a third and smaller machine, the Pon Cat 310, was introduced and placed as input with the Pon Cat 320 and Hitachi Zeron ZE210. The last construction machine has a battery capacity of 150 kWh and is charged with 40 kW from the AC outlet. Work hours is set to 7 hours, and current drawn to 75 A. This machine was chosen, mainly to add an appliance with a smaller capacity, but also because Aneo was familiar with it. The results from Case 2 are presented in Section 5.2.

(a) *Pon Cat 320 Excavator [102].* (b) *Pon Cat 310 Excavator [103].*

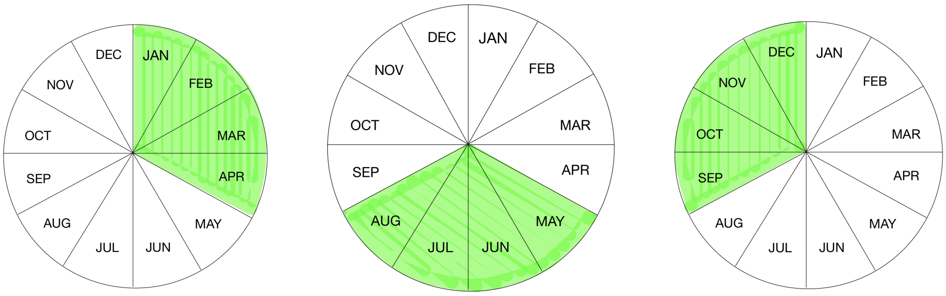


(c) *Hitachi Zeron ZE210 Excavator [104].*

Figure 4.12: Photos of the construction machines used in Case 2 .

4.6 Case 3

Lastly, the difference made by executing a project during different times of the year was explored in Case 3. Here, one Pon Cat 320 construction machine was decided as an input. NO3 and Tensio again were chosen as the price area and grid owner. Subcase 3a was executed from January through April. Then, the same project was analyzed with a duration from May through August. This is referred to as Subcase 3b. Lastly, the duration was changed to September through December in Subcase 3c. In Figure 4.13 the duration of the Subcases are illustrated. The results from Case 3 are presented in Section 5.3.



(a) *Duration Subcase 3a.* (b) *Duration Subcase 3b.* (c) *Duration Subcase 3c.*

Figure 4.13: The duration of the different subcases in Case 3.

5 Results

To evaluate the economic value of using a charging container for peak shaving, the cases mentioned in Section 4.5 were developed. To investigate the influence of the different inputs, several analyses were performed. The results from the model simulation of these cases will be presented in this section.

5.1 Case 1

The variable inputs for Case 1 are price area and network company. Section 4.5.1 presents the different variations and subcases. The results from Subcase 1a, where NO1 and Elvia were chosen as inputs, are presented in Table 5.1.

Table 5.1: Economic calculations for case 1a

Case 1a	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	75 000	56 000	131 000
With charging container	40 000	63 000	103 000
Economic savings	35 000	-7 000	28 000

The table shows that this fictitious project has total economic savings of 28 000 kr due to peak shaving. The cost of the grid tariff and power cost is 103 000 kr with the charging container and 131 000 without. This means that approximately 21.4% of the original total cost is cut solely due to peak shaving with the charging container. One notable result is that the economic savings for power cost is negative. Further, Table 5.2 shows the results generated by the model in Subcase 1b. In this subcase, NO3 and Tensio were the chosen price area and grid operator.

Table 5.2: Economic calculations for Subcase 1b

Subcase 1b	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	58 000	33 000	91 000
With charging container	31 000	38 000	69 000
Economic savings	27 000	-5 000	22 000

In this subcase, peak shaving caused 22 000 kr in savings. This amounts to 24.2% of the power cost and grid tariff cost that would have been paid if the fictitious project did not use the charging container. In Subcase 1b, like Subcase 1a, has a negative value for economic savings for power cost. Next, Table 5.3 shows the economic values for Subcase 1c. In this subcase, the fictitious project had NO4 and Arva as inputs.

Table 5.3: Economic calculations for Subcase 1c

Subcase 1c	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	36 000	24 000	60 000
With charging container	29 000	27 000	56 000
Economic savings	7 000	-3 000	4 000

In this subcase, the economic savings are smaller than in Subcase 1a and Subcase 1b. In Subcase 1c, 4 000 kr is saved, which makes up approximately 6.7% of the total cost without the charging container. This subcase also has a negative value for power cost, but smaller than the two previous subcases. In Figure 5.1, the total costs with and without the charging container are illustrated in a bar chart. The chart amplifies the differences between the price areas. The percentage savings in power cost are also plotted.

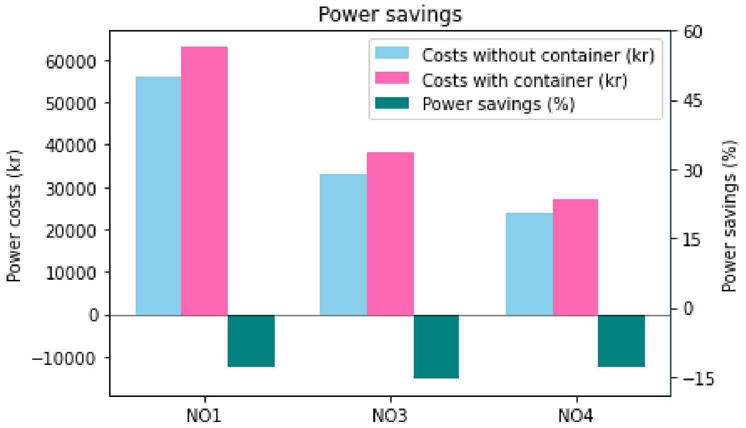


Figure 5.1: Bar chart of savings in Case 1.

5.2 Case 2

In Case 2, the effect of having different sized machine parks is explored. In Section 4.5.2, the different subcases and inputs are explained. Table 5.4 shows the results from Subcase 2a, where one construction machine identical to the machine used in the Nidarvoll project is used.

Table 5.4: Economic calculations for Subcase 2a

Subcase 2a	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	58 000	33 000	91 000
With charging container	31 000	38 000	69 000
Economic savings	27 000	-5 000	22 000

The table shows that in Subcase 2a, 22 000 kr is saved due to peak shaving. This makes up 24.2% of the original total cost without the charging container. In this subcase, the value for economic savings for power cost is negative, like the previous subcases. This will be discussed in Chapter 6. Further, Table 5.5 shows an overview over the grid tariff, power cost and total cost for Subcase 2b. In this case, a fictitious project with both the construction machine used in the Nidarvoll project and the machine used in the Valle Hovin project were analyzed.

Table 5.5: Economic calculations for Subcase 2b

Subcase 2b	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	88 000	73 000	161 000
With charging container	41 000	69 000	110 000
Economic savings	47 000	4 000	51 000

In Subcase 2b, 51 000 kr was saved because of peak shaving with the charging container. As the total cost without the container would have been 161 000 kr, the savings make up roughly 31.2% of the costs. Subcase 2b has a positive value for economic savings for power costs, unlike the previous subcases. This will also be discussed in Chapter 6. Further, the last subcase for Case 2, Subcase 2c, contains three construction machines. These include the machine from the Nidarvoll project, the machine from the Valle Hovin project and one smaller construction machine that is mainly charged with the AC outlet. Table 5.6 displays the results of this subcase.

Table 5.6: Economic calculations for Subcase 2c

Subcase 2c	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	93 000	86 000	179 000
With charging container	45 000	83 000	128 000
Economic savings	48 000	3 000	51 000

As the table shows, 51 000 kr is saved in Subcase 2c. This accounts for approximately 28.5% of the total cost without a charging container. This subcase has a positive value for power cost economic savings, similar to Subcase 2b.

In Figure 5.2, the charging curve for the machines and the BoostCharger are plotted for Subcase 2a, in Figure 5.3 for Subcase 2b and Figure 5.4 for Subcase 2c. The plots show how the container must recharge to be able to supply the machines with the necessary power. They are plotted with power in kW on the y-axis and hour on the x-axis.

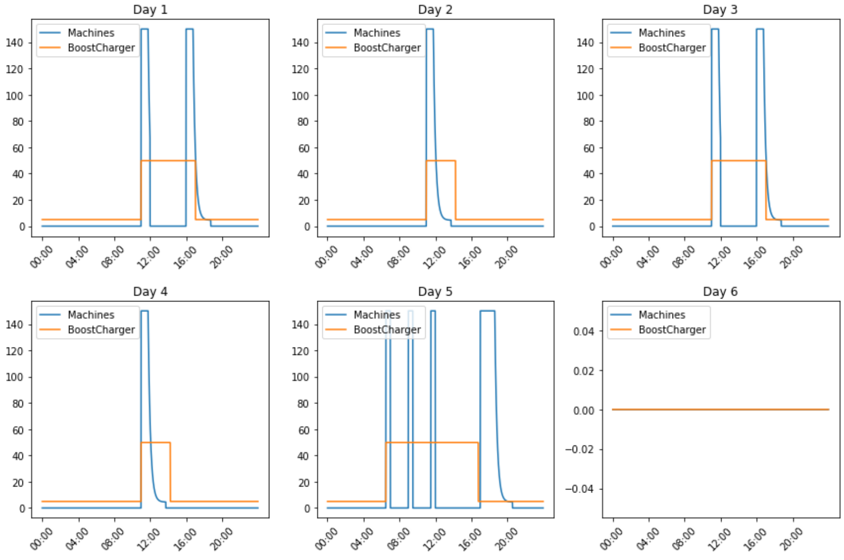


Figure 5.2: *Charging curve of container and machine for Subcase 2a.*

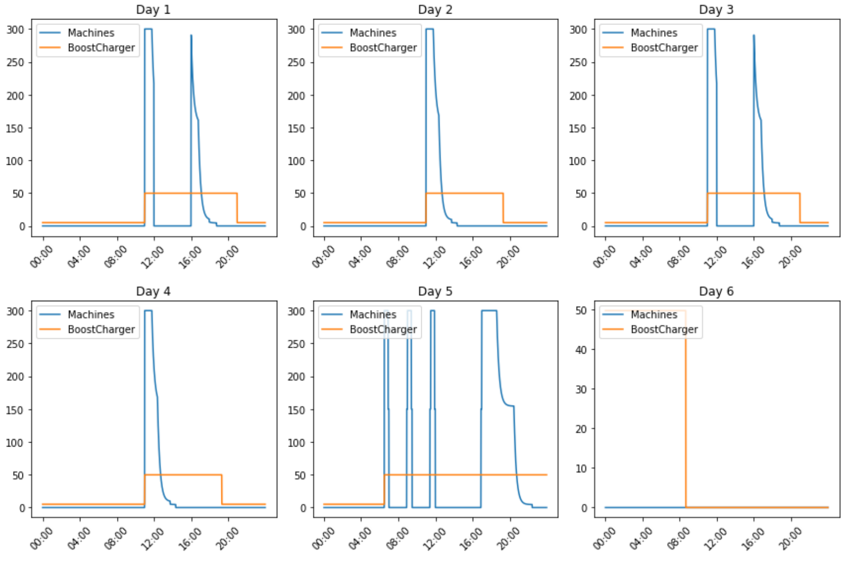


Figure 5.3: *Charging curve of container and machines for Subcase 2b.*

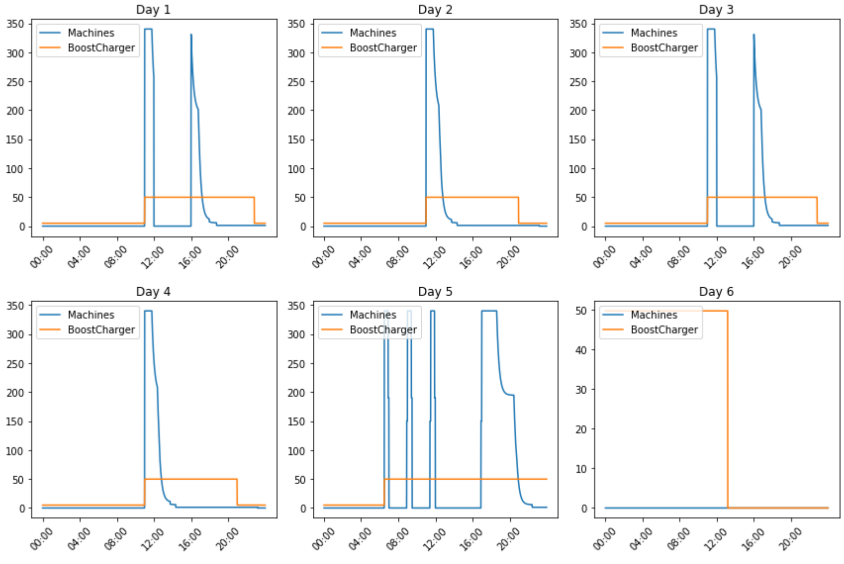


Figure 5.4: *Charging curve of container and machines for Subcase 2c.*

5.3 Case 3

In Case 3, the goal was to explore the influence that executing a project different times during a year has on peak shaving. All parameters were set to the values explained in Section 4.5. Table 5.7 provides an overview over the economic values in Subcase 3a. This subcase is set to take place from January through April.

Table 5.7: Economic calculations for Subcase 3a

Subcase 3a	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	23 000	9 000	32 000
With charging container	8 000	11 000	19 000
Economic savings	15 000	-2 000	13 000

The table shows that during this period, 13 000 kr is saved. With the total cost without the charging container being 32 000 kr, the savings make up around 40.6%. Additionally, the total economic savings for power cost is negative, like several previous subcases. Further, the results of the analysis of Subcase 3b are presented in Table 5.8. In this subcase, the time period is set from May through August.

Table 5.8: Economic calculations for Subcase 3b

Subcase 3b	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	23 000	9 000	32 000
With charging container	8 000	10 000	18 000
Economic savings	15 000	-1 000	14 000

In this table, the economic savings are 14 000 kr. This makes up approximately 43.8% of the original cost of grid tariff and power cost without the charging container. This subcase also has a negative value for power cost savings. Lastly, the results from Subcase 3c are presented in Table 5.9. The project in this subcase was set to start in September and last through December. The other parameters are the same as the other subcases in Case 3.

Table 5.9: Economic calculations for Subcase 3c

Subcase 3c	**Grid tariff (kr)**	**Power cost (kr)**	**Total (kr)**
Without charging container	23 000	9 000	32 000
With charging container	8 000	10 000	18 000
Economic savings	15 000	-1 000	14 000

This table shows economic savings of 14 000 kr. This makes up 43.8%, which is the same percentage as Subcase 3b. Here, the power cost savings also have a negative value.

Table 5.10 shows a summary of the specifications for each subcase as well as the most significant findings from the analyses. The savings for each category is provided both in kr and with the percentage.

Table 5.10: An overview over significant results from the different subcases

Subcase	**Specification**	**Grid tariff savings (kr)**	**Grid tariff savings (%)**	**Power cost savings (kr)**	**Power cost savings (%)**	**Total savings (kr)**	**Total savings (%)**
1a	NO1	35 000	46.7	-7 000	-12.5	28 000	21.4
1b	NO3	27 000	46.6	-5 000	-15.2	22 000	24.2
1c	NO4	7 000	19.4	-3 000	-12.5	4 000	6.7
2a	1 machine	27 000	46.6	-5 000	-15.2	22 000	24.2
2b	2 machines	47 000	53.4	4 000	5.5	51 000	31.2
2c	3 machines	48 000	51.6	3 000	3.5	51 000	28.5
3a	Jan-Apr	15 000	65.2	-2 000	-22.2	13 000	40.6
3b	May-Aug	15 000	65.2	-1 000	-11.1	14 000	43.8
3c	Sept-Dec	15 000	65.2	-1 000	-11.1	14 000	43.8

This table shows that Case 1 undoubtedly has the highest percentage in savings. However, Subcase 2b and Subcase 2c have the highest total savings in kr. These subcases are also the only subcases with a positive value for power cost savings. Subcase 1c has the clearly lowest savings. The most interesting finds from these results will be discussed in Chapter 6.

6 Discussion

The transition from fossil energy sources to renewable energy sources is necessary to reduce the climate gas emissions and decrease the damage done by climate change. This transition does offer some challenges, which need to be addressed for the transition to be achievable.

As presented in Chapter 2.1, 3.4% of the total amount of climate gas emissions made up by Norwegian industry and households comes from the building and construction industry. Multiple of the largest Norwegian cities have committed to making this industry emission free by 2030. Although this only applies to some cities, other cities will hopefully take inspiration and start the process of decreasing the amount of climate gas emission in their construction projects.

As 95% of the emissions on a construction site comes from transporting and operating construction machines, replacing fossil fuel powered machines with electric machines will most likely have a significant effect on the amount of climate gas emitted from construction sites. This might lead to a decrease of hundreds of thousands of tons climate gas emissions.

Additionally, around 31.2% of the people that are employed in the construction industry in Norway are employed in the cities that signed the declaration to ensure emission free construction sites by 2030. This gives an insight to the impact it can have if these cities are successful in reaching their goals.

Although not all of Norway has committed to making the construction industry emission free, it can be argued that the large cities might have a great influence on other cities. With almost one third of all construction workers in Norway being employed in the committing cities, it is likely that a large fraction of the country's total emission can be cut if these cities reach their goals of zero-emission construction sites. These cities reaching this goal means that almost one third of construction workers in Norway work with emission free projects. Trondheim, Bergen, Oslo, Drammen, Tromsø, Stavanger and Kristiansand are among the biggest cities, and therefore, it can be argued that they are influential cities in the country as well. Hopefully, other areas will follow their example. This can have an even greater effect on the climate.

If the claim that non-mobile machines can reduce emissions with 4 million tons by 2030 proves to be correct, it can be argued that the success is largely due to electrifying machine parks nationwide. This will require a great expantion and upgrade of the Norwegian power grid, as there are already multiple areas that face challenges regarding the capacity of the grid. Although there are several laws and regulations that state the obligations and responsabilities network companies have to supply their customers with power.

Electrifying Norwegian construction sites will most likely lead to a higher strain on the grid, which will result in more power loss, electronic bottlenecks as well as other issues. However, it can be argued that the biggest and most pressing issue related to the electric grid today is capacity. In Trøndelag, it appears like smaller municipalities, such as Lierne, as well as large city centers, such as Trondheim Cathedral school, experience challenges with the grid not having the adequate capacity.

Another challenge the electric grid faces is maintaining a stable balance between power production and consumption. Sudden surges in consumption can cause frequency deviations, which can lead to blackouts of entire areas. Managing the power balance might be especially challenging in Norway, because most of the power is produced with renewable, weather dependent sources.

While these challenges are already substansial in 2023, it is plausible that the circumstances will worsen in the coming years. Many industries are planning on increasing their electrification and new power consuming industry is expected to emerge. For the grid to be able to manage this increased load, new solutions and grid upgrades can be seen as necessary.

A grid upgrade would be beneficial regarding several of the beforementioned technical issues. However, grid development can be extremely costly. Additionally, an extensive nature intervention that would be inevitable and the aquisition of consession can take substansial amounts of time.

Therefore, implementing alternative, long-term solutions can be beneficial concerning the grid capacity issues. The new model for grid tariff is an example of this. Making high power peaks costly, the new model can potentially decrease the urgency of the need for a grid upgrade. Many Norwegians might become more aware of their power use because of this, including both personal life and professional activities like construction work. Therefore, the strain on the electric grid can decrease due to the new system for grid tariff, which enables a more stable power flow and supply.

Peak shaving can be a useful tool in the future energy network. By distributing the load of the grid to be more even, the stress and losses are reduced. Therefore, it can be argued that peak shaving can be advantageous both cost-wise for the customers, as well as the power grid, the grid operator and to society due to a reduced need for grid development.

The new grid tariff model promotes peak shaving because this approach leads to more inexpensive grid tariffs. There are many ways to achieve peak shaving, and which approach is the most beneficial depends on the goal of peak shaving. For this thesis, the economic value of using a charging container for peak shaving is the objective.

Peak shaving can be seen in the construction industry, as Aneo has provided charging solutions to multiple projects. Although peak shaving might not always be the main motivation behind renting charging solutions, like seen at Trondheim Cathedral School, peak shaving is achieved nonetheless.

Not only can peak shaving be cost reducing regarding grid tariffs. Due to fluctuations in power prices from day hour to hour, it can be beneficial to strategically use electricity during cheap hours. However, the power prices are generally much lower during the night than the day. This might not be beneficial for a construction machine rapid charging in the lunch break. Additionally, rapid charging rather than slow charging causes high power peaks, resulting in high grid tariff prices.

With the newly implemented grid tariff model, peak shaving might be more relevant for the Norwegian people. However, the success of the new grid tariff model depends greatly on the Norwegian people complying to being aware of their power use pattern, as well as having the knowledge and willingness to shift their power consumption patterns. Additionally, it requires people to have a certain understanding of electricity. Therefore, estimating the effectiveness of the new grid tariff model is challenging. It is impossible to determine whether or not the Norwegian people is willing to learn about electricity. In addition, the amount of time and energy people are willing to put into shifting their energy loads is uncertain. However, economic savings might be appealing to many people and can function as motivation to attempt achieveing peak shaving. Especially for industries with high power demand, where there can be large savings from peak shaving.

Energy storage can be beneficial for the purpose of peak shaving. Avoiding high power peaks on a construction site with an electric machine park is most likely nearly impossible. However, drawing large amounts of power from an energy storage system does not create a high load in the grid and high power peaks. Using an ESS that slow charges from the power grid and supplies power to the construction machines by rapid charging is therefore cost saving.

There are certain criteria consider for a construction site with an electric machine park that need an ESS. For larger construction projects, it might be necessary to move the ESS to avoid belting of the construction machines. Mobility is therefore an advantage for the ESS. The applications are charged at high power rates, making it necessary for the ESS to deliver large amounts of power and have a high power density. This is also important due to the power grid not having the adequate capacity to deliver the necessary power in certain areas.

There is a large variety of different technologies used for energy storage. Multiple technologies are presented in Section 2.3. Now, their advantages and disadvantages will be discussed. In addition, the different chemical battery technologies will be discussed.

Hydrogen is a flexible method for storing energy, regarding the large variety in production techniques and energy sources that can be used in the process. Different production methods and feedstock have each their advantages and disadvantages. The large variety of methods and feedstock options is beneficial in itself. As non-renewable energy is rarely used for electricity in Norway, this will not be discussed as an option for hydrogen energy storage in this thesis.

Renewable energy can be used in hydrogen energy storage, and emission-free HES is therefore possible. Another positive aspect is that it can diminish the need for transporting the renewable energy, because renewable power plants sometimes are located in remote areas. Although there are multiple beneficial characteristics to using renewable energy sources in hydrogen energy storage, there are some traits that might make HES less suitable for construction sites. Due to renewable power plants depending heavily on weather conditions, the access can be unpredictable. Not being able to generate the power when needed for the hydrogen can be an issue. However, it can be argued that it is more likely that *surplus* power is used for energy storage purposes, and that in situations where the production is low, supplying the electricity directly to the grid is a more efficient solution. Therefore, hydrogen energy storage can be seen as a solution to unpredictable access to renewable energy, rather than the unpredictable access to renewable energy being considered a disadvantage to HES.

A significant argument against hydrogen as the preferred solution for energy storage is energy efficiency. Energy loss and reduced energy efficiency means that energy is practically wasted. This results in economic loss as well. However, the most pressing aspect might be the lack of hydrogen stations in Norway. Few possibilities to fill hydrogen is a substantial limitation for the usage of HES. Notwithstanding, this does not mean that there never will be enough hydrogen stations in Norway. If HES technology becomes more prominent nationwide, it might be more relevant to install more hydrogen stations in the future. However, in today's situation, HES might not be the most accessible and advantageous energy storage technology.

Pumped hydroelectric energy storage is another method that is used for energy storage purposes. A PHES power plant can, like other forms of energy storage, provide flexibility and stability in the electric system. Most of the power production in Norway comes from hydro power, and there are many hydro power plants nationwide. The efficiency of a PHES power plant is high, which means that there is a low degree of electricity loss. While this is undoubtedly a positive characteristic, a PHES's dependability on the weather conditions is an unfavorable aspect. Finally, PHES systems are stationary and can therefore be deemed unfit to power construction sites.

A third energy storage method that was introduced in Section 2.3 is flywheel technology. A flywheel's power rating and modularity are positive aspects, in addition to the charging and discharging speed. A low-speed flywheel is rather inexpensive but can supply power for a short amount of time. As a construction site requires electricity supply above the capacity of a low-speed flywheel, this version of the technology can be considered unsuitable for a construction site. However, a high-speed flywheel has larger capacity than a low-speed. Although the probability of a high-speed flywheel being able to supply a construction site with electricity is higher than a low-speed one, they are much more expensive in comparison to a low-speed. Therefore, it can appear like flywheels in general do not qualify for operating as an energy storage solution for a construction site.

Thermal energy storage is another technology that can be utilized. However, there are many specific characteristics concerning the storage vessel that are required for this type of technology. As the main TES technologies are underground and water tanks that can have a volume of several thousand cubic meters, it can be assumed that TES technology is often stationary. Therefore, TES technology is most likely not the most beneficial option for powering a construction site.

In terms of the battery used for the container, there are several reasonable options. As mentioned, the power and energy density are determining factors. The ideal battery would be mobile, have a fast recharge time, a long lifetime and be safe to operate. Of the mentioned battery chemistry variations in this thesis, lithium-ion batteries have the best performance regarding capacity factors. This can be seen in Table 2.3. Because of this, lithium-ion is presumably the best option in use for a construction site.

There are several factors that affect the charging process and capacity of the battery. In this thesis, there has not been an in depth consideration of these factors. In this section, some of the factors which could have an influence on the total cost of the project will be described, as well as the reasons why they were not considered.

The charging and discharging of a battery have an impact on the lifetime and capacity. For the analyses in this thesis, no specific information about the batteries or lifetime of the appliances is provided. In the analysis, the capacity and power of the machine are assumed from the charging curve. The age of the battery will influence the charging time and energy consumed by the appliance. These factors are not taken in consideration for the model, the first reason being that there is a limit to the information the project owners have about the appliances. To make the model adjust to these factors, more information about the chemistry of the battery is necessary. It cannot be expected that the project owners know very specific details about the conditions and technology of the batteries in the machine park.

Another reason this is not further investigated is the impact for cost. Although the battery's characteristics influence the charge time and capacity, this is expected to have low impact on the total cost. As batteries age, their capacity is reduced, and they need to charge more often, and the charging time will be shorter. This makes the peaks occur for shorter periods than with a new battery. Considering this would require much more specific data and detailed information. In all probability, this does not make large difference in the calculations.

The temperature of which the LIB is operating affects the performance of the battery. For LIBs, the acceptable temperature region is -20 °C - 60 °C. For low temperatures, the energy density of the battery is reduced, and the fast-charging capability is limited. It is possible for the temperature to exceed below -20 °C in Norway, meaning these issues can occur for the appliances used for the construction sites in the model. The battery container will most likely not have this problem because of the heat-pump system, which will keep the temperature at a reasonable level. Therefore, this is not taken into accound in the model. Additionally, such low temperatures are rather rare, even in Norway. Therefore, the risk of temperaturs having a high impact on the battery's characteristics is considered low.

As established, energy storage systems have great benefits concerning economy and peak shaving. Furthermore, ESS also have the advantage of providing flexibility to the power grid. With a higher demand for renewable energy due to a reduction in fossil fuel usage, there is a need for developing the production of renewable energy in Norway. However, building renewable energy power plants takes time. Simultaneously, the demand increases, making the issue even more time sensitive. With a higher demand, and a smaller growth in supply, it becomes more difficult to keep the balance between supply and demand. This results in a less steady supply and a lower power balance.

The dependency on renewable energy sources is a potential challenge for the Norwegian power supply. Due to renewable energy being heavily weather dependant, there is a lack of flexibility. Although pumped hydroelectric energy storage systems have beneficial flexibility in their possibility to charge and discharge when needed, they are entirely reliant on rainfall. In periods with little amounts of rain, a PHES system is not able to contribute to the flexibility of Norwegian power production to a high degree.

With advances in technology for energy storage systems like batteries and hydrogen, there can be a higher degree of flexibility in the future power system. In periods with a high degree of power production and low energy demand, the power can be stored. This way, the energy is utilized in the most efficient way, and large fluctuations in prices are avoided. It is also beneficial for the power grid that the load is smaller, and smaller fluctuations that make the system more balanced.

The transition to renewable sources is not only happening in Norway, but also in the rest of Europe. These countries are also working on implementing more solar, wind, and hydro power. The Norwegian power prices are influenced by the prices in the rest of Europe due to the expansion in international power lines. The new connections do not only contribute to secure the power production but can also be used to improve prices for the costumers. When prices are low in another country, this power can be imported and give the costumer a relatively lowe price.

The general power price in Norway is expected to increase in the coming years because of the connections to the rest of Europe and the CO_2 price. As the number of renewable sources increases, the CO_2 price will have less impact on the power prices. Therefore, the prices will decrease as the renewable portion increases.

As the transition progresses, the energy mix in Europe will in all likelihood become more similar to the Norwegian. One weakness with this is the risk of a common low production all over Europe, in which no countries would be able to export due to weather conditions. In the case of a common low power production in Europe, because of the large amount of renewable energy, a surge in power price will occur all over Europe. If the weather conditions are in unfavorable over a long time, the power prices could stay high over longer periods of time. This is why the advance in energy storage technology can be considered a necessity for the power stability in the future.

For the same reasons, the value of peak shaving for economic savings might increase in the future. When replacing the fossil sources with renewable sources, the fluctuations in power price will be greater because of the lack of flexibility. With more fluctuations and larger peaks, peak shaving will have a more significant impact on the price for the consumer. Unless there are sufficient technological developments in the flexibility for renewable sources, peak shaving will be an alternative to stabilize the power prices.

For the calculations in this thesis, the power prices are assumed to be the same for each month. This is because of limitations in data and to ensure a reasonable workload. Without taking in account different hourly power prices for each day, the calculations might be inaccurate. In the model, the power prices can be replaced with more detailed or updated power price data. For this thesis, the accuracy of the power prices is not of the highest importance. The power prices thar are used, most likely give a realistic estimate of the value of peak shaving. They might not be entirely realistic for each day, but they are based on a reality and an average and still give a rather realistic result.

The model produced for this thesis is based on the previous projects Aneo has been involved in. The use for battery containers for construction sites is a rather new practice, which limits the amount of data and information available.

Two projects were presented to use as a base for developing the model. These projects are quite different from each other, making it more challenging to determine repeating patterns. For the model to be able to estimate a total power cost and grid tariff, specific charging patterns through the project period must be assumed. The charging pattern on a construction site varies and depends on a multitude of factors, such as the number of appliances, power of appliances and usage tendensies. Additionally, limitations such as insufficient grid capacity should be taken into account.

To determine a realistic charging pattern, it is necessary to examine the earlier projects as a base and use the information about the characteristics of the appliances to calculate an estimation of economic value. Throughout the period of working with this thesis and model, many assumptions have been made. The probability of these assumptions being realistic, as well as the effects of the assumptions will be discussed to determine the reliability of the model.

The assumption that no more than three construction machines would be used is based on communication with Aneo Build, a lack of data and to ensure that the scope of the model was within reasonable limits. Aneo Build stated that using more than three construction machines simultaneously is rare. Therefore, it is likely that it is an assumption that will not affect the degree of realisticness and flexibility to a large extent. However, if the model is used for projects with more than three machines, the model returns an error message. Developing the model to manage more machines might lead to more realistic results and a larger area of use.

However, with more machines, the higher degree of uncertainty is to be expected of the model. Because the preset charging patterns are approximations and simplifications, a certain degree of uncertainty is associated with the model. It is heavily based on assumptions, and the probability of all assumptions being correct is lower when many machines are used because more assumptions must align with reality.

The charging pattern would most likely be different with more machines than with one to three, but the charging habits for such projects are unknown. For instance, it is uncertain if each machine would have multiple short charging periods each to ensure that all machines have enough power to be able to operate. Perhaps the lunch charging session would be longer so all machines could rapid charge in this period, or maybe different workers would have their lunch break at different times to charge the machines sufficiently during the break.

Lunch break is assumed to be from 11 o'clock to 12 o'clock every day. The authors of this thesis do not have enough knowledge regarding constriction sites and construction workers to determine the feasibility of this assumption. However, frequent observations of charging sessions around that time of day substantiate the assumption. Five day work weeks is an assumption that is mainly based on logic and the knowledge that most work places have work-free weekends.

Assuming that the rapid chargers are used instead of the AC outlet for the larger machines is based on the assumption that the construction workers want to work efficiently and not have to spend large parts of their work day passively waiting for the machines to charge. In projects with more than two construction machines that use rapid chargers, however, it is not possible that all machines rapid charge simultaneously. Therefore, the assumption is not completely accurate. On the other side, there are no assumptions that appear more accurate that enable efficient work days with a minimum of inactive time spent waiting for the necessary charging time.

Further, it is assumed that electric vehicles used on the construction site do not use the charging container during the night due to their possibility of being transported and charged somewhere with better grid capacity. In addition, it might not always be necessary to charge vehicles overnight. This is also an assumption made due to the authors of this thesis not obtaining enough knowledge about construction site practices. How much the vehicle is used in a day, in addition to battery capacity and other factors, determine the need for overnight charging. This could have been taken into account in the model so that the user could give information about this. Nevertheless, this is not done in order to limit the scope of the model and thesis. Additionally, the smaller electrical appliances would likely not account for an extensive effect on the calculations due to their relatively low charging capacity.

The approach for selecting hourly power prices is heavily based on assumptions. 2021 is assumed to be a more representative year to collect data from then 2022. If hourly power prices from earlier years were available, it would most likely be more realistic in future projects. However, due to the lack of data, this was not done. The model is designed to be modifiable. If the power prices change in the future, the user can easily change this factor. It is impossible to predict power prices exactly, and this approach would resemble the reality best out of the approaches that were discussed while making the model.

Generally, the assumptions made in regards to the model hopefully do not affect the results of the model to a large extent. The model only provides estimates to the economic value of peak shaving, it is not intended to give exact numbers. It would be impossible to make a model that produces exact values for this type of thesis. For this to be possible, the model would have to accurately predict power prices for every individual hours during the project period. Grid tariff prices also change over time, so this would be another aspect that would need to be precisely predicted in order to make a model that provides exact and correct results. Additionally, a multitude of precise information about the batteries in the charging container and devices that are charged would be necessary. This is also an unrealistic expectation. Therefore, the output value is rounded off.

It can be argued that some assumptions and simplifications related to the model lead to an underestimation of cost, while other lead to an overestimation. In some cases, the underestimation might cancel out the overestimation. However, it appears like most assumptions and simplifications might lead to underestimated values. For example, no charging of electric vehicles overnight and excluding the AC outlets from the model contribute to lower simulated peaks and general charging pattern. This leads to the model calculating lower costs, which again leads to a lower calculated economic value of peak shaving than in reality.

A simplification that might cause an overestimation of economic value is the power price approach. As 2021 was a year with unusually high power prices, it can be seen as likely that the prices will decrease in the future. If the power prices in the model are not changed, the estimated value will be higher that the real economic value. However, Aneo Build has been notified of this and will be able to take it into consideration when consulting their clients.

Because the data outliers are replaced with zeros and their actual values are unknown, this may be an uncertainty in the results of both the Nidarvoll and the Valle Hovin analyses. However, this uncertainty has a larger impact on the results of the calculated costs than the consumption profiles. As the intention of analyzing Nidarvoll and Valle Hovin is to get an understanding of charging patterns for construction cites, this error does not affect the reliability of the charging patterns chosen for the model.

In the analyses, the savings for the Nidarvoll and Valle Hovin projects were calculated. The Nidarvoll project was located in NO3 and had a duration of 7 months and had total savings of 8000 kr, while Valle Hovin was in NO1 and lasted 4 months with total savings of 19 000 kr. Nidarvoll had a smaller machine park than Valle Hovin, but had a larger total power consumption. With lower power peaks and higher energy cost, there are less savings for grid tariff. In addition, the power prices in this area are lower than NO1, which can be reasons for the smaller total savings. Valle Hovin had higher power peaks, and was located in a area with both higher grid tariffs and power prices. This will result in higher grid tariff savings, and a higher total value of peak shaving.

To evaluate the economic value of peak shaving with the charging container, several fictitious cases were developed. These cases are intended to represent construction projects of different sizes, at different locations and with duration at different times of the year. The results of these cases will be compared and discussed.

In Case 1, the geographical location is the investigated input. The results from this case are presented in Section 5.1. Regarding the power prices for Case 1, all of the subcases have negative savings, meaning losses. When only using one machine, a larger amount of the power cost goes to operating the battery container as the container draws 5kW from the grid continuously. If only considering the power costs, charging directly on the grid would therefore be beneficial. The losses in power cost from the charging container for NO1 and NO4 is 12.5%, while it is 15.2% for NO3. However, due to all subcases saving a great amount of money from the grid tariffs when using the battery container for charging the machines, the total economic savings for all cases are positive. The amount of total savings are much larger in NO1 than NO4, but if looking at the savings percentage wise they are quite similar, which can be seen in Figure 5.1.

Considering the savings from grid tariff costs, there is a large difference in these savings depending on the price area. NO1 and NO3, or Subcase 1a and 1b, have quite similar savings with 46.7% and 46.6%, correspondingly. The last area, NO4, or Subcase 1c, has very low savings compared to the others with only 19.4%. The reason for this is most likely the large difference in grid tariff prices between the grid operators, which are provided in Appendix C. With lower grid tariff prices for NO4, the difference between charging directly on the grid and through the container decreases, also reducing savings. For NO1 and NO3, there is a greater price difference between the different price levels, which leads to a greater value of peak shaving than for NO4.

NO3 has the highest percent wise total savings with 24.2% . This is also the area with the highest percentage of losses in power cost. The reason this area has the largest total savings is that the grid tariff cost for NO3 is closer to the corresponding price level in NO1, which is quite high compared to the prices in NO4. Concerning the power cost, NO3 is in between NO1 and NO4 in power price, as can be seen in Figure 4.1. In total, the difference between the grid tariff cost and power cost without battery container is larger for NO3 than the other price areas. This results in higher total savings. For NO1, the total savings are close to NO3 with 21.4% while NO4 only has 6.7% in total savings.

For Case 2, the impact of the size in machine park is evaluated. These are presented in Section 5.2. The case takes place in NO3 and lasts from January through December.

Subcase 2a had one machine charging at 150 kW, this Subcase has the same results as Subcase 1b as they have all the same inputs. The negative value for power cost is due to the amount of power drawn by the battery container it self, like in Case 2. This cost does not contribute to any peak shaving, and is only an additional cost for operating the container. When there are few machines used in a project, this additional costs makes up a larger amount of the total power cost, which in this case results in a deficit in power cost. However, the total savings when including grid tariff costs are still positive.

For Subcase 2b there are two machines charging at 150 kW on the CCS charger outlets. This gives higher savings in grid tariff than Subcase 2a, with 53.4%. The change in savings for power cost from Subcase 2a is much larger, in this subcase, there is a positive power cost saving with 5.5%, meaning a 20.7 percentage point difference between the two. As mentioned, the noticeable distinction in power cost savings is due to a larger power consumption. When charging two machines at 150 kW, the power costs for operation of the battery container has less impact on the total power cost.

In the next Subcase, 2c, three machines were used in the simulation, two of them charging at 150 kW on the CCS charger outlets and one charging on the AC outlet at 40 kW. The savings from the grid tariff are close to the 2b Subcase, but a little lower at 51.6%. Considering that this subcase has higher power peaks than 2b, one might think that the grid tariff savings would be higher. The reason this is not true is because of the price levels that determine the grid tariff. In Appendix C, the grid tariff for different grid owners is provided. 300 kW is the highest price level, meaning when the peaks exceed 300 kW, the economic savings will not increase parallelly with the consumption. If there was a price level above 300 kW, this subcase could have had higher savings.

The savings in power cost are also less in this subcase compared to 2b, at 3.5%. From Figures 5.2, Figure 5.3 and Figure 5.4, the charging pattern of the three subcases are graphed. This shows that the battery container needs to charge over a longer time to recharge in Subcase 2c. This longer period of recharging increases the total power cost for the container, and may result in less savings in power costs. Additionally, as the power prices vary hourly during the day, a possible reason for less power savings in Subcase 2c than 2b might be due to higher power prices for the extra hours the BoostCharger needs to charge in Subcase 2c.

The last of the simulated cases is intended to evaluate the impact of the time period the project takes place. In all subcases, one machine charging at 150 kW is used. Subcase 3a is simulated from January through April. In this period, the grid tariff savings were 65.2%. This is the same for all the three subcases, as they all have the same duration, charging pattern and takes place in the same area. In 3a, there are losses in power cost at -22.2%. Nevertheless, the percentage total saving in this subcase when using the battery container, reach the highest of all cases at 40.6%. However, the value of the total amount saved in kr, the savings are relatively modest in magnitude for subcase 3a.

For Subcase 3b, the project lasts from May through August. In this period, there are less losses in power cost compared to Subcase 3a at -11.1%. This results in higher total savings with 43.8%. Subcase 3c with duration from September through December has the same results as 3b. It should be noted that the numbers provided in Chapter 5 are rounded off. The results from the model did give a small difference between these two, but because of rounding, this was presented as the same in results. This is because the model is intended to provide an estimate, as exact values are impossible to predict.

When comparing all three cases, the third case has the highest savings percent wise. All the savings are from the grid tariff, which are the same for all the subcases in Case 3. The difference between the subcases are only affected by the power prices, and these differences are rather small. The reason there are such large savings in grid tariff for the subcases can be the variable cost of the grid tariff. The variable cost is solely dependent on the amount of energy consumed. With these projects only lasting four months, instead of a year like the other cases, there is a much smaller energy consumption, resulting in less variable cost. Despite this, the total economic savings in kr are rather low for Case 3, compared to Case 1 and 2.

The total economic value was the most significant in Case 2b when using two machines with total power peaks at 300 kW, which is the highest price level for grid tariff costs. The results for Case 1 also showed that the economic value of peak shaving increased when considering NO1 due to the grid tariff prices for this area. It is conceivable that a larger machine park in this area will derive the greatest value from utilizing battery containers.

7 Conclusion

Throughout this thesis, several aspects concerning construction sites, the power grid, peak shaving, energy storage technology, and the model have been presented and discussed. This chapter will provide conclusions regarding these subjects.

It has become evident that the electric grid in Norway is not dimensioned for the electric load it is subjected to. Especially with the increased level of electrification that is expected over the next years, the power grid faces several challenges related to capacity. Some areas in Norway experience not having access to sufficient amounts of power. This in spite of multiple laws and regulations stating that the grid operators are obligated to supply their customers with electricity.

Due to the poor grid capacity and electrification of the building and construction industry in several large Norwegian cities, energy storage technology will be a substantial part of future construction sites. Batteries are the preferred technology for this sector, because their characteristics are well suited for the purpose. There are multiple different battery technologies on the market, but the most used and most favorable is lithium-ion. It has great performance in regards of capacity factors and the high energy density makes it advantageous for transport.

Not only do energy storage solutions enable construction sites gaining access to sufficient power to meet their demand, such technology also contributes to economic savings. Peak shaving is an approach that is based on shifting the energy consumption to low-demand periods. With the new grid tariff model in Norway, drawing large amounts of power from the grid simultaneously leads to high costs. Therefore, energy storage technology is economically beneficial on construction sites with electric construction machines.

Energy storage solutions can also undoubtedly contribute to a more stable power grid, because the grid is dependent on having a stable balance between production and consumption. With the increase in renewable energy sources in Europe, larger fluctuations in production and prices are anticipated. Solutions to distribute the power more evenly will therefore be necessary to stabilize the power system.

The model developed from this thesis estimates the economic value of peak shaving for battery energy storage. From simulations conducted with the model, it is evident that the price area and grid operator are the factors with the largest impact on total value of peak shaving. This is because of the large differences in grid tariff and power price between the areas.

Concerning the time of year the project takes place has little influence on the value of peak shaving. For projects of shorter duration, the percentage wise savings can be quite significant because of the low variable grid tariff cost.

The total economic value by peak shaving was shown to be most significant for an increasing size of machine park. However, this is only true until the total power peaks for the machine park exceed the highest price level for grid tariffs. This is because after the highest price level for the grid tariff is reached, an increasing size of the machine park will only contribute to a higher loss in power cost. Additionally, the most costly price area for grid tariffs, NO1, will have a higher total economic value of using peak shaving.

8 Further work

This thesis and the economic model have been produced over the course of several months. Yet, there are aspects of the projects that have the potential for further work. This is mainly due to data limitations that have restricted the scope of the work, and due to time limitations. In this chapter, a list of potential improvements for further work is provided. The further work section mainly applies to the model that has been created.

- Become familiarized with and gain a deeper insight into construction workplace routines, such as lunch break habits, number of work days per week or month, as well as starting time and ending time of the workday. This would most likely enable more accurate charging patterns, because they are currently based on assumptions, observations of charging patterns and communication with Aneo Build. Potentially, information like this could be made into inputs that must be answered by the customer.
- More previous projects can be analyzed to ensure more representative charging patterns.
- Updated and more accurate power prices can be found by using newer data and more data points. Doing this would provide more accurate results from the model for future and present projects. Although it is not possible to predict the power prices accurately, the trends for power prices can be helpful when changing the power prices.
- Updating the grid tariff prices in the model can lead to more realistic results for economic value.
- Enable calculating the economic value of peak shaving for a project with a duration over two different years in one operation. Currently, if the starting month of the project is later during a year than the finishing month, or if the project duration is more than a year, the calculation must be done with multiple operations. This would not make a difference in the output, but it might make the model more convenient for the user.
- Enable using more than three construction machines in the model.
- Change the charging patterns to include short periods of charging electric vehicles and smaller appliances.
- Add electric vehicles and smaller appliances as possible inputs, as well as the necessary battery and charging information. This would ensure more realistic and accurate charging pattern and results.
- Change the maximum power supplied from the AC outputs to the correct value. This was not done due to lack of data, and the maximum is currently set to 50 kW after observing the AC outputs when analyzing the two previous projects, except from the clear outliers.
- Consider CV charging for the charging container, not only for the construction machines. This would change the pattern for the charging container's charging pattern from the grid.
- Instead of assuming a linear graph for SoC, find the actual graph. Currently, the SoC is assumed to be linear, which is most likely not the reality. Finding more realistic graphs for SoC would make the results from the model closer to reality.

- Include power losses for machines that are not charged overnight, as well as power losses in the charging container for the calculations in the model. This would affect the amount of consumed power.
- Either make the model adapt to the different charging solutions by Aneo Build, or make separate models for the different solutions. Currently, the model only considers the BoostCharger, and not the Hummingbird, BoostPoint, or AutoPower. This was not done due to lack of data from projects involving the Hummingbird, and because the BoostPoint and AutoPower are not yet being used on construction sites. Doing this would make the model more versatile an perhaps more convenient for Aneo Build.
- Making it possible to split the simulation in the model into different stages of a construction project. If different machines are used during different stages in a project, it is currently necessary to simulate the economic savings for each stage or change in machine park. This can also lead to inaccurate results, because the grid tariff is based on the average of the three highest power peaks during a month. Splitting up a month will therefore influence the results.
- To make the code more applicable to non-Norwegian speakers, the code for the model could be translated to English. This was not done due to time limitations.

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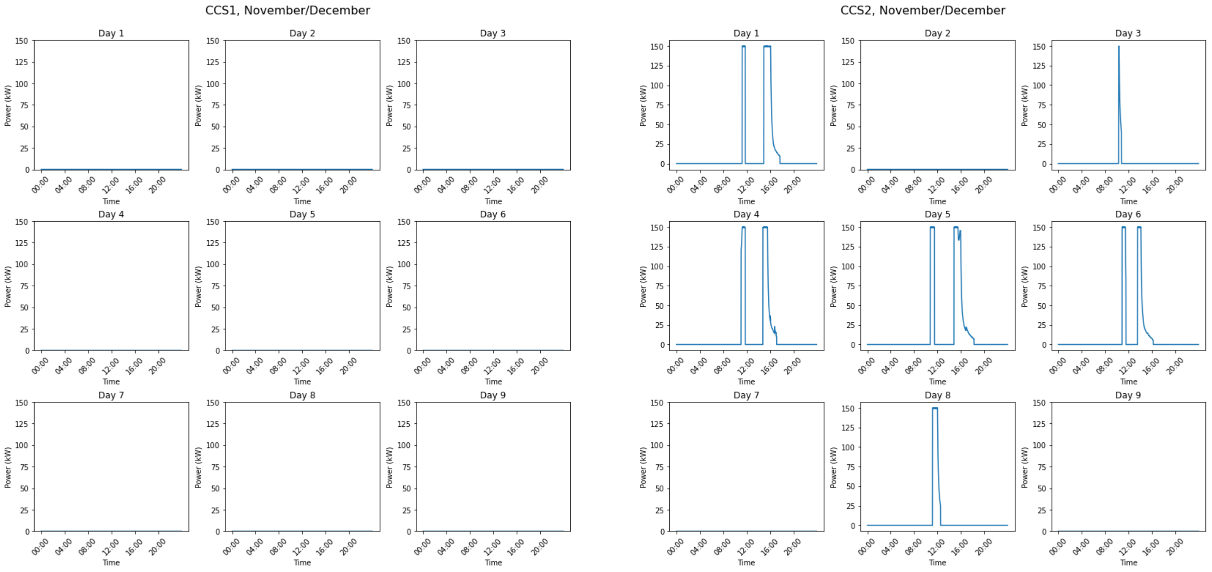
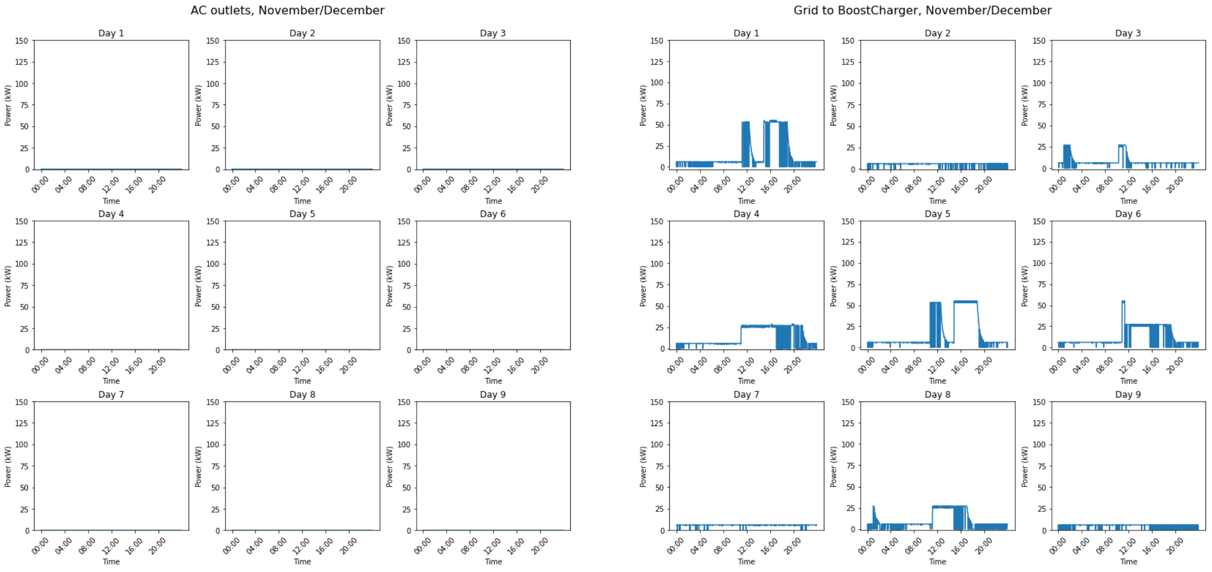
A Appendix B - Data analysis, Nidarvoll project

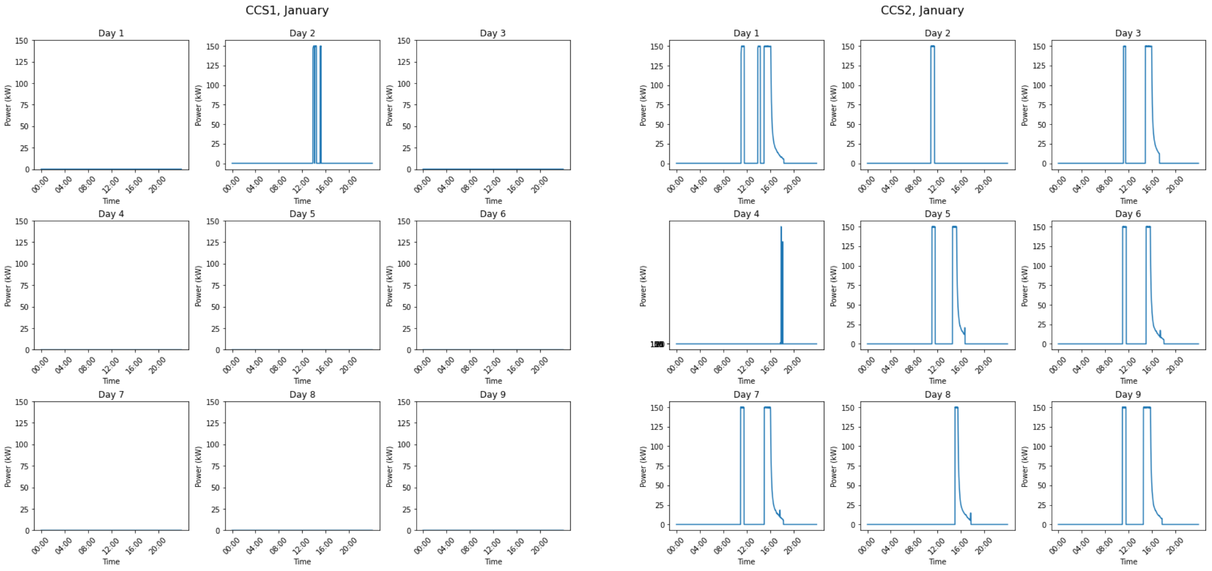


(a) CCS outlet 1 *(b) CCS outlet 2*



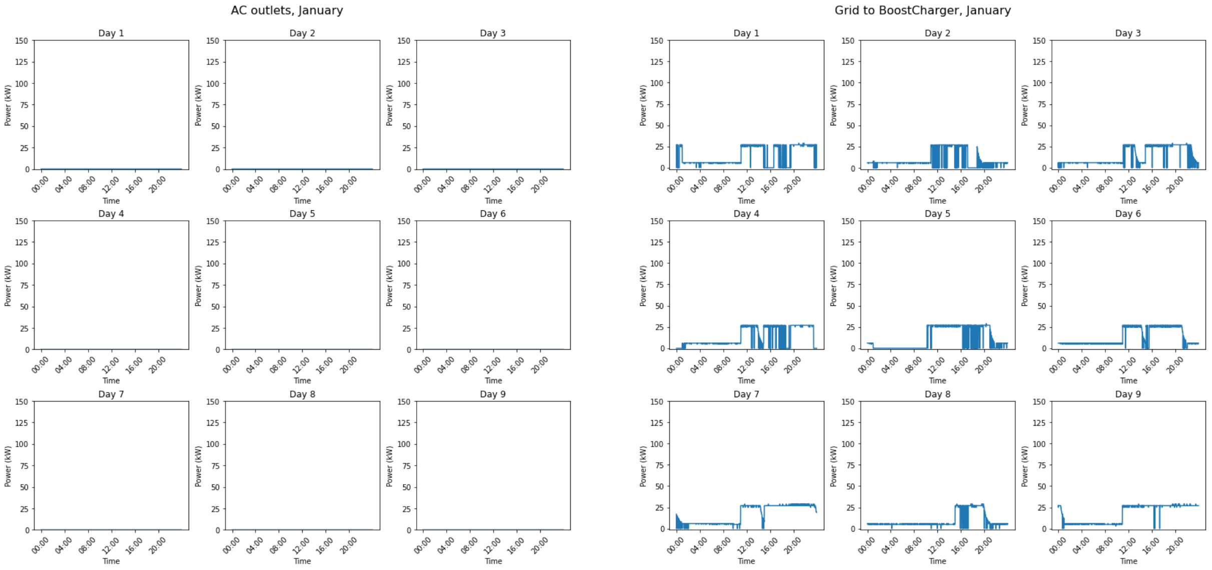
(c) AC box *(d) BoostCharger - Grid*

Figure A.1: November/December, Data Nidarvoll project



(a) CCS outlet 1

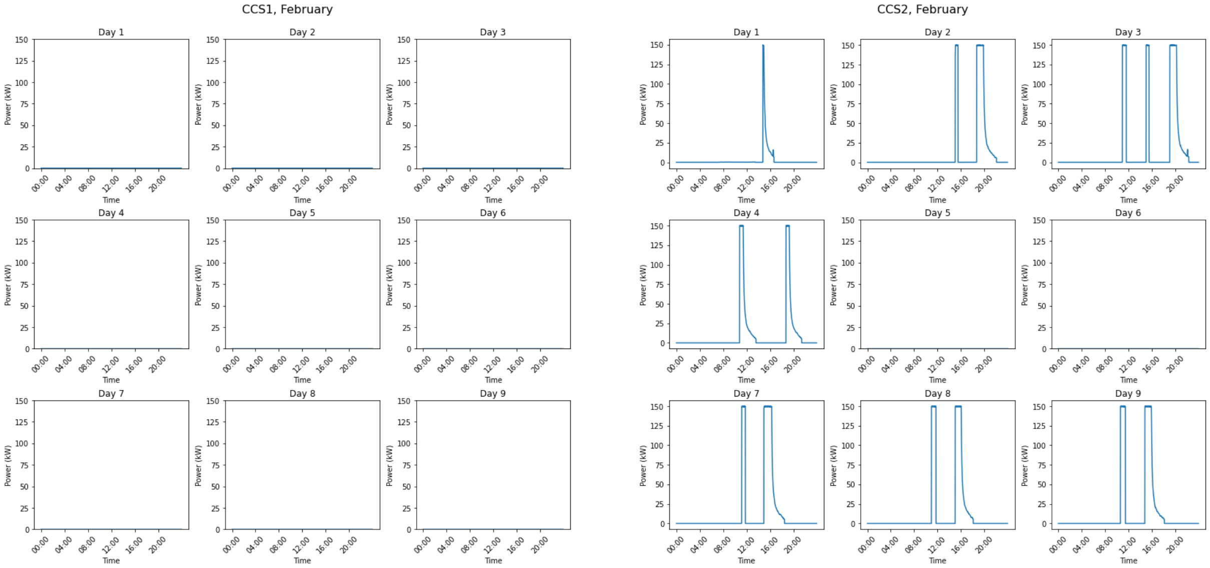
(b) CCS outlet 2



(c) AC box

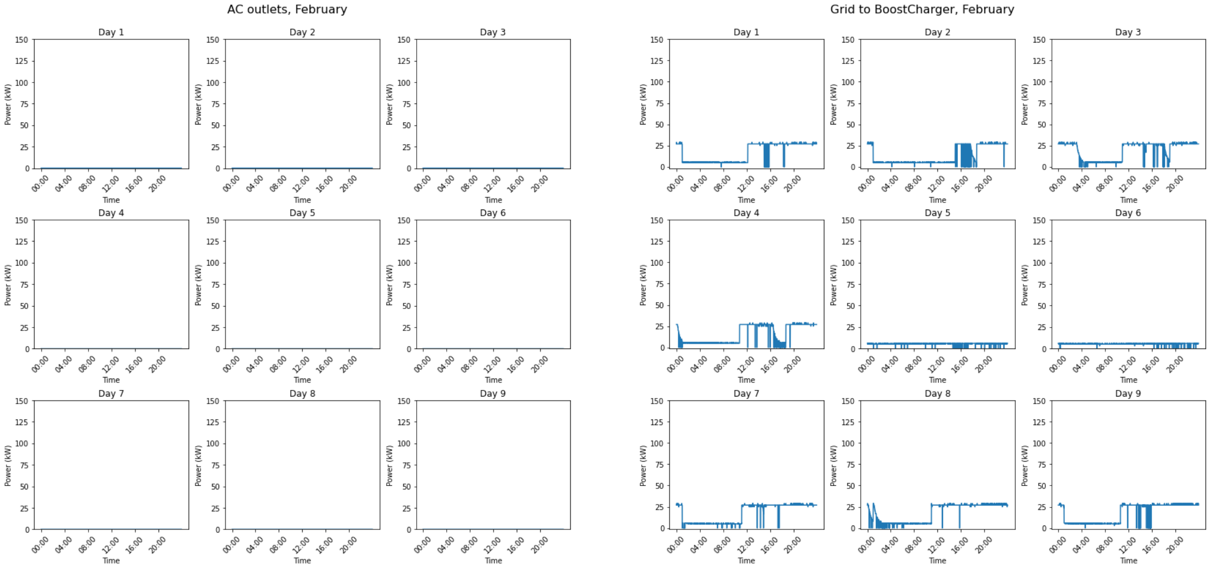
(d) BoostCharger - Grid

Figure A.2: January, Data Nidarvoll project



(a) CCS outlet 1

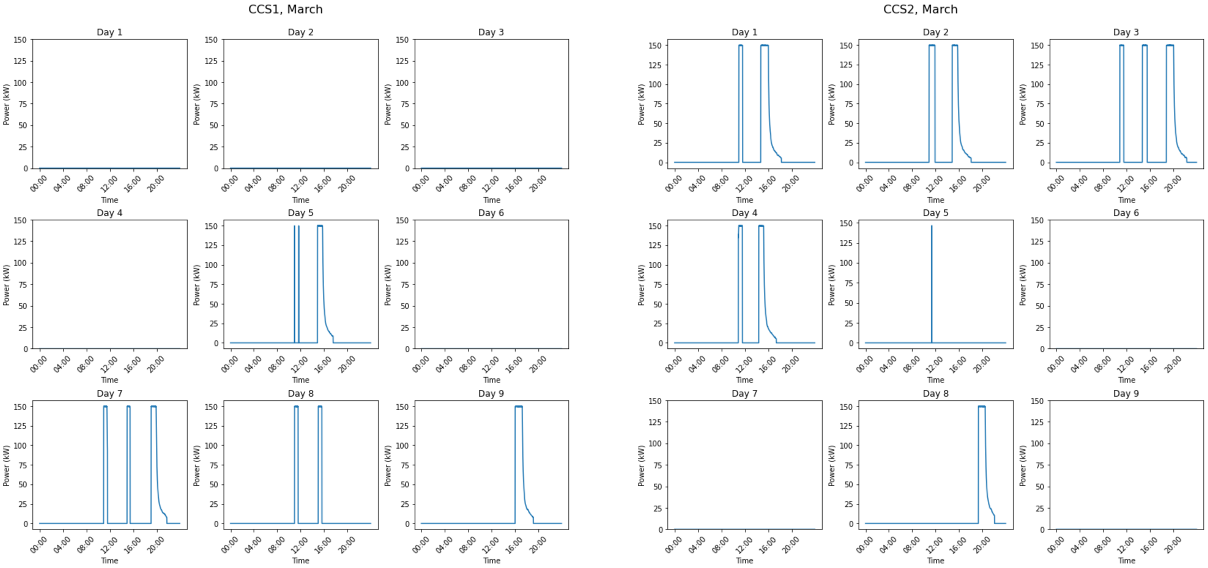
(b) CCS outlet 2



(c) AC box

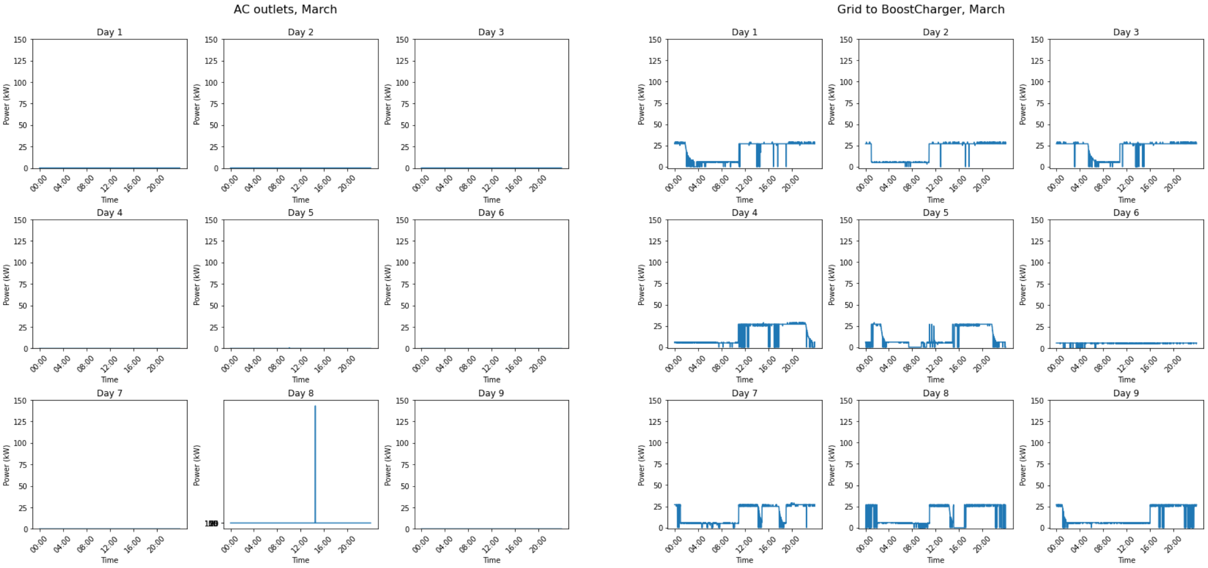
(d) BoostCharger - Grid

Figure A.3: February, Data Nidarvoll project



(a) CCS outlet 1

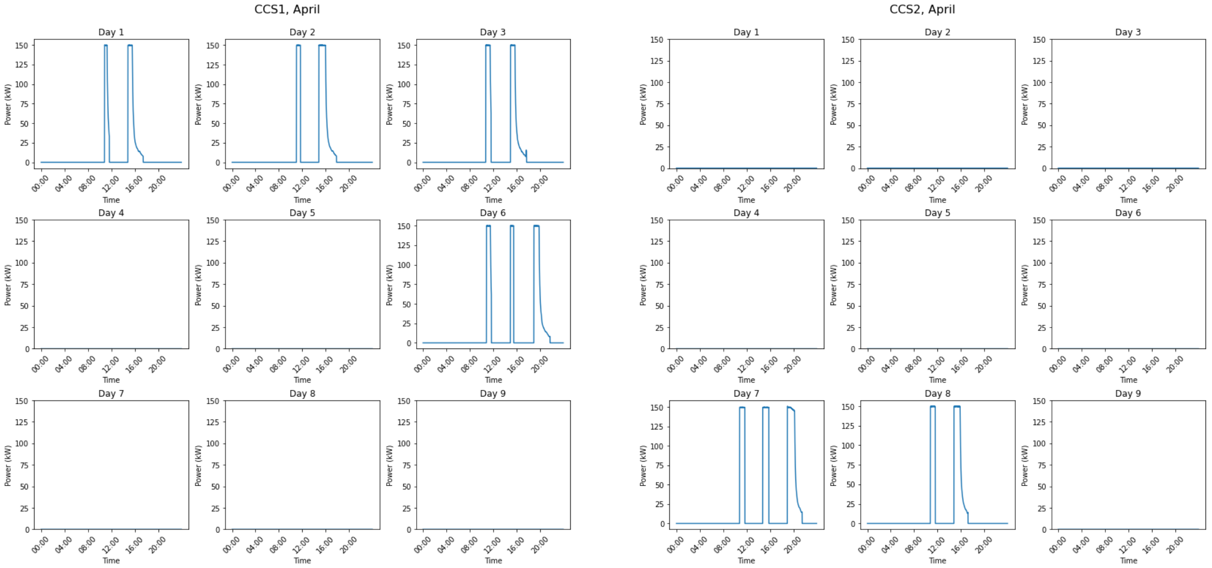
(b) CCS outlet 2



(c) AC box

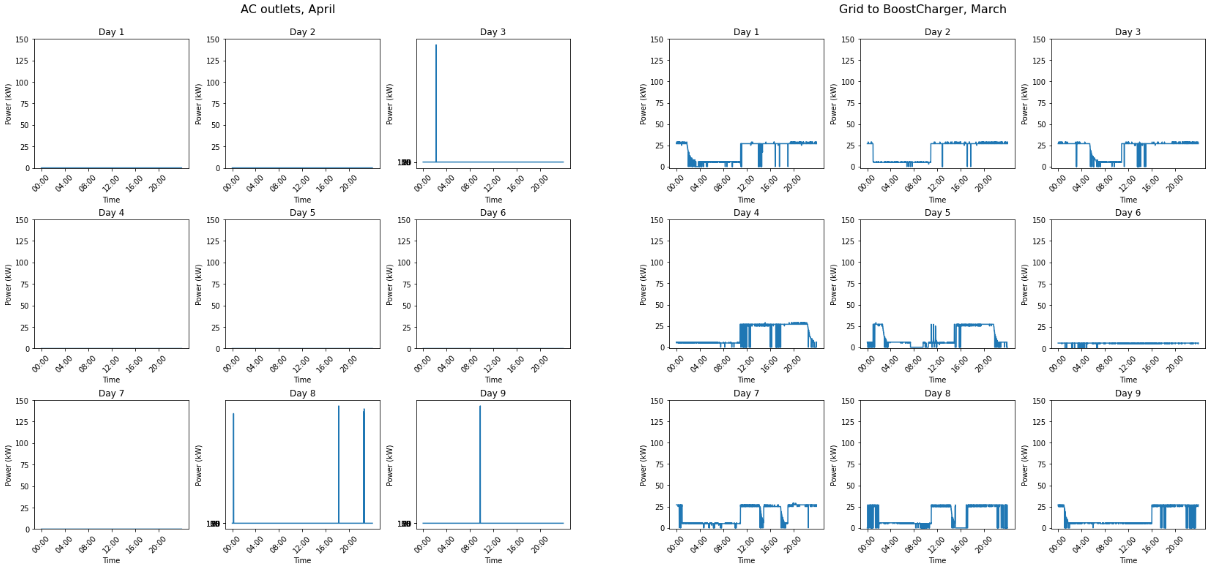
(d) BoostCharger - Grid

Figure A.4: March, Data Nidarvoll project



(a) *CCS outlet 1*

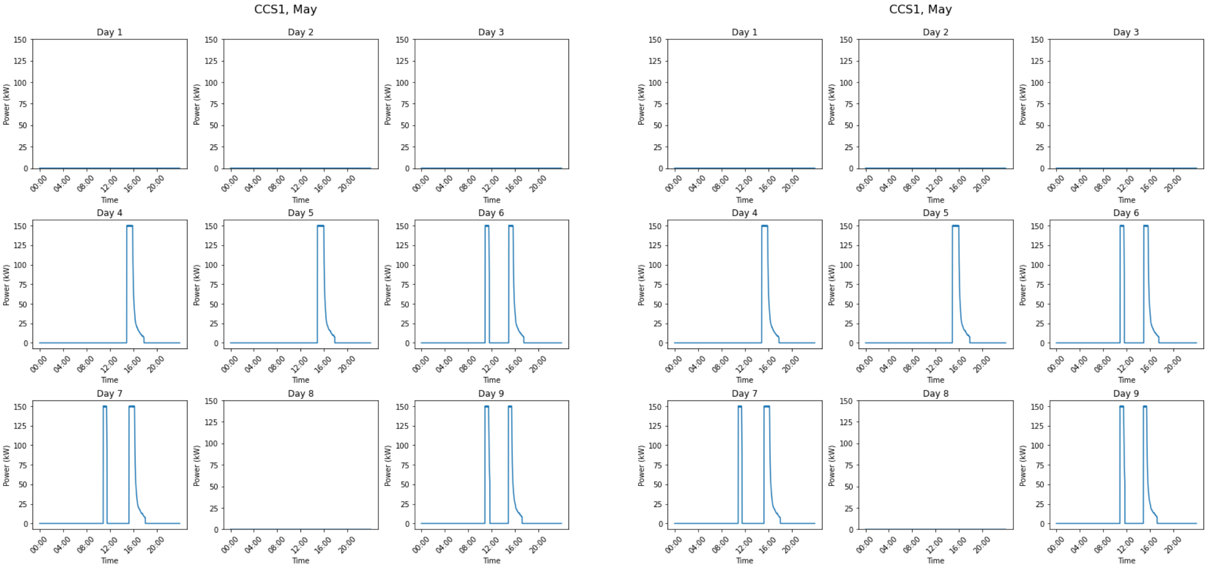
(b) *CCS outlet 2*



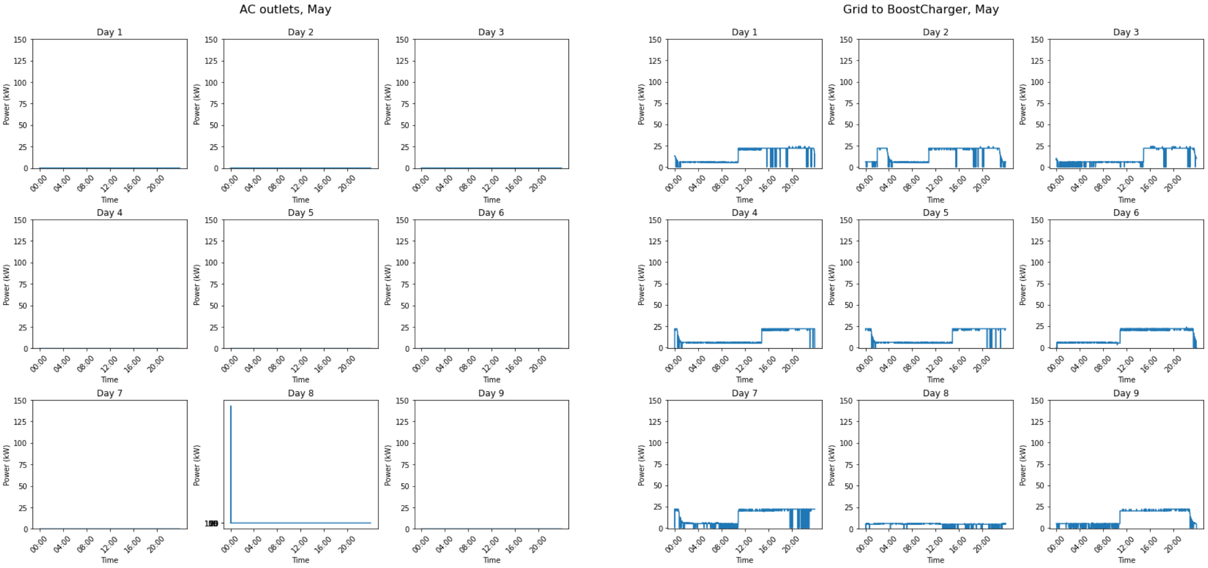
(c) *AC box*

(d) *BoostCharger - Grid*

Figure A.5: April, Data Nidarvoll project

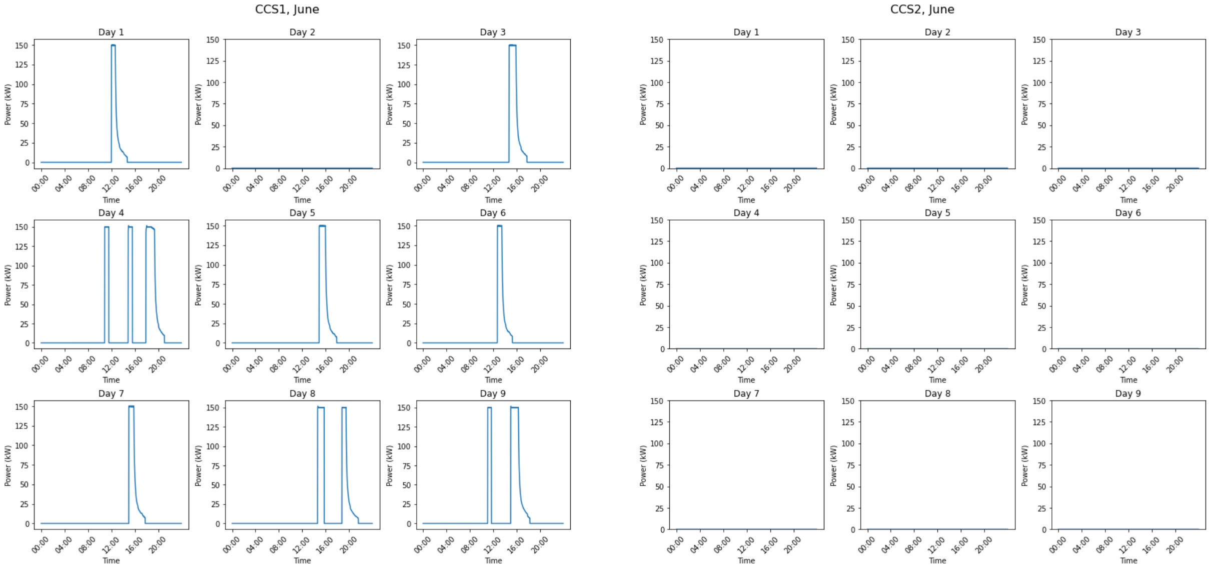


(a) *CCS outlet 1* (b) *CCS outlet 2*

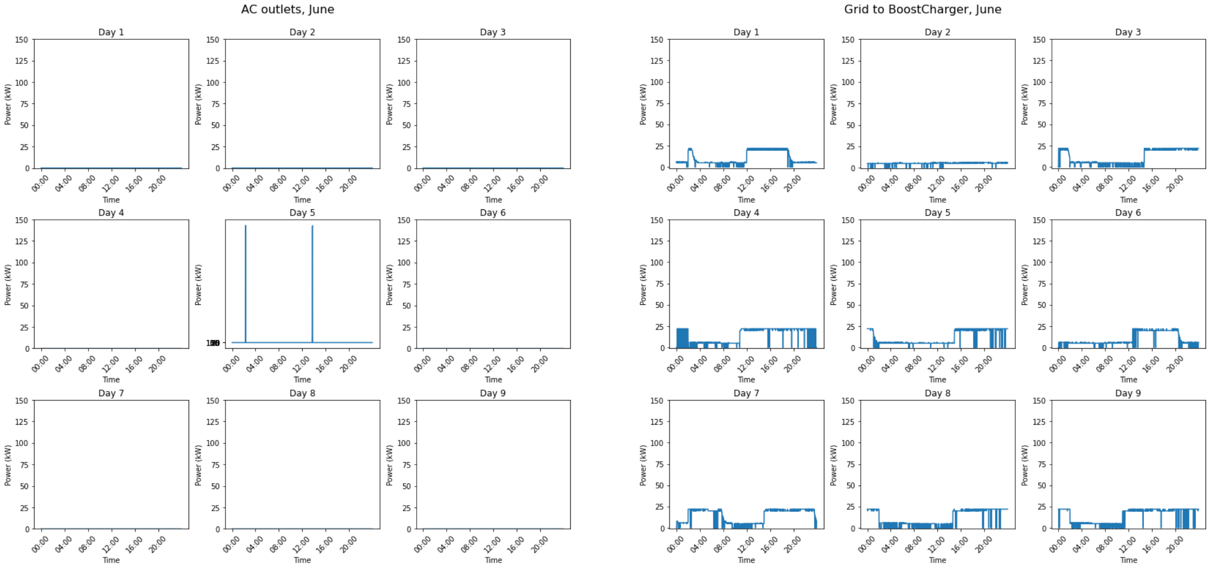


(c) *AC box* (d) *BoostCharger - Grid*

Figure A.6: May, Data Nidarvoll project



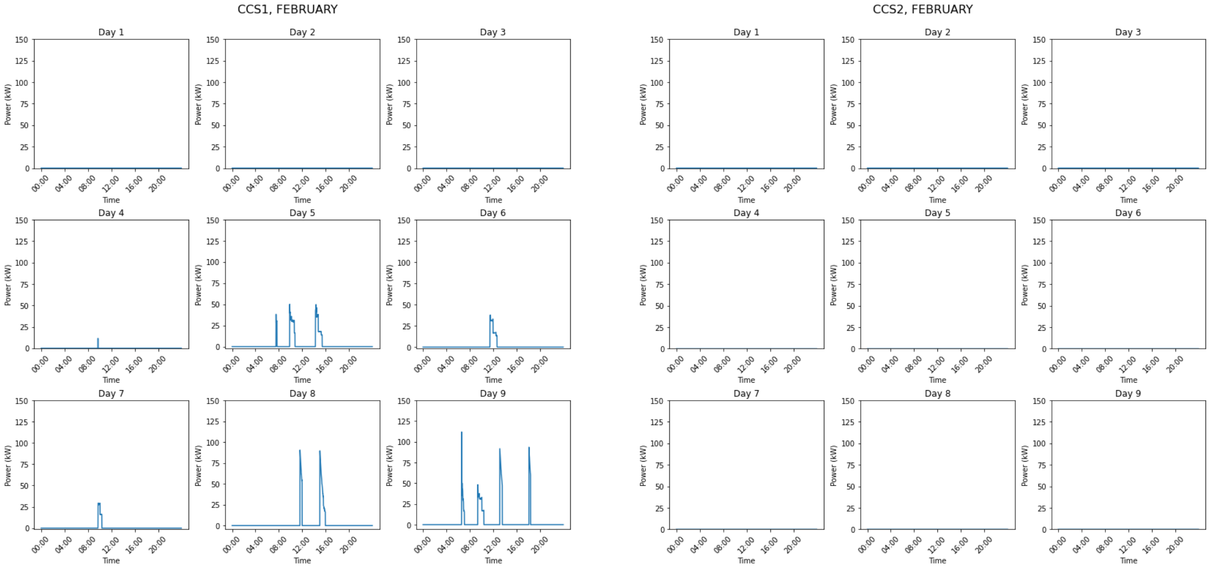
(a) CCS outlet 1 (b) CCS outlet 2



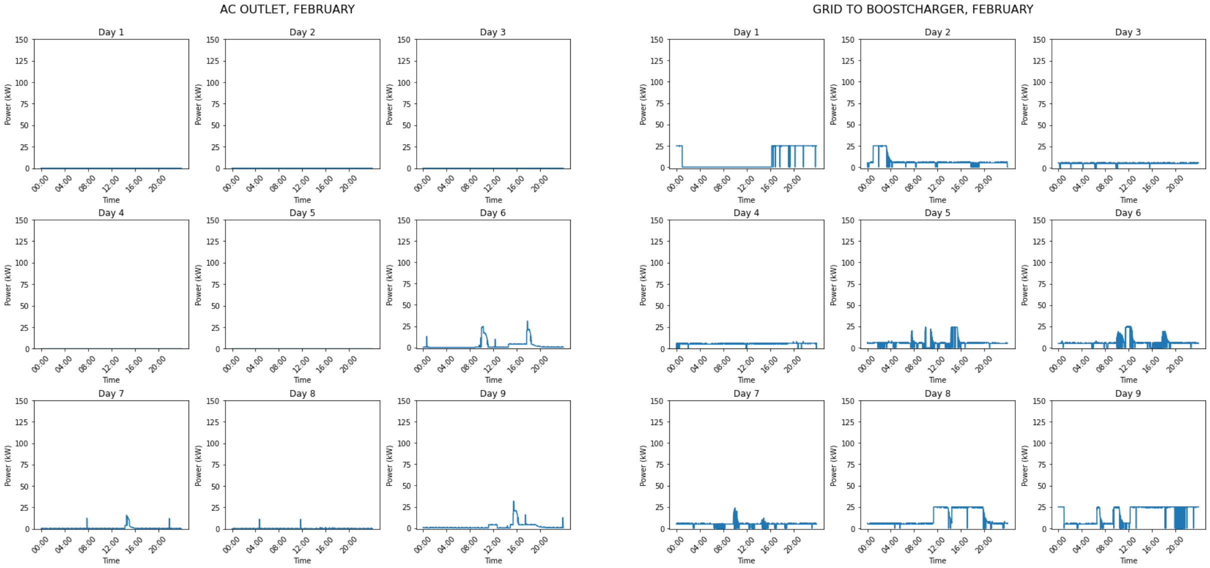
(c) AC box (d) BoostCharger - Grid

Figure A.7: June, Data Nidarvoll project

B Appendix C - Data analysis, Valle Hovin

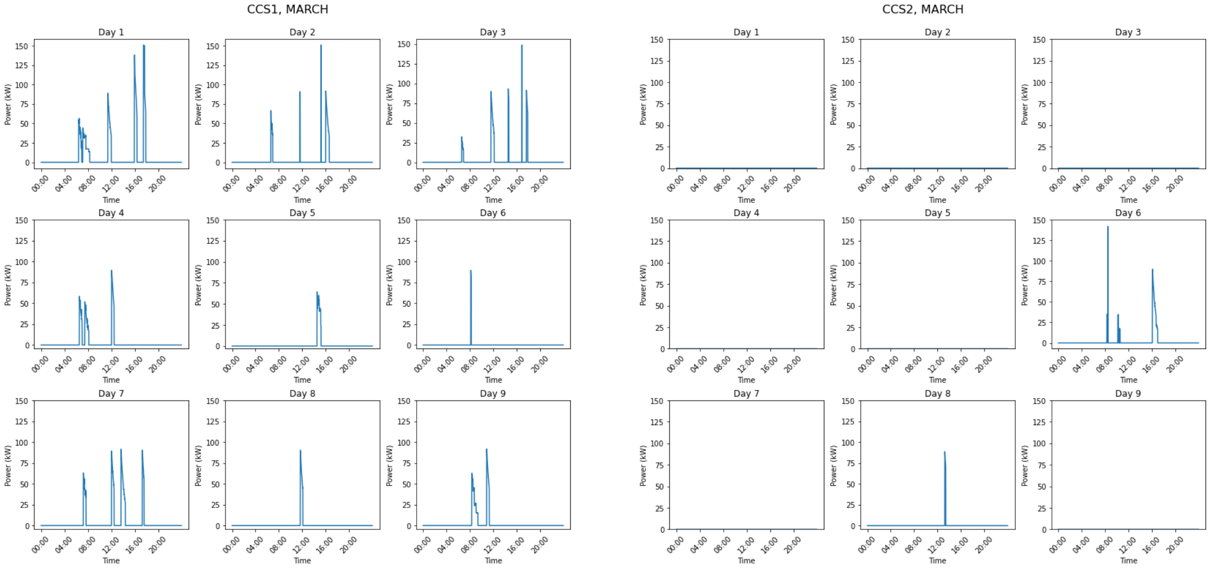


(a) CCS outlet 1 *(b) CCS outlet 2*

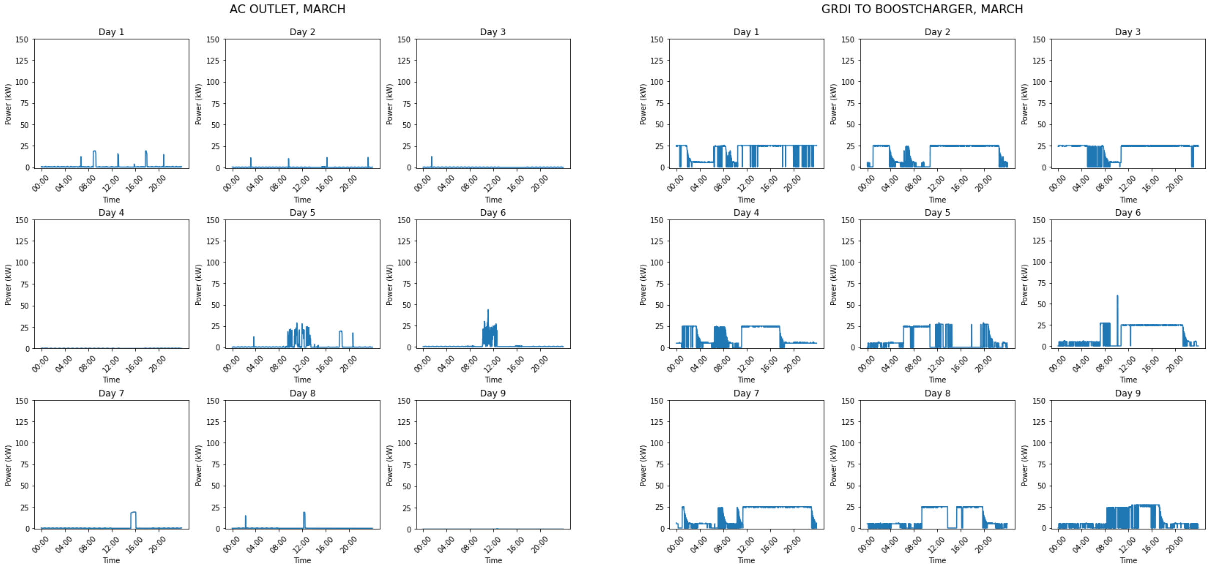


(c) AC box *(d) BoostCharger - Grid*

Figure B.1: February, Data Valle Hovin project

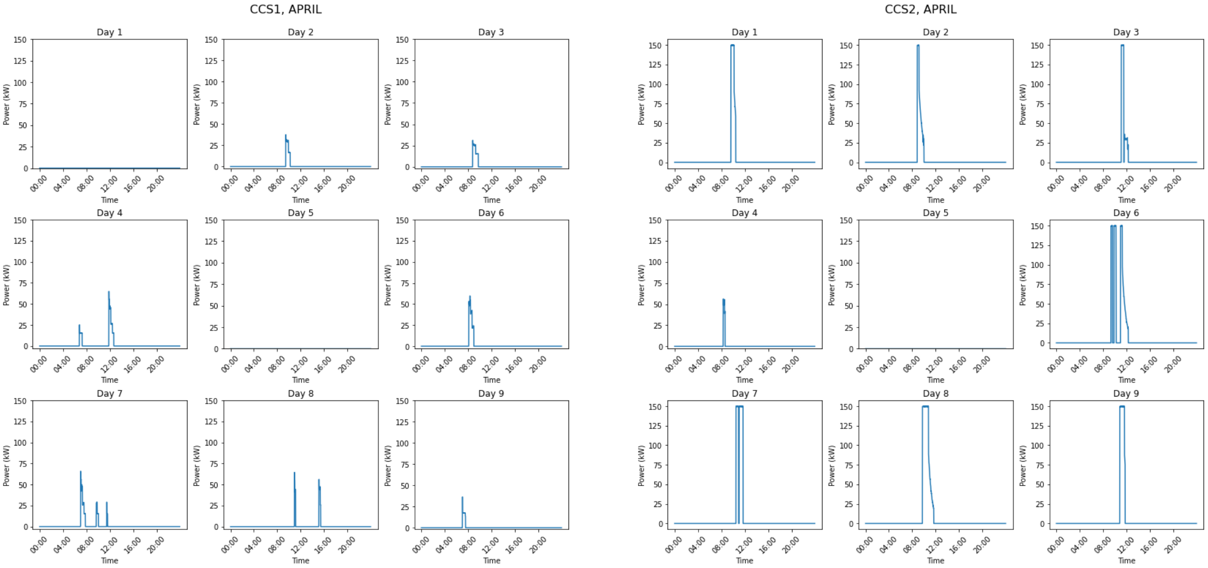


(a) CCS outlet 1 *(b) CCS outlet 2*



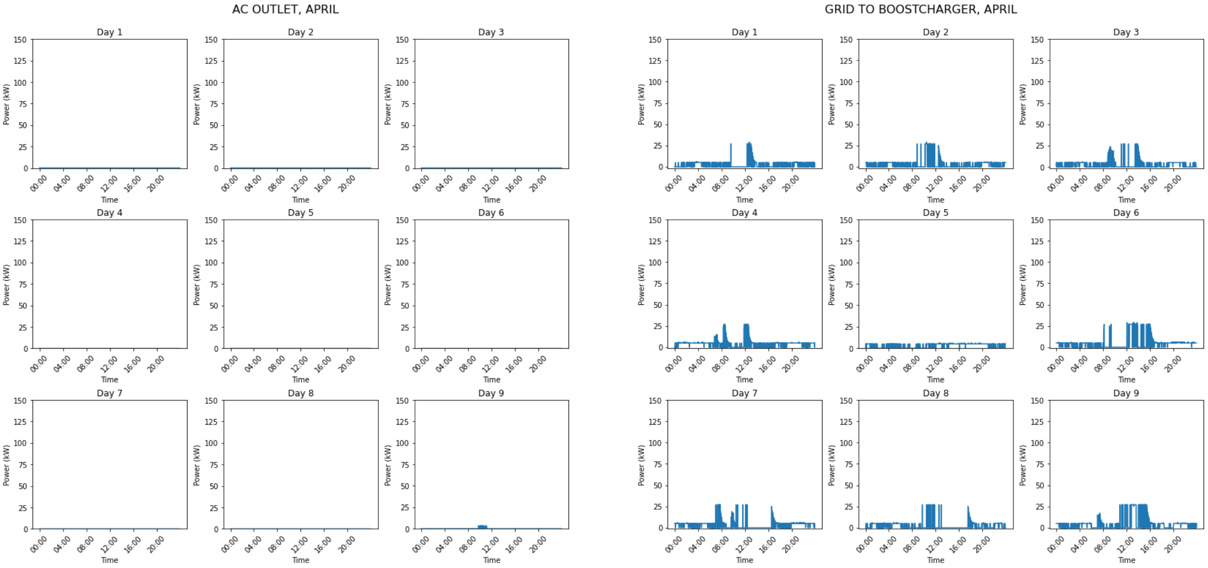
(c) AC box *(d) BoostCharger - Grid*

Figure B.2: March, Data Valle Hovin project



(a) *CCS outlet 1*

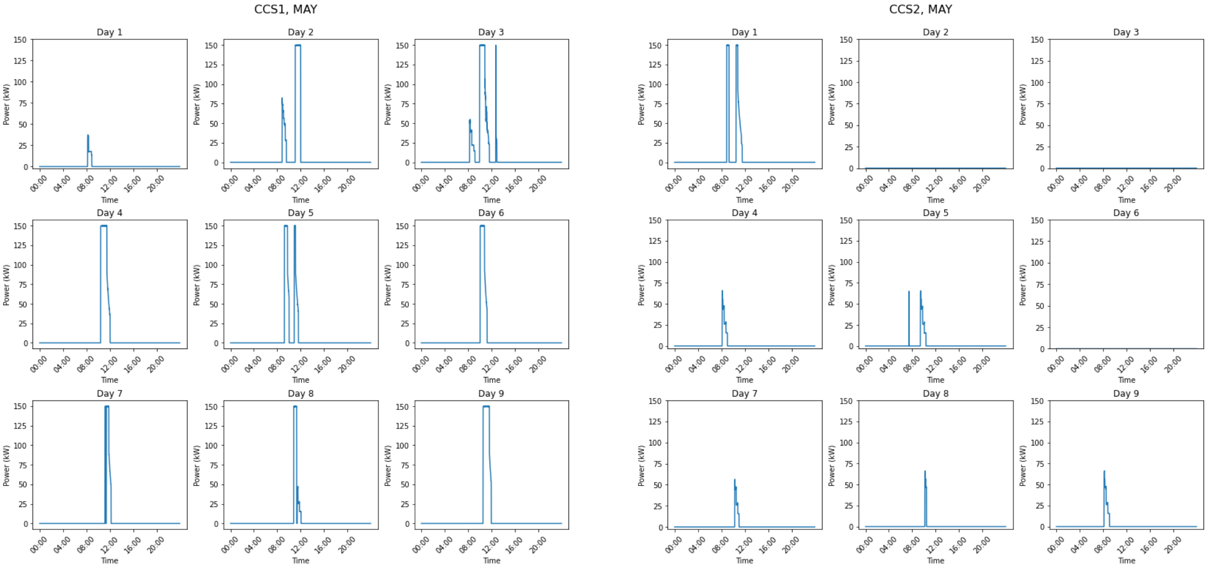
(b) *CCS outlet 2*



(c) *AC box*

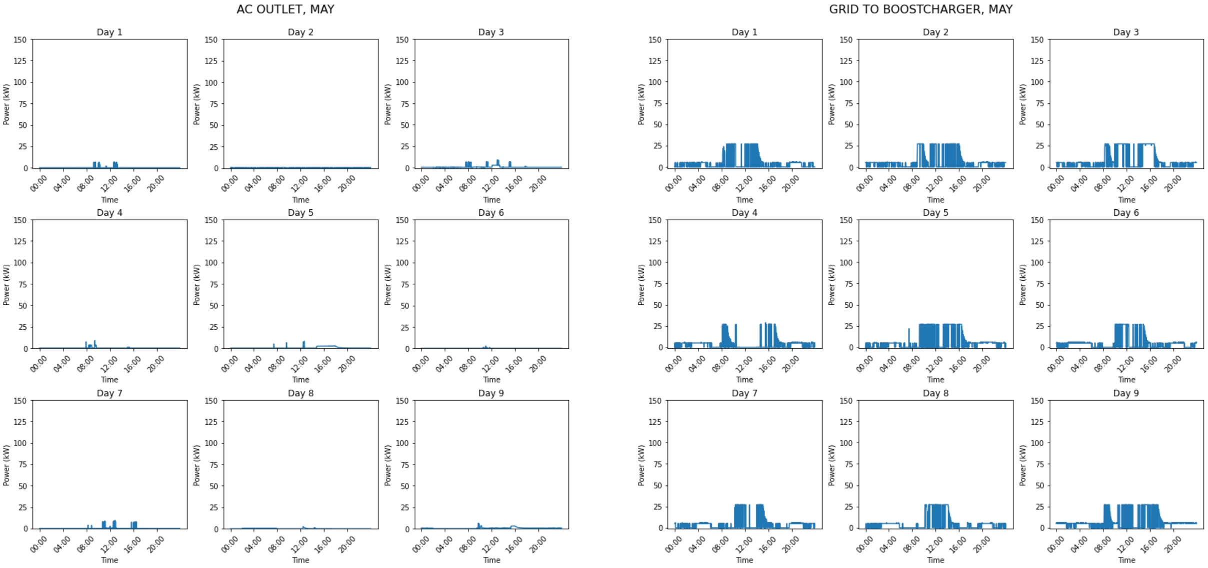
(d) *BoostCharger - Grid*

Figure B.3: April, Data Valle Hovin project



(a) CCS outlet 1

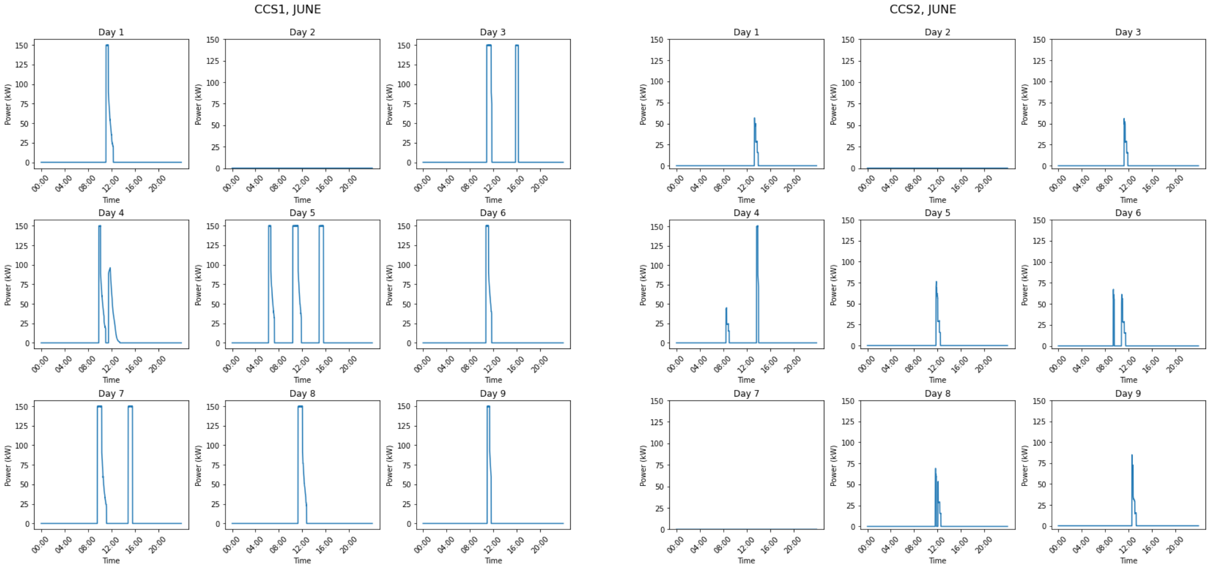
(b) CCS outlet 2



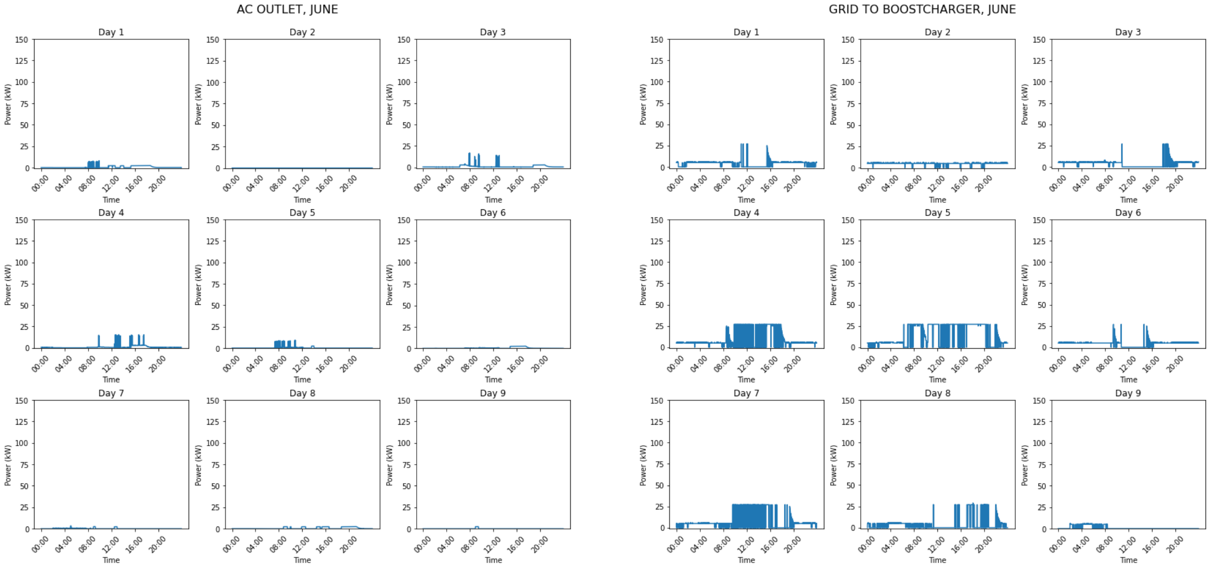
(c) AC box

(d) BoostCharger - Grid

Figure B.4: May, Data Valle Hovin project



(a) CCS outlet 1 (b) CCS outlet 2



(c) AC box (d) BoostCharger - Grid

Figure B.5: June, Data Valle Hovin project

C Appendix D - Grid Tariff Prices

Table C.1: Grid Tariff prices from different grid owners for expected power consuption under 100 000 kWh

Expected yearly consumption under 100 000 kWh						
	Fixed price, per month					
	25 - 50 kW	**50 -75 kW**	**75-100 kW**	**100-150 kW**	**150-200 kW**	**200 - 300 kW**
Tensio	kr 729,00	kr 1 144,00	kr 1 560,00	kr 2 253,00	kr 3 084,00	kr 4 469,00
Elvia	kr 1 126,67	kr 1 626,67	kr 2 126,67	kr 4 186,67	kr 4 186,67	kr 4 186,67
Lyse/L-nett	kr 1 200,00	kr 1 700,00	kr 2 200,00	kr 4 000,00	kr 4 000,00	kr 4 000,00
Norgesnett	kr 1 680,00	kr 2 630,00	kr 3 580,00	kr 5 802,00	kr 5 802,00	kr 5 802,00
Agder energi	kr 2 400,00	kr 3 200,00	kr 4 400,00	kr 6 000,00	kr 6 000,00	kr 6 000,00
Glitre	kr 1 500,00	kr 2 348,00	kr 3 196,00	kr 5 180,00	kr 5 180,00	kr 5 180,00
Lede	kr 974,00	kr 1 553,00	kr 2 131,00	kr 2 999,00	kr 4 156,00	kr 5 892,00
Linea	kr 940,00	kr 1 540,00	kr 2 140,00	kr 3 040,00	kr 4 240,00	kr 6 040,00
Mørenett	kr 690,33	kr 759,33	kr 828,33	kr 1 227,33	kr 1 227,33	kr 1 227,33
BKK Nett	kr 1 200,00	kr 1 775,00	kr 2 350,00	kr 4 650,00	kr 4 650,00	kr 4 650,00
Arva	kr 308,33	kr 308,33	kr 308,33	kr 1 079,17	kr 1 079,17	kr 1 079,17

Table C.2: Grid Tariff prices for different grid owners for expected power consuption under 100 000 kWh, variable price

Expected Consumption under 100 000 kWh		
Variable Price, per kWh		
	Day	**Night**
Tensio	kr 0,13	kr 0,06
Elvia	kr 0,18	kr 0,13
Lyse/ L-nett	kr 0,22	kr 0,16
Norges Nett	kr 0,29	kr 0,19
Agder Energi	kr 0,26	kr 0,18
Glitre	kr 0,37	kr 0,27
Lede	kr 0,17	kr 0,17
Linea	kr 0,20	kr 0,11
Møre Nett	kr 0,16	kr 0,10
BKK Nett	kr 0,24	kr 0,16
Arva	kr 0,16	kr 0,15

Table C.3: Grid Tariff prices for different grid owners for expected power consumption above 100 000 kWh

Expected Consumption above 100 000 kWh					
	Fixed Cost, per kW/month		**Variable Cost, per kWh**		**Additional Cost, per month**
	Winter (nov-apr)	**Summer (may-oct)**	**Winter (nov-apr)**	**Summer (may-oct)**	
Tensio	kr 46,00	kr 30,00	kr 0,04	kr 0,04	kr 257,50
Elvia	kr 90,00	kr 40,00	kr 0,09	kr 0,06	kr 273,33
Lyse/ L-nett	kr 77,00	kr 7,00	kr 0,07	kr 0,06	kr 1 500,00
Norges Nett	kr 95,66	kr 95,66	kr 0,08	kr 0,05	kr 576,42
Agder Energi	kr 90,00	kr 30,00	kr 0,09	kr 0,07	kr 350,00
Glitre	kr 92,00	kr 12,00	kr 0,11	kr 0,08	kr 350,00
Lede	kr 48,75	kr 35,74	kr 0,05	kr 0,03	kr 250,00
Linea	kr 50,50	kr 50,50	kr 0,05	kr 0,03	kr 1 389,42
Møre Nett	kr 40,00	kr 17,00	kr 0,05	kr 0,03	kr 666,67
BKK Nett	kr 59,00	kr 49,00	kr 0,07	kr 0,06	kr 875,00

D Appendix E -Python, analysis Nidarvoll

```
# import pandas lib as pd
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import funksjoner_nidarvollcase as fn



import os
os.chdir(r'C:\Users\rebja\OneDrive\Dokumenter\fornybar siste semester\Bachelor\Python_bachelor\Kraftdata-20230322T102406Z-001\Kraft

# In[1]:

#Relevant cloudtags
Out_charging_power1=str('327111b5034c4295831d08d9996b4f94')
Out_charging_power2=str('365e8c8d184c4acb833008d9996b4f94')
Outlet_SupplyPower=str('56e580ac43384d5b834b08d9996b4f94')
IPC_AFE_IN_Power=str('8a52cf466a0c420c831808d9996b4f94')


# Read the CSV files provided by Aneo

  ##DESEMBER/NOVEMBER
data_1 = pd.read_csv('2021-11-24-tag-values.csv',decimal='.', sep=',')
data_2 = pd.read_csv('2021-11-27-tag-values.csv',decimal='.', sep=',')
data_3 = pd.read_csv('2021-11-30-tag-values.csv',decimal='.', sep=',')
data_4 = pd.read_csv('2021-12-01-tag-values.csv',decimal='.', sep=',')
data_5 = pd.read_csv('2021-12-03-tag-values.csv',decimal='.', sep=',')
data_6 = pd.read_csv('2021-12-09-tag-values.csv',decimal='.', sep=',')
data_7 = pd.read_csv('2021-12-13-tag-values.csv',decimal='.', sep=',')
data_8 = pd.read_csv('2021-12-17-tag-values.csv',decimal='.', sep=',')
data_9 = pd.read_csv('2021-12-21-tag-values.csv',decimal='.', sep=',')

  ##JANUAR

data_10 = pd.read_csv('2022-01-03-tag-values.csv',decimal='.', sep=',')
data_11 = pd.read_csv('2022-01-06-tag-values.csv',decimal='.', sep=',')
data_12 = pd.read_csv('2022-01-10-tag-values.csv',decimal='.', sep=',')
data_13 = pd.read_csv('2022-01-13-tag-values.csv',decimal='.', sep=',')
data_14 = pd.read_csv('2022-01-17-tag-values.csv',decimal='.', sep=',')
data_15 = pd.read_csv('2022-01-21-tag-values.csv',decimal='.', sep=',')
data_16 = pd.read_csv('2022-01-24-tag-values.csv',decimal='.', sep=',')
data_17 = pd.read_csv('2022-01-28-tag-values.csv',decimal='.', sep=',')
data_18 = pd.read_csv('2022-01-31-tag-values.csv',decimal='.', sep=',')

  ##FEBRUAR

data_19 = pd.read_csv('2022-02-01-tag-values.csv',decimal='.', sep=',')
data_20 = pd.read_csv('2022-02-04-tag-values.csv',decimal='.', sep=',')
data_21 = pd.read_csv('2022-02-08-tag-values.csv',decimal='.', sep=',')
data_22 = pd.read_csv('2022-02-11-tag-values.csv',decimal='.', sep=',')
data_23 = pd.read_csv('2022-02-14-tag-values.csv',decimal='.', sep=',')
data_24 = pd.read_csv('2022-02-18-tag-values.csv',decimal='.', sep=',')
data_25 = pd.read_csv('2022-02-22-tag-values.csv',decimal='.', sep=',')
data_26 = pd.read_csv('2022-02-25-tag-values.csv',decimal='.', sep=',')
data_27 = pd.read_csv('2022-02-28-tag-values.csv',decimal='.', sep=',')

   ##MARCH
data_28 = pd.read_csv('2022-03-01-tag-values.csv',decimal='.', sep=',')
data_29 = pd.read_csv('2022-03-04-tag-values.csv',decimal='.', sep=',')
data_30 = pd.read_csv('2022-03-08-tag-values.csv',decimal='.', sep=',')
data_31= pd.read_csv('2022-03-11-tag-values.csv',decimal='.', sep=',')
data_32= pd.read_csv('2022-03-15-tag-values.csv',decimal='.', sep=',')
data_33= pd.read_csv('2022-03-18-tag-values.csv',decimal='.', sep=',')
data_34= pd.read_csv('2022-03-22-tag-values.csv',decimal='.', sep=',')
data_35= pd.read_csv('2022-03-25-tag-values.csv',decimal='.', sep=',')
data_36= pd.read_csv('2022-03-28-tag-values.csv',decimal='.', sep=',')

   ##APRIL
data_37= pd.read_csv('2022-04-01-tag-values.csv',decimal='.', sep=',')
data_38= pd.read_csv('2022-04-05-tag-values.csv',decimal='.', sep=',')
data_39 = pd.read_csv('2022-04-08-tag-values.csv',decimal='.', sep=',')
data_40= pd.read_csv('2022-04-12-tag-values.csv',decimal='.', sep=',')
data_41 = pd.read_csv('2022-04-15-tag-values.csv',decimal='.', sep=',')
data_42 = pd.read_csv('2022-04-19-tag-values.csv',decimal='.', sep=',')
data_43= pd.read_csv('2022-04-22-tag-values.csv',decimal='.', sep=',')
data_44= pd.read_csv('2022-04-26-tag-values.csv',decimal='.', sep=',')
data_45= pd.read_csv('2022-04-29-tag-values.csv',decimal='.', sep=',')

  ##MAY
data_46 = pd.read_csv('2022-05-02-tag-values.csv',decimal='.', sep=',')
data_47= pd.read_csv('2022-05-06-tag-values.csv',decimal='.', sep=',')
data_48= pd.read_csv('2022-05-09-tag-values.csv',decimal='.', sep=',')
data_49= pd.read_csv('2022-05-13-tag-values.csv',decimal='.', sep=',')
data_50= pd.read_csv('2022-05-16-tag-values.csv',decimal='.', sep=',')
data_51= pd.read_csv('2022-05-20-tag-values.csv',decimal='.', sep=',')
data_52= pd.read_csv('2022-05-23-tag-values.csv',decimal='.', sep=',')
data_53= pd.read_csv('2022-05-27-tag-values.csv',decimal='.', sep=',')
data_54= pd.read_csv('2022-05-30-tag-values.csv',decimal='.', sep=',')

   ##JUNE
data_55 = pd.read_csv('2022-06-02-tag-values.csv',decimal='.', sep=',')
data_56= pd.read_csv('2022-06-06-tag-values.csv',decimal='.', sep=',')
```

```
data_57= pd.read_csv('2022-06-09-tag-values.csv',decimal='.', sep=',')
data_58= pd.read_csv('2022-06-13-tag-values.csv',decimal='.', sep=',')
data_59= pd.read_csv('2022-06-16-tag-values.csv',decimal='.', sep=',')
data_60= pd.read_csv('2022-06-20-tag-values.csv',decimal='.', sep=',')
data_61= pd.read_csv('2022-06-23-tag-values.csv',decimal='.', sep=',')
data_62= pd.read_csv('2022-06-27-tag-values.csv',decimal='.', sep=',')
data_63= pd.read_csv('2022-06-30-tag-values.csv',decimal='.', sep=',')

import pandas as pd


#FUNTION FOR FIXING ERROR VALUES IN THE UPLOADED DATA AND REPLACE WITH ZERO
def replace_value(dataframe, column_name):
    dataframe[column_name] = pd.to_numeric(dataframe[column_name], errors='coerce')
    dataframe.loc[dataframe[column_name] > 151, column_name] = 0

# Apply the function to each DataFrame
for i in range(1, 64):
    df = globals()[f"data_{i}"]  # Access the DataFrame using globals()
    replace_value(df, 'Value')  # Replace 'column_name' with the actual column name




# In[2]:
               ### Analysis: charging pattern of construction machine from BoostCharger ###

##CCS 1
ts_maskinlist,maskinlading_list,Forbruk_maskinlist=fn.databehandling(Out_charging_power1,data_1,data_2,data_3,data_4,data_5,data_6,
tsjan,mlad_jan,Forbruk_maskinjan=fn.databehandling(Out_charging_power1,data_10,data_11,data_12,data_13,data_14,data_15,data_16,data
tsfeb,mlad_feb,Forbruk_maskinfeb=fn.databehandling(Out_charging_power1,data_19,data_20,data_21,data_22,data_23,data_24,data_25,data
tsmar,mlad_mar,Forbruk_maskinmar=fn.databehandling(Out_charging_power1,data_28,data_29,data_30,data_31,data_32,data_33,data_34,data
tsap,mlad_ap,Forbruk_maskinap=fn.databehandling(Out_charging_power1,data_37,data_38,data_39,data_40,data_41,data_42,data_43,data_44
tsmai,mlad_mai,Forbruk_maskinmai=fn.databehandling(Out_charging_power1,data_46,data_47,data_48,data_49,data_50,data_51,data_52,data
tsjun,mlad_jun,Forbruk_maskinjun=fn.databehandling(Out_charging_power1,data_55,data_56,data_57,data_58,data_59,data_60,data_61,data


##CCS 2
ts_maskinlist2,maskinlading_list2,Forbruk_maskinlist2=fn.databehandling(Out_charging_power2,data_1,data_2,data_3,data_4,data_5,data
tsjan2,mlad_jan2,Forbruk_maskinjan2=fn.databehandling(Out_charging_power2,data_10,data_11,data_12,data_13,data_14,data_15,data_16,d
tsfeb2,mlad_feb2,Forbruk_maskinfeb2=fn.databehandling(Out_charging_power2,data_19,data_20,data_21,data_22,data_23,data_24,data_25,d
tsmar2,mlad_mar2,Forbruk_maskinmar2=fn.databehandling(Out_charging_power2,data_28,data_29,data_30,data_31,data_32,data_33,data_34,d
tsap2,mlad_ap2,Forbruk_maskinap2=fn.databehandling(Out_charging_power2,data_37,data_38,data_39,data_40,data_41,data_42,data_43,data
tsmai2,mlad_mai2,Forbruk_maskinmai2=fn.databehandling(Out_charging_power2,data_46,data_47,data_48,data_49,data_50,data_51,data_52,d
tsjun2,mlad_jun2,Forbruk_maskinjun2=fn.databehandling(Out_charging_power2,data_55,data_56,data_57,data_58,data_59,data_60,data_61,d


##AC Outlet
ts_maskinlistAC,maskinlading_listAC,Forbruk_maskinlistAC=fn.databehandling(Outlet_SupplyPower,data_1,data_2,data_3,data_4,data_5,da
tsjanAC,mlad_janAC,Forbruk_maskinjanAC=fn.databehandling(Outlet_SupplyPower,data_10,data_11,data_12,data_13,data_14,data_15,data_16
tsfebAC,mlad_febAC,Forbruk_maskinfebAC=fn.databehandling(Outlet_SupplyPower,data_19,data_20,data_21,data_22,data_23,data_24,data_25
tsmarAC,mlad_marAC,Forbruk_maskinmarAC=fn.databehandling(Outlet_SupplyPower,data_28,data_29,data_30,data_31,data_32,data_33,data_34
tsapAC,mlad_apAC,Forbruk_maskinapAC=fn.databehandling(Outlet_SupplyPower,data_37,data_38,data_39,data_40,data_41,data_42,data_43,da
tsmaiAC,mlad_maiAC,Forbruk_maskinmaiAC=fn.databehandling(Outlet_SupplyPower,data_46,data_47,data_48,data_49,data_50,data_51,data_52
tsjunAC,mlad_junAC,Forbruk_maskinjunAC=fn.databehandling(Outlet_SupplyPower,data_55,data_56,data_57,data_58,data_59,data_60,data_61


##TOTAL ENERGYCONSUMPTION OF CCS1,CCS2 AND AC OUTLET EACH MONTH
Forbruk_novdes=fn.add_lists(Forbruk_maskinlist,Forbruk_maskinlist2, Forbruk_maskinlistAC)
Forbruk_jan=fn.add_lists(Forbruk_maskinjan,Forbruk_maskinjan2, Forbruk_maskinjanAC)
Forbruk_feb=fn.add_lists(Forbruk_maskinfeb,Forbruk_maskinfeb2, Forbruk_maskinfebAC)
Forbruk_mars=fn.add_lists(Forbruk_maskinmar,Forbruk_maskinmar2, Forbruk_maskinmarAC)
Forbruk_april=fn.add_lists(Forbruk_maskinap,Forbruk_maskinap2, Forbruk_maskinapAC)
Forbruk_mai=fn.add_lists(Forbruk_maskinmai,Forbruk_maskinmai2, Forbruk_maskinmaiAC)
Forbruk_juni=fn.add_lists(Forbruk_maskinjun,Forbruk_maskinjun2, Forbruk_maskinjunAC)

mlad_febtot=fn.add_lists(mlad_feb,mlad_feb2,mlad_febAC)

#ENERGYCONSUMPTION FOR THE WHOLE PROJECT PERIODE
Forbruk_prosjekt=[Forbruk_novdes,Forbruk_jan,Forbruk_feb,Forbruk_mars,Forbruk_april,Forbruk_mai,Forbruk_juni]



## MEASURED VS ESTIMATED CV-CHARGING CURVE
test=(mlad_feb2[7])[963:1087]
minutt=liste = [tall for tall in range(1, 124)]

import math
I_t = []
for t in minutt:
    I_t.append((227*math.exp(-0.065*t) + 7.05)*0.630) #630 er den konstante max spenningen



plt.plot([float(x) for x in test],label='Measured CV-charging curve')
plt.plot([float(x) for x in I_t],label='Estimated CV-charging curve')

plt.xlabel("Time")
plt.ylabel('Power (kW)')
plt.legend(['Measured','Estimated'])
plt.suptitle("CV-charging curve")
plt.show()
```

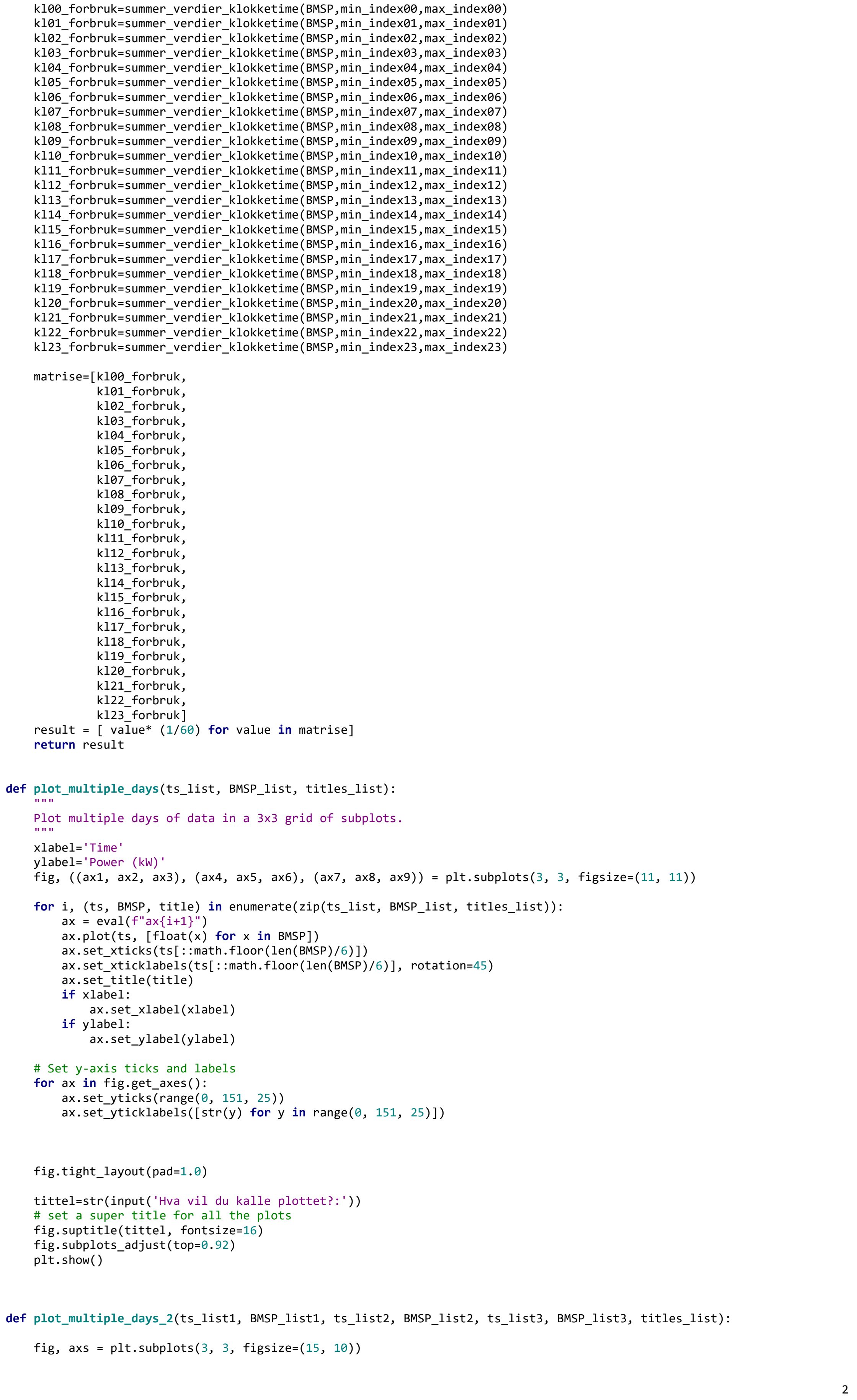
```
    ##Plotting charging pattern
titles_list = ["Day 1", "Day 2", "Day 3", "Day 4", "Day 5", "Day 6", "Day 7", "Day 8", "Day 9"] ##liste for plotting

A=0
if A==1:
    fn.plot_multiple_days(ts_maskinlist, maskinlading_list, titles_list) #Plotting consumption from CCS1 outlet

B=0
if B==1:
    fn.plot_multiple_days(ts_maskinlist2, maskinlading_list2, titles_list) #Plotting consumption from CCS1 outlet

C=1
if C==1:
    fn.plot_multiple_days(ts_maskinlistAC, maskinlading_listAC, titles_list) #Plotting consumption from CCS1 outlet



# In[3]:

                    ###Analysis: power delivered from grid to BoostCharger###
ts_INPlist,INP_list,ForbrukINP=fn.databehandling(IPC_AFE_IN_Power,data_1,data_2,data_3,data_4,data_5,data_6,data_7,data_8,data_9)
tsjanINP,mlad_janINP,Forbruk_INPjan=fn.databehandling(IPC_AFE_IN_Power,data_10,data_11,data_12,data_13,data_14,data_15,data_16,data
tsfebINP,mlad_febINP,Forbruk_INPfeb=fn.databehandling(IPC_AFE_IN_Power,data_19,data_20,data_21,data_22,data_23,data_24,data_25,data
tsmarINP,mlad_marINP,Forbruk_INPmar=fn.databehandling(IPC_AFE_IN_Power,data_28,data_29,data_30,data_31,data_32,data_33,data_34,data
tsapINP,mlad_apINP,Forbruk_INPap=fn.databehandling(IPC_AFE_IN_Power,data_37,data_38,data_39,data_40,data_41,data_42,data_43,data_44
tsmaiINP,mlad_maiINP,Forbruk_INPmai=fn.databehandling(IPC_AFE_IN_Power,data_46,data_47,data_48,data_49,data_50,data_51,data_52,data
tsjunINP,mlad_junINP,Forbruk_INPjun=fn.databehandling(IPC_AFE_IN_Power,data_55,data_56,data_57,data_58,data_59,data_60,data_61,data

#ENERGYCONSUMPTION FOR THE WHOLE PROJECT PERIODE, BOOSTCHARGER
Forbruk_prosjekt_con=[ForbrukINP,Forbruk_INPjan,Forbruk_INPfeb,Forbruk_INPmar,Forbruk_INPap,Forbruk_INPmai,Forbruk_INPjun]

E=0
if E==1:
    fn.plot_multiple_days(ts_INPlist, INP_list, titles_list) #Plot: consumption profile, boostcharger


# In[4]:
      ##ENERGYCONSUMPTION, BOOSTCHARGER VS MACHINES
F=0
if F==1:
    plt.plot([float(x) for x in Forbruk_feb[2]],label='Energy concumption machines')
    plt.plot([float(x) for x in Forbruk_INPfeb[2]],label='Energy consumption Boostcharger')

    plt.xlabel("Time")
    plt.ylabel('Energy (kWh)')
    plt.legend(['Machines','Boostcharger'])
    plt.suptitle("Energy consumption")
    plt.show()

    ##POWERCONSUMPTION, BOOSTCHARGER VS MACHINES

G=0
if G==1:
    plt.plot([float(x) for x in mlad_febtot[2]],label='Power concumption machines')
    plt.plot([float(x) for x in mlad_febINP[2]],label='Power consumption Boostcharger')

    plt.xlabel("Time")
    plt.ylabel('Power (kW)')
    plt.legend(['Machines','Boostcharger'])
    plt.suptitle("Power consumption")
    plt.show()

# In[5]:
#Power prices from Nordpool
from Powerprices import powerprice as PP #Power prices matrix

PP_NO3=PP[2]
PP_des=PP_NO3[11]
PP_jan=PP_NO3[0]
PP_feb=PP_NO3[1]
PP_mar=PP_NO3[2]
PP_apr=PP_NO3[3]
PP_mai=PP_NO3[4]
PP_jun=PP_NO3[5]
PP_list=[PP_des,PP_jan,PP_feb,PP_mar,PP_apr,PP_mai,PP_jun]
# In[6]:

D=1
if D==1:


     Nettleiepriser = pd.read_csv('Nettleiepriser_underrr100.csv')
     import csv
     with open('Nettleiepriser_underrr100.csv', 'r') as file:
         reader = csv.reader(file)
         data = [row[:11] for row in reader]

         #Convert the data into a DataFrame
         Nettleiepriser_data = pd.DataFrame(data)

         ### Analysis: power costs and grid tariff costs when NOT using BoostCharger for peak shaving

         strompris_prosjekt_con,strompris_prosjekt_con_sum=fn.strompris_prosjekt(PP_list,Forbruk_prosjekt_con)#Total power costs
```

3

```
         nettpris_medcon=fn.Nettleiepriser(Nettleiepriser_data,Forbruk_prosjekt_con,25,7)  #Total grid tariff costs, (25kW power pe
         Prosjektpris_medcon=strompris_prosjekt_con_sum+nettpris_medcon #Total of grid tariff and power costs

         ### Analysis: power costs and grid tariff costs when NOT using BoostCharger for peak shaving
         strompris_prosjekt,strompris_prosjekt_sum=fn.strompris_prosjekt(PP_list,Forbruk_prosjekt) #Total power costs
         nettpris_utencon=fn.Nettleiepriser(Nettleiepriser_data,Forbruk_prosjekt,150,7) #Total grid tariff costs, (150 kW power pea
         Prosjektpris_utencon=float(strompris_prosjekt_sum)+float(nettpris_utencon) #Total of grid tariff and power costs


         from tabulate import tabulate

         data = [["   ", "Grid tariff (kr)", "Energyprice (kr)", "Total(kr)"],
                 ["Without batterycontainer",nettpris_utencon ,strompris_prosjekt_sum,Prosjektpris_utencon],
                 ["With batterycontainer", nettpris_medcon, strompris_prosjekt_con_sum,Prosjektpris_medcon],
                 ["Economic savings", nettpris_utencon-nettpris_medcon, strompris_prosjekt_sum-strompris_prosjekt_con_sum,Prosjektp

         table = tabulate(data, headers="firstrow", tablefmt="grid")
         print(table)


# In[7]:
```

E Appendix F -Python, functions Nidarvoll

```
# -*- coding: utf-8 -*-
import numpy as np
import matplotlib.pyplot as plt
import math


def convert_to_int(vektor):   #converts from np.array to float list
    lst = vektor
    lst_int = []
    for i in lst:
        lst_int.append(float(i))
    return lst_int




def plot_subplots(ts_list, B_list):  #plots 3x3 fig
    fig, axs = plt.subplots(3, 3, figsize=(11, 11))
    axs = axs.ravel()
    for i, (ts, B) in enumerate(zip(ts_list, B_list)):
        ax = axs[i]
        ax.plot(ts, [float(x) for x in B])
        ax.set_xticks(ts[::math.floor(len(B)/5)])
        ax.set_xticklabels(ts[::math.floor(len(B)/5)], rotation=45)
        ax.set_title(f"Dag {i+1}")
    fig.tight_layout(pad=1.0)
    plt.show()

def koordinater_klokketime(ts_BMSdag,klokketime): #Finds the coordinates for given value in two lists
    if klokketime !=[]:
        min_index = min([i for i, s in enumerate(ts_BMSdag) if s in klokketime])
        max_index = max([i for i, s in enumerate(ts_BMSdag) if s in klokketime])
    else:
        min_index=0
        max_index=0
    return min_index, max_index

def summer_verdier_klokketime(BMSP,min_index,max_index): #summarises energyconsumption in the same clock hours
    kl_values=BMSP[min_index:max_index]
    kl09_vint=convert_to_int(kl_values)
    kl09_forbruk=sum(kl09_vint)
    return kl09_forbruk


def forbruk_ved_klokketimer(ts_BMS,BMSP):           #Takes in a list of power consumption (kW) each minute during a day
    kl00=[s for s in ts_BMS if s.startswith('00:')] #Then it estimates the enery consumption (kWh) each hour during the day
    kl01=[s for s in ts_BMS if s.startswith('01:')]
    kl02=[s for s in ts_BMS if s.startswith('02:')]
    kl03=[s for s in ts_BMS if s.startswith('03:')]
    kl04=[s for s in ts_BMS if s.startswith('04:')]
    kl05=[s for s in ts_BMS if s.startswith('05:')]
    kl06=[s for s in ts_BMS if s.startswith('06:')]
    kl07=[s for s in ts_BMS if s.startswith('07:')]
    kl08=[s for s in ts_BMS if s.startswith('08:')]
    kl09=[s for s in ts_BMS if s.startswith('09:')]
    kl10=[s for s in ts_BMS if s.startswith('10:')]
    kl11=[s for s in ts_BMS if s.startswith('11:')]
    kl12=[s for s in ts_BMS if s.startswith('12:')]
    kl13=[s for s in ts_BMS if s.startswith('13:')]
    kl14=[s for s in ts_BMS if s.startswith('14:')]
    kl15=[s for s in ts_BMS if s.startswith('15:')]
    kl16=[s for s in ts_BMS if s.startswith('16:')]
    kl17=[s for s in ts_BMS if s.startswith('17:')]
    kl18=[s for s in ts_BMS if s.startswith('18:')]
    kl19=[s for s in ts_BMS if s.startswith('19:')]
    kl20=[s for s in ts_BMS if s.startswith('20:')]
    kl21=[s for s in ts_BMS if s.startswith('21:')]
    kl22=[s for s in ts_BMS if s.startswith('23:')]
    kl23=[s for s in ts_BMS if s.startswith('24:')]

    min_index00, max_index00=koordinater_klokketime(ts_BMS,kl00)
    min_index01, max_index01=koordinater_klokketime(ts_BMS,kl01)
    min_index02, max_index02=koordinater_klokketime(ts_BMS,kl02)
    min_index03, max_index03=koordinater_klokketime(ts_BMS,kl03)
    min_index04, max_index04=koordinater_klokketime(ts_BMS,kl04)
    min_index05, max_index05=koordinater_klokketime(ts_BMS,kl05)
    min_index06, max_index06=koordinater_klokketime(ts_BMS,kl06)
    min_index07, max_index07=koordinater_klokketime(ts_BMS,kl07)
    min_index08, max_index08=koordinater_klokketime(ts_BMS,kl08)
    min_index09, max_index09=koordinater_klokketime(ts_BMS,kl09)
    min_index10, max_index10=koordinater_klokketime(ts_BMS,kl10)
    min_index11, max_index11=koordinater_klokketime(ts_BMS,kl11)
    min_index12, max_index12=koordinater_klokketime(ts_BMS,kl12)
    min_index13, max_index13=koordinater_klokketime(ts_BMS,kl13)
    min_index14, max_index14=koordinater_klokketime(ts_BMS,kl14)
    min_index15, max_index15=koordinater_klokketime(ts_BMS,kl15)
    min_index16, max_index16=koordinater_klokketime(ts_BMS,kl16)
    min_index17, max_index17=koordinater_klokketime(ts_BMS,kl17)
    min_index18, max_index18=koordinater_klokketime(ts_BMS,kl18)
    min_index19, max_index19=koordinater_klokketime(ts_BMS,kl19)
    min_index20, max_index20=koordinater_klokketime(ts_BMS,kl20)
    min_index21, max_index21=koordinater_klokketime(ts_BMS,kl21)
    min_index22, max_index22=koordinater_klokketime(ts_BMS,kl22)
    min_index23, max_index23=koordinater_klokketime(ts_BMS,kl23)
```



```
    kl00_forbruk=summer_verdier_klokketime(BMSP,min_index00,max_index00)
    kl01_forbruk=summer_verdier_klokketime(BMSP,min_index01,max_index01)
    kl02_forbruk=summer_verdier_klokketime(BMSP,min_index02,max_index02)
    kl03_forbruk=summer_verdier_klokketime(BMSP,min_index03,max_index03)
    kl04_forbruk=summer_verdier_klokketime(BMSP,min_index04,max_index04)
    kl05_forbruk=summer_verdier_klokketime(BMSP,min_index05,max_index05)
    kl06_forbruk=summer_verdier_klokketime(BMSP,min_index06,max_index06)
    kl07_forbruk=summer_verdier_klokketime(BMSP,min_index07,max_index07)
    kl08_forbruk=summer_verdier_klokketime(BMSP,min_index08,max_index08)
    kl09_forbruk=summer_verdier_klokketime(BMSP,min_index09,max_index09)
    kl10_forbruk=summer_verdier_klokketime(BMSP,min_index10,max_index10)
    kl11_forbruk=summer_verdier_klokketime(BMSP,min_index11,max_index11)
    kl12_forbruk=summer_verdier_klokketime(BMSP,min_index12,max_index12)
    kl13_forbruk=summer_verdier_klokketime(BMSP,min_index13,max_index13)
    kl14_forbruk=summer_verdier_klokketime(BMSP,min_index14,max_index14)
    kl15_forbruk=summer_verdier_klokketime(BMSP,min_index15,max_index15)
    kl16_forbruk=summer_verdier_klokketime(BMSP,min_index16,max_index16)
    kl17_forbruk=summer_verdier_klokketime(BMSP,min_index17,max_index17)
    kl18_forbruk=summer_verdier_klokketime(BMSP,min_index18,max_index18)
    kl19_forbruk=summer_verdier_klokketime(BMSP,min_index19,max_index19)
    kl20_forbruk=summer_verdier_klokketime(BMSP,min_index20,max_index20)
    kl21_forbruk=summer_verdier_klokketime(BMSP,min_index21,max_index21)
    kl22_forbruk=summer_verdier_klokketime(BMSP,min_index22,max_index22)
    kl23_forbruk=summer_verdier_klokketime(BMSP,min_index23,max_index23)

    matrise=[kl00_forbruk,
             kl01_forbruk,
             kl02_forbruk,
             kl03_forbruk,
             kl04_forbruk,
             kl05_forbruk,
             kl06_forbruk,
             kl07_forbruk,
             kl08_forbruk,
             kl09_forbruk,
             kl10_forbruk,
             kl11_forbruk,
             kl12_forbruk,
             kl13_forbruk,
             kl14_forbruk,
             kl15_forbruk,
             kl16_forbruk,
             kl17_forbruk,
             kl18_forbruk,
             kl19_forbruk,
             kl20_forbruk,
             kl21_forbruk,
             kl22_forbruk,
             kl23_forbruk]
    result = [ value* (1/60) for value in matrise]
    return result


def plot_multiple_days(ts_list, BMSP_list, titles_list):
    """
    Plot multiple days of data in a 3x3 grid of subplots.
    """
    xlabel='Time'
    ylabel='Power (kW)'
    fig, ((ax1, ax2, ax3), (ax4, ax5, ax6), (ax7, ax8, ax9)) = plt.subplots(3, 3, figsize=(11, 11))

    for i, (ts, BMSP, title) in enumerate(zip(ts_list, BMSP_list, titles_list)):
        ax = eval(f"ax{i+1}")
        ax.plot(ts, [float(x) for x in BMSP])
        ax.set_xticks(ts[::math.floor(len(BMSP)/6)])
        ax.set_xticklabels(ts[::math.floor(len(BMSP)/6)], rotation=45)
        ax.set_title(title)
        if xlabel:
            ax.set_xlabel(xlabel)
        if ylabel:
            ax.set_ylabel(ylabel)

    # Set y-axis ticks and labels
    for ax in fig.get_axes():
        ax.set_yticks(range(0, 151, 25))
        ax.set_yticklabels([str(y) for y in range(0, 151, 25)])



    fig.tight_layout(pad=1.0)

    tittel=str(input('Hva vil du kalle plottet?:'))
    # set a super title for all the plots
    fig.suptitle(tittel, fontsize=16)
    fig.subplots_adjust(top=0.92)
    plt.show()



def plot_multiple_days_2(ts_list1, BMSP_list1, ts_list2, BMSP_list2, ts_list3, BMSP_list3, titles_list):

    fig, axs = plt.subplots(3, 3, figsize=(15, 10))
```

```
    for i, (ts1, BMSP1, ts2, BMSP2, ts3, BMSP3, title) in enumerate(zip(ts_list1, BMSP_list1, ts_list2, BMSP_list2, ts_list3, BMSP_
        row = i // 3
        col = i % 3
        ax = axs[row, col]
        ax.plot(ts1, [float(x) for x in BMSP1], label='Graph 1')
        ax.plot(ts2, [float(x) for x in BMSP2], label='Graph 2')
        ax.plot(ts3, [float(x) for x in BMSP3], label='Graph 3')
        ax.set_xticks(ts1[::math.floor(len(BMSP1)/5)])
        ax.set_xticklabels(ts1[::math.floor(len(BMSP1)/5)], rotation=45)
        ax.set_title(title)

    fig.tight_layout(pad=1.0)

    tittel=str(input('Hva vil du kalle plottet?:'))
    # set a super title for all the plots
    fig.suptitle(tittel, fontsize=16)
    fig.subplots_adjust(top=0.92)
    plt.show()



from datetime import datetime

def combined_function(Måling, navn_på_fil):
    Cloudtag = [Måling]                      #Takes in relevant measurements from a data file for a day.
    navn_på_matrise = []                     #If a minute during the day have no measurements, it adds a zero
    time_strings = []                        #Ends up with a list representing power consumption each minute during a day
    for tag in Cloudtag:
        test_matrise = navn_på_fil[navn_på_fil["CloudTagId"].str.startswith(tag)]
        data_11_23_array = test_matrise.to_numpy()
        navn_på_matrise = data_11_23_array[:, [0, 2, 3]]

        A_1 = navn_på_matrise
        B_1 = A_1[:, 2]

        timestamp_BMS = A_1[:, 1]

        # Convert timestamps to dates
        dates = [datetime.fromtimestamp(ts).strftime('%H:%M') for ts in timestamp_BMS]
        ts_1 = dates

        # Create an array of time strings
        for hour in range(24):
            for minute in range(60):
                time_string = f"{hour:02d}:{minute:02d}"
                time_strings.append(time_string)

        # Create the matrix with time_strings as the first column and zeros as the second column
        matrixx = np.column_stack((time_strings, np.zeros(len(time_strings))))

        # Iterate through both arrays and update values in the matrix
        for i in range(len(matrixx)):
            for j in range(len(B_1)):
                if matrixx[i, 0] == ts_1[j]:
                    matrixx[i, 1] = B_1[j]


        # Return the updated matrix
        return matrixx


   #FUNCTION THAT TAKES IN RELEVANT MEASUREMENT FOR DIFFERENT DAYS, AND RETURNS A LIST REPRESENTING EACH MINUTE DURING A DAY
def databehandling(måling,dag1,dag2,dag3,dag4,dag5,dag6,dag7,dag8,dag9):
    A_1 = combined_function(måling,dag1)
    ts_1=A_1[:,0]
    B_1=A_1[:,1]
    Forbruk1_maskin=forbruk_ved_klokketimer(ts_1,B_1)  #Gjør om til kwh og summerer sammen forbruket per time

    #25.NOVEMBER
    A_2=combined_function(måling,dag2) #cloudtag,timestamp og verdi
    B_2=A_2[:,1] #bare verdien
    ts_2=A_2[:,0]
    Forbruk2_maskin=forbruk_ved_klokketimer(ts_2,B_2)

    #26.NOVEMBER
    A_3=combined_function(måling,dag3) #cloudtag,timestamp og verdi
    B_3=A_3[:,1] #bare verdien
    ts_3=A_3[:,0]
    Forbruk3_maskin=forbruk_ved_klokketimer(ts_3,B_3)

    #27.NOVEMBER
    A_4=combined_function(måling,dag4) #cloudtag,timestamp og verdi
    B_4=A_4[:,1] #bare verdien
    ts_4=A_4[:,0]
    Forbruk4_maskin=forbruk_ved_klokketimer(ts_4,B_4)

    #28.November
    A_5=combined_function(måling,dag5) #cloudtag,timestamp og verdi
    B_5=A_5[:,1] #bare verdien
    ts_5=A_5[:,0]
    Forbruk5_maskin=forbruk_ved_klokketimer(ts_5,B_5)

    #29.November
    A_6=combined_function(måling,dag6) #cloudtag,timestamp og verdi
```

```
    B_6=A_6[:,1] #bare verdien
    ts_6=A_6[:,0]
    Forbruk6_maskin=forbruk_ved_klokketimer(ts_6,B_6)

    #30.November
    A_7=combined_function(måling,dag7) #cloudtag,timestamp og verdi
    B_7=A_7[:,1] #bare verdien
    ts_7=A_7[:,0]
    Forbruk7_maskin=forbruk_ved_klokketimer(ts_7,B_7)

    #30.November
    A_8=combined_function(måling,dag8) #cloudtag,timestamp og verdi
    B_8=A_8[:,1] #bare verdien
    ts_8=A_8[:,0]
    Forbruk8_maskin=forbruk_ved_klokketimer(ts_8,B_8)

    #30.November
    A_9=combined_function(måling,dag9) #cloudtag,timestamp og verdi
    B_9=A_9[:,1] #bare verdien
    ts_9=A_9[:,0]
    Forbruk9_maskin=forbruk_ved_klokketimer(ts_9,B_9)

    ts_list=[ts_1,ts_2,ts_3,ts_4,ts_5,ts_6,ts_7,ts_8,ts_9]
    BMSP_list=[B_1,B_2,B_3,B_4,B_5,B_6,B_7,B_8,B_9]
    Forbruk_list=[Forbruk1_maskin,Forbruk2_maskin,Forbruk3_maskin,Forbruk4_maskin,Forbruk5_maskin,Forbruk6_maskin,Forbruk7_maskin,F

    return ts_list, BMSP_list, Forbruk_list



def estimate_power_consumption(Forbruk_maskinlist): #Estimates total power consumption for night and day
    summed_lists = []
    for lst in Forbruk_maskinlist:
        dag = sum(lst[6:21])
        natt = sum(lst[22:23])+sum(lst[0:5])
        summed_lists.append([dag, natt])
    return summed_lists



#FUNCTION THAT ESTIMATES THE GRID TARIFF COSTS FOR A PROJECT FOR CHOSEN GRID COMPANY
def Nettleiepriser(Nettleiepriser,Forbruk_maskinlist,Effekttopp,Måneder):
    Ten = Nettleiepriser.iloc[0]
    Tensi=Ten.values
    Elv = Nettleiepriser.iloc[1]
    Elvi=Elv.values
    Lys = Nettleiepriser.iloc[2]
    Lysenet=Lys.values
    Nor = Nettleiepriser.iloc[3]
    Norgesnet=Nor.values
    Agd = Nettleiepriser.iloc[4]
    Agderenerg=Agd.values
    Gli = Nettleiepriser.iloc[5]
    Glitr=Gli.values
    Led = Nettleiepriser.iloc[6]
    Leder=Led.values
    Lin = Nettleiepriser.iloc[7]
    Line=Lin.values
    Møre = Nettleiepriser.iloc[8]
    Mørenet=Møre.values
    BKK = Nettleiepriser.iloc[9]
    BKKnet=BKK.values
    Arv = Nettleiepriser.iloc[10]
    Arv=Arv.values


    print(f'Du har valget mellom følgende nettselskaper:')
    print('1: Tensio'.rjust(25))
    print('2: Elvia'.rjust(24))
    print('3: Lysenett'.rjust(27))
    print('4: Norgesnett'.rjust(29))
    print('5: Agder Energi'.rjust(31))
    print('6: Glitre'.rjust(25))
    print('7: Lede'.rjust(23))
    print('8: Linea'.rjust(24))
    print('9: Mørenett'.rjust(27))
    print('10: BKKnett'.rjust(26))
    print('11: Arva'.rjust(23))
    Nettselskap=int(input('Hvilket nettselskap bruker du? (skriv tall):'))

    Priser=[]
    if Nettselskap==1:
        Priser=Tensi
    elif Nettselskap==2:
        Priser=Elvi
    elif Nettselskap==3:
        Priser=Lysenet
    elif Nettselskap==4:
        Priser=Norgesnet
    elif Nettselskap==5:
        Priser=Agderenerg
    elif Nettselskap==6:
        Priser=Glitr
    elif Nettselskap==7:
```

```
    Priser=Leder
elif Nettselskap==8:
    Priser=Line
elif Nettselskap==9:
    Priser=Mørenet
elif Nettselskap==10:
    Priser=BKKnet
elif Nettselskap==11:
    Priser=Arv
else:
    print('Ingen nettselskap ved dette navnet')

Kapasitetsledd=[]
if 25<= Effekttopp <=50:
    Kapasitetsledd=Priser[0]
elif 50<= Effekttopp <=75:
    Kapasitetsledd=Priser[1]
elif 75<= Effekttopp <=100:
     Kapasitetsledd=Priser[2]
elif 100<= Effekttopp <=150:
     Kapasitetsledd=Priser[3]
elif 150<= Effekttopp <=200:
     Kapasitetsledd=Priser[4]
elif 200<= Effekttopp <=300:
     Kapasitetsledd=Priser[5]
else:
    Kapasitetsledd=Priser[5]

Energiledd_dag=[]
Energiledd_natt=[]
if Nettselskap==1:
    Energiledd_dag=Tensi[6]
    Energiledd_natt=Tensi[7]
elif Nettselskap==2:
    Energiledd_dag=Elvi[6]
    Energiledd_natt=Elvi[7]
elif Nettselskap==3:
    Energiledd_dag=Lysenet[6]
    Energiledd_natt=Lysenet[7]
elif Nettselskap==4:
    Energiledd_dag=Norgesnet[6]
    Energiledd_natt=Norgesnet[7]
elif Nettselskap==5:
    Energiledd_dag=Agderenerg[6]
    Energiledd_natt=Agderenerg[7]
elif Nettselskap==6:
    Energiledd_dag=Glitr[6]
    Energiledd_natt=Glitr[7]
elif Nettselskap==7:
    Energiledd_dag=Leder[6]
    Energiledd_natt=Leder[7]
elif Nettselskap==8:
    Energiledd_dag=Line[6]
    Energiledd_natt=Line[7]
elif Nettselskap==9:
    Energiledd_dag=Mørenet[6]
    Energiledd_natt=Mørenet[7]
elif Nettselskap==10:
    Energiledd_dag=BKKnet[6]
    Energiledd_natt=BKKnet[7]
elif Nettselskap==11:
    Energiledd_dag=Arv[6]
    Energiledd_natt=Arv[7]
else:
    print('Ingen nettselskap ved dette navnet')


summed_listnov=estimate_power_consumption(Forbruk_maskinlist[0])
summed_listjan=estimate_power_consumption(Forbruk_maskinlist[1])
summed_listfeb=estimate_power_consumption(Forbruk_maskinlist[2])
summed_listmar=estimate_power_consumption(Forbruk_maskinlist[3])
summed_listap=estimate_power_consumption(Forbruk_maskinlist[4])
summed_listmai=estimate_power_consumption(Forbruk_maskinlist[5])
summed_listjun=estimate_power_consumption(Forbruk_maskinlist[6])




# Summer forbruket for dag
first_sum1 = sum([sublist[0] for sublist in summed_listnov])
first_sum2 = sum([sublist[0] for sublist in summed_listjan])
first_sum3 = sum([sublist[0] for sublist in summed_listfeb])
first_sum4 = sum([sublist[0] for sublist in summed_listmar])
first_sum5 = sum([sublist[0] for sublist in summed_listap])
first_sum6 = sum([sublist[0] for sublist in summed_listmai])
first_sum7 = sum([sublist[0] for sublist in summed_listjun])
first_sum=first_sum1+first_sum2+first_sum3+first_sum4+first_sum5+first_sum6+first_sum7

# Summer forbruket for natt
second_sum1 = sum([sublist[1] for sublist in summed_listnov])
second_sum2 = sum([sublist[1] for sublist in summed_listjan])
second_sum3 = sum([sublist[1] for sublist in summed_listfeb])
second_sum4 = sum([sublist[1] for sublist in summed_listmar])
second_sum5 = sum([sublist[1] for sublist in summed_listap])
```

```
    second_sum6 = sum([sublist[1] for sublist in summed_listmai])
    second_sum7 = sum([sublist[1] for sublist in summed_listjun])

    secound_sum=second_sum1+second_sum2+second_sum3+second_sum4+second_sum5+second_sum6+second_sum7

    Energiledd=(float(first_sum)*float(Energiledd_dag)*20/9)+(float(secound_sum)*float(Energiledd_natt)*20/9) #assuming 20 workingd

    Forbruksavgift=0.1541*(float(Energiledd_dag)+float(Energiledd_natt)) #0.1541kr/kWh per måned
    Enova_avgift=67*Måneder #67kr/måned

    Pris=(float(Kapasitetsledd)*Måneder)+Energiledd+Forbruksavgift+Enova_avgift

    return Pris

def add_lists(list1, list2, list3):
    result_list = []
    for i in range(len(list1)):
        inner_list = []
        for j in range(len(list1[i])):
            value = float(list1[i][j]) + float(list2[i][j]) + float(list3[i][j])
            inner_list.append(value)
        result_list.append(inner_list)
    return result_list


                #FUNCTIONS FOR ESTIMATING POWER COSTS
def strompris_dag(PP_måned,forbrukdag):

    result = [(x)*0.001 for x in PP_måned] #from kr/MWh to kr/kWh
    a=[(x*y) for x, y in zip(result, forbrukdag)] #kr/kWh * kWh
    b=sum(a)
    return b

def strompris_måned(PP_måned,Forbruk_maskinlist):
    strompris1_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[0]) #Power costs day 1
    strompris2_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[1]) #Power costs day 2
    strompris3_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[2]) #Power costs day 3
    strompris4_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[3]) #Power costs day 4
    strompris5_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[4]) #Power costs day 5
    strompris6_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[5]) #Power costs day 6
    strompris7_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[6]) #Power costs day 7
    strompris8_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[7]) #Power costs day 8
    strompris9_maskin=strompris_dag(PP_måned,Forbruk_maskinlist[8]) #Power costs day 9

    strompris_maskin_list=[strompris1_maskin,strompris2_maskin,strompris3_maskin,strompris4_maskin,strompris5_maskin,strompris6_mas
    return strompris_maskin_list


def strompris_prosjekt(PP_list,Forbruk_prosjekt):
    A=strompris_måned(PP_list[0],Forbruk_prosjekt[0]) #nov/des
    B=strompris_måned(PP_list[1],Forbruk_prosjekt[1]) #january
    C=strompris_måned(PP_list[2],Forbruk_prosjekt[2]) #february
    D=strompris_måned(PP_list[3],Forbruk_prosjekt[3]) #march
    E=strompris_måned(PP_list[4],Forbruk_prosjekt[4]) #april
    F=strompris_måned(PP_list[5],Forbruk_prosjekt[5]) #may
    G=strompris_måned(PP_list[6],Forbruk_prosjekt[6]) #june

    tot=[A,B,C,D,E,F,G]
    summer=(sum(A)+sum(B)+sum(C)+sum(D)+sum(E)+sum(F)+sum(G))*20/9 #assuming 20 workingdays each month

    return tot, summer
```

F VedleggG -Python, model

```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import math

import os
os.chdir(r'C:\Users\rebja\OneDrive\Dokumenter\fornybar siste semester\Bachelor\Modell_ANEO')

import Funksjoner_modell as fm

# In[1]: CONSUMPTION MACHINES

##INPUT AMOUNT OF MACHINES CONSIDERED
Antall_maskiner_CCS=int(input('Hvor mange store maskiner skal lades?: '))

if Antall_maskiner_CCS==1:
    A1,A2,A3=fm.Forbruksmønster_CCS(1) #output: power consumption 3 different patterns
    Totalt_forbruk1 = A1
    Totalt_forbruk2 = A2
    Totalt_forbruk3 = A3
    zeros_list = [0] * 1440
    Ladeuke=[Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk3,zeros_list]
elif Antall_maskiner_CCS==2:
    A1,A2,A3=fm.Forbruksmønster_CCS(1) #1=150kW outlet, 2=300 kW uttak
    B1,B2,B3=fm.Forbruksmønster_CCS(2)
    Totalt_forbruk1 = []
    Totalt_forbruk2 = []
    Totalt_forbruk3 = []
    zeros_list = [0] * 1440
    for i in range(len(A1)):
        Totalt_forbruk1.append(A1[i] + B1[i])
        Totalt_forbruk2.append(A2[i] + B2[i])
        Totalt_forbruk3.append(A3[i] + B3[i])
        zeros_list = [0] * 1440
        Ladeuke=[Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk3,zeros_list]
elif Antall_maskiner_CCS==3:
    A1,A2,A3=fm.Forbruksmønster_CCS(1)
    B1,B2,B3=fm.Forbruksmønster_CCS(1)
    C1,C2,C3=fm.Forbruksmønster_CCS(3) #3=AC outlet (max 50kW)
    Totalt_forbruk1 = []
    Totalt_forbruk2 = []
    Totalt_forbruk3 = []
    for i in range(len(A1)):
        Totalt_forbruk1.append(A1[i] + B1[i] + C1[i])
        Totalt_forbruk2.append(A2[i] + B2[i] + C2[i])
        Totalt_forbruk3.append(A3[i] + B3[i] + C3[i])
        zeros_list = [0] * 1440
        Ladeuke=[Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk1,Totalt_forbruk2,Totalt_forbruk3,zeros_list] #adds list of zeros fo

Totalt_forbruk_list = []   #List of power consumption (kW) per minute
for i in range(len(Totalt_forbruk1)):
    Totalt_forbruk_list.append(Totalt_forbruk1[i]+ Totalt_forbruk1[i] +Totalt_forbruk2[i] + Totalt_forbruk2[i] + Totalt_forbruk3[i]



Forbruk_klokketimer=fm.forbruk_klokketime(Totalt_forbruk_list) #Energy consumption (kWh/h) for the 5 working days
Forbruk_klokketimer1=fm.forbruk_klokketime(Totalt_forbruk1)
Forbruk_klokketimer2=fm.forbruk_klokketime(Totalt_forbruk2)
Forbruk_klokketimer3=fm.forbruk_klokketime(Totalt_forbruk3)

# In[2]:  COSTS WITHOUT CHARGING CONTAINER

        ##INPUT: CONSIDERED PRICE AREA AND LENGHT OF PROJECT
print('Du har valget mellom følgende prisområder:')
print('1: NO1'.rjust(25))
print('2: NO2'.rjust(25))
print('3: NO3'.rjust(25))
print('4: NO4'.rjust(25))
print('5: NO5'.rjust(25))
prisområde=int(input('Hvilket prisområde bruker du? (skriv tall):'))

print('Sett inn tall for for måneden du oppgir, Feks 6 for juni osv:')
Prosjekt_start=int(input('Når starter prosjetperioden (måned)?: '))-1
Prosjekt_slutt=int(input('Når slutter prosjetperioden (måned)?: '))-1
Måneder=int(Prosjekt_slutt-Prosjekt_start+1)

# POWER PRICES
from Powerprices import powerprice as PP

NO=[]
if prisområde==1:
    NO = PP[0]
elif prisområde==2:
    NO=PP[1]
elif prisområde==3:
    NO=PP[2]
elif prisområde==4:
    NO=PP[3]
elif prisområde==5:
    NO=PP[4]
else:
    print('Dette prisområdet eksisterer ikke')
```

```
#POWER COSTS WITHOUT CHARGING CONTAINER
Strompris_vek,Strompris_sum=fm.strompris(Forbruk_klokketimer, NO, Prosjekt_start,Prosjekt_slutt)



        ##GRID TARIFF
D=1
if D==1:

     #UPLOADING GRID TARIFF PRICES
     Nettleiepriser = pd.read_csv('Nettleiepriser_underrr100.csv')
     import csv
     with open('Nettleiepriser_underrr100.csv', 'r') as file:
         reader = csv.reader(file)
         data = [row[:11] for row in reader]  # Keep only the first 11 columns

         #Convert the data into a DataFrame
         Nettleiepriser_data = pd.DataFrame(data)

         #GRID TARIFF COSTS WITHOUT CHARGING CONTAINER
         nettpris_utencon=fm.Nettleiepriser(Nettleiepriser_data,Forbruk_klokketimer,340,Måneder)

# In[3]: ESTIMATING CHARGING PATTERN FOR CHARGING CONTAINER



Batterikontainer_kapasitet=int(input('Hvilken kapasitet har batterikontaineren (kWh)?: '))
Batterikontainer_setup_vol=int(input('Er kontaineren koblet til 230V AC, eller 400V AC?: '))
Batterikontainer_setup_cur=int(input('Merkestrøm for tilkoblet kurs (63-125A): '))
Batterikontainer_setup_pow=math.sqrt(3)*Batterikontainer_setup_vol*Batterikontainer_setup_cur/1000



A_1=1
if A_1==1:


    #CHARGING PATTERN DAY 1:
    Ladetid1=(sum(Forbruk_klokketimer1)*60/Batterikontainer_setup_pow)
    Lading1=[Batterikontainer_setup_pow]*int(Ladetid1)
    if int(Ladetid1)>779:
        Rest1=(int(Ladetid1)-779)*[Batterikontainer_setup_pow]
    else:
        Rest1=[]

    Forbruk_container1=[5]*660 + Lading1[0:780] + [5]*(1440-660-len(Lading1[0:780]))

    #CHARGING PATTERN DAY 2:
    Ladetid2=(sum(Forbruk_klokketimer2)*60/Batterikontainer_setup_pow)
    Lading2=[Batterikontainer_setup_pow]*int(Ladetid2)
    if int(Ladetid2)>779:
        Rest2=(int(Ladetid2)-779)*[Batterikontainer_setup_pow]
    else:
        Rest2=[]

    Forbruk_container2=Rest1[0:660] + [5]*(660-len(Rest1[0:660])) + Lading2[0:780] + [5]*(1440-len(Rest1[0:660])-(660-len(Rest1[0:6

    #CHARGING PATTERN DAY 3:
    Ladetid3=(sum(Forbruk_klokketimer1)*60/Batterikontainer_setup_pow)
    Lading3=[Batterikontainer_setup_pow]*int(Ladetid3)
    if int(Ladetid3)>779:
        Rest3=(int(Ladetid3)-779)*[Batterikontainer_setup_pow]
    else:
        Rest3=[]
    Forbruk_container3=Rest2[0:660] + [5]*(660-len(Rest2[0:660])) + Lading3[0:780] + [5]*(1440-len(Rest2[0:660])-(660-len(Rest2[0:6

    #CHARGING PATTERN DAY 4:
    Ladetid4=(sum(Forbruk_klokketimer2)*60/Batterikontainer_setup_pow)
    Lading4=int(Ladetid4)*[Batterikontainer_setup_pow]
    if int(Ladetid4)>779:
        Rest4=(int(Ladetid4)-779)*[Batterikontainer_setup_pow]
    else:
        Rest4=[]
    Forbruk_container4=Rest3[0:660] + [5]*(660-len(Rest3[0:660])) + Lading4[0:780] + [5]*(1440-len(Rest3[0:660])-(660-len(Rest3[0:6

    #CHARGING PATTERN DAY 5:
    Ladetid5=(sum(Forbruk_klokketimer3)*60/Batterikontainer_setup_pow)
    Lading5=int(Ladetid5)*[Batterikontainer_setup_pow]
    if int(Ladetid5)>1050:
        Rest5=(int(Ladetid5)-1049)*[Batterikontainer_setup_pow]
    else:
        Rest5=[]
    Forbruk_container5=Rest4[0:390] + [5]*(390-len(Rest4[0:390])) + Lading5[0:1050] + [5]*(1440-len(Rest4[0:390])-(390-len(Rest4[0:

    #CHARGING PATTERN DAY 6 (WEEKEND)
    Forbruk_container_helg=Rest5[0:1440] + [0]*(1440-len(Rest5[0:1440]))

    #TOT CHARGING PATTERN WEEK
    Ladeuke_container=[Forbruk_container1, Forbruk_container2, Forbruk_container3, Forbruk_container4, Forbruk_container5, Forbruk_

    Totaltforbruk_list_con = []   #List of power consumption (kW) per minute
    for i in range(len(Totalt_forbruk1)):
        Totaltforbruk_list_con.append(Forbruk_container1[i]+ Forbruk_container1[i] +Forbruk_container2[i] + Forbruk_container2[i] +
```

```
    Forbruk_klokketimer_con=fm.forbruk_klokketime(Totaltforbruk_list_con)

    #COSTS
    nettpris_medcon=fm.Nettleiepriser(Nettleiepriser_data,Forbruk_klokketimer_con,Batterikontainer_setup_pow,Måneder)
    Strompris_vek_con,Strompris_sum_con=fm.strompris(Forbruk_klokketimer_con, NO,Prosjekt_start,Prosjekt_slutt)


# In[4]
from tabulate import tabulate

#RESULTS ECONOMIC SAVINGS TABLE
data = [["   ", "Grid tariff (kr)", "Energyprice (kr)", "Total(kr)"],
        ["Without batterycontainer",nettpris_utencon ,Strompris_sum,nettpris_utencon+Strompris_sum ],
        ["With batterycontainer", nettpris_medcon, Strompris_sum_con,nettpris_medcon+Strompris_sum_con],
        ["Economic savings", nettpris_utencon-nettpris_medcon, Strompris_sum-Strompris_sum_con,nettpris_utencon+Strompris_sum-nettp

table = tabulate(data, headers="firstrow", tablefmt="grid")
print(table)



import matplotlib.pyplot as plt
import matplotlib.dates as mdates


#PLOTTING CHARGING PATTERN MACHINES VS CHARGING CONTAINER

# Create the figure and subplots
fig, axs = plt.subplots(2, 3, figsize=(12, 8))

# Set the x-axis tick positions and labels
x_ticks = np.arange(0, 1440, 240)  # Ticks every 4 hours
x_tick_labels = ['00:00', '04:00', '08:00', '12:00', '16:00', '20:00']

# Iterate over the subplots and plot the corresponding sublists
for i, ax in enumerate(axs.flat):
    sublist1 = Ladeuke[i]
    sublist2 = Ladeuke_container[i]
    ax.plot(sublist1, label='Machines')
    ax.plot(sublist2, label='BoostCharger')
    ax.set_title(f'Day {i+1}')
    ax.legend()
    ax.legend(loc='upper left')  # Set the location of the legend box

    # Set the x-axis ticks and labels
    ax.set_xticks(x_ticks)
    ax.set_xticklabels(x_tick_labels,rotation=45)

# Adjust the spacing between subplots
plt.tight_layout()

plt.subplots_adjust(hspace=0.3)

# Display the plot
plt.show()
```

G Appendix -Python, model functions

```
# -*- coding: utf-8 -*-
"""
Created on Wed May  3 14:05:08 2023

@author: rebja

"""


import numpy as np
import matplotlib.pyplot as plt


def plot_power_prices(NO3_sum):
    # Ensure the length of 'NO3_sum' is a multiple of 24
    num_months = len(NO3_sum) // 24 * 24

    # Define the x-axis labels representing the months
    x_labels = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', 'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']

    # Create an array of x-axis tick positions
    x_ticks = np.linspace(0, num_months - 1, num=len(x_labels))

    # Plot the power prices
    plt.plot(NO3_sum[:num_months])

    # Set the x-axis tick positions and labels
    plt.xticks(x_ticks, x_labels)

    # Set the x-axis label
    plt.xlabel('Months, 2021')

    # Set the y-axis label
    plt.ylabel('Power Prices (kr/MWh)')

    # Show the plot
    plt.show()


def plot_multiple_power_prices(NO3_sum1, NO3_sum2, NO3_sum3):
    # Ensure the lengths of the lists are multiples of 24
    num_months = min(len(NO3_sum1), len(NO3_sum2), len(NO3_sum3)) // 24 * 24

    # Define the x-axis labels representing the months
    x_labels = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', 'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']

    # Create an array of x-axis tick positions
    x_ticks = np.linspace(0, num_months - 1, num=len(x_labels))

    # Plot the power prices for each list
    plt.plot(NO3_sum1[:num_months], label='NO1', color='coral', linewidth=0.8)
    plt.plot(NO3_sum2[:num_months], label='NO3', color='hotpink', linewidth=0.8)
    plt.plot(NO3_sum3[:num_months], label='NO4', color='teal', linewidth=0.8)

    # Set the x-axis tick positions and labels
    plt.xticks(x_ticks, x_labels)

    # Set the x-axis label
    plt.xlabel('Months, 2021')

    # Set the y-axis label
    plt.ylabel('Power Prices (kr/MWh)')

    # Adjust the thickness of the plotted lines
    plt.gca().spines['top'].set_linewidth(0.5)
    plt.gca().spines['bottom'].set_linewidth(0.5)
    plt.gca().spines['left'].set_linewidth(0.5)
    plt.gca().spines['right'].set_linewidth(0.5)

    # Show the legend
    plt.legend()

    # Show the plot
    plt.show()


def plot_charging_curve(Ladem⌀nster3):
    title=input('Hva vil du kalle grafen?: ')
    timestamps = []
    for hour in range(24):
        for minute in range(60):
            timestamp = f"{hour:02d}:{minute:02d}"
            timestamps.append(timestamp)

    fig, ax = plt.subplots()
    ax.plot([float(x) for x in Ladem⌀nster3],label='Estimated charging curve')

    # Set the x-axis tick locations and labels
    xticks = np.arange(0, 1440, 240)
    ax.set_xticks(xticks)
    ax.set_xticklabels([timestamps[i] for i in xticks])
```

```
    # Set the x-axis label and title
    ax.set_xlabel('Time (hh:mm)')
    ax.set_ylabel('Power (kW)')
    ax.set_title(title)

    # Display the plot
    plt.show()


from datetime import datetime, timedelta

def plot_energy_usage(energy_list):
    x_values = range(24)
    y_values = energy_list
    plt.plot(x_values, y_values)
    plt.xticks(range(0, 24, 4))
    plt.xlabel('Time (hour of the day)')
    plt.ylabel('Energy usage (kWh)')
    plt.show()

def plot_ladekurve(Ladeuke):
    import matplotlib.pyplot as plt

    # Sample data (replace with your actual data)


    # Create the figure and subplots
    fig, axs = plt.subplots(2, 3, figsize=(12, 8))

    # Hide the x and y axis labels
    for ax in axs.flat:
        ax.set(xticklabels=[], yticklabels=[])

    # Set the title of the x and y axes
    for ax in axs[0, :]:
        ax.set_xlabel('Time (hh:mm)')
    for ax in axs[:, 0]:
        ax.set_ylabel('Power (kW)')

    # Iterate over the subplots and plot the corresponding sublist
    for i, ax in enumerate(axs.flat):
        ax.plot(Ladeuke[i])
        ax.set_title(f'Day {i+1}')

    # Add x-axis labels to the subplots in the second row
    for ax in axs[1, :]:
        ax.set_xlabel('Time (hh:mm)')

    # Adjust the layout and spacing
    plt.tight_layout()

    # Display the plot
    plt.show()


def ladetid(Timer_arbeid_før_lading,Varighet,ladetid_cc):  #Funksjon som regner ut hvilken SOC batteriet er i før det lades og hvor

    SOC1=Varighet-Timer_arbeid_før_lading  #NB!! SKJEKK AT MAN KAN REGNE UT SOC PÅ DENNE METODEN
    SOC1_prosent=SOC1/Varighet
    DOD1=1-SOC1_prosent  #depth of discharge

    ladetid_DOD_cc=ladetid_cc*DOD1
    ladetid_DOD_cc_min=round(ladetid_DOD_cc*60,0)

    return ladetid_DOD_cc_min,SOC1_prosent

def ladetid_2(SOC,ladetid_cc):  #Funksjon som regner ut hvilken SOC batteriet er i før det lades og hvor lang tid det tar å ladet b

    DOD1=1-SOC  #depth of discharge
    ladetid_DOD_cc=ladetid_cc*DOD1
    ladetid_DOD_cc_min=round(ladetid_DOD_cc*60,0)
    return ladetid_DOD_cc_min

import math

def CV_P_estimat(batterikap,Ladestrøm,Ladeeffekt):
    Ladestrøm_low=Ladestrøm*0.03
    I_1 = Ladestrøm-Ladestrøm_low
    Ladespenning =Ladeeffekt/Ladestrøm
    I = []
    sum_I = 0
    x = 1
    while sum_I <= (batterikap*0.15*60):
        value = ((I_1 * math.exp(-0.065 * x) + Ladestrøm_low) * Ladespenning)
        I.append(value)
        sum_I += value
        x += 1
    return I[:len(I)-1]

def CV_P_estimat_con(batterikap,Ladestrøm,Ladeeffekt,Current_limit):
    Ladestrøm_low=Current_limit
    I_1 = Ladestrøm-Ladestrøm_low
    Ladespenning =Ladeeffekt/Ladestrøm
```

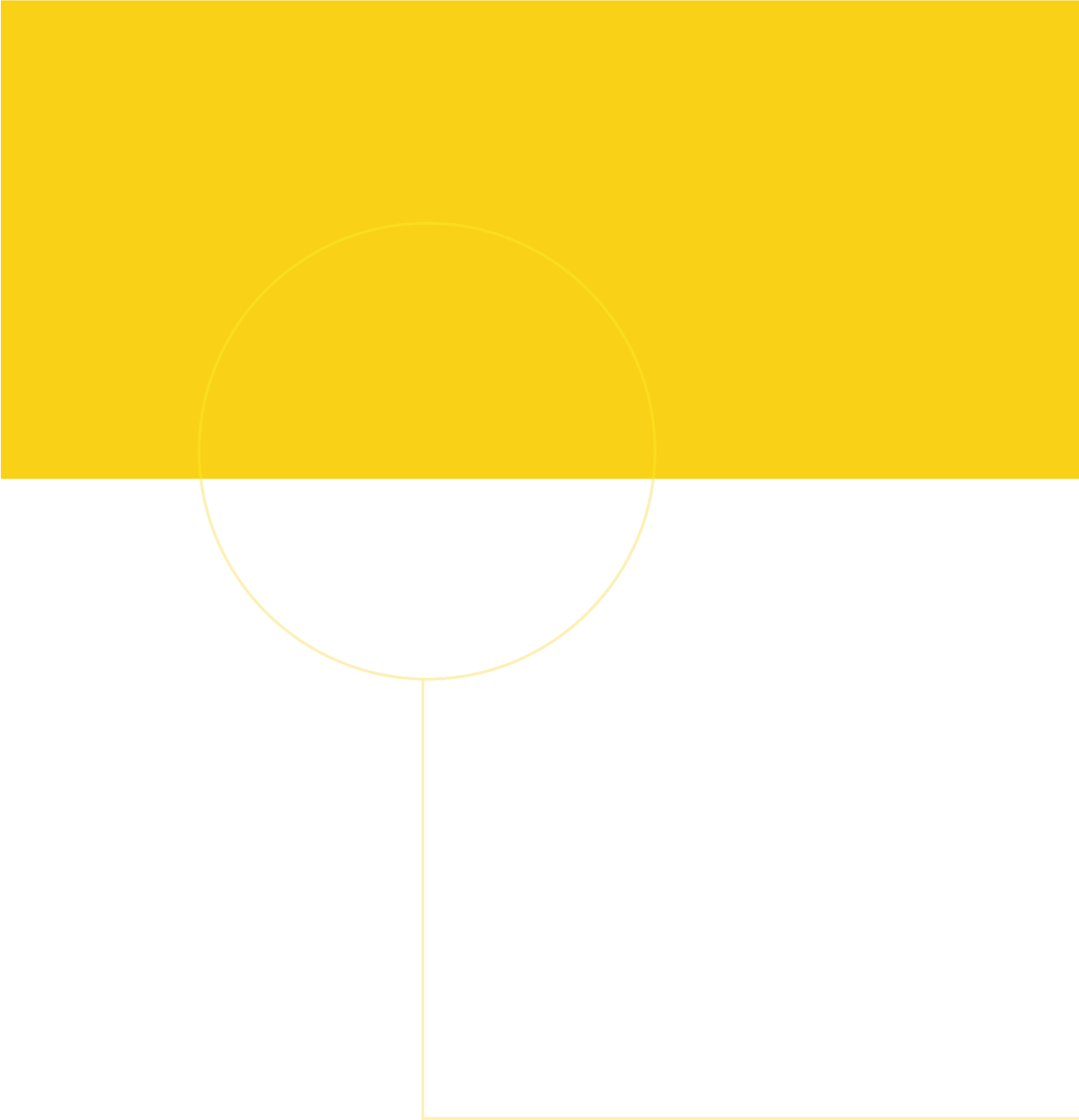
```
    I = []
    sum_I = 0
    x = 1
    while sum_I <= (batterikap*0.15*60):
        value = ((I_1 * math.exp(-0.055 * x) + Ladestrøm_low) * Ladespenning)
        I.append(value)
        sum_I += value
        x += 1
    return I[:len(I)-1]



def Forbruksmønster_CCS(Lademønster):
    import math

    batterikapasitet=int(input('Batterikapasiteten til maskinen: '))
    Ladeeffekt_input=int(input('Effekten maskinen lader på (kW): '))


    if Lademønster==1: #CCS outlet with max charging rate at 150kW
        Ladeeffekt=0
        if Ladeeffekt_input>150:
            Ladeeffekt+=150
        else:
            Ladeeffekt+=Ladeeffekt_input

    if Lademønster==2: #CCS outlet with max charging rate at 300kW
        Ladeeffekt=0
        if Ladeeffekt_input>300:
            Ladeeffekt+=300
        else:
            Ladeeffekt+=Ladeeffekt_input


    if Lademønster==3: #AC outlet with max charging rate at 50kW
        Ladeeffekt=0
        if Ladeeffekt_input>90:
            Ladeeffekt+=90
        else:
            Ladeeffekt+=Ladeeffekt_input


    Ladestrøm=int(input('Strømmen maskinen lader på (A): '))                          #Charging rate machine (A)
    Varighet=int(input('Forventet max timer maskinen kan arbeide på kontinuerlig: ')) #Max working hours machine
    Ladespenning=(Ladeeffekt/Ladestrøm) #Voltage while charging
    Utladig_pertime=batterikapasitet/Varighet #discharging per hour (kW/h)


    ##CHARGING PATTERN 1, 11-12 and 16-->100%
    CV_P1=CV_P_estimat(batterikapasitet,Ladestrøm,Ladeeffekt)  #CV charging curve

    #Before lunchbreak
    ladetid_cc=batterikapasitet*0.85/(Ladeeffekt*0.925)  #Charging time from 0-85% SOC and Li-ion efficiency at 92.5%
    ladetid_DOD_cc_11,SOC1_prosent=ladetid(3,Varighet,ladetid_cc)  #Charging time from estimated SOC to 85%
    Fullading_11=[Ladeeffekt]*int(ladetid_DOD_cc_11) + CV_P1  #CC-CV charging pattern from SOC to 100%

    if 60 <= ladetid_DOD_cc_11:
        Lading_pause1=[Ladeeffekt]*60 #kW
    else:
        Lading_pause1=Fullading_11[0:60]

    #After lunchbreak
    Batterikap_etterlunsj1=(batterikapasitet*SOC1_prosent)+(sum(Lading_pause1)*1/60) #Battery capasity after charging during lunch
    Utlading_etterlunsj=Utladig_pertime*4 #Discharging after lunchbreak, 4 hours work

    SOC13=(Batterikap_etterlunsj1-Utlading_etterlunsj)/batterikapasitet #SOC after 4 hours work
    ladetid_DOD_cc12=(SOC13)*60*(batterikapasitet*0.85)/Ladeeffekt  #Charging time from SOC to 85%

    Fullading_12=[Ladeeffekt] * int(ladetid_DOD_cc12) + CV_P1 #CC-CV charging from SOC to 100%

    #resulted charging pattern 1:
    Lademønster1=[0]*660 + Lading_pause1 + [0]*240 + Fullading_12 + [0]*(1440-660-len(Lading_pause1)-240 -len(Fullading_12))



    ##CHARGINGPATTERN 2, 11-->100%

    Lademønster2=[0]*660 + Fullading_11 + [0]*(1440-660-len(Fullading_11))

    Utlading_etterlunsj=Utladig_pertime*3  #Batterycapacity (kWh) when ended working day, (3 hours work after fully charged)
    SOC21=(batterikapasitet-Utlading_etterlunsj)/batterikapasitet #SOC when ended working day



    ##CHARGING PATTERN 3, 6.30-7, 9-9.30, 11.30-12, 17-->100%

    #Charging session 6.30-7:
    Ladetid_cc_morgen3=(SOC21)*60*(batterikapasitet*0.85)/Ladeeffekt
    Lading_morgen3=[Ladeeffekt]*int(Ladetid_cc_morgen3)

    #Charging session 9-9.30
    Batterikap_ettermorgen=(batterikapasitet*0.2)+(sum(Lading_morgen3)*1/60) #Kapasitet før lunsjlading + kapasitet ladet
    Utlading_r2=Utladig_pertime*2 #4 timer arbeid etter lunsj før neste lading
```

```
    SOC32=(Batterikap_ettermorgen-Utlading_r2)/batterikapasitet #ved siste lading
    ladetid_DOD_cc32=(1-SOC32)*60*(batterikapasitet*0.85)/Ladeeffekt  #Tiden det tar å lade til 85% på runde 2, lademønster 3, (kl.


    Fullading_32=[Ladeeffekt] * int(ladetid_DOD_cc32) + CV_P1

    #Charging session 11.30-12
    Batterikap_etter_r2=(batterikapasitet*SOC32)+(sum(Fullading_32[0:30])*1/60) #Kapasitet før lunsjlading + kapasitet ladet
    Utlading_r3=Utladig_pertime*2 #4 timer arbeid etter lunsj før neste lading
    SOC33=(Batterikap_etter_r2-Utlading_r3)/batterikapasitet #ved siste lading
    ladetid_DOD_cc33=(1-SOC33)*60*(batterikapasitet*0.85)/Ladeeffekt  #Tiden det tar å lade til 85% på runde 2, lademønster 3, (kl.


    Fullading_33=[Ladeeffekt] * int(ladetid_DOD_cc33) + CV_P1

    #Charging session 17-->100%
    Batterikap_etter_r3=(batterikapasitet*SOC33)+(sum(Fullading_33[0:30])*1/60) #Kapasitet før lunsjlading + kapasitet ladet
    Utlading_r4=Utladig_pertime*4 #4 timer arbeid etter lunsj før neste lading
    SOC34=(Batterikap_etter_r3-Utlading_r4)/batterikapasitet #ved siste lading
    ladetid_DOD_cc34=(1-SOC34)*60*(batterikapasitet*0.85)/Ladeeffekt  #Tiden det tar å lade til 85% på runde 2, lademønster 3, (kl.


    Fullading_34=[Ladeeffekt] * int(ladetid_DOD_cc34) + CV_P1
    Fullading_334=[]
    if len(Fullading_34)>420:
        Fullading_334=Fullading_34[0:420]
    else:
        Fullading_334=Fullading_34

    #resulted charging pattern 3:
    Lademønster3=[0]*390 + Lading_morgen3[0:30] + [0]*120 + Fullading_32[0:30] + [0]*120 + Fullading_33[0:30] + [0]*300 + Fullading


    return Lademønster1,Lademønster2,Lademønster3




def estimate_power_consumption(Forbruk_maskinlist):
    summed_lists = []
    for lst in Forbruk_maskinlist:
        dag = sum(lst[6:21])
        natt = sum(lst[22:23])+sum(lst[0:5])
        summed_lists.append([dag, natt])
    return summed_lists


def Nettleiepriser(Nettleiepriser,Forbruk_klokketimer,Effekttopp,Måneder):
    Ten = Nettleiepriser.iloc[0]
    Tensi=Ten.values
    Elv = Nettleiepriser.iloc[1]
    Elvi=Elv.values
    Lys = Nettleiepriser.iloc[2]
    Lysenet=Lys.values
    Nor = Nettleiepriser.iloc[3]
    Norgesnet=Nor.values
    Agd = Nettleiepriser.iloc[4]
    Agderenerg=Agd.values
    Gli = Nettleiepriser.iloc[5]
    Glitr=Gli.values
    Led = Nettleiepriser.iloc[6]
    Leder=Led.values
    Lin = Nettleiepriser.iloc[7]
    Line=Lin.values
    Møre = Nettleiepriser.iloc[8]
    Mørenet=Møre.values
    BKK = Nettleiepriser.iloc[9]
    BKKnet=BKK.values
    Arv = Nettleiepriser.iloc[10]
    Arv=Arv.values

    #Nettselskaputvalg=['Tensio','Elvia','Lysenett','Norgesnett','Agderenergi','Glitre','Lede','Linea','Mørenett','BKKnett','Arva']
    print(f'Du har valget mellom følgende nettselskaper:')
    print('1: Tensio'.rjust(25))
    print('2: Elvia'.rjust(24))
    print('3: Lysenett'.rjust(27))
    print('4: Norgesnett'.rjust(29))
    print('5: Agder Energi'.rjust(31))
    print('6: Glitre'.rjust(25))
    print('7: Lede'.rjust(23))
    print('8: Linea'.rjust(24))
    print('9: Mørenett'.rjust(27))
    print('10: BKKnett'.rjust(26))
    print('11: Arva'.rjust(23))
    Nettselskap=int(input('Hvilket nettselskap bruker du? (skriv tall):'))

    Priser=[]
    if Nettselskap==1:
        Priser=Tensi
    elif Nettselskap==2:
        Priser=Elvi
    elif Nettselskap==3:
        Priser=Lysenet
    elif Nettselskap==4:
```

4

```
        Priser=Norgesnet
    elif Nettselskap==5:
        Priser=Agderenerg
    elif Nettselskap==6:
        Priser=Glitr
    elif Nettselskap==7:
        Priser=Leder
    elif Nettselskap==8:
        Priser=Line
    elif Nettselskap==9:
        Priser=Mørenet
    elif Nettselskap==10:
        Priser=BKKnet
    elif Nettselskap==11:
        Priser=Arv
    else:
        print('Ingen nettselskap ved dette navnet')

    Kapasitetsledd=[]
    if 25<= Effekttopp <50:
        Kapasitetsledd=Priser[0]
    elif 50<= Effekttopp <75:
        Kapasitetsledd=Priser[1]
    elif 75<= Effekttopp <100:
         Kapasitetsledd=Priser[2]
    elif 100<= Effekttopp <150:
         Kapasitetsledd=Priser[3]
    elif 150<= Effekttopp <200:
         Kapasitetsledd=Priser[4]
    elif 200<= Effekttopp:
         Kapasitetsledd=Priser[5]
    else:
        Kapasitetsledd=Priser[5]

    Energiledd_dag=[]
    Energiledd_natt=[]
    if Nettselskap==1:
        Energiledd_dag=Tensi[6]
        Energiledd_natt=Tensi[7]
    elif Nettselskap==2:
        Energiledd_dag=Elvi[6]
        Energiledd_natt=Elvi[7]
    elif Nettselskap==3:
        Energiledd_dag=Lysenet[6]
        Energiledd_natt=Lysenet[7]
    elif Nettselskap==4:
        Energiledd_dag=Norgesnet[6]
        Energiledd_natt=Norgesnet[7]
    elif Nettselskap==5:
        Energiledd_dag=Agderenerg[6]
        Energiledd_natt=Agderenerg[7]
    elif Nettselskap==6:
        Energiledd_dag=Glitr[6]
        Energiledd_natt=Glitr[7]
    elif Nettselskap==7:
        Energiledd_dag=Leder[6]
        Energiledd_natt=Leder[7]
    elif Nettselskap==8:
        Energiledd_dag=Line[6]
        Energiledd_natt=Line[7]
    elif Nettselskap==9:
        Energiledd_dag=Mørenet[6]
        Energiledd_natt=Mørenet[7]
    elif Nettselskap==10:
        Energiledd_dag=BKKnet[6]
        Energiledd_natt=BKKnet[7]
    elif Nettselskap==11:
        Energiledd_dag=Arv[6]
        Energiledd_natt=Arv[7]
    else:
        print('Ingen nettselskap ved dette navnet')


    dag = sum(Forbruk_klokketimer[6:21])  #For alle fem dagene i uken
    natt = (sum(Forbruk_klokketimer[22:23]) + sum(Forbruk_klokketimer[0:5]))  #For alle fem dagene i uken


    # Summer forbruket for dag


    Energiledd=(float(dag)*float(Energiledd_dag)*4)+(float(natt)*float(Energiledd_natt)*4) #antar 20 arbeidsdager per måned

    Forbruksavgift=0.1541*(float(dag)+float(natt))  #kr/kWh * kWh
    Enova_avgift=67*Måneder

    Pris=(float(Kapasitetsledd) + Energiledd + Forbruksavgift+Enova_avgift)*Måneder  #Totalpris nettleie for hele prosjektperioden

    return Pris


def forbruk_klokketime(forbruksgraf_dag):
    A=forbruksgraf_dag[0:60]
```

```
    B=forbruksgraf_dag[60:120]
    C=forbruksgraf_dag[120:180]
    D=forbruksgraf_dag[180:240]
    E=forbruksgraf_dag[240:300]
    F=forbruksgraf_dag[300:360]
    G=forbruksgraf_dag[360:420]
    H=forbruksgraf_dag[420:480]
    I=forbruksgraf_dag[480:540]
    J=forbruksgraf_dag[540:600]
    K=forbruksgraf_dag[600:660]
    L=forbruksgraf_dag[660:720]
    M=forbruksgraf_dag[720:780]
    O=forbruksgraf_dag[780:840]
    P=forbruksgraf_dag[840:900]
    Q=forbruksgraf_dag[900:960]
    R=forbruksgraf_dag[960:1020]
    S=forbruksgraf_dag[1020:1080]
    T=forbruksgraf_dag[1080:1140]
    U=forbruksgraf_dag[1140:1200]
    V=forbruksgraf_dag[1200:1260]
    W=forbruksgraf_dag[1260:1320]
    X=forbruksgraf_dag[1320:1380]
    Y=forbruksgraf_dag[1380:1440]

    matrise=[sum(A),sum(B),sum(C),sum(D),sum(E),sum(F),sum(G),sum(H),sum(I),sum(J),sum(K),sum(L),sum(M),sum(O),sum(P),sum(Q),sum(R)
    Forbruk_klokketime = [ value* (1/60) for value in matrise]

    return Forbruk_klokketime



def strompris_dag(forbruk_klokketimer,NO):
    result = [(x)*0.001 for x in NO]
    a=[(x*y) for x, y in zip(result, forbruk_klokketimer)]
    b=sum(a)
    return b


def strompris(forbruk_klokketimer,NO,Prosjekt_start,Prosjekt_slutt):

    Jan=strompris_dag(forbruk_klokketimer,NO[0])*4 #gang med antall arbeidsuker antatt den måneden
    Feb=strompris_dag(forbruk_klokketimer,NO[1])*4 #gang med antall arbeiduker antatt den måneden
    Mar=strompris_dag(forbruk_klokketimer,NO[2])*4 #gang med antall arbeidsuker antatt den måneden
    Apr=strompris_dag(forbruk_klokketimer,NO[3])*4 #gang med antall arbeidsdager antatt den måneden
    Mai=strompris_dag(forbruk_klokketimer,NO[4])*4 #gang med antall arbeidsdager antatt den måneden
    Jun=strompris_dag(forbruk_klokketimer,NO[5])*4 #gang med antall arbeidsdager antatt den måneden
    Jul=strompris_dag(forbruk_klokketimer,NO[6])*4 #gang med antall arbeidsdager antatt den måneden
    Aug=strompris_dag(forbruk_klokketimer,NO[7])*4 #gang med antall arbeidsdager antatt den måneden
    Sep=strompris_dag(forbruk_klokketimer,NO[8])*4 #gang med antall arbeidsdager antatt den måneden
    Okt=strompris_dag(forbruk_klokketimer,NO[9])*4#gang med antall arbeidsdager antatt den måneden
    Nov=strompris_dag(forbruk_klokketimer,NO[10])*4 #gang med antall arbeidsdager antatt den måneden
    Des=strompris_dag(forbruk_klokketimer,NO[11])*4#gang med antall arbeidsdager antatt den måneden

    Strompris_år=[Jan,Feb,Mar,Apr,Mai,Jun,Jul,Aug,Sep,Okt,Nov,Des]
    Strompris_prosjekt=Strompris_år[Prosjekt_start:Prosjekt_slutt]

    Strompris_prosjekt_sum=sum(Strompris_prosjekt)

    return Strompris_prosjekt,Strompris_prosjekt_sum


def modify_charging(charging_list, capacity):
    new_charging_list = []
    total_charging = 0
    for charging_rate in charging_list:
        if total_charging + charging_rate >= capacity*60:
            if charging_rate < 29:
                new_charging_list.append(charging_rate)
            else:
                new_charging_list.append(29)
        else:
            new_charging_list.append(charging_rate)

        total_charging += charging_rate
    return new_charging_list
```



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