Bachelor's thesis

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

Jenny Kogstad
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Calculating emission savings at electric construction sites

Bachelor's thesis in Engineering, Renewable Energy
Supervisor: Mihir Mouchum Hazarika
Co-supervisor: Anna Dorthea Willassen and Siri Førsund Bjerland (Aneo)
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Preface

This bachelor thesis is written as the final part of the three year study program, Bachelor in engineering, Renewable energy at the Norwegian University of Science and Technology (NTNU), Department for energy and Process Engineering. It was written in the spring semester of 2023 by two students. The program is a total of 180 credits, and the bachelor thesis makes up 20 credits.

The project description was provided by Aneo. The task was to make a model to calculate emission savings from electric construction sites, that Aneo can use to show to their customers.

We would like to thank our internal supervisor, Mihir Mouchum Hazarika, for providing guidance through the semester. We would also like to thank our supervisors from Aneo, Anna Dorthea Willassen and Siri Førsund Bjerland, for providing necessary information to complete the thesis, and providing help and feedback. A special thanks to Anders Dahl from Aneo, for giving us a nice tour of the charging containers, as well as providing a nice description of the technology. We would also like to thank Jacob Lamb for helping us with the life cycle assessments, and Marianne Kjendseth Wiik from SINTEF and Magnus Hexeberg from NOx-fondet for answering our questions.

Abstract

Norway set a goal to achieve a zero-emission construction sector by 2030. To make this possible, is it necessary to find alternative energy sources to power construction sites. Aneo Build offers a solution by providing mobile battery containers, that enables fully electric construction sites. The focus for this thesis was to enhance the calculations conducted by Aneo for emission savings for electric construction sites when compared with a diesel-powered construction site.

To enhance the calculations, the group incorporated emission from production of diesel, diesel engine and batteries in the charging containers. To find these emissions, data from three LCAs was collected. To calculate emission savings from the operational phase, the thesis utilizes properties set by Aneo, some of the properties needed updating. The calculations for emission savings was done in an Excel model. The intention for the model is that Aneo can utilize it to calculate emission savings for future projects and for finished projects. The results is presented in a understandable way, enabling Aneo to showcase the model to their customers.

One of Aneo's previous projects were used to present results obtained from the model. The results presented that the project had large amount of emission savings during the operational phase, but if the production was included there would be no emission savings from the electric construction site. An equivalent project would have to be carried out approximately 1,5 times to get any emission savings. This is due to the fact that battery production has a larger amount of emission compared to the production of diesel of diesel engine. However diesel has a larger amount of emission during operation. The results show that the charging containers is beneficial in terms of emission savings.

The battery containers have the potential to relieve the power grid during periods with high peak demand, enables access to a stable power supply on construction sites regardless of the capacity limitations of the local power grid. To reduce the emission on-site also improves the working environment.

Sammendrag

Norge har satt seg et mål om å ha en utslippsfri byggebransje innen 2030. For at dette skal være mulig er det nødvendig å finne en alternativ energikilde for å drifte byggeplassene. Aneo Build har en løsning der de leverer mobile batterikontainere som åpner muligheten for hel-elektriske byggeplasser. Fokuset for denne oppgaven var å utvikle de beregningene Aneo har gjort på utslippsbesparelser for en elektrisk byggeplass sammelignet med en byggeplass som er driftet på diesel.

For å utvikle beregningene ble det tatt med utslipp fra produksjonen av diesel, dieselmotoren og batteriene brukt i ladekontainerene. For å finne disse utlippenene ble det hentet inn data fra tre livsløpsanalyser. For å regne ut utslippsbesparelsene fra driftfasen ble tall oppgitt av Aneo brukt, i tillegg ble noen tall oppdatert. Beregningene for utslippsbesparelsene ble gjort i en Excelmodell. Hensikten bak denne modellen er at Aneo skal bruke den til å gjøre beregninger for kommende prosjekter og prosjekter som er ferdig. Resultatene er presentert på en forståelig måte slik at Aneo kan vise modellen for kunder.

Det ble brukt et av Aneo sine tidligere prosjekt for å presentere resultatene fra modellen. For dette prosjektet viste det seg at prosjektet hadde høye utslippsbesparelser i driftfasen, men at hvis produksjonen ble inkludert i beregningene ville ikke prosjektet ha noe besparelser. Tilsvarende prosjekt måtte utføres omtrent 1,5 ganger for å få noen utslippsesparelser. Dette kommer av at produksjonen av batterier har høyere utslipp enn produksjonen av diesel og dieselmotor. Derimot har diesel mye høyere utslipp i driftefasen. Resultatene viser derfor at batterikonteinerene vil være lønnsomme med tanke på utslippsbesparelser.

Batterikontainerene vil også ha potensialet til å avlaste strømnettet under perioder med høy etterspørsel, og gjøre det mulig å få god tilgang til strøm på byggeplass uavhengig av kapasiteten til strømnettet i området. Å redusere utslipp på byggeplassen vil også gi et forbedret arbeidsmiljø.

List of Abbreviations

Abbreviations

AC	Alternating current
BESS	Battery energy storage systems
CCS	Combined Charging System
DC	Direct current
EES	Electrochemical energy storage
ES	Electrochemical energy storage
eq	Equivalent
GHG	Green house gas
GWP	Global warming potential
kWh	kilowatt-hour
LCA	Life Cycle Assessment
LCO	Lithium Cobolt Oxide
LFP	Lithium Iron Phosphate
LIB	Lithium ion battery
LMO	Lithium Manganate
MRS	Mineral Resource Scarcity
NCS	Norwegian Continental Shelf
NMC	Lithium Nickel Manganese Cobolt Oxide
SDG	Sustainable Development Goals
VOC	Volatile organic compounds

Chemical formulas

SO_2	Sulfur dioxide
CO	Carbon monoxide
NO_x	Nitrogen oxides
CO_2	Carbon dioxide

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1 Introduction

Climate change is a pressing matter, and has led to a number of challenges for the environment, the society, economy and human health. To fight the catastrophic consequences of global warming the global community agreed on the Paris Agreement in 2015, which is a global agreement to reduce emissions to reach the 2 degrees goal, limiting global warming to less than 2 degrees Celsius. This agreement means that all participating nations are obligated to undertake measures to reduce their emissions. Norway in particular, often set ambitious goals for themselves. This requires changes across multiple industries, among them the construction industry. [1]

This section presents the background and motivation, the objective and the structure of the thesis.

1.1 Background and motivation

Norway is currently in a process of embracing and adjusting to a more sustainable way of life, often referred to as “the green transition”. Industries and various sectors are actively transitioning toward more sustainable alternatives, with a notable shift towards electricity as a preferred choice. The demand for electricity have increased. The power grid faces many challenges in the future due to the increase. Smart solutions to relieve the power grid is highly needed.

Norway has set an ambitious target of reducing emissions by 55% by 2030. Within the country, the construction and building sector is responsible for 1.2% of the green house gas (GHG) emissions, with 95% attributed to the transportation and operation of machinery in this sector [2]. The Norwegian government set the goal of an emission free construction sector within 2030 [3]. Since most of the GHG emission comes from the combustion of diesel in construction machines, there is a large potential of emission savings by electrifying the construction sector.

To manage the electrification of the construction sector, a reliable source of electricity is essential. The distribution grid is in many places not able to deliver the amount of power needed. A solution to this problem is using mobile charging containers. The batteries in the container can be charged when the demand is low, and the containers are equipped with a rapid charger so that the machines can rapid charge during the work day.

Aneo Build offers a range of charging containers to its customers, and this thesis will focus on two of these containers: the BoostCharger and the Hummingbird [4]. The containers produce very low emissions during operation, with the only emissions originating from the local electricity mix they rely on. During the production however, batteries contribute to a larger amount of emission. Determining the emissions generated during production in comparison to the emission savings achieved during operation will show if the battery containers actually is a solution that reduces the emission.

The United Nations defined 17 Sustainable Development Goals (SDG). They work as a global common work plan for the whole world to eradicate poverty, fight inequality and stop climate change by 2030. The battery containers contribute to 4 SDGs, number 7, 9, 11 and 13. Number 7 is called “Affordable and Clean Energy”, it focuses on working to ensure that everyone has access to energy, and that the energy is reliable, sustainable and not too expensive. Number 9 is called “Industry, Innovation and Infrastructure”, it focuses on building a solid infrastructure and promote sustainable industry and innovation. Number 11 is called “Sustainable Cities and Communities”, it focuses on making cities and communities safer, robust and sustainable. Goal number 13 is called “Climate Action”, it addresses the challenges that comes from climate change, and how important it is to reduce the emission of GHG and other toxic gasses. It explains how important renewable energy is to make that happen. The 4 goals are illustrated in Figure 1.1. [5]

Figure 1.1: The UNs SDGs 7, 9, 11 and 13 [6]

1.2 Objective

The main objective in the thesis is to improve the calculations used to determine emissions resulting from the operation of a diesel-powered construction site and an electric construction site. Furthermore, the thesis aims to develop an Excel model that effectively calculates and presents the emission savings from utilizing the electric option in an understandable way. The thesis will compare the life cycle impact associated with both the electric construction site and the diesel-powered construction site. In order to conduct a comparison between the diesel-powered and electric construction sites, the thesis will collect data from Life-cycle assessments (LCA) to estimate the emissions from producing the battery packs in the charging containers, as well as the production of diesel and manufacturing of diesel engines. These estimated emissions will be included when calculating the total emission savings.

The objective of the thesis was developed in collaboration with Aneo Build and the authors of the thesis, the results are presented in a model that can easily be adapted to each of their individual project. This way, Aneo can present the results to their customers.

The objective addressed in this thesis through the following approach:

- Present the relevant theory to get an understanding of the theme for this thesis
- Collect relevant data for the emission calculations, specifically emission from production of diesel, diesel engine and batteries
- Make a model that can predict the emission saved for future projects, as well as make a model that tells the exact emission savings from a completed project
- Compare the calculations from a diesel-powered construction site and an electric construction site in that model
- Investigate if it is beneficial with electric construction site, possibly find how many of equivalent projects needed to be carbon neutral throughout the life cycle
- Discuss the results, find possible reasons for the results

1.3 Structure of the thesis

Chapter 1 - *Introduction* explains the background and the objective of the thesis, to offer an idea of the thesis content.

Chapter 2 - *Theory* explains the theoretical aspects needed to understand the topic. This section will look at the construction sector, explaining both diesel-powered and electric construction machines. The the section looks at electrochemical energy storage, and lithium ion batteries, before explaining the technology in the mobile charging battery containers. The section will end with an explanation of the GHG that are relevant for the thesis.

Chapter 3 - *Methodology* contains a system description, and presents the tools used to make the model where the results are presented. The section then explains all the calculations done in the thesis, as well as explaining all the assumptions made through the thesis.

Chapter 4 - *Results* presents the results from calculating the emission from the Petersrønningen project.

Chapter 5 - *Discussion* discusses the results.

Chapter 6 - *Conclusion* provides a conclusion to the objective.

Chapter 7 - *Scope for future work* presents solutions to improve the work in the future, if the work is to be continued.

2 Theory

This section of the thesis aims to present relevant theory connected to the thesis. It starts with the building and construction sector with a focus on the current situation of the industry. Followed by an overview of construction machines, including both electric and diesel-powered machines. Further, an overview of the current power grid in Norway. Additionally, this section provides insight into the theoretical principles behind energy storage systems and batteries, specifically LIB. Finally, the component of a charging containers is explained, and the section concludes with presenting the different emissions relevant for the thesis.

2.1 Construction sector

Historically, the construction industry has accounted for a significant portion of greenhouse gas emissions and environmental impact. The construction sector is at the forefront of efforts to change this.

Currently, the majority of construction sites in Norway rely on fossil fuels for their energy demands. However, there has been growing concern about the need to reduce the GHG emissions, there has also been concerns about the local air pollution. The construction sector alone contributes to 660 000 tonnes of CO_2eq emissions each year, making up approximately 1.2% of Norway's annual total emissions. As mentioned, a significant portion of these emissions - around 95% - comes directly from operation of the diesel-powered construction machines. [2]

Given that diesel combustion is the primary source of emissions from construction machines, electrification of the building and construction sector presents a significant opportunity for emission reduction.

The municipalities of Oslo, Bergen, Trondheim, Stavanger, Drammen, and Tromsø have committed to a goal of commissioning only emission-free construction work by 2025. A declaration was signed in 2021 where they set a target that within 2030 the entire building and construction sector - both public and private sector - would be emission free. According to the Norwegian Directorate of the Environment ("Miljødirektoratet") emission free construction sites contain no emission of harmful substances such as CO_2

and NO_x, also particles from the energy consumption on the construction site. Emission free includes that all construction machines are hydrogen or electric powered [3]. This thesis focuses on the electric powered option.

2.2 Construction machines

Meeting the goal of emission-free construction sites requires a significant shift in the market for construction machines. The current diesel-powered machines must be replaced with a more sustainable and renewable option. Electric power presents a promising solution, as it offers opportunities for renewable production and has sufficient energy density to power larger construction machines. By transitioning to electric-powered construction machines, emissions from diesel combustion can be eliminated entirely, it is a 100% reduction in direct emissions on the construction site. This represents a crucial step forward in achieving a more sustainable and environmental friendly future in the construction sector. [7]

During a construction project, several types of machines are utilized. The machines used by Aneo are 10 tonne and 25 tonne machines. The thesis will therefore focus on these specific machines.

2.2.1 Electric construction machines

In recent years, there has been a rapid development of electric construction machines, with Norway leading the way in the electrification of construction sites. Although there has been progress in the development of electric construction machines, the current market still offers limited electric options. To overcome this challenge, construction machines are shipped to Norway without an engine, then the electric engines are developed and installed domestically in Norway. These machines are built to be durable, with a lifespan of 10 years or more. [2]

There are new challenges that need to be addressed when transitioning to electric machines. One example is that the machines have to run for an entire working day without any problem. It can be challenging to operate electric construction machines when access to the power grid is limited. It can be difficult to operate an entire electrical construction site if it is located in rural areas where the power grid is not well developed.

Due to their limited range, electric construction machines cannot run for an entire working day, they require at least one daily recharge. However, charging them can be challenging in areas with insufficient power supply.

Charging the machines on high capacity can be damaging on the power grid, but if the charging containers charges with a low capacity during the night, that can be avoided. Too much electricity flowing can lead to overheating of wires and transformers, that can lead to equipment failure or fire. [8]

Nasta is a supplier of electrical construction machines manufactured by Hitachi. The first construction machine is the Zeron ZE85, as shown in Figure 2.1a. It is a roughly 10 tonnes excavator. It can operate at 60% of maximum capacity, providing a run time of up to 4 hours. The excavator has a maximum digging depth of 4.6 m, a range of 6.9 m, and a shovel capacity of 400 liters. [9]

(a) Zeron ZE85 [9] *(b) Zeron ZE210 [10]*

Figure 2.1: (a) is a 10 tonne electric excavator and (b) is a 25 tonne electric excavator

The second excavator is the Zeron ZE210, as shown in Figure 2.1b. It is also an electric excavator, at roughly 25 tonnes. Operating at 60% of maximum capacity it can run for 3.5 - 4 hours. The excavator has a maximum digging depth of 6.7 m, a range of 9.9 m, and a shovel capacity of 1 200 liters. [10]

Electric motor

Electric motors are electrically powered machines that convert electrical energy into mechanical energy. The majority of electric motors function by utilizing the interaction between the magnetic field of the motor and the electrical current in a wire winding. This interaction generates force in the form of torque that is applied to the motor's shaft. One notable feature of electric motors is that they can be powered by direct current sources such as batteries, allowing for increased versatility and mobility in their applications.[11]

Electricity demand

Electric construction machines require a constant flow of electricity, which varies depending on the size the machine. Therefore, it is crucial to ensure access to a reliable power supply. It is dependent on the power grid being sufficient and able to supply the needs of the project at all times.

2.2.2 Diesel-powered construction machines

Diesel-powered construction machines have been a main part of the construction sector for decades, providing the power and versatility needed to complete a wide range of projects. These machines are typically fueled by diesel, which is a petroleum-based fuel that produces significant amounts of GHG emissions when combusted. While diesel engines are known for their power and durability, they also have a significant environmental impact, contributing to air pollution and climate change. [2]

The emission produced by the diesel-powered machines comes mainly from the combustion of diesel. That means that most of the emission is released during operating hours. But there is also emission associated with producing diesel and the manufacturing of the engine.

(a) Hitachi ZX210 [12] *(b) Hitachi ZX210[13]*

Figure 2.2: (a) is a 10 tonne excavator and (b) is a 25 tonne excavator

The excavator shown in Figure 2.2a is a 10 tonne diesel-powered construction machine [14], while Figure 2.2b shows a 25 tonne diesel-powered construction machine. Both machines are manufactured by Hitachi, the same manufacturer as the electric construction machines. They look the same, have the same measurements and perform equal to the electric machines. [13]

Diesel engine

An internal combustion engine is a heat engine that utilizes the process of internal combustion to convert the potential energy stored in fuel into mechanical work. The fuel, in this case is diesel. The basic working principle of an internal combustion engine involves four stages; intake, compression, combustion and exhaust. During the intake stroke, a mix of diesel and air is drawn into the combustion chamber through an intake valve as the piston moves down. In the compression strokes, the piston moves upward, compressing the diesel and air mixture to a high pressure and temperature. Due to high pressure and high temperature the diesel and air mix ignites resulting in an explosion and rapid expansion of gases in the combustion chamber. The hot gases serves as the heat-carrying medium for the machine. [15]

Diesel engines function on the principle of self-ignition and only clean air is introduced into their cylinders. The high compression ratio in diesel engines (1:22) leads to a compression pressure in the combustion chamber of over 3 MPa, and a temperature that is sufficiently high, around 600°C, to cause the fuel oil to self-ignite when it is injected into the combustion chamber around the top dead center of the piston. The powerful expansion from the combustion drives the piston down in the cylinder with a big force. The piston has a linear motion. That motion is transferred to rotary power via a crankshaft. That downward motion is generating mechanical energy that can be harnessed to perform work.

In the exhaust stoke, the piston moves upward again, pushing the gases out from the combustion chamber through an exhaust valve. And then the whole process repeats itself over and over again. [16]

Diesel production

Diesel is a product from crude oil and biomass. Crude oil is a fluid mix of different hydrocarbons. Hydrocarbons is a compound consisting of hydrogen and carbons. Crude oil is formed out of dead organisms, algae and zooplankton and it is found underneath sedimentary rock and exposed to heat and pressure. Crude oil is extracted by oil drilling. There have been oil drilling in on the Norwegian continental shelf since the 1970s. [17]

After crude oil is found on the NCS it is transported to a refinery where the crude oil is separated in a distillation tower where different hydrocarbons is boiled off at different temperatures, and then they are being converted into usable petroleum products. Diesel is the product from crude oil that is used as fuel in motors, mainly in construction machines. [18]

Extracting crude oil and converting it to diesel has a small amount of emission. The biggest emission connected to diesel is the combustion of the diesel in internal combustion engines. Even though the emission from diesel production is small, it is still relevant to take it into account in the calculations.

2.3 Power grid

The Norwegian power grid is an important infrastructure for the country. The grid has three main functions, these are production, transfer and turnover. In a modern society like Norway, it is important to have well-developed power grid. A secure access to electricity is considered a matter of course. Important tasks in society and functions are critically dependent on a well-functioning power system with a reliable power supply. [19]

Electricity is a perishable commodity, which means that it must be used in the same second that it is generated. Therefore, it is important to maintain a balance between what is consumed and what is produced at all times. Given the large distances between production and consumption in Norway, a well-developed power grid is crucial so that the power can reach households and other consumers far away.

The power grid distinguishes between the transmission grid, the regional grid and the distribution grid;

- **Transmission grid:** The transmission grid links the large producers and the consumers in a nationwide system. The grid is at a high voltage level, around 300 to 420 kV. In some parts of the country is the voltage at 132 kV. The grid network is long, it stretches out 11,000 km. Statnett operates the transmission grid.

- **Regional grid:** The regional grid connects the transmission grid and the distribution grid. The regional grid has a voltage level of 33 kV to 132 kV. It stretches out 19,000 km.
- **Distribution grid:** It is the distribution grid that makes sure that every household in Norway have access to electricity supplied by the power grid. It connects the power to the small consumers. The distribution grid has voltages up to 22 kV, which is a part of the high voltage section of the grid. The grid has a low-voltage part as well, that starts from 1 kV and lower. The low-voltage part of the grid is normally at 400 V or 230 V. The low-voltage lines goes into the normal households. The distribution grid stretches 100 000 km. [19]

Figure 2.3: Transmission grid in Norway [20]

The transmission grid in Norway is in Figure 2.3, represented by the red line that spans across the nation. Notably, the transmission grid does not cover the entirety of Norway, indicating that certain regions may not have access to the transmission grid.

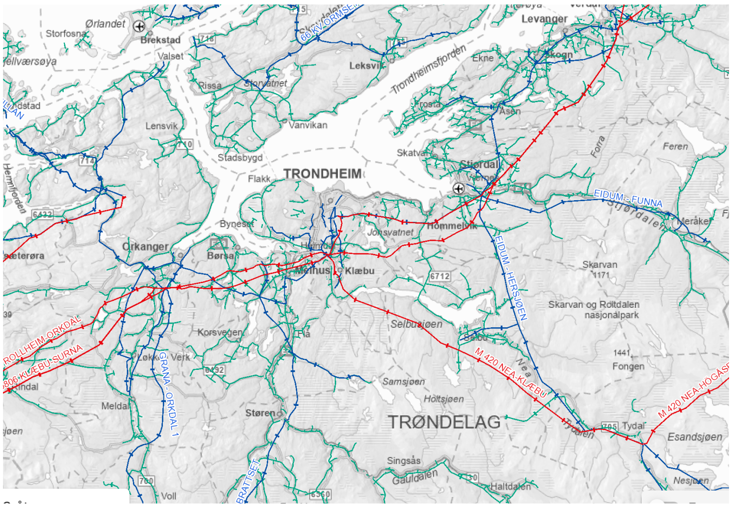


Figure 2.4: Power grid in Trondheim [20]

Figure 2.4 shows an image of the power grid in Trondheim. The red line is the transmission grid, the blue line is the regional grid and the green lines is the distribution grid. The distribution grid is the longest. The image shows parts of the country with poor connection to the power grid.

The power grid faces many challenges, and the challenges will continue to grow in the future. The society is electrifying, that will lead to an enormous increase in demand for electricity. It is a future goal to replace all fossil energy sources with renewable energy sources, which means that the load on the power grid is increasing. For the power grid to have the same efficiency and function it has today, in the future, it must be able to handle the large increase in demand and increase in power production. The network must be able to maintain instantaneous balance [19]. A method to restore the balance is peak shaving.

2.3.1 Peak shaving

Peak periods of energy consumption occur when people require electricity at the same time. This typically occurs in the morning from 7am to 9am when people engage in their morning routines before starting their day, and in the evening from 6pm to 9pm when people get home for the day. These periods of high energy demand place a significant burden on the power grid, which can lead to grid instability and potential outages. Figure 2.5 shows a graph of when the peaks occur. Norway is a cold and dark country during the winter, therefore the electricity demand for heating is especially high during the winter.

[21]

Peak shaving is a method to manage the demand of power by eliminating the short-term demand spikes. It is the short-term demands that creates the high peaks in the demand. The method smooths out peak loads. It is important to smooth out the peaks to have a stable power grid. The demand for electricity is increasing to a point where the power grid is having trouble handling the peaks. [21]

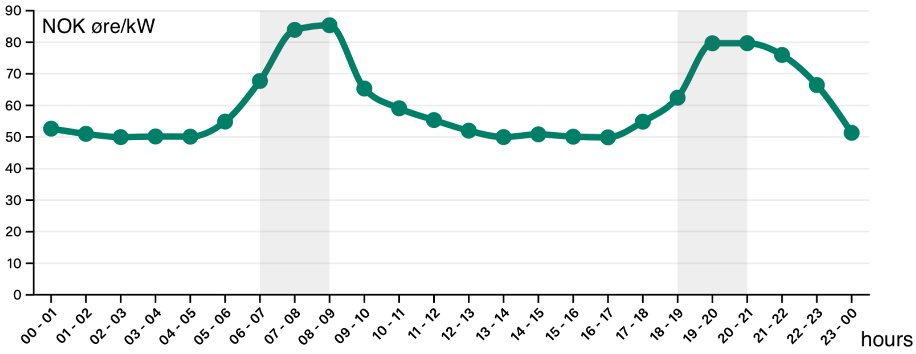


Figure 2.5: Peaks during a day [22]

The graph in Figure 2.5 represent the peaks in the power demand. The curve in the graph is based on the price, NOK øre/kWh, every hour. The demand correlates with the price of the power. The electricity is at the most expensive when the peaks occur in the morning and in the evening. The electricity is cheapest during the night between 10pm and 7am, these are called the off-peak hours. [22]

Due to the increasing demand of electricity, the peaks must be reduced. The consequences is that the power grid is unable to handle the demand. A solution to reduce the peak power demand is to use energy storage. [23]

2.4 Electrochemical Energy Storage

Energy storage is a vital component of a modern energy system, enabling excess energy to be stored and used when demand is high or when unreliable energy sources are not producing. This helps to balance the supply and demand of electricity, increasing the efficiency and reliability of the grid and providing backup power during outages. When the use of renewable energy sources increases, the need for energy storage will follow. By storing energy when it is available, and releasing it when demand is high, energy storage systems can help to maximize the use of renewable energy sources, reducing the reliance on fossil fuels and contributing to a more sustainable and secure energy future. [24]

There are various types of energy storage technologies available, one being electrochemical energy storage (EES). EES involves the conversion of electrical energy into chemical energy, which can later be converted back into electrical energy if needed. Fuel cells and supercapacitors are examples of EES technologies, but one of the most commonly used technology is batteries. Rechargeable batteries, also known as secondary batteries, operate by converting electrical energy into chemical energy during charging and then releasing it as electrical energy during discharge. [25]

Renewable energy sources, such as wind and solar energy, are characterized by their intermittent nature, meaning that their production is not constant or predictable. This intermittency creates challenges in balancing electricity supply and demand in real-time. Energy storage systems, such as batteries, offer a solution to address this issue. Excess energy during periods of high production can be stored in batteries. Later, when the demand exceeds production, the stored energy can be released and supplied to the grid, ensuring a reliable power supply. This also ensures that no energy goes to waste if the production that exceeds the demand. [26]

Additionally, energy storage systems has the potential to play a crucial role in supporting the power grid during peak periods of energy demand. In 2.3.1 the term peak shaving was explained. Energy storage have the potential to help solving this problem by supplying power during the hours of peak demand. Then during periods of low demand, energy can be stored for later use. Energy can be stored both from the grid itself, or from other energy sources like wind and solar. This avoids waste and helps optimizing the efficiency of the energy system. [26]

The utilization of energy storage can also bring economic benefits. By storing energy during low-demand periods when electricity costs are more affordable and utilizing it during high-demand periods when costs and demand are high, significant cost savings can be realized. This use of energy storage has the potential to reduce peak electricity prices by reducing the intensity of peak demand periods. This not only contributes to overall cost reduction but also enhances grid stability and reliability. [27, 23]

2.5 Battery

A battery is a power source that stores chemical energy, and converts it into electrical energy. A battery usually consists of several electrochemical cells, where each cell consists of two electrodes separated by an electrolyte. Batteries can be made in several different shapes, sizes, and materials. [28]

Batteries can be divided into two main groups, primary batteries and secondary batteries. Primary batteries are disposable single-use batteries, and are designed to power small appliances like calculators and flashlights. The other group is secondary batteries, which are rechargeable batteries. These are the batteries used in smartphones, laptops and electric vehicles. Primary batteries are typically cheaper to produce, and has a low self-discharge rate, meaning that the loss of charge if the battery is not being used is low. However, the secondary battery has the advantage of being rechargeable, so it can last longer, and deliver more energy compared to the primary battery. Therefore, the cost per cycle is lower for the secondary battery. [25, 29]

Both the primary and the secondary battery has its advantages and disadvantages, and the use depends on the specific use and requirements for the specific application. In this thesis the focus will be on secondary batteries, specifically the lithium ion battery.

2.6 Lithium ion battery

In recent years, the Lithium ion battery (LIB) has gained immense popularity as a rechargeable battery technology. This is due to its high energy density, low self-discharge rate, long life-span, and ability to power a wide range of electronic devices. Its reliability and efficiency has made it a preferred choice for portable electronics. The demand for LIB is expected to continue to grow, as it remains one of the most sought-after battery technologies available today. [30]

2.6.1 Structure

The LIB typically consists of the anode, the cathode, electrolyte, separator and two current collectors, as illustrated in Figure 2.6.

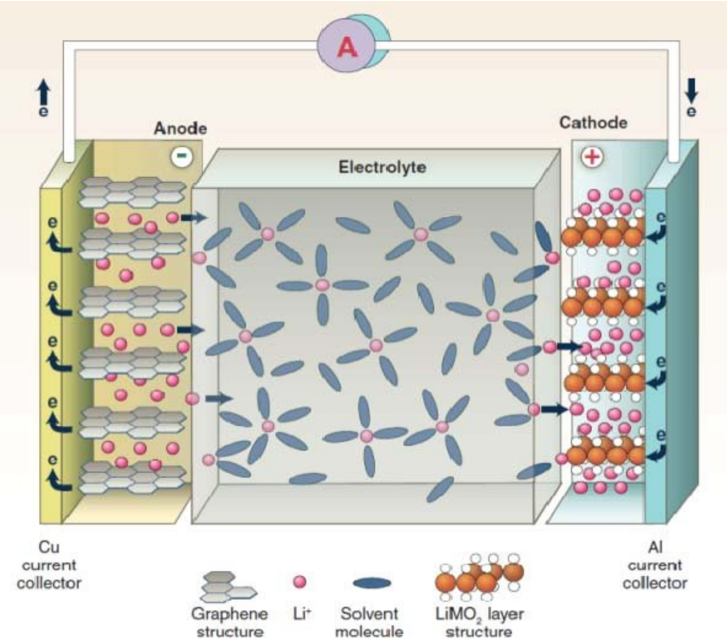


Figure 2.6: Model of a Lithium ion battery cell during discharging [31]

The anode is the negative electrode where oxidation occurs during discharge of the battery, and reduction occurs during charging. This means that during discharging, the anode releases lithium ions to the cathode, which causes electrons to move from the now negative anode to the cathode through the current collectors. When charging the battery, the opposite happens [32]. The anode is typically made from some type of carbon particles, the most popular anode material being graphite. Graphite is popular because of its high energy density, power density, low cost and long cycle life [33]. However, several newer batteries are using other anode materials, like silicon or titania [25].

The cathode is the positive electrode, where reduction occurs during discharge, and oxidation occurs during charging. The materials used in the cathode are transition metal oxides. They are preferred because of their flexibility in terms of oxidation numbers [25]. The lithium-ion battery can refer to several different cathode materials, like Lithium Nickel Manganese Cobolt Oxide (NMC), Lithium Cobolt Oxide (LCO), Lithium Iron Phosphate (LFP) and Lithium Manganate (LMO), the two most common being NMC and LCO [34]. Table 2.1 shows information about commonly used cathode materials.

Different metal oxides are used based on the use of the battery. As shown in Table 2.1, LCO has a high specific energy, but it has a relatively short lifespan. LCO is mostly used in phones and laptops. LMO has a lower specific energy, but is safer than LCO. LMO is commonly used in power tools and medical devices. LFP has a long life span, and is very safe, but has a lower specific energy, and is mainly used for energy storage. NMC is used in everything from power tools, to electric vehicles and electric bikes. It has a high specific energy, and is the preferred chemistry for many uses. [35]

Table 2.1: Different types of lithium ion battery cathode chemistries, obtained from [36]

Cathode Material	**Chemistry**	**Voltage (V)**	**Specific Energy (Wh/kg)**
Lithium Cobalt Oxide (LCO)	$LiCoO_2$	3.60	150-190
Lithium Manganese Oxide (LMO)	$LiMn_2O_4$	3.70	100-135
Lithium Iron Phosphate (LFP)	$LiFePO_4$	3.30	90-120
Lithium Nickel Manganese Cobalt Oxide (NMC)	$LiNiMnCoO_2$	3.70	140

When making the batteries, a conducting additive and a binding agent is added to the electrodes. The conductive additive is carbon black, and is added to improve the conductivity of the battery. How much carbon black is added usually vary between 1-5%. Additives do not contribute to energy storage, so for batteries that need high energy density, the amount of additives is minimized. On the other hand, batteries designed for high power output require good conductivity and contact, so a higher amount of additives may be used. The binder is added to connect the electrode particles to each other and the current collectors. The most common binding agent for Lithium ion batteries is polyvinylidene fluoride (PVDF). [37]

Electrolyte is added between the anode and the cathode, as well as the pores of the electrodes [37]. The electrolyte is what allows an electrical charge to pass between the anode and cathode. In the lithium ion battery, the electrolyte is what transports the lithium ions between the anode and the cathode [38]. The electrolyte is usually lithium salt dissolved in a mixture of organic solvents. Most of the time, the salt is lithium hexafluorophosphate salt (LiPF6), dissolved in a mixture of ethylene carbonate (EC), dimethyl carbonate (DMC), propylene carbonate (PC), diethyl carbonate (DEC), and/or ethyl methyl carbonate (EMC). The electrolyte is what decides the current density and the safety of the battery, due to it being in contact with most of the components in the battery. [39]

The separator is placed between the anode and the cathode to prevent contact [40]. It is usually a porous material, either organic, polymeric or like fiber glass [25]. It is usually between 12-25 micrometer thick. Thin separators are used when the goal is to minimize the resistance, and thick separators are used when maximizing the safety is prioritized. [37]

As mentioned, the li-ion battery consists of two current collectors, one on the anode and one on the cathode. The current collector typically consists of copper on the anode, and aluminium on the cathode, as shown in Figure 2.6. [25] The current collector collect the electrical current generated at the electrodes and connect with external circuits. [40]

2.6.2 Safety

Even though li-ion batteries are well suited for many purposes, there are some challenges associated with the batteries.

One challenge with lithium ion batteries is the safety. The safety of the batteries is determined by the cell chemistry. One of the biggest safety concerns with lithium ion batteries is thermal runaway. The operation of a battery generates heat, and if not properly managed, this heat can lead to thermal runaway. Thermal runway is a phenomenon where overheating of the battery causes a chemical reaction that further increases uncontrolled heat generation. This can ultimately result in a fire or explosion [41]. Several factors can contribute to thermal runaway, including internal failures such as short circuits, overcharging, or exposure to high temperatures. Batteries are manufactured with controls meant to prevent this, but if they are not properly integrated these factors can cause thermal runaway [42].

Fire in a lithium ion battery is difficult to extinguish, and can release toxic gases. The battery is prone to reigniting, and will burn until all the energy in the battery is used up [43]. This makes it all the more important to prevent fires from happening.

2.6.3 Emissions from lithium ion batteries

Lithium ion batteries can be used in electric vehicles and as energy storage devices, which are often associated with being environmentally friendly, as it reduces the dependence of fossil fuels.

The production of lithium ion batteries is responsible for emissions, both during the mining of the raw materials needed in the battery, and in the manufacturing phase. Materials like lithium is not the most easily accessible. Most lithium is extracted from hard rock or from brine reservoirs, and the energy used in the extraction mostly comes from fossil fuels, causing emissions [44].

The manufacturing of the battery also requires large amounts of energy. Today, the majority of lithium ion batteries are manufactured in China, where the primary energy source is coal [44]. This increases the environmental impact from the battery. A lithium ion battery produced in a place where the electricity mix has lower emissions, would have a lower impact. A comparative analysis done in 2020 of the manufacturing of lithium ion batteries in China compared to EU shows that the GHG emissions per kWh of battery cell produced in EU are 38-41% lower than in China [45].

During the use of the batteries, the emissions from the battery is limited to the emissions from the local electricity mix where it is used. In a country like Norway with a high proportion of renewable energy, the impact in the use-phase will be low.

2.7 Charging container

Charging containers, also known as battery containers, are portable charging solutions designed to provide convenient access to power anytime and anywhere.

An overview of a charging container is shown in Figure 2.7. The figure shows the container from above, to get a clear image of all the components inside. The image was provided by Aneo, and shows the container relevant for this thesis. A detailed description of the charging containes and the components was provided by Anders Dahl from Aneo Build via email communication (20.04.23).

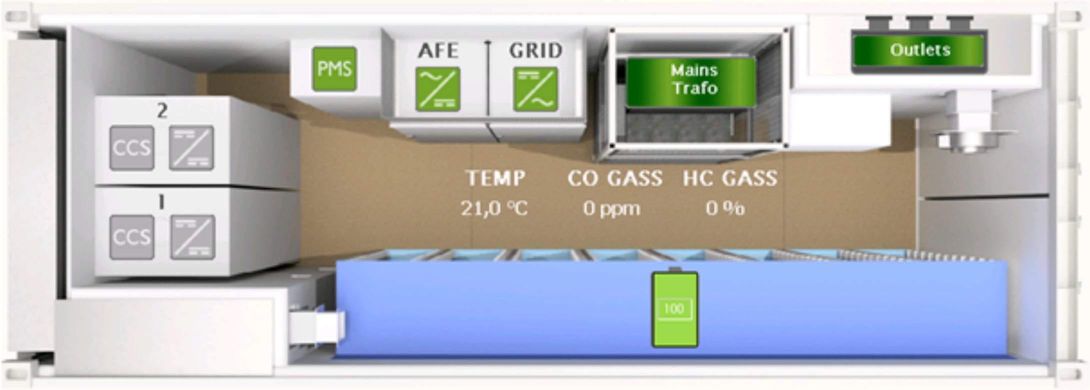


Figure 2.7: Overview of the components in a Boostcharger

The charging containers are equipped with batteries where the energy is stored, as well as several other equipment necessary for the charging, for monitoring and keeping the containers safe.

Charging containers can be used when there is limited or no access to power from the grid, or just to minimize the costs, by charging the batteries when the electricity price is low, and delivering during peak hours. This also helps to relieve the power grid during said peak hours.

The most important component of the charging containers is the batteries. This is where the energy is stored, and what makes the charging possible. To charge up the batteries, power from the grid is used. As mentioned, the distribution grid delivers voltage at 400 V or 230 V. For internal operation and charging the batteries, 400 V is used. The charging container therefore contains a transformer, for instances where the grid supplies 230 V.

The batteries charge with direct current (DC) , while power from the grid is alternating current (AC). The current therefore has to be converted through an active front end (AFE) drive. The AFE contains protective devices and contractors for overload and short-circuit protection. The DC is then used to charge the batteries, and is delivered to the rapid chargers (CCS).

CCS stands for Combined Charging System. The CCS drive gets power from the batteries and the AFE drive, and is what drives the charging cables and the CCS plug on the outside for fast charging of the electric machines.

The container also contains a Ugrid, which uses the DC from the batteries and the AFE drive, and converts it to AC to supply the transformer to the construction power cabinet.

The construction power cabinet is located at the outside of the container. It has a capacity for 250 A on 400 V. Through this the construction can AC charge the machines, as well as using it for supplying the rest of the construction site, like the barracks. This also makes it possible to use the container as grid support, and supply power back to the grid.

The container also contains a performance measurement system (PMS). All of the electronics, communication units and the programmable logic controller (PLC) is here. The power supply to the Air Condition units also comes from the control cabinet.

2.7.1 Safety

When storing energy in batteries, there is a risk for fire in the cells, so safety measures are necessary in every energy storage device. Some measures is for monitoring and maintaining temperature, to prevent fires from happening. The air condition is in place to provide a safe operating temperature for the battery cells, and there is also individual cell monitoring for the temperature of all the battery cells [46].

The container is also made air tight to prevent dust from reaching the power electronics, and insulated with flame retardant and fire-stopping El60 insulation. In addition to this, the container has an active fire/gas detection, notification and ventilation system. [46]

2.8 Emissions

The thesis covers a wide range of emissions originating from various processes. This section aims to provide an explanation of the various GHG emissions, as well as other pollutants associated with the processes. Moreover, the project includes GHG, NO_x, SO_2, CO, NMVOC, and PM. This section provides a better understanding of the environmental impact and the effect the pollutants have on human health. The emissions are measured in CO_2 equivalents, a unit of measure that enables comparisons between different types of emissions. 3.1

Greenhouse gases (GHG)

GHG are defined as atmospheric gases that absorbs infrared radiation emitted from the Earth's surface and subsequently re-radiating it back towards the surface, thereby contributing to the greenhouse effect. The most significant GHG include carbon dioxide

(CO_2), methane (CH_4), nitrous oxide (N_2O), and water vapor (H_2O). In the context of this thesis, the focus is directed towards the GHG of CO_2 and CH_4. [47]

The greenhouse effect is a fundamental component of the Earth's energy balance, as it regulates the temperature of the planet's atmosphere and ultimately determines the habitability of the planet. [48]

CO_2 emission have doublet the last fifty years. The global emission of CO_2 was in 2022 around 37,5 billion tonnes CO_2 [49]. CO_2 has a significantly longer atmospheric lifetime than most other greenhouse gases. It is primarily produced from combustion of fuel, gas, coal and emission from industries. [50]

CH_4 is the second most important GHG following CO_2. It is emitted during the production and transport of coal, natural gas and oil. It is also emission from agricultural practices and land use. High levels of CH_4 can reduce the amount of oxygen in the air that can lead to poor air quality, which has a big effect on human health [47]. CH_4 has a shorter atmospheric lifetime, but it is much more effective at absorbing infrared radiation and re-radiating it back to earth. CH_4 is responsible for approximately 16% of the total global warming effect. [51]

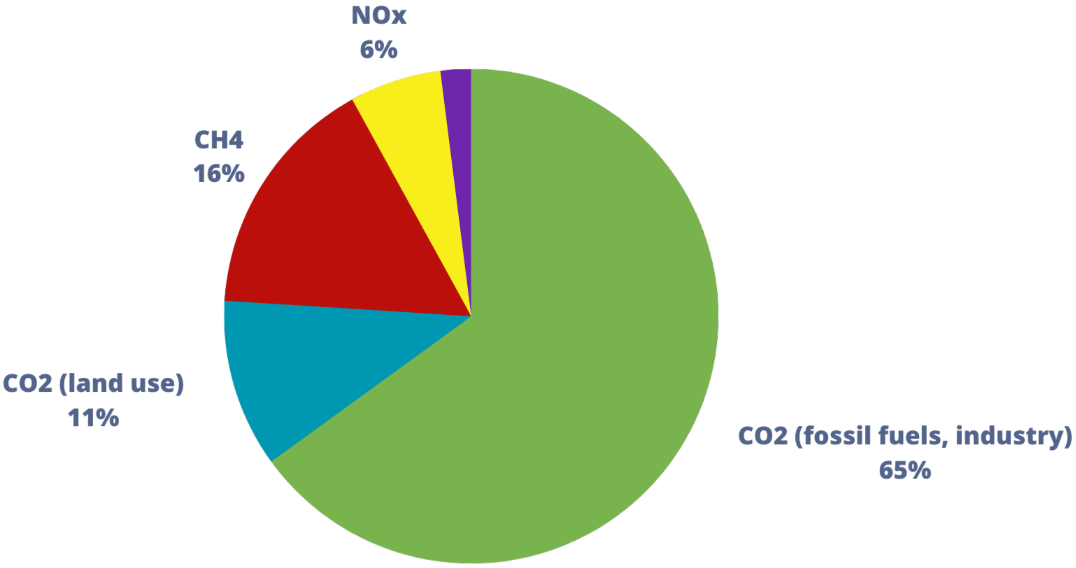


Figure 2.8: Total global emissions [51]

Figure 2.8 shows a circular diagram with the global emission. The largest amount of emission comes from CO_2, 65 % from fossil fuels and industry, while 11 % comes from land use activities, such as forestry, agriculture and degradation of soils. CH_4 accounts for 16 % of the global emission and finally NO_x accounts for 6%. [51]

Nitrogen oxides (NO_x)

NO_x is not a GHG, but it has an effect on the climate through the influence on the ozone layer. NO_x is a common term for the nitrogen compounds NO and NO_2. NO_x gas is formed during combustion. The production of NO_x occurs mainly in high temperature processes like in engines, power plant, boilers, and other industrial processes. In Norway, a majority of the emission comes from transport, shipping, and energy production.

This gas is toxic for humans to inhale. Exposure to NO_x is known to have deleterious effects on human respiratory function, and is a key contributor to the formation of smog and brown clouds that are often observed in densely populated urban areas. The presence of NO_x can contribute to poor air quality, which has been linked to respiratory and cardiovascular health problems. Acidic rain, which can result from the deposition of NO_x, can have consequences for ecosystems, including soil degradation, forest decline, and reduced crop yields. [52]

Carbon monoxide (CO)

Carbon monoxide is a highly toxic gas that is both colourless and odorless. It is slightly lighter than air and has the potential to be explosive when mixed with air. CO is produced by the incomplete combustion of organic materials. While natural processes do contribute to its emission, man-made sources are the main producers of CO emission in terms of health effects. In Norway, the most significant sources of carbon monoxide emissions are wood burning and traffic. Despite generally low concentrations of CO in the atmosphere, certain environments such as tunnels and parking facilities can exhibit higher levels of CO.[53]

The gas is toxic to humans, so high concentration can have a big effect on the human health. CO binds to hemoglobin in red blood cells, displaces oxygen, and prevents the uptake and transport of oxygen from the lungs to the rest of the body. That can effect the heart, the nerve system and fetal development when pregnant. [53]

Sulfur dioxide (SO_2)

Sulfur dioxide is a colourless and toxic non-flammable gas characterized by a sharp, unpleasant smell. SO_2 can be found in volcanic gases and is also emitted into the atmosphere as a result of various human activities. Combustion of crude oil and coal that contain sulfur, as well as combustion of wood are one of the main contributors to SO_2 emission in the environment.

SO_2 is toxic to humans, so exposure to SO_2 can have adverse effects on both human health and the environment. In low concentration SO_2 can be irritant to the respiratory system. Trouble breathing and coughing can occur. It is also irritating on the eye. In addition, like NO_x it contributes to acid rain. [54]

Non-methane volatile organic compound (NMVOC)

NMVOCs are a collection of organic compounds that differ widely in their chemical composition but display similar behaviour in the atmosphere. NMVOCs are emitted into the atmosphere from a large number of sources including combustion activities, solvent use and production processes. NMVOCs contribute to the formation of ground level ozone, the trophospheric. VOC is similar to NMVOC, the difference is that it includes methane as well.[55]

Particular matter (PM)

Particulate matter is a broad term for small particles that have the ability to remain suspended in the air for an extended period of time. PM is made of particles of solids or liquids, like soot or dust. The particles can originate from various sources, including industrial emissions and car traffic.

The effect PM has on human health is directly proportional to its concentration. Exposure to PM can contribute to premature death. Prolonged exposure can lead to the development of cardiovascular and respiratory disorders. The size and chemical composition of PM are important factors that determine their effect on human health, with some substances being more harmful that others. [56]

2.9 Goals for the thesis

Within the thesis, three distinct goals have been defined from the objective in Introduction. They serve as a guiding framework for the research. These goals lay the foundation for the calculations, analysis and theoretical exploration.

The three goals are:

1. Develop an improved and more detailed method to calculate emission savings at an electric construction site.
2. Create a model in excel that Aneo can use to calculate the emission savings from electric construction site in an efficient and simple way.
3. The excel model aims to present the results to costumers in an understandable way.

3 Methodology

In this section the methodology used in this thesis is described. The methodology is an important aspect of any research, providing a structured approach to collecting, analyzing and interpreting data. The methodology adopted for this thesis begins with a detailed system description, followed by the analysing tools and methods used. The section then moves on to the data collection and treatment processes, where all of the calculations are being explained, providing clarity on how the results were obtained. Finally, the assumptions made throughout the study are described.

3.1 System description

The charging solutions that are the focus of this project is the BoostCharger and the Hummingbird, two charging containers that are produced by Nordic Booster, and delivered by Aneo. The containers contain Lithium-ion NMC battery cells along with various other components essential for their operation and safety. The battery cells have a cycle life of up to 8000 cycles. [46, 57]

On each project Aneo calculated that one Hummingbird can power two electric vehicles or machines. If the project is larger and contains more than two machines, then they would need multiple Hummingbirds or replace them with a BoostCharger.

3.1.1 BoostCharger

The BoostCharger is a 20-foot container with a 390 kWh capacity, and it is the largest charging solution that Aneo delivers. It is suited for projects with low capacity in the power grid and/or high power requirements. The BoostCharger has two CCS2 rapid charger outlets, which both can deliver 150 kW to an electrical machine at the same time [58]. It has a lifetime of up to 10 years [46]. Figure 3.1 shows a simple animation of the BoostCharger which was provided by Aneo.

Figure 3.1: Animation of the BoostCharger charging container

3.1.2 Hummingbird

The Hummingbird is a mobile rapid-charger. The trailer is small, compact and on wheels. It has an installed battery capacity of 192 kWh and it has one CCS2 rapid charger outlet at 150 kW. It is designed to have a total lifetime of 10 years. Figure 3.2 shows an animation of the Hummingbird, provided by Aneo. [58, 57]

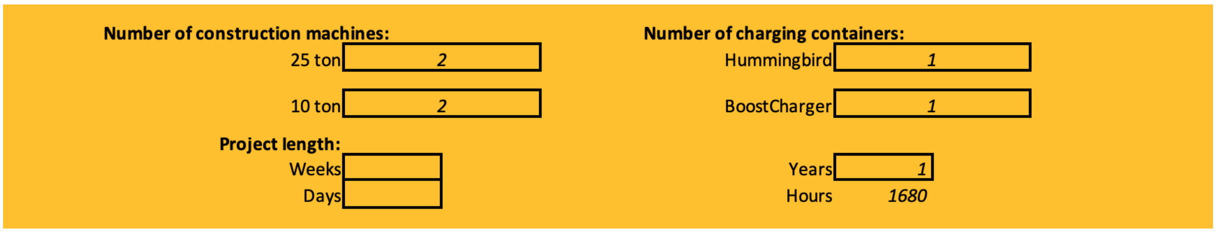
Figure 3.2: Hummingbird

Because it is a mobile solution, the Hummingbird is easier to move around the construction site than the BoostCharger. The Hummingbird is encapsulated in a custom lightweight container to ensure that the total weight with trailer and batteries does not exceed 3.500kg. This makes it possible to hook it up to pickup trucks, SUVs and minivans and transport it around to where the machines are stationed within each project. That eliminates excessive moving of the machines. Figure 3.2 shows an animation of the Hummingbird, provided by Aneo. [58, 57]

3.2 Analysing tools

The analysing tool used in this thesis is Microsoft Excel. Microsoft Excel is a spreadsheet software program, a data visualization and analysis tool. In this thesis Microsoft Excel is used to make a model that Aneo can use to calculate the emission savings from projects and also estimate the emission savings for future projects.

The spreadsheet is designed to analyse emission savings from projects. There are two different analyses available to do in the spreadsheet. The first analysis is to estimate the emission savings for a future project. The inputs needed is the duration of the project, number of construction machines and the number of BoostChargers and Hummingbirds. From those inputs, the estimated liters of diesel and the estimated energy consumption is calculated. Further, the total emission savings for a project is calculated.



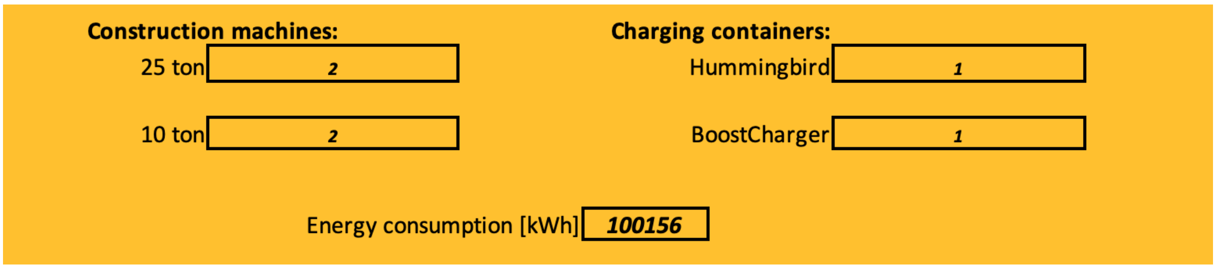
Number of construction machines:
25 ton 2
10 ton 2
Project length:
Weeks
Days

Number of charging containers:
Hummingbird 1
BoostCharger 1
Years 1
Hours 1680

Figure 3.3: Input to analysis for a future project

The second analysis is from a project where the amount of power consumption is known. This is from calculating the savings throughout the project, or at the end of a project. The only inputs needed for this analysis is the number of construction machines, the number of BoostChargers and Hummingbirds used, and the energy consumption from the project.

The emission savings is calculated by subtracting the total emission from the electric construction site from an equivalent diesel-powered construction site. The total amount



Construction machines:
25 ton 2
10 ton 2

Charging containers:
Hummingbird 1
BoostCharger 1

Energy consumption [kWh] ***100156***

Figure 3.4: Input to analysis of a finished/started project

of energy combustion is used to calculate the amount of diesel combusted. There are three factors that goes into calculating the total emission from a diesel-powered construction site; the emission from diesel production, emission from the production of a diesel engine, and lastly the emission from combustion of diesel. These three factors are then summarized.

When calculating the total emission for electric constriction site, there are two different factors accounted for. The first one is the production of batteries in the charging containers. The second factor is the energy consumption, which is multiplied by the emission factor of the Norwegian electricity mix, 0.011 kg per kWh [59]. These two factors are summarized. Finally to get the kg CO_2eq saved in total, the total emission from electric construction site is subtracted from the total emission of diesel-powered construction sites. The excel model also estimates kg NO_x saved during the operational phase of the project, by using Equation 3.2.

3.2.1 Input

The model is made to be adapted to each individual project. To present the results from the Excel model in this thesis, numbers from a previous project Aneo has done is used. The project is called Petersrønningen, and includes water and drainage work combined with construction work. [60]

The inputs are as following:

- 1 Hummingbird and 1 BoostCharger
- Energy consumed is 100 156 kWh
- 4 electric construction machines
- The project started September 2021 and ended October 2022, so it lasted for

approximately 1 working year, which equals 42 working weeks

3.3 Data collection and treatment

This section covers the data collected and methods used to calculate the relevant CO_2eq, and other relevant factors associated with battery production, diesel production and diesel engine manufacturing. This section will provide a detailed description of the calculations used, including the formulas, and data sources employed in the analysis.

3.3.1 CO_2 equivalent

The CO_2eq measurement is determined by converting the amount of emissions into the equivalent amount of CO_2 with the same Global Warming Potential (GWP). This is achieved by multiplying the emissions by the associated GWP value, as shown in Equation 3.1. GWP is a measure of a specific type of emission's ability to trap heat in the atmosphere relative to CO_2. It is normally calculated over 100 years, that is why it is called GWP(100, global). [61]

$$CO_2eq = amount\ of\ emission \cdot GWP \tag{3.1}$$

3.3.2 NO_x factor

To calculate the emissions associated with NO_x, Equation 3.2 is employed. The density of diesel fuel used in this calculation is assumed to be 0.85 kg per liter [2], while the NO_x-factor is 5 grams per kilogram [52].

$$\begin{aligned} Diesel\ [kg] &= diesel\ [l] \cdot density\ [kg/l] \\ NO_x\ [g] &= diesel\ [kg] \cdot NO_x - factor\ [g/kg] \\ NO_x\ kg &= \frac{NO_x\ g}{1000} \end{aligned} \tag{3.2}$$

3.3.3 Emission factor for diesel

The emission factor for diesel refers to the quantity of kg CO_2eq emission generated per liter of diesel combusted. The emission factor is based on the average carbon content of fuels used in Norway. To determine the emission factor for diesel, the Norwegian Environment Agency ("Miljødirektoratet") calculates the emission factor based solely on direct emissions resulting from on-site diesel combustion, with a value of 2.66 kg CO_2eq/l diesel [62].

3.3.4 Emission from electric construction sites during operation

An electric construction machine produces no direct emissions. This does not mean that an electric construction machine has no emissions, as there are still indirect emissions linked to the machines. This thesis employs a predefined parameter for the CO_2eq per kWh of electricity supplied by the Norwegian Water Resources and Energy Directorate (NVE). The parameter used is 11 g CO_2/kWh, that equals 0.011 kg CO_2eq/kWh consumed. The predefined parameter is the Norwegian electricity mix during the year 2021. [59]

To calculate the total emissions associated with an electric construction site, one can multiply the amount of electricity consumed in kWh by the factor of 0.011 kg CO_2eq/kWh.

Future project

For a future project it is estimated that a 10 tonne construction machines uses 13.4 kWh per hour of work, while a 25 tonne machines uses 24.5 kWh per hour. Knowing the length of the project and the numbers of electric construction machines, Equation 3.3 shows the final calculation of emission from the electric site.

$$kg\,CO_2eq\,el = ((x \cdot 13.4\,kWh/h)\ +\ (y \cdot 24.5\ kWh/h) \cdot z \cdot 40\ h)) \cdot 0.011\ kg/kWh \quad (3.3)$$

In the equation, x represent the amount of 10 tonnes construction machines, y is the amount of 25 tonnes machines and z is the number of working weeks the project is planned to last. That information makes up the estimated energy consumption, and finally the energy consumption is multiplied by the Norwegian electricity mix with the value of 0.011 kg/kWh.

Finished project

For a project that is finished, the total amount of energy consumption is known, making the calculations easier. The only step is to multiply the known energy consumption with the Norwegian electricity mix. It is shown in Equation 3.4.

$$kgCO_2eq.kWh = Energy\ consumption\ kWh \cdot 0.011\ kg/kWh \tag{3.4}$$

3.3.5 Emission from diesel-powered construction site during operation

Today, Aneo does calculations of diesel-powered construction machines, where they estimate the total CO$_2$eq for projects if they where powered by diesel. The same calculations will be used to calculate the total CO$_2$eq from heavy construction machines.

Future project

Equation 3.5 shows how the total amount of CO$_2$eq during a future project is calculated. The total diesel consumption is multiplied by the emission factor of diesel. It is estimated that the different sized construction machines consumes different amount of fuel. The 10 tonne construction machine consumes 3.75 liters per hour of work and the 25 tonne machine consumes 6.875 liters per hour of work. One week of working is assumed to be combined 40 hours of work divided on 4 days. The diesel consumption is calculated by multiplying the amount of hours of the project with liters of diesel combusted depended on the amount of construction machines.

$$kg\ CO_2eq\ diesel = diesel\ consumption\ [l] \cdot emissionfactor\ [kg\ CO_2eq/l\ diesel] \tag{3.5}$$

Finished project

To calculate the exact CO_2eq from one project after it is done, the total diesel consumption is needed. It is calculated from the total power consumption, in kWh. First, the total power consumption is multiplied by the total energy efficiency of electric machines divided by the total energy efficiency of diesel machines as shown in Equation 3.6 to find the diesel consumption in kWh. Then the diesel consumption in kWh is used to calculate the diesel in liter by dividing the diesel consumption [kWh] by the energy density [kWh/L] of diesel as shown in Equation 3.7. Finally, to find the CO_2eq from the diesel after a project is done, the total diesel consumption is multiplied by the emission factor for diesel, as shown in Equation 3.5.

$$Diesel\ [kWh] = power\ [kWh] \cdot \frac{energy\,efficiency\,electric\,machine}{energy\,efficiency\,diesel - powered\,machine} \tag{3.6}$$

$$Diesel\ consumption\ [l] = \frac{diesel\ consumption\ [kWh]}{energy\ density\ [\frac{kWh}{l}]} \tag{3.7}$$

The energy efficiency of electric machines is 85% and the energy efficiency of diesel-powered machines is 30%, both these parameters are given by SINTEF. The energy density of diesel is 10.1 kWh/l. [2]

3.3.6 Emission from battery production

To calculate the emissions from the battery production data from an LCA conducted in 2020 was used. After reviewing several LCAs for the NMC battery, this particular LCA was chosen due to its similarities to the battery relevant to this thesis. It has a lifespan of 7043 cycles, which is comparable to the 8000 cycle lifespan expectancy of the battery in the BoostCharger and Hummingbird, making it a suitable option for comparison. The size of the battery pack, 8.1 kWh also seemed credible. Additionally, the LCA conducted was cradle-to-gate, providing results of emissions from production to the point of entry the battery packs into the market. [63]

When calculating the emission from the production of batteries, start by determining the amount of CO_2eq generated during the manufacturing of battery packs. A systematic approach to this determination involves examining the quantity of battery packs required for each container. Each battery pack has a specified capacity of 8.1 kWh [63]. By dividing the total capacity of the container by the capacity of one battery pack, the number of battery packs necessary for each container can be determined. This is expressed in Equation 3.8.

$$\begin{gathered} BoostCharger : \frac{390\ kWh}{8.1\ kWh} = 48.2\ stk. = 48\ stk. \\ Hummingbird : \frac{192\ kWh}{8.1\ kWh} = 23.7\ stk. = 24\ stk. \end{gathered} \tag{3.8}$$

Considering the BoostCharger, which is equipped with NMC with a storage capacity of 390 kWh. By dividing this capacity by 8.1 kWh, the number of battery packs required for the BoostCharger is calculated to be 48.2 packs. Since the number of packs must be an integer, the value of 48 packs is selected, which results in an assumed capacity of the BoostCharger of 388.8 kWh, given the specified capacity of each battery pack.

The Hummingbird is equipped with NMC with a storage capacity of 192 kWh. To determine the number of battery packs required to achieve this capacity, Equation 3.8 shows that the total battery capacity is divided by 8.1 kWh. Based on this calculation, the Hummingbird would require 23.7 battery packs to reach its full storage capacity. Assuming a battery capacity of 194.4 kWh, the number of battery packs required would be rounded up to 24. [63]

Next, CO_2eq for one battery pack is calculated. To determine the emission from the manufacturing of one battery pack, the emission per unit of energy must be established. The manufacturing process for the battery pack generates 201 kg CO_2eq/kWh. The capacity of the pack is multiplied by the emission from manufacturing, as shown in Equation 3.9. This calculation has a result of 1 628.1 kg CO_2eq per battery pack. [63]

$$201\ kg\ CO_2eq/kWh \cdot 8.1\ kWh = 1628.1\ kg\ CO_2eq \tag{3.9}$$

Finally, to get the total CO_2eq for the BoostCharger and for the Hummingbird, the emission for each battery pack, as shown in Equation 3.9 is multiplied by the number of battery packs each container require, as shown in Equation 3.8. The calculation is presented in Equation 3.10. Based on this calculation, the BoostCharger, which requires 48 battery packs, has a manufacturing emission of 78 148.8 kg CO_2eq. The slightly smaller Hummingbird, which requires 24 battery packs, has a manufacturing emission of 39 074 kg CO_2eq.

$$\begin{aligned} BoostCharger:&\ 1628.1\ kg\ CO_2eq \cdot 48\ stk. = 78\ 148.8\ kg\ CO_2eq \\ Hummingbird:&\ 1628.1\ kg\ CO_2eq \cdot 24\ stk. = 39\ 074\ kg\ CO_2eq \end{aligned} \tag{3.10}$$

3.3.7 Emission from diesel production

The emission from diesel production was found from a LCA done by Statoil. This LCA was chosen because the diesel used in the LCA is norwegian, meaning that it is relevant for this thesis. [64]

In the calculation of the emissions resulting from diesel production there are different emissions to consider from the LCA of diesel production; energy consumption, CO, CO_2 and NO_x. The first is energy consumption. The energy consumption is measured in megajoules (MJ), so it is necessary to convert the energy consumption to kWh. This conversion is achieved by multiplying the total energy consumption by a conversion factor of 0.2778 [65]. The total energy consumption for diesel production is 1960 MJ and converted to 544.5 kWh, as shown in Equation 3.11 [64]. To determine the CO_2eq emissions, this value is multiplied by the Norwegian electricity mix [59]. This results in a total CO_2eq of 5.99 kg CO_2eq.

$$1960\,MJ\ \cdot 0.2778\,kWh/MJ\ =\ 544.5\,kWh \tag{3.11}$$

In order to calculate the CO_2eq for emissions of CO and CO_2, it is necessary to multiply the emissions by the relevant GWP factor. The GWP for CO ranges between 1.0 and 3.0, with a value of 2.0 used for ease of calculation. The CO_2eq emissions for CO_2 are equivalent to the emissions in CO_2, resulting in a 1:1 conversion factor. Applying these conversion factors, the CO emissions equals 0.046 kg CO_2eq, while those from CO_2 remain at 120 kg CO_2eq. For NO_x, the calculation results in 0.57 kg. [64] Table 4.1 shows an overview of the emissions from production on 1 000 liters diesel.

Table 3.1: The total emissions from the diesel production, obtained from [64]

	Emission	**Results [kg CO_2eq]**
Energy consumption	1960 [MJ]	5.99
CO_2	120 [kg]	120
CO	0.023 [kg]	0.046
NO_x	0.57 [kg]	-
SO_2	0.25	-
VOC	2.26	-
Sum:		**126.04**

The determination of the CO_2eq emissions resulting from the production of 1 000 liters of diesel involves the summation of emissions from CO, CO_2 and energy consumption. In order to determine the CO_2eq emissions for the production of a single liter of diesel, the total emission value is divided by 1,000, as shown in Equation 3.12. This calculation enables the environmental impact of diesel production in a standardized and comparable unit of measurement. Table 4.1 shows an overview over the relevant emission. [64]

$$Diesel\ [1l] = \frac{126.04\ [kg]}{1000\ [l]} = 0.126\ [kg/l] \tag{3.12}$$

The contribution of SO_2 and VOC to the overall emissions resulting from diesel production can be negligible, as their emission levels are so low that they are unlikely to significantly impact the final CO_2eq calculation. Therefore, the focus of emission reduction strategies primarily targets the major contributors to diesel production emissions, and those are CO, CO_2, and the energy consumption.

3.3.8 Emission from diesel engine production

The emission from diesel engine manufacturing is calculated from a LCA done in China. The materials is extracted in China and shipped to North America where the engine is assembled. This LCA was chosen due to the fact that the diesel engine is produced in China and the US, which are two countries that are big engine manufacturers. Additionally, because the LCA is a cradle-to-gate, the processes included are only the manufacturing of the diesel engine.

The total energy consumption is 2 296.21 kWh. Since the production is happening in North America, a electricity mix from North America is being used to calculate the CO_2eq. [66]

The electricity mix in North America is significantly higher in carbon emissions when compared to that of Norway. The North American electricity mix is estimated to be at 387.8 g CO_2eq/kWh. The carbon emissions can be attributed to the United States' power production. Specifically, the power production in North America is derived from a combination of sources, with 60.2% of the electricity generated from fossil fuels, 18.2% from nuclear, and only 21.4% from renewable energy sources. [67]

The electricity mix is multiplied by the total amount of energy consumption from the production of the diesel engine, as shown in Equation 3.13.

$$Diesel\ engine : 2296.21\ kWh \cdot \frac{387.8\ g\ CO_2eq/kWh}{1000} = 890.47\ kg\ CO_2eq \tag{3.13}$$

3.3.9 Comparisons

The emission saving from the operation is compared to emissions from other categories, for people to more easily understand the results. The categories used is annual emissions from diesel and gasoline cars, and a round trip Oslo - New York.

The emissions from driving a diesel and gasoline car for one year are found from Statistics Norway (SSB). The numbers from SSB are presented in Table 3.2. To find the CO_2eq the numbers are multiplied with the GWP. The GWP for CO_2 is 1, GWP for CH_4 is 25 and finally for N_2O it is 298 [68]. The sum of these is then multiplied 11 097 km, which is the average yearly distance driven by a passenger car in Norway, also obtained from SSB [69]. Then the emission saving is divided by the emission for the passenger cars, resulting in number of years it takes of a car driving to save up the emission savings for using the electric machines. The numbers will change according to the specific project.

Table 3.2: GHG emissions from diesel and gasoline passenger cars, obtained from [70]

	Fuel consumption [g/km]	CO2 [g/km]	CH4 [mg/km]	N2O [mg/km]
Diesel	49.99	156.47	7.68	1.64
Gasoline	41.04	130.09	0.56	4.39

The emissions from a round trip Oslo - New York by plane was found to be 1900 kg CO_2

[71]. Comparing the results are done similarly as for the passenger cars, with dividing the emission savings by the emissions from the flight.

When including the emissions from the life cycle the containers may not have a positive impact for some projects, seeing as for the electric construction sites the emissions are in the production phase of the containers, but for diesel powered construction sites the emissions come from the burning of diesel during operation. Therefore the model includes how many equivalent projects are needed for the emissions from the diesel-powered construction site to be higher than the emissions from the electric construction site. This shows how much the containers have to be used before it pays off in regards to emission savings. This is found by dividing the emissions from the electricity and the production of the batteries by the total emissions from diesel-powered construction site.

3.4 Assumptions and properties

In order to set a solid framework for the thesis, a number of assumptions have been made. The assumptions are built on the previous calculations Aneo have already made, and some are made specifically for this thesis. In addition, properties from Aneo is also used in the calculations.

3.4.1 Assumptions

The excel-model will calculate the estimated emission savings for future projects. These assumptions are made in order to make the calculations:

- **Working week**: During one week there is approximately 10 hours work per day, and there is 4 working days per week.
- **Diesel consumption**: It is estimated that a standard 10 tons construction machine consumes 3.75 liters diesel per hour of work. A 25 tons machine consumes 6.875 liters diesel per hour of work.
- **Diesel consumption in one week**: One week of one 25 tonne machine have a total emission of 731 CO_2eq and one 10 tonne machine have a total emission of 399 CO_2eq.
- **Working year**: One year of work on a project equals 42 weeks of 10 days of work.

Another assumption is that the electricity mix used in the projects is energy produced in Norway, so that the CO_2eq/kWh is 11 g. This is an increase from 2020, when it was at 8 g/kWh. This increase is caused by the oversea cable that links Norway and Germany. Germany has a higher consumption of fossil power, that is reflected in the emission calculations in Norway. Even though the factor has increased, it is still lower than the rest of Europe, with a CO_2-factor of above 300 g CO_2eq/kWh. The numbers are from NVE. [59]

Regarding the life cycle emissions from the charging containers, only the battery systems were taken into consideration. Assuming that the batteries will contribute with considerable more emissions than the rest of the components. This assumption is backed by a LCA done on a Battery Energy Storage System (BESS), which is a similar technology. This LCA shows that during manufacturing, the battery cells accounts for more than 70 % of the impact [72]. The battery systems, including a inverter and packaging will have an even larger impact. Seeing that the LCA for the charging containers used in this thesis is not available, by only looking at the battery system is a sufficient estimate. In addition, there is an assumption that the BoostCharger and Hummingbird contains 8.1 kWh battery packs [63].

The rebuilding process of electric engine in the study done by SINTEF is done on a 17.5 tonne machine, not a 10 or 25 tonne machine like the ones studied in this thesis. From the SINTEF study the results show that the emissions generated by rebuilding an electric engine on the 17.5 tonne machine is minimal, and therefore safely can be neglected. There is therefore made the assumption that this is the case for the 10 and 25 tonne machines as well, and the emission generated by rebuilding an electric engine is neglected in the calculations carried out in this thesis. [73]

3.4.2 Properties

The thesis relies on many properties, which are applied to various calculations throughout the methodology. This section provides a summary of all the properties utilized within the thesis. These properties form the foundation for the calculations and are essential for ensuring accuracy and reliability of the results obtained.

First, Table 3.3 presents the properties utilized in the computation of emission generated by a construction site during operation.

Table 3.3: Properties for calculating CO_2eq during operation

Parameter	**Value**	**Source**
Energy efficiency electric machine	85 %	SINTEF [2]
Energy efficiency diesel machine	30 %	SINTEF [2]
Energy density diesel	10.1 kWh/l	SNL [74]
CO_2eq per liter diesel	2.66 kg/l	Miljødirektoratet [62]
CO_2eq per kWh	11 g/kWh	NVE [59]

The next properties in Table 3.4 are used when calculating the NO_x emission during the operational phase.

Table 3.4: Properties for NO_x calculations

Parameter	**Value**	**Source**
Diesel density	0,85 [[kg/l]]	NOx-fondet [75]
NO_x-factor	5 [g/kg]	NOx-fondet [75]

The properties in Table 3.5 are used to when calculating the estimated diesel consumption and the estimated power consumption for a project in the future.

Table 3.5: Diesel and power consumption, the numbers are obtained from Aneo

Construction machine	**Diesel per hour**	**Energy consumption**
10 tonn	3.750 l/h	13.4 kWh/h
25 tonn	6.875 l/h	24.5 kWh/h

4 Results

The following section presents the results obtained from the study, with the aim of providing a clear and comprehensive overview of the findings. All of the methods utilized to find the results are presented in Chapter 3, Methodology. The results consists of results from three different LCA studies, Excel calculations and other relevant calculations.

4.1 Life cycle analysis of NMC battery

In 2020, a LCA was conducted on several lithium ion chemistry methods. The LCA was a cradle to gate analysis of an 8.1 kWh battery pack consisting of LFP-C, NMC-C, NCA-C, LMO-C, and NCO-LTO cathode chemistries. This thesis will focus primarily on the NMC-C battery pack, which is the one used to calculate the emission from the charging containers in this thesis. [63]

According to the LCA findings, the 8.1 kWh NMC battery pack was found to have an emission of 201 kg CO_2eq per kWh [63]. The calculations from 3.3.6 show that using the numbers from this LCA, the manufacturing from the batteries in the BoostCharger emits 78 148.8 CO_2eq while the Hummingbird emits 39 074 CO_2eq.

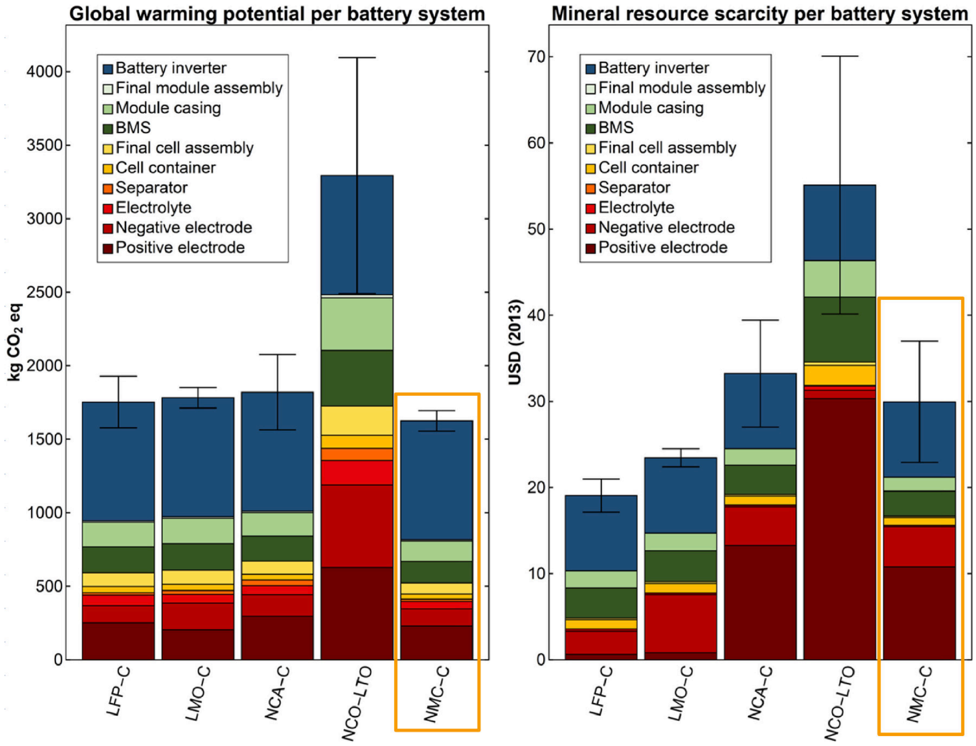


Figure 4.1: The GWP and resource scarcity per battery system

Figure 4.1 shows the global warming potential and the mineral resource scarcity (MRS) per battery system. Resource scarcity is when the demand for a natural resource exceeds the available supply of that natural resource. The NMC battery is the column to the far right in the figure. As shown in the figure, the inverter is responsible for most of the global warming potential, measured in CO_2eq. Regarding mineral resource scarcity (MRS), the positive electrode has the biggest impact. This is due to the nickel and cobolt used in the cathode. [63]

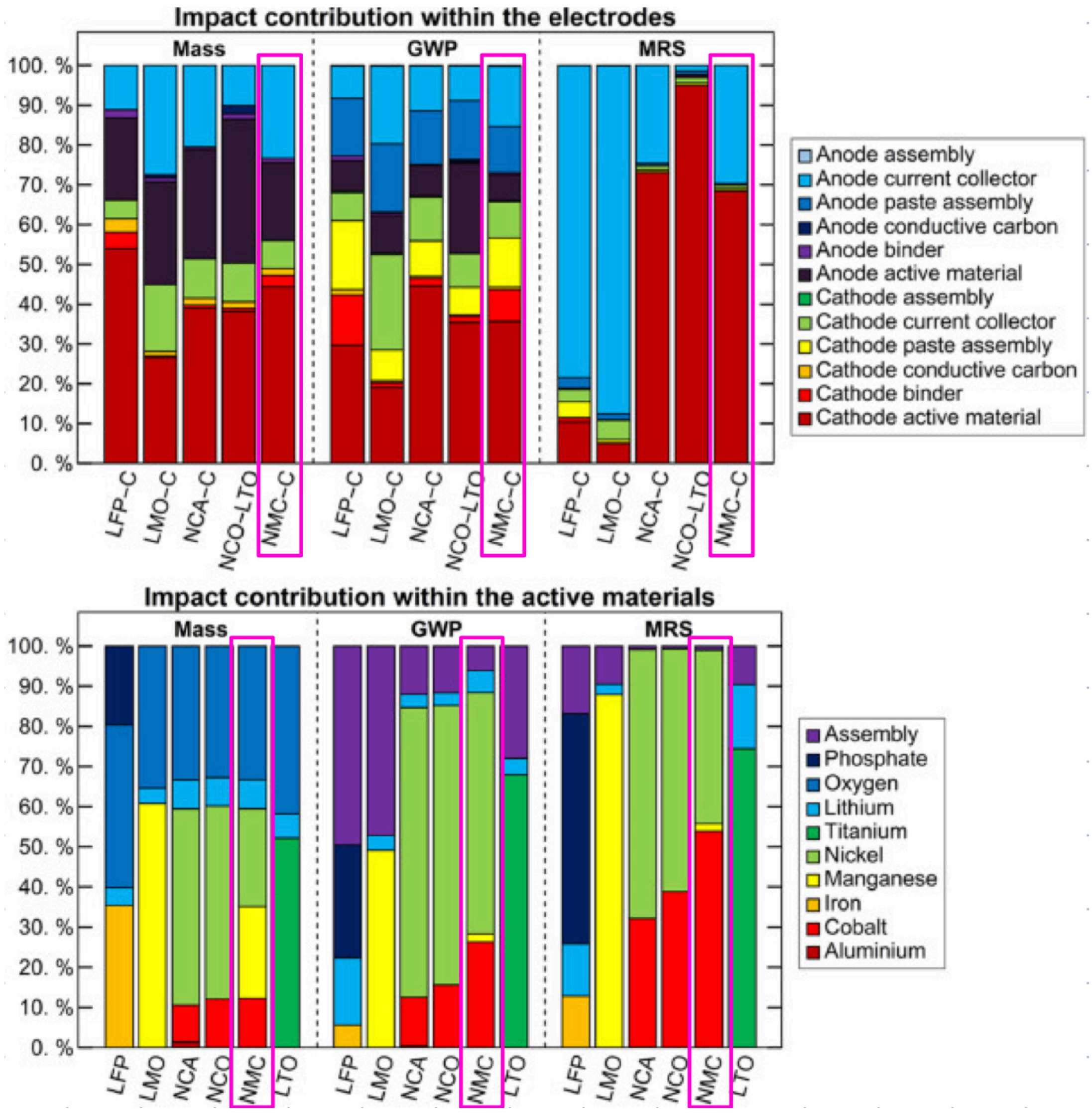


Figure 4.2: The impact contribution within the electrodes for mass, GWP and MRS

Figure 4.2 shows the impact contribution within the electrodes for mass, GWP and MRS. The cathode active material has the biggest impact across all the categories, biggest for MRS. For GWP the rest of the impact is divided relatively equally between multiple components. For MRS the anode current collector, made of copper, has the next biggest impact, and together with the cathode active material, makes up almost all of the impact on the mineral resource scarcity. The bottom graphs, with impact contribution within the active materials, confirm that it is the cobolt and nickel from the cathode that makes up mots of the impact on both the GWP and MRS. [63]

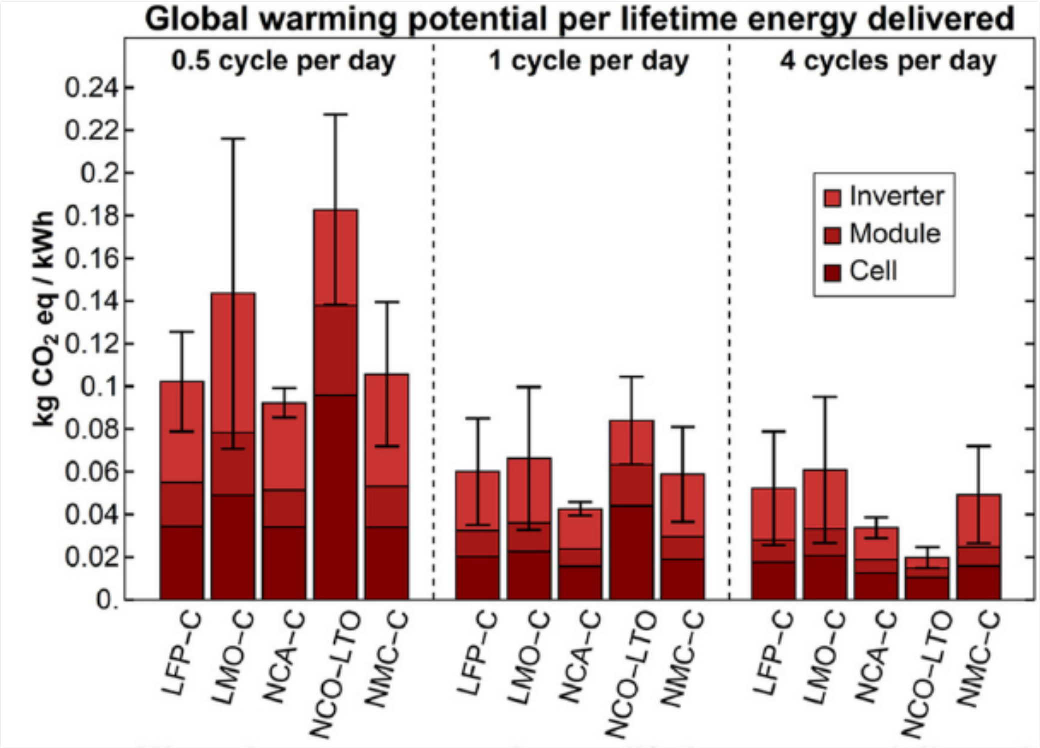


Figure 4.3: The impact the batteries has on GWP dependent on cycles.

Another result from the LCA is shown in Figure 4.3. The figure shows that the more cycles per day, the less impact per kWh, regarding both the GWP and MRS. Utilizing the battery frequently results in a lower impact per unit of energy delivered compared to using it frequently. For the NMC-C battery the impact is almost twice as much for 0.5 cycles per day compared to 4 cycles per day, while there is not much difference between 1 cycle per day and 4 cycles per day. This means that more than 1 cycle per day is ideal for the battery. [63]

4.2 Life cycle analysis of diesel production

Statoil did an analysis on Norwegian diesel, where they looked at the emission from production of 1000 liters of diesel. The diesel in this thesis is extracted on the Norwegian continental shelf (NCS). The fuel is assumed to be consumed in Norway. That makes the transportation of the diesel relatively short. The calculations in methodology shows that the emission from production of diesel is 0.126 kg/l combusted diesel including the CO_2eq from the energy consumption, CO and CO_2 like shown in Table 4.1. In addition NO_x emits 0.57 kg. [64]

Table 4.1: The total emissions from the diesel production, obtained from [64]

	Results kg CO_2eq
Energy consumption	5.99
CO_2	120
CO	0.046
Sum:	**126.04**

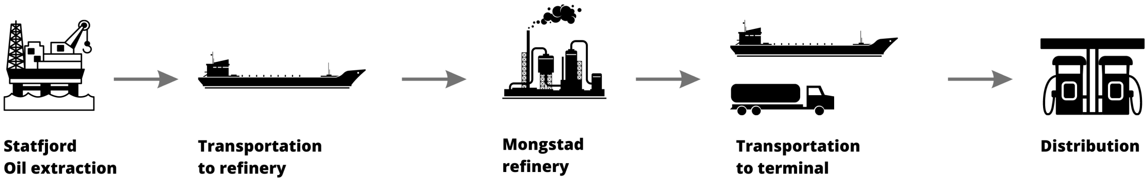


Figure 4.4: System description and boundaries

The production chain of diesel is divided into five different steps; oil extraction, transport to refinery, refining, transport to terminal and distribution. Energy consumption is largest at the refining step. The most emission of CO_2 is also at the refining step of the chain. While the largest emission of NO_x is during the transport to terminal before the distribution. There is a large emission of SO_2 during both refining and transportation to terminal. Emission of VOC is during the transportation to the refinery. The refinery and the oil production platform contributes most to emission of CO_2, while transport and distribution contributes most to SO_2, NO_x and VOC.

The potential environmental impacts of producing 1000 liters of diesel is relatively little. The main reasons for that is because the transport distance is short, the production facilities are strict when it comes to emission standards, and diesel have a low energy requirement overall during production. [64]

4.3 Life cycle analysis of diesel engine

Jinan Fuqiang power Co., Ltd, a Chinese engine manufacturing company analysed the life cycle of one diesel engine. The aim of the study is to analyze the energy consumption and the environmental impact associated with the life cycle of a diesel engine. Nonetheless, this thesis focuses solely on the manufacturing phase, the cradle-to-gate segment. [66]

There are different materials that goes into making a diesel engine, among them are steel, cast iron, aluminum, and alloy. These materials account for 98.9 % of the total materials in the engine. Other products is neglected due to the fact that the energy consumption and resources consumed in producing these materials are so low. The materials is transported from Shanghai to North America where the diesel engine is manufactured.[66]

The inventory list is divided into the different engine components; Cylinder block and head, craft shaft, connection rod, gear box, flywheel shell, flywheel, in addition to the components there is "others" as well. Lastly there is the energy consumption from assembling the engine. Table 4.2 shows the energy consumption of each of the different components. [66]

Table 4.2: Total energy consumption from manufacturing a diesel engine, the information is obtained from [66]

Engine components	**Energy consumption [kWh]**
Cylinder block and head	378.35
Crankshaft	291.26
Connection rod	58.69
Gear box	39.62
Flywheel shell	36.09
Flywheel	21.44
Other	922.35
Assembly	548.41
Total:	**2296.21**

The analysis reveals that the production of a single diesel engine utilizing the current North American electricity mix results in a total emission of 890.47 kg CO_2eq. Most of the emissions comes from the assembly phase and the category labeled as "other". "Other" is for example bolts, water pump, belt pulley and so on. [66]

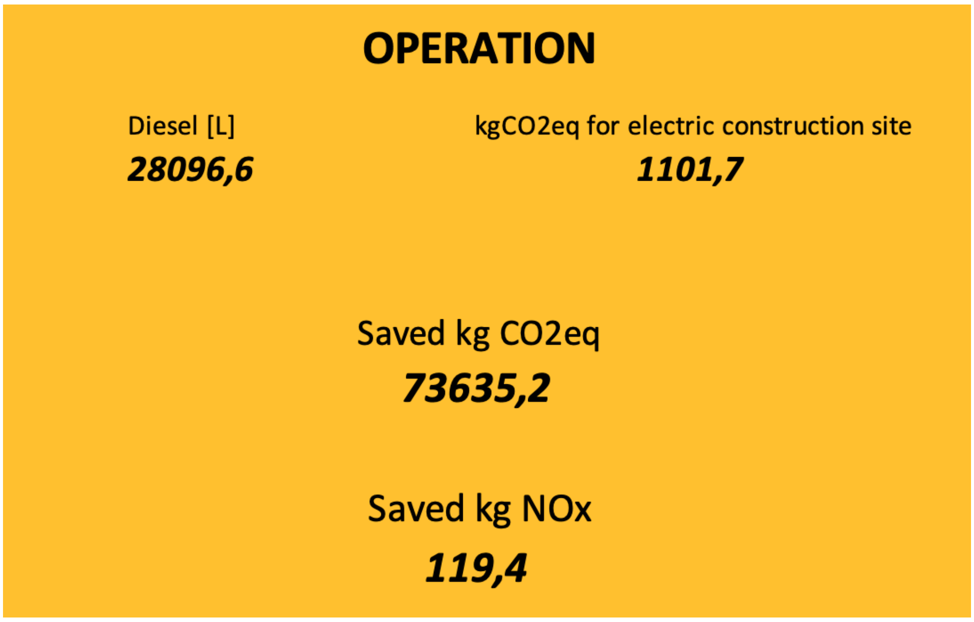
In the comprehensive assessment of the life cycle of a diesel engine, the production phase does not contribute the most to the total emissions. In fact, this phase only accounts for approximately 5% of the overall emissions from the life cycle of a diesel engine. Instead, a significantly higher proportion of emissions comes from the combustion of diesel fuel during the operational phase of the vehicle. [66]

4.4 Model for started project

In this section is the results from the analysis of the Petersrønningen project done in the excel model. The model is divided into two different sections. One section looks exclusively at the emission during operation and the second section looks at the total emission for the whole project.

4.4.1 Emission savings during operational phase

The first section in the Excel model is the emission savings during a project's operational phase. That means the project actual on-site emission. Essentially, it only considers the emission from combustion of diesel and the emission from the energy consumption. The important information needed to do these calculations is the amount of energy consumed, which is an input in the model. This number is used to calculate the amount of diesel this would correspond to, and how much emission is saved by selecting the electric option.



OPERATION

Diesel [L]
28096,6

kgCO2eq for electric construction site
1101,7

Saved kg CO2eq
73635,2

Saved kg NOx
119,4

Figure 4.5: Results of emission savings during the operational phase

The project's overall energy consumption has a total of 100 156 kWh, that equals 28 096.57 liters of diesel. The total emission from the on-site combustion of diesel in the diesel-powered construction machines are 74 736.87 kg CO_2eq. The CO_2eq for the complete emission from the energy combustion is the amount of energy multiplied by the emission factor for the Norwegian electricity. That equals 1101.7 kg CO_2eq. So the final emission savings for the Petersrønningen project during operation is 73 635.15 kg CO_2eq, like illustrated in the Figure 4.5 which shows the excel model. In addition to the CO_2eq, is also the NO_x emission from combustion of diesel included. In the Petersrønningen project that is 119.4 kg.

The comparisons used to make the project more understandable is shown in Figure 4.6. These results show how much the results from the operation corresponds to in other categories. The emission saving during operation is, as mentioned before, 73 635,2 kg CO_2eq. The first comparison is as shown in the figure, annual consumption of diesel and gasoline cars. The emission savings during operation corresponds to 50 diesel cars and 42 gasoline cars driving for a year in Norway.

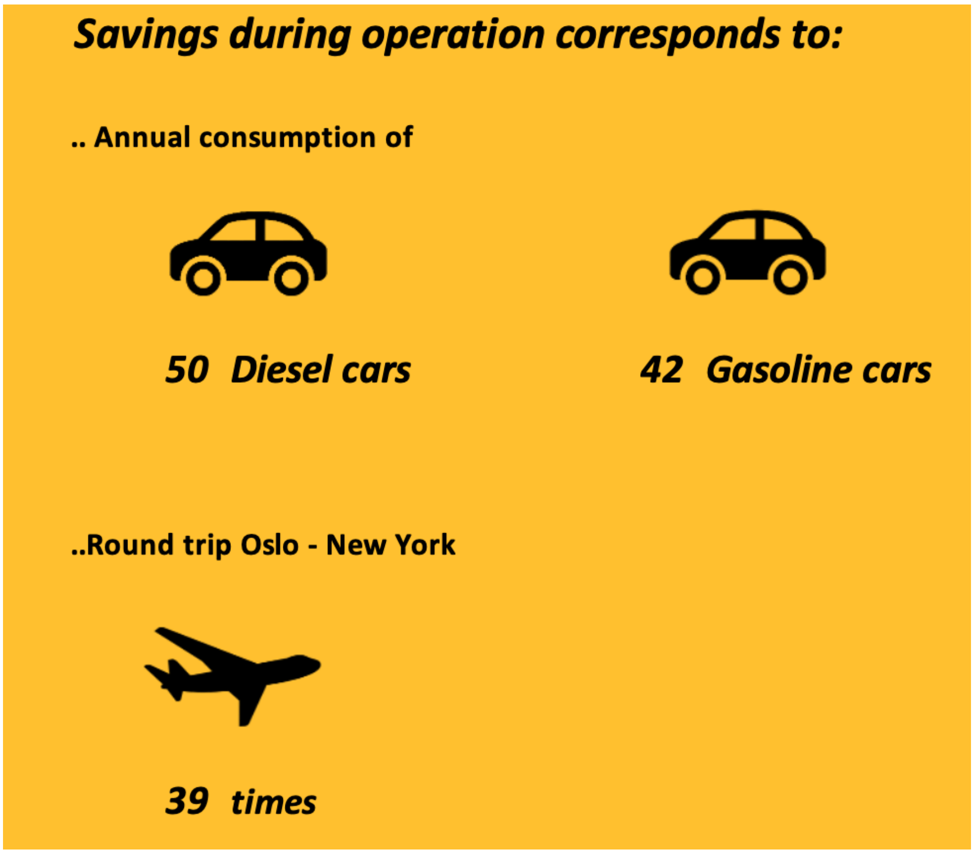
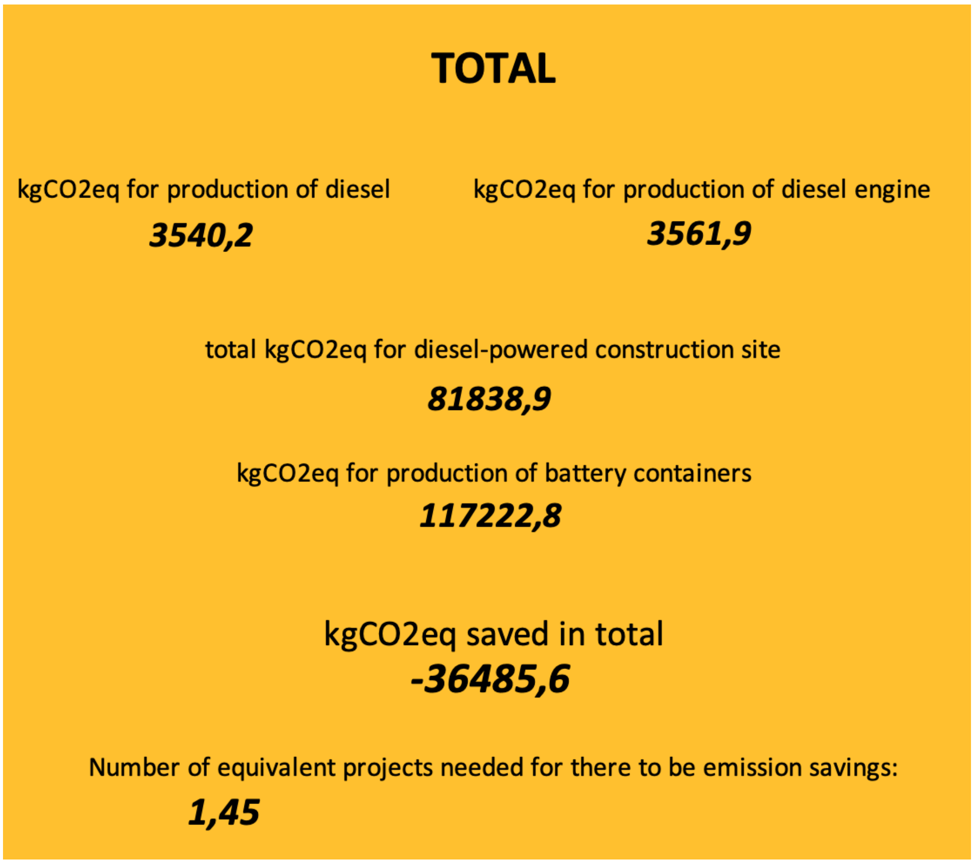


Figure 4.6: Comparisons the emission savings during the operational phase

The second compare how many round trips Oslo - New York is needed to make up the emissions during operation in the Petersrønningen project. As shown in Figure 4.6, the emissions corresponds to flying Oslo - New York round trip 49 times.

4.4.2 Emission savings from the total life cycle

The total section of the excel model shows the emissions from the whole life cycle of the diesel, diesel engine and the charging containers. This is to get an idea of the total environmental impact of the different scenarios. As mentioned, the production of the charging container has a higher impact than the production of the diesel and the diesel engine. This section is therefore important to see if switching to electric actually pays off. The results can be seen in Figure 4.7.



TOTAL

kgCO2eq for production of diesel
3540,2

kgCO2eq for production of diesel engine
3561,9

total kgCO2eq for diesel-powered construction site
81838,9

kgCO2eq for production of battery containers
117222,8

kgCO2eq saved in total
-36485,6

Number of equivalent projects needed for there to be emission savings:
1,45

Figure 4.7: Total emission savings from the complete life cycle of the construction sites

The Petersrønningen project used a total of 100 156 kWh during the project. This equals to 28 096.57 litres of diesel. Using the LCA for production of diesel, this equals to 3540.2 kg CO_2eq. The project also used 4 construction machines, 2 of the 10 tonne machines and 2 of the 25 tonne machines. This equals 2561.88 kg CO_2eq for the production of the diesel engines used during the project. This, along with the emissions from the burning of the diesel, gives the total CO2 emissions for the project if it was diesel-powered, which equals 81 838.9 kg CO_2eq.

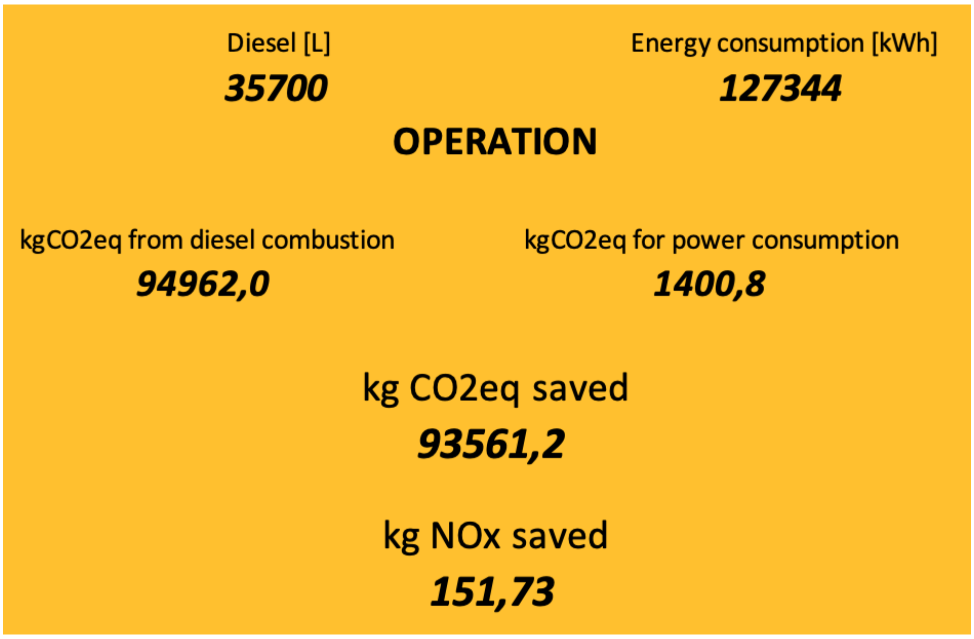
The project used two charging containers, one BoostCharger and one Hummingbird. As shown in Figure 4.7, the emission from the production of these is 117 222.8 kg CO_2eq. That makes the kg CO_2eq saved in total for the whole life cycle -36 485.6, which means that the project released more emissions than it saved. There is also included how many equivalent projects needed for the life cycle impact to be less than that of the diesel-powered construction site. For Petersrønningen, you have to repeat the project 1.45 times for the life cycle impact to be less than that of the diesel construction site.

4.5 Model for future project

In this section is the results from the analysis in excel of the estimated emission for the Petersrønningen project. Similar to the analysis of the started project, this analysis is divided into two sections, the operational phase and the total emission.

4.5.1 Emission savings during operational phase

Figure 4.9 shows the emissions savings during the operational phase.



Diesel [L]
35700

Energy consumption [kWh]
127344

OPERATION

kgCO2eq from diesel combustion
94962,0

kgCO2eq for power consumption
1400,8

kg CO2eq saved
93561,2

kg NOx saved
151,73

Figure 4.8: Emission savings during the operational phase for future projects

The first results are looking at the emission during the operational phase. The total diesel consumption and energy consumption is calculated from the inputs. The diesel consumption is 35 700 liters and the energy consumption is 127 344 kWh. The diesel combustion equals 94 962.0 kg CO_2eq emission, and the energy consumption equals 1400.8 kg CO_2eq emission. The on-site emission for the operational phase is the emission from diesel combustion subtracted by the emission from energy consumption. That equals 93 561.2 kg CO_2eq, as illustrated in Figure 4.8. In addition the NO_x emission for the future project is 151.73 kg CO_2eq.

The comparisons in Figure 4.9 shows the results from the operational phase. The emission savings of 93 561.2 kg CO_2eq equals the average annual consumption of fuel in 64 diesel cars and 54 gasoline cars. The emission savings equals a round trip by plane Oslo - New York 49 times.

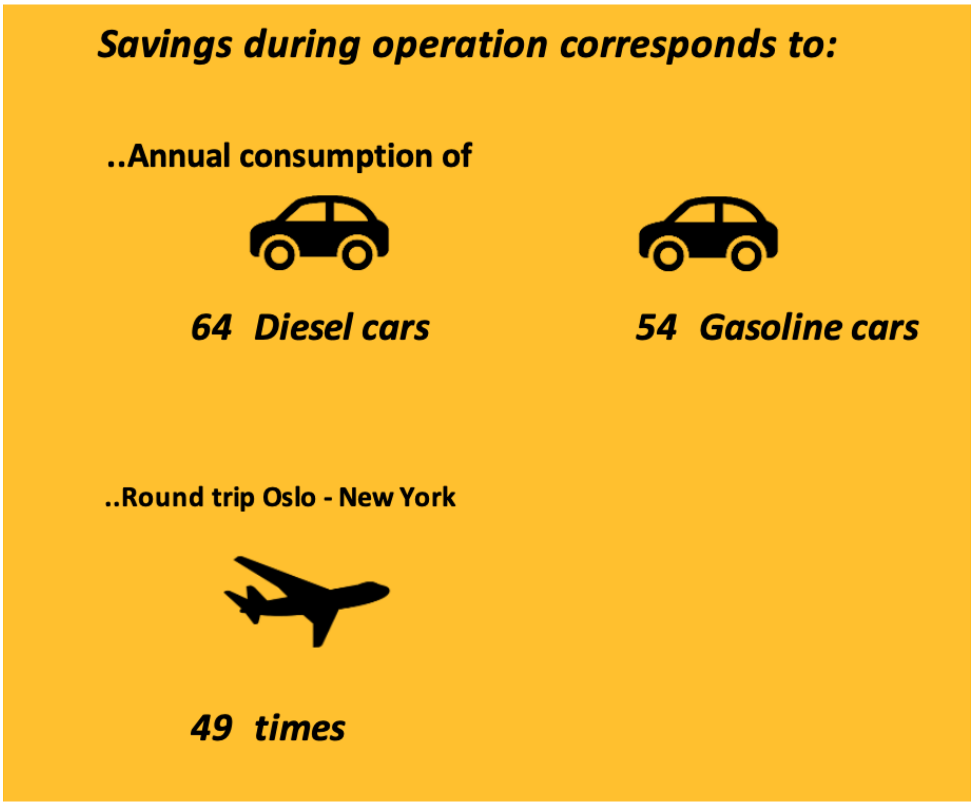
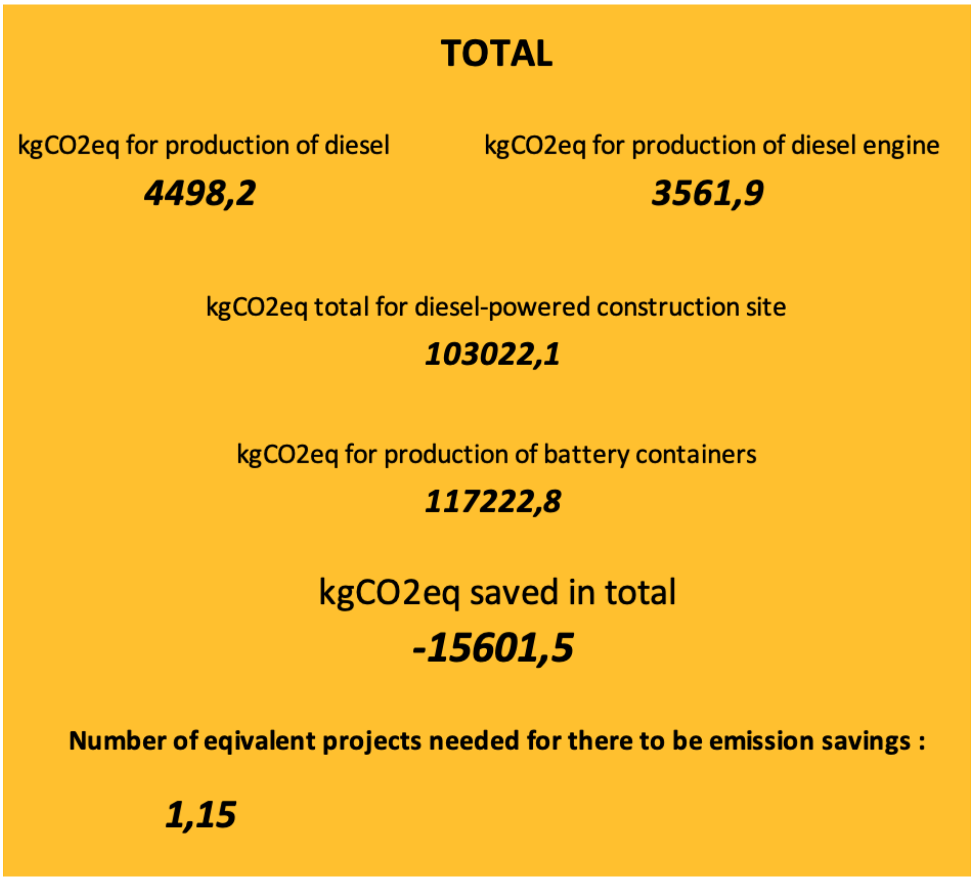


Figure 4.9: Comparisons of the results from emission savings from the operational phase for future projects

4.5.2 Emission savings from the total life cycle

Figure 4.10 shows the total emission savings including the life cycle of the charging containers and the diesel and diesel engines. The project used 2 10 tonne machines and 2 25 tonne machines. The emission for the production of the diesel engines in these machines is 3561,88 kg CO_2eq. For the future project the diesel used is calculated to be 117 600 litres. The production of this diesel equals 4498.2 kg CO_2eq. Along with the burning of the diesel, the emissions from the diesel-powered construction site is 103 022.1 kg CO_2eq.

The project used two charging containers, one BoostCharger and one Hummingbird. As shown in Figure 4.8, the project used 127 344 kWh. The emissions from the two charging containers equals 117 222.8 kg CO_2eq. This gives the total emission saved to be -15 601.5 kg CO_2eq.



TOTAL

kgCO2eq for production of diesel

4498,2

kgCO2eq for production of diesel engine

3561,9

kgCO2eq total for diesel-powered construction site

103022,1

kgCO2eq for production of battery containers

117222,8

kgCO2eq saved in total

-15601,5

Number of eqivalent projects needed for there to be emission savings :

1,15

Figure 4.10: Total emission savings from the complete life cycle of future construction sites.

This model also demonstrates the number of equivalent projects for the life cycle impact to be less than that of the diesel construction site. In the case of this project, the future model indicates that only 1.15 projects need to be completed, implying that the electric construction site has to repeat 15% of the project for the electric solution to be beneficial.

5 Discussion

This chapter presents a discussion of the results that were previously presented in Chapter 4, Results. Firstly, the batteries in the charging containers are discussed, then the Excel model for finished projects, and the model for projects in the future. Next is the advantages and challenges associated with the on-site working environment and lastly the power grid. Overall, this chapter aims to highlight both the positive and the negative aspects to the results, and provide a clear understanding of their implications.

5.1 Batteries

As presented in Chapter 4.1, the production of the NMC batteries have quite a large amount of emission. The results took both GWP and MRS into consideration. In regards to the whole battery system, the battery inverter and the positive electrode, or the cathode, had the most impact both on the GWP and the MRS. The cathode had an even higher impact on the MRS. Even though NMC is the focus of this thesis, when looking at the other cathode materials pictured in the results, it is clear that the NMC has a slightly lower GWP per battery system than the other cathode materials, which substantiates the choice of using NMC.

The reason behind the cathode having the highest impact on MRS can be seen by examining the contribution of the active materials. Among these materials, nickel and cobalt accounted for a significant portion of the impact. A similar trend was observed for GWP, where nickel had the highest impact followed closely by cobalt. In the case of most cathode materials, the cathode contributed with the highest impact. Although substituting these materials with less impactful alternatives would be beneficial, currently this is not an alternative.

5.2 Model for finished project

The model for finished project discusses the results from emission savings from the the excel model where the energy consumption is already known. The model shows the real emission savings both from the operational phase and the total emission savings where the LCAs for battery production, diesel production and diesel engine manufacturing are included in the calculations.

5.2.1 Emission savings during operational phase

This section discusses the results from operational phase of the Petersrønningen project. The first calculation in the model for finished project is the emission from diesel combustion. In Petersrønningen project the emission is 74 736.9 kg CO_2eq from 28 096.6 liters of diesel. In the life-cycle of diesel, it is during combustion that there are by far the most emission. This supports the large amount of emission generated from diesel combustion during operation. That large amount of emission can make it unpleasant to work on a construction site.

The emission from electric energy consumption is 1 101.7 kg CO_2eq. This makes the emission savings from the project 73 635.2 kg CO_2eq. The majority of electricity production in Norway come from hydropower, which makes the emission factor for the electricity mix small compared to the rest of Europe. Due to the hydropower, it is beneficial to use the Norwegian power. Due to the substantial emissions generated by diesel combustion and the low emissions resulting from energy consumption, the operational phase offers significant emission reduction. This large contrast emphasizes the environmental benefits associated with utilizing electric machines.

The emission of NO_x from combustion of diesel is 119.4 kg, which a substantial amount due to the amount of diesel combusted. Reducing NO_x emissions is beneficial for environmental protection and public health. By reducing NO_x it decreases the effect NO_x has on the ozone layer around the earth. Reducing the NO_x will also decrease the poor air quality. In general, NO_x emissions are a major contributor to air pollution. Therefore, any amount of NO_x emissions should be minimized to the greatest extent possible. The utilization of electric machines has demonstrated significant benefits both for the environment and the work environment, owing to their complete absence of NO_x emissions.

The purpose of comparing operational emissions is to provide a relatable reference point for people to understand the results. The average person often struggles to grasp the extend of 74 000 kg CO_2eq emissions. Using cars is something most people have experience with, so this provides a better understanding of the results. Plane rides is also something people associate with large emissions, so comparing to this shows the magnitude of the emission savings. This is also included due to the fact that the model is for Aneo to show to their customers. The reference points will give their customers a deeper understanding of the results.

5.2.2 Emission savings from the total life cycle

The total section of the results includes the LCAs to show the total emissions from the life cycles. When looking just at the emissions from the production and not the operation, the emission savings are shown as negative, which means that the emissions from the charging container is significantly higher than the production of the diesel and diesel engine. That means that in the early life of the charging container, it will be the less environmental option. From the diesel powered construction site, the majority of the emissions will come from the combustion of diesel, not the production. Therefore, the impact will start low, but rise during the operation. On the other hand, the electric construction site has close to none emission from the operation. The electric construction site will have a high impact production, but during operation it will flatten out.

It may look like the diesel-powered construction site is the better solutions due to these results, but the life cycle emissions from the diesel site is expected to surpass that of the electric site during the life span of the charging containers, which is 10 years.

To show this, the results include how many equivalent projects are needed for the life cycle emissions from the electric construction site to be less than that of the diesel construction site. For the Petersrønningen project, that number is 1.45, meaning that the project need to be repeated 1.45 times to be the more environmentally friendly option. The Petersrønningen project had a duration of 1 year, which means that the charging container would only need to operate 1,45 years to be the better option emission-wise. With a life time of 10 years, these results show that the electric construction site is clearly the optimal choice from an environmental perspective.

These results are very favorable to the electric construction site, as the emission savings are substantial. In reality, the savings will most likely be a little smaller. The LCA used for the batteries included the battery system, which forms part of the charging container. However, there are several other components in the container that were not accounted for in the used LCA. The thesis made the assumption that the batteries will stand for the majority of the emissions. The other components will most likely not change the results very much, but the emissions will be slightly higher from the production of the containers.

5.3 Model for future project

This section discusses the model for future projects. Like the analysis for finished or started projects this analysis is also divided into two sections, emission savings during the operational phase of the project, and emission savings in total.

The future project's results are based on the same calculations as the completed project, and so the discussions from the previous section will also apply to these results. Therefore, the differences between the two models will be examined in this section.

The results from the operation in the model for future projects are little higher than the results from the finished project, with savings of 93 561.2 kg CO_2eq, from 35 700 l diesel. For the finished project, the diesel that would have been used was 28 096.6 l, which equals emission saving of 73 635.2 kg CO_2eq. That means that the project seems slightly better in terms of emission savings when looking at both the operation and the total results. The main difference is in the operation phase, seeing as the project uses the same amount of construction machines and charging containers, the difference is in the amount of diesel combusted, and therefore also the production of this diesel.

As the calculations for emissions savings from the two models are the same, the difference is the inputs. In the future model the estimated time used on the project is entered, and the diesel/electricity use is calculated from this. Using the amount of time the actual Petersrønningen project took, the results should be the same. The differences can be explained due to the machines not always running on full capacity, which makes the future model slightly too high. The results will therefore present the maximum potential of saving if the machines are run on full capacity for the duration of the project.

5.4 On-site

The charging time of the electric construction machines presents a potential challenge with the electric option. On average, these machines require approximately 80 minutes to charging time, with variations based on machine size. For projects with limited time, or on a time schedule, the need for charging can be an inconvenience. In regards to this, the diesel-powered construction site has an advantage, seeing as refueling with diesel does not require much time compared to charging the electric machines. Ideally, the charging time should be reduced to a mid-day charge during lunch breaks to gain efficiency. For some of the smaller machines, this is already possible.

An advantage that results from electric machines is that they do not pollute the local air quality. There is no emission of GHG, NO_x, CO, SO_2, PM or NMVOC (also VOC) that pollutes the local air quality on-site. This leads to significant health benefits for the local population and on-site workers. The reduction in emission is crucial as these pollutants can have a profound impact on the environment and human health, with some of the gases being toxic and harmful when present in large quantities. So to reduce them in any possible way is positive.

Electric construction machines are often described as silent, although they do produce some noise. However, they generate significantly less noise compared to the diesel-powered construction machines. This makes it easier to communicate on site and fewer people developing hearing damage as a result of the loud noises. Another advantage is that since the machines do not require diesel, engine oils or other fuels. Resulting in less spillage directly into nature. The electric machines contribute to a cleaner working place, that benefits both the working environment and the nature.

5.5 Power grid

The electric option is not only more environmental friendly, but it can also provide assistance to the power grid. The construction sector is headed into a phase where everything is electrified. That will result in a substantial increase in the demand for power. The charging containers can relieve the power grid of the large power demands. By charging the containers on a low capacity during off-peak hours, over the night, the demand peaks are avoided. This can make the containers attractive not only in the construction sector, but also for other uses.

The charging container can also help to protect the power grid from any damages from high electricity flow, by reducing the need for rapid charging from the grid.

The power grid may not be able to handle the demand for power with high capacity in the rural areas. By utilizing the containers, it is possible to avoid the development of the power grid, which can cost the government a significant amount of money. This makes it easier to carry out projects in said areas, making access to power more accessible. Also the electricity from the power grid is cheaper during the off-peak hours which is economically beneficial.

For Norway to be able to reach the goal of emission-free construction sites by 2030 is it necessary to have a smart solution to the high electricity demand that will occur in the future. Using charging containers where the electricity can be stored, will insure a stable flow of electricity when needed. That is crucial for an electric construction site so that everything can run smoothly.

6 Conclusion

The objective of this thesis was to improve the calculations used to determine emissions savings resulting from electric construction sites compared to diesel-powered construction sites. This was executed by looking at both the emissions during the operation phase and the total life cycle.

Three different LCAs were included in the data collection, one for a diesel engine, one for diesel production and one for a NMC battery pack. These LCAs were analysed, and the results show that the production of one BoostCharger emitted 78 148,8 kg CO_2eq, and the production of one Hummingbird emitted 39 074 kg CO_2eq. The production of one diesel engine emitted 890.47 kg CO_2eq, while production of 1 liter of diesel emitted 0.127 kg CO_2eq. The amount of emission of the battery containers in the production phase was much larger than for the diesel and the diesel engine, but the electric construction site had a significantly lower emission during the operational phase.

The three LCAs were included in the Excel model to calculate the emission savings both for the model estimating the emission savings for a future project, and the model calculating the exact emission savings from a project. Based on an analysis of a project previously carried out by Aneo, it was found that the emission savings during the operational phase generally was larger than the emission savings from the complete life cycle. When looking at the complete life cycle of the reference construction site, the diesel option was more environmentally friendly than the electric option. But if the project was to be repeated half a time more, the electric site would surpass the diesel-powered site and be the more environmental friendly option.

The study has looked at some advantages that comes from using charging containers, but also some challenges. The containers can help relieve the power grid, by charging them during off-peak hours. This can help to avoid the peak demand, and make construction possible in remote areas with limited power grid. The reduced emissions on the construction site also works to improve the work environment, with better air quality and reduced noise levels. The primary challenge lies in the charging process. Rapid charging of the batteries can be done during the lunch break so the limitations are not to big, but it is still a limiting factor compared to diesel-powered machines. Regardless, the advantages makes up for the challenges, and for Norway to reach the goal of emission-free construction sector, the charging containers are necessary.

The model confirmed a significant reduction in emission by using battery containers compared to diesel. This makes the model valuable for Aneo, because they can showcase these emission savings to their costumers.

7 Scope for future work

This section present the scope for future work to improve the emission saving calculations done in this thesis, if it where to be continued.

In this thesis, only a part of the battery containers are being taken into account. To make the calculations more accurate in the future, the scope for future work would include looking at emission from the complete life cycle analysis of the two different charging containers. The life cycle analysis used in the thesis is a part of the data collection, but for future work life cycle analysis should be done for every component.

To get the most accurate results, an LCA should be done on these specific containers. This would further increase the reliability of the results.

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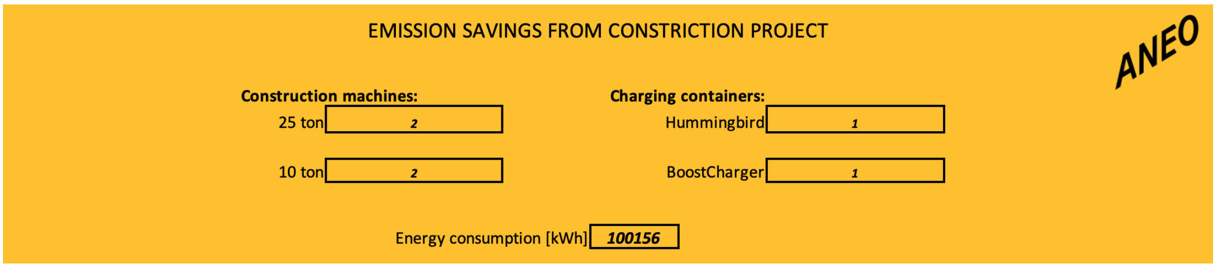
Appendix

A Excel model



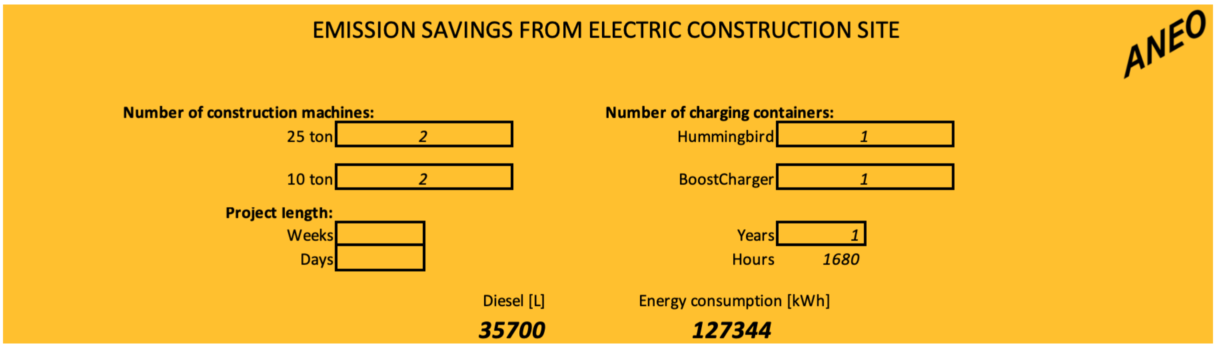
EMISSION SAVINGS FROM CONSTRICTION PROJECT

Construction machines:
25 ton 2
10 ton 2

Charging containers:
Hummingbird 1
BoostCharger 1

Energy consumption [kWh] 100156

Figure A.1: Excel model, header from finished project



EMISSION SAVINGS FROM ELECTRIC CONSTRUCTION SITE

Number of construction machines:
25 ton 2
10 ton 2

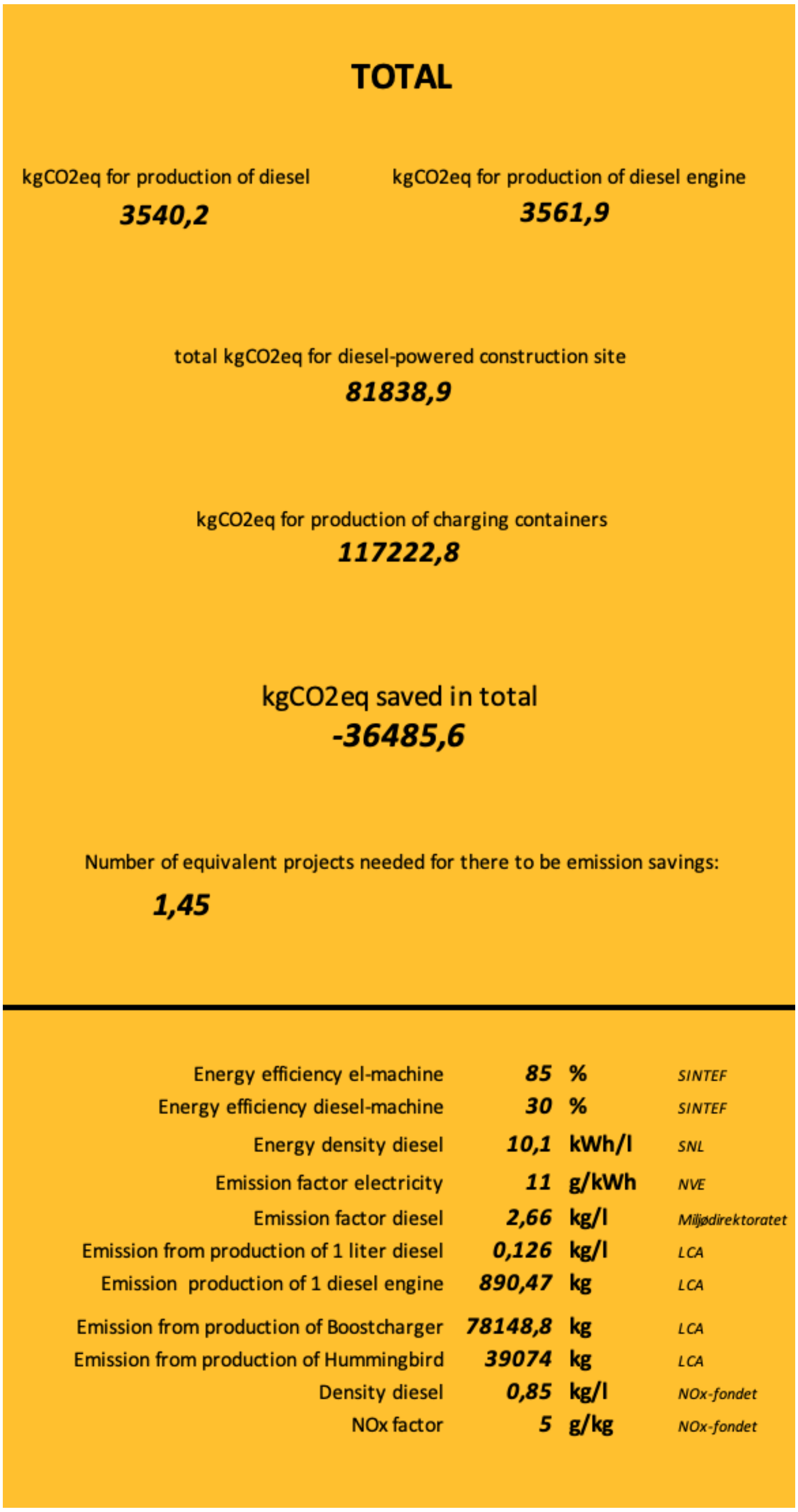
Number of charging containers:
Hummingbird 1
BoostCharger 1

Project length:
Weeks
Days

Years 1
Hours 1680

Diesel [L] 35700
Energy consumption [kWh] 127344

Figure A.2: Excel model, header from future project



TOTAL

kgCO2eq for production of diesel
3540,2

kgCO2eq for production of diesel engine
3561,9

total kgCO2eq for diesel-powered construction site
81838,9

kgCO2eq for production of charging containers
117222,8

kgCO2eq saved in total
-36485,6

Number of equivalent projects needed for there to be emission savings:
1,45

Energy efficiency el-machine	**85**	**%**	*SINTEF*
Energy efficiency diesel-machine	**30**	**%**	*SINTEF*
Energy density diesel	**10,1**	**kWh/l**	*SNL*
Emission factor electricity	**11**	**g/kWh**	*NVE*
Emission factor diesel	**2,66**	**kg/l**	*Miljødirektoratet*
Emission from production of 1 liter diesel	**0,126**	**kg/l**	*LCA*
Emission production of 1 diesel engine	**890,47**	**kg**	*LCA*
Emission from production of Boostcharger	**78148,8**	**kg**	*LCA*
Emission from production of Hummingbird	**39074**	**kg**	*LCA*
Density diesel	**0,85**	**kg/l**	*NOx-fondet*
NOx factor	**5**	**g/kg**	*NOx-fondet*

Figure A.3: Excel model "TOTAL" from finished project

OPERATION

Diesel [L]
28096,6

kgCO2eq for electric construction site
1101,7

Saved kg CO2eq
73635,2

Saved kg NOx
119,4

Savings during operation corresponds to:

.. Annual consumption of

50 Diesel cars

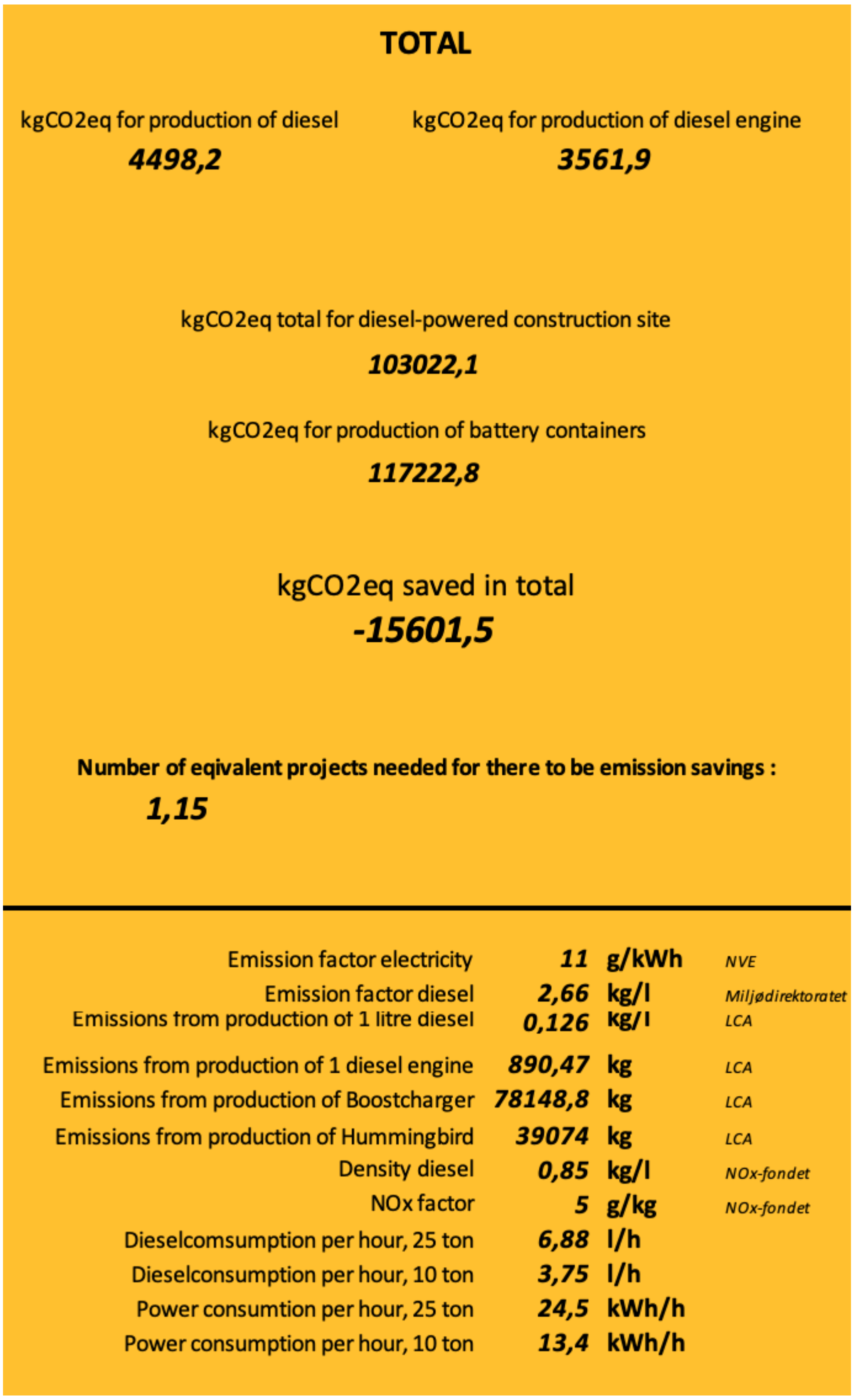
42 Gasoline cars

..Round trip Oslo - New York

39 times

Annual emission from cars			
Gasoline	*1743,9*	kgCO2eq/year	SSB
Diesel	*1458,28*	kgCO2eq/year	SSB
Emission from airplane			
Round trip Oslo - New York	*1900*	kgCO2eq	Borgar Aamaas

Figure A.4: Excel model "OPERATION" from finished project



TOTAL

kgCO2eq for production of diesel
4498,2

kgCO2eq for production of diesel engine
3561,9

kgCO2eq total for diesel-powered construction site
103022,1

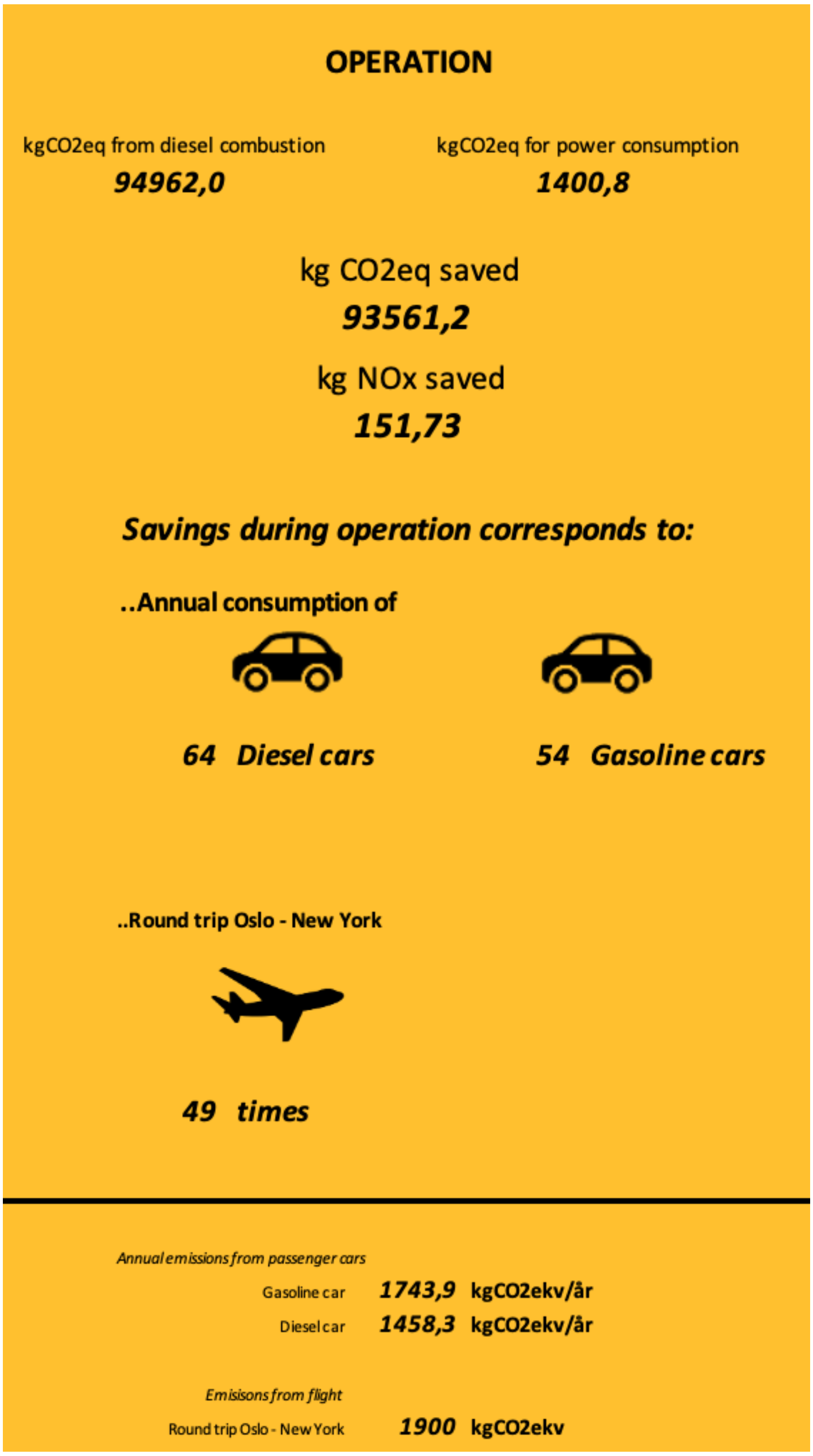
kgCO2eq for production of battery containers
117222,8

kgCO2eq saved in total
-15601,5

Number of eqivalent projects needed for there to be emission savings :
1,15

Emission factor electricity	**11**	**g/kWh**	*NVE*
Emission factor diesel	**2,66**	**kg/l**	*Miljødirektoratet*
Emissions from production of 1 litre diesel	**0,126**	**kg/l**	*LCA*
Emissions from production of 1 diesel engine	**890,47**	**kg**	*LCA*
Emissions from production of Boostcharger	**78148,8**	**kg**	*LCA*
Emissions from production of Hummingbird	**39074**	**kg**	*LCA*
Density diesel	**0,85**	**kg/l**	*NOx-fondet*
NOx factor	**5**	**g/kg**	*NOx-fondet*
Dieselcomsumption per hour, 25 ton	**6,88**	**l/h**	
Dieselconsumption per hour, 10 ton	**3,75**	**l/h**	
Power consumtion per hour, 25 ton	**24,5**	**kWh/h**	
Power consumption per hour, 10 ton	**13,4**	**kWh/h**	

Figure A.5: Excel model "TOTAL" from future project



OPERATION

kgCO2eq from diesel combustion
94962,0

kgCO2eq for power consumption
1400,8

kg CO2eq saved
93561,2

kg NOx saved
151,73

Savings during operation corresponds to:

..Annual consumption of

64 Diesel cars

54 Gasoline cars

..Round trip Oslo - New York

49 times

Annual emissions from passenger cars

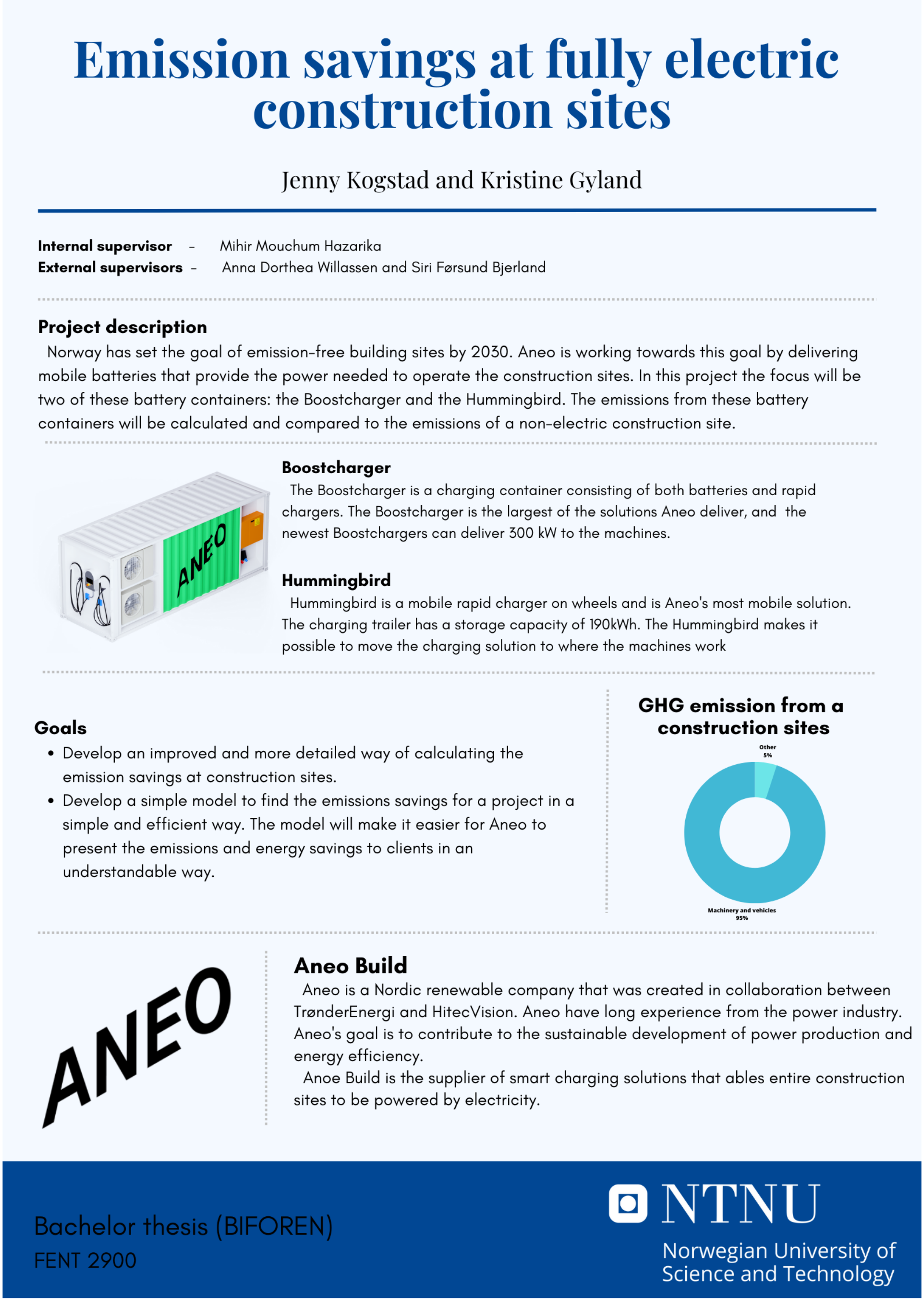
Gasoline car	***1743,9***	**kgCO2ekv/år**
Diesel car	***1458,3***	**kgCO2ekv/år**

Emissions from flight

Round trip Oslo - New York	***1900***	**kgCO2ekv**

Figure A.6: Excel model ”OPERATION” from future project

B Poster



Emission savings at fully electric construction sites

Jenny Kogstad and Kristine Gyland

Internal supervisor – Mihir Mouchum Hazarika
External supervisors – Anna Dorthea Willassen and Siri Førsund Bjerland

Project description

Norway has set the goal of emission-free building sites by 2030. Aneo is working towards this goal by delivering mobile batteries that provide the power needed to operate the construction sites. In this project the focus will be two of these battery containers: the Boostcharger and the Hummingbird. The emissions from these battery containers will be calculated and compared to the emissions of a non-electric construction site.

Boostcharger

The Boostcharger is a charging container consisting of both batteries and rapid chargers. The Boostcharger is the largest of the solutions Aneo deliver, and the newest Boostchargers can deliver 300 kW to the machines.

Hummingbird

Hummingbird is a mobile rapid charger on wheels and is Aneo's most mobile solution. The charging trailer has a storage capacity of 190kWh. The Hummingbird makes it possible to move the charging solution to where the machines work

Goals

- Develop an improved and more detailed way of calculating the emission savings at construction sites.
- Develop a simple model to find the emissions savings for a project in a simple and efficient way. The model will make it easier for Aneo to present the emissions and energy savings to clients in an understandable way.

GHG emission from a construction sites

Aneo Build

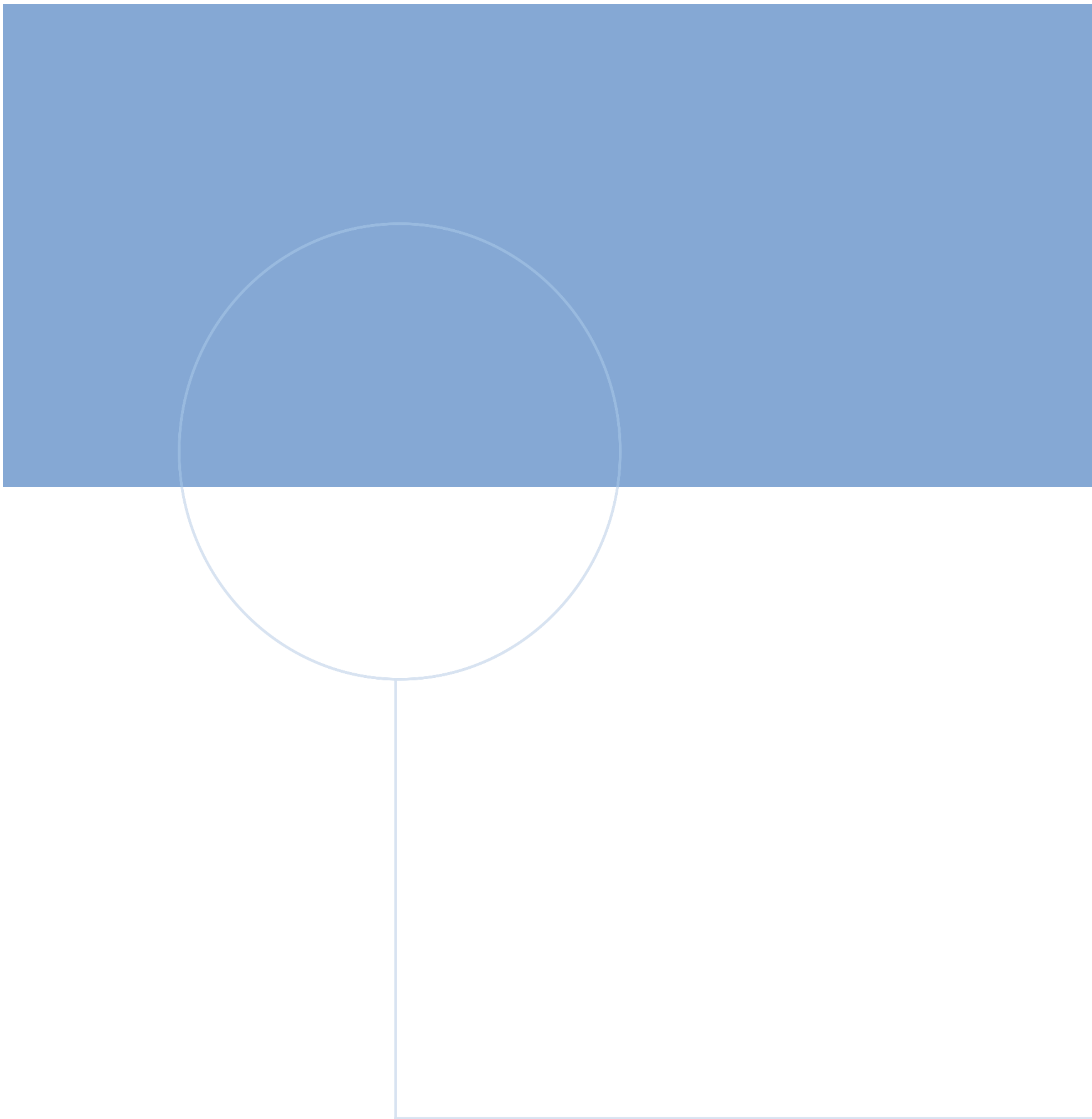
Aneo is a Nordic renewable company that was created in collaboration between TrønderEnergi and HitecVision. Aneo have long experience from the power industry. Aneo's goal is to contribute to the sustainable development of power production and energy efficiency.

Anoe Build is the supplier of smart charging solutions that ables entire construction sites to be powered by electricity.

Bachelor thesis (BIFOREN)
FENT 2900

NTNU
Norwegian University of Science and Technology

Figure B.1: Poster for the bachelorthesis



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Science and Technology