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Variation Management Strategies for Future Construction Sites

A study to address role of an equipment rental business in the energy transition

Master's thesis in Industrial Ecology

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Abstract

Construction sites are facing challenges with high power peaks due to electrification of heavy equipment where potential consequences are increased power tariffs locally and risk of limited power supply. Another development is an increased intermittent power supply due to more wind- and solar power in the electricity system, which causes price fluctuations. These two developments strengthen the incentive to look at flexibility services. This study investigates different strategies to handle these two challenges in an equipment Rental business and how they can contribute with flexibility measures at construction sites for the electricity system.

The methods used in this study were an interview study and a case study where a model of the electricity demand at a construction site was created. In the case, the potential of using battery storage at a construction site for peak shaving and load shifting was evaluated. This was done by optimizing the system cost at the case to see if it is efficient to invest in a battery and be flexible with the load, or purchase electricity directly from the grid. The interviews were a part of mapping the challenges faced by the Rental business and construction sites related to power supply and a changed electricity system. Further, the purpose of the interviews was to evaluate the barriers to using different flexibility services at a construction site. Some output from the interviews was also used for making assumptions in the model about the use of equipment to estimate the power demand of electrified equipment.

One outcome of the interview study was that the Rental business has a role in providing comprehensive solutions to the customer and enabling climate-neutral construction sites. Another conclusion was that the Rental business could have an educating role and recommending the most suitable option when electrifying a construction site, which in the future can include flexibility services such as battery storage. The case showed that it was efficient to invest in battery storage to shift the electricity demand. The optimal battery size was mainly affected by electricity prices during the observed time period, the magnitude of the peaks, and the recurrence of peaks. Another outcome was that critical peak loads can occur in an early phase of construction due to homogeneous charging behaviors of vehicles during breaks. This suggests a selection of batteries with high discharge capacity. Additionally, a combination with charging strategies was effective to reduce costs.

Keywords: Battery Storage, Variation Management, Flexibility Services, Peak Shaving, Load Shifting, Demand Side Management, Rental business, Electrification, Construction equipment, Construction sites

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Ellen Blanksvärd, Frida Svensson, Gothenburg, June 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BESS	Battery Energy Storage System
VRE	Variable Renewable Energy
DSM	Demand Side Management
CPP	Critical Peak Pricing
TOU	Time Of Use
V2G	Vehicle To Grid
EV	Electric Vehicle
DSO	Distribution System Operator
SOC	State Of Charge
GHG	Greenhouse gas

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1
Introduction

Society today faces significant challenges entering a transition towards a sustainable energy system (Bogdanov, Gulagi, Fasihi, & Breyer, 2021). Climate change caused by human activities through greenhouse gas emissions (GHG) could have adverse effects on the natural system, human health, and economies if mitigation actions are not taken(Intergovernmental Panel on Climate Change, 2023). GHG emissions have increased cumulatively since 1850 and the sources are mainly related to energy use, but also lifestyles, land use, and industrial activities. On the one hand, there have been improvements in energy intensity, reducing CO_2 emissions from fossil fuels. On the other hand, increasing global activity in energy supply, transport, buildings, etc. has contributed to a net increase in emissions.

Rising GHG emissions have created the need for climate mitigation efforts that have been agreed upon globally to keep the temperature rise well below 2 degrees and to further strive to keep the temperature below 1.5 degrees according to the Paris Agreement (United Nations Framework Convention on Climate Change (UNFCCC), 2015). To reach the goal, GHG emissions in the energy sector must be phased out by 2050, including power, heat, transport, and industry, together constituting approximately 75% of all CO_2 emissions(Bogdanov et al., 2021). Sweden has a national goal of achieving net zero GHG emissions until 2045, which aligns with the Paris Agreement(Naturvårdsverket, n.d.).

The International Renewable Energy Agency (IRENA) estimates that a 2/3 share of the global energy supply will be provided by renewable generation by the year 2050 (Taibi et al., 2018). As a response to this development, low-emission technology development has increased due to market opportunities, push from policies, and behavioral changes (Intergovernmental Panel on Climate Change, 2023). For example, the cost of technologies such as solar- and wind energy and lithium-ion batteries has decreased since 2010 and provided renewable energy and low-emission solutions for the building-, transport-, and industry- sectors. Mitigation technologies such as Demand Side Management (DSM) and energy efficiency are also becoming more cost-effective because of this development. Consequently, the technological development of electric engines has started to compare with the traditional combustion engines and battery energy storage technologies have become more viable (Naturvårdsverket, 2021).

Due to the transition to a low-carbon economy with more renewable sources, the demand for flexibility services such as providing energy storage increases to ensure the supply. Flexibility services are different strategies that can manage fluctuations in the energy system because of weather-dependent supply, and cope with limited capacity locally in the grid (Heffron, Körner, Wagner, Weibelzahl, & Fridgen, 2021). Limited capacity is a further effect of increased electrification (Metais, Jouini, Perez, Berrada, & Suomalainen, 2022). For example, several fast-charging electric vehicles have been shown to stress the infrastructure because of high power peaks relative to high mobility. This leads to conflicting interests due to limited charging infrastructure when several sectors are electrified (Hartvigsson, Jakobsson, Taljegard, & Odenberger, 2022).

The construction sector is one of several actors actor in this transition, which constitutes around 21 % of the GHG emissions in Sweden(Boverket, Accessed: 2023-05-04). Furthermore, according to Mawdsley and Helbig (2021) construction equipment from different sectors contributed 2019 to 6.5% of the total emissions in Sweden(Mawdsley & Helbig, 2021). Strategies towards achieving net zero emissions in Sweden and in the construction sector include phasing out fossil-fueled construction equipment. Mawdsley and Helbig (2021) furthermore state that less than 1% of the heavy equipment such as compact excavators and wheel loaders was electric year 2020, constituting approximately 100 heavy vehicles in Sweden in total. The electric equipment in operation is mostly light equipment about six to seven tonnes, but there are also a few medium size excavators with a maximum of 20 tonnes. Additionally, most of the smaller equipment is excluded from this number and is for example used for indoor work, which has been electric since many years back, including trucks, small wheel loaders, and compactors.The development of electrified equipment has however developed fast from 2022, and ambitious goals for construction sites are emerging(Fossilfritt Sverige, n.d.). There have for example been pilot projects which have succeeded in creating a construction site that has zero net CO_2 emissions with the goal of 10% of the machine hours constituting by electrified equipment and where the rest is fueled by HVO(Volvo, 2022).

The role of a construction rental business is to rent out machines and various construction equipment (small to medium size), to construction companies, and moreover to provide sufficient grid infrastructure at construction sites(Skanska Rental, 2023). The rental business investigated in this study has a goal to achieve climate neutrality by 2045 and to further reduce GHG emissions by 50% by 2030(Skanska Rental, n.d.), aligning with the goals of the entire construction industry (Byggföretagen, 2023). To reach the goals, further electrification of the heavy equipment must increase, leading to infrastructural challenges for the rental business to manage.

In a scenario of conflicting interests among actors, when several vehicles require charging such as cargo trucks, vehicles, and public transportation in urban regions there could be tangible effects on the grid (Taljegård, 2019). It has therefore become relevant to investigate the role of the construction industry. According to Sveriges Kommuner och Landsting (2015) strategic plans for urbanization include the densification of cities and the UN has estimated that an increase from 54% to 60% of the world population will live in urban regions by 2030 (Sveriges Kommuner och Landsting, 2015). Sweden also faces the challenge of Urbanisation and national goals include allocating construction to urban areas. The use of equipment in construction projects results in the need for temporary power connections during the construction phase, which is further replaced by a permanent power connection in the operating phase (*Svensk Elmarknadshandbok 17B*, 2017). Due to the project-based nature of a construction site, the possibility to achieve a power connection depends on the local prerequisites. It is therefore relevant to look into the role of the construction sector in the sustainability transition.

Additionally, electricity prices have increased, leading to incentives for new business models and changed behaviors by investigating the possibility of applying demand-side management which is one category of flexibility services. For example, charging equipment or a battery when prices are low due to high production of wind and solar. It could also mean allocating tasks to low-load hours to manage peaks. It can however be challenging to change these kinds of behaviors. There is also a need for investments related to the development, such as battery storage, which creates uncertainties about future profitability, which depends on how large the investment cost is, and the profitability of owning a battery. This creates an incentive to investigate flexibility services to handle future challenges in a case of limited power, transitioning into a new energy system.

1.1 Aim

The aim of this study is to analyze a construction equipment rental Business's role in the energy transition. This will be done by mapping and analyzing the use of some construction equipment to investigate the suitability of implementing different flexibility services for possible future scenarios in the energy system. Furthermore, challenges and barriers will be examined to analyze the potential of flexibility services.

The following research questions will be answered to fulfill the aim:

- What are the challenges and barriers that the rental business is facing regarding the climate targets of zero GHG emissions?
- How can a construction equipment rental Business use flexibility services to manage fluctuations in a current and future energy system?
- What kind of flexibility services have potential in different time periods near future, middle future, and long term?

1.2 Limitations

This study will investigate the role of one single rental business, where one case study has been investigated. Hence, the conditions have been constrained to the area of Stockholm and for a small-scale housing project. The flexibility services/variation management strategies investigated in the case study have been limited to Peak Shaving and Load Shifting including stationary battery storage.

2

Theory

In the following sections theory related and relevant to the thesis will be presented.

2.1 Systems approach to sustainability transitions

A transition towards sustainability can be defined as a long-term change of a system that serves a societal function such as energy supply (Elzen & Wieczorek, 2005). This includes changes in different dimensions such as technical, socio-economic, and environmental. A development characterized by a change in all these dimensions is called "co-evolution". A transition also includes an interplay between different actors, factors, and levels, and is hence a complex process. The complexity of sustainability transitions is also acknowledged by Grin, Rotmans, and Schot (2010) who describes that such a transition also means a radical change rather than an incremental one. It means that it is not only a technical development where technologies are being developed from existing technologies. This means that such a trajectory faces significant barriers such as technological lock-ins, where the entire system is built upon a current structure. Technological lock-in means that people and organizations are adapted around the current structures, where standardizations, rules, and routines create stability and lock-in of the socio-technical system.

The system approach deviates from the traditional way of managing challenges, which has been shown to neglect the origin of the problems observed with a too-narrow framing of the system (Meadows, n.d.). Framing a system means choosing relevant parameters that are to be further investigated that are selected as driving mechanisms for the problem observed. They are typically causally related and exist in a dynamic context (Meadows, n.d.). A narrow framing of a system could potentially neglect the causal relationship among events in the system, which is why the solution-oriented approach has been shown to neglect important mechanisms causing other problems to occur, that were not foreseen at an initial state (Holmberg & Holmén, 2020). Hence, the system approach has the benefit of managing sustainability challenges by finding a common vision, collecting the viewpoints of multiple perspectives to map the origin of the problem observed and collectively gathering experiences to find strategies forward.

2.1.1 Backcasting and expidition

Organizations aim to be relevant for the future, but at the same time keep up with current business models, routines, and behaviors (Holmberg & Holmén, 2020). Current structures are "locked in" into the current technical system and presumptions. One strategy can be to implement a backcasting approach. Backcasting was first developed due to the growing demand for renewable energy and energy efficiency. The early studies showed possible futures with renewable energy, where the future scenarios had a starting point with creating a desirable future, and not what is forecast due to previous trends.

Backcasting can according to Holmberg and Holmén (2020)be explained in four steps where the first step is to explain a desirable future where we are looking for guidance to think beyond the current system, and questions such as "what is important" can be answered. The author furthermore claims that this makes it crucial to engage in why it is important to embrace the challenge and the goal. The second step is to look at the current situation related to the goal, and answer questions such as "Are we working in the right direction?". In this stage, it becomes important to get different perspectives. By creating a common map, significant challenges and the roots of the challenges can be brought to the surface. One approach to address this is to use system mapping. The third step is about finding possible areas of intervention in the gap between the future and the present state by answering the question: "Where is the potential for change?". The purpose is to minimize the gap and to examine whether improvements eventually lead to achieving the desirable future, or if it lacks potential. Hence, before looking at specific solutions, it is important to ensure that the right problem is addressed. The last step is about finding more tangible actions that can address the areas of intervention, that can lead to a desirable future.

2.2 Energy system transition

Transitioning into a carbon-neutral energy system dominated by renewables faces challenges of implementing new technologies based on the current sociotechnical landscape (Grin et al., 2010). There are mainly two tracks that the following chapters will highlight. One is the challenge of implementing Variable Renewable Energy sources (VRES) into the current system. Göransson, Walter, Ullmark, and Johnsson (2020) claim that implementing VRES into the current system has shown to be a driving mechanism toward amplified price fluctuations. The other part is the challenge of providing sufficient grid infrastructure to manage the rising demand for electricity in urban areas which pushes for additional investments in new infrastructure (Taljegard, Göransson, Odenberger, & Johnsson, 2019).

The electricity market in the Nordic countries is based on an interconnected system where energy is transferred through transmission lines across borders. This makes Sweden dependent on the constitution of energy supply in other countries. According to Göransson et al. (2020) the future energy system will likely be dominated by intermittent supply such as wind and solar. Because of the rapid decrease in prices that has occurred during the past years, VRE generation offers lower production costs than other renewable sources accessible in the market. Denmark has a goal of achieving 100% renewable generation and Germany has a goal of reaching 80% renewables in 2050 which has consequently led to a larger share of VRE:s (Lund et al., 2015). Because of the transition in other countries, it appears that such development has a tangible effect on the prices in Sweden. Another effect is that a larger installed capacity of intermittent supply tend to cause systems to be fragile to disturbances(Göransson et al., 2020).

The reason for fragility in the electricity system is because of the importance of keeping the balance between demand and supply. Electricity is provided by generators or converters maintaining a frequency level of 50 Hz (Lund et al., 2015). The electricity market is unlike other markets in the sense that supply must be provided instantaneously as it is consumed (Svenska Kraftnät, 2023). Any utilization of energy must be corrected to maintain a frequency level of 50 Hz (Soder & Amelin, 2006). If supply cannot meet demand instantaneously it will cause frequency disturbances. Steam turbines are typically sensitive to frequencies below 47.5 Hz whereas hydropower turbines can manage frequency disturbances down to 45.0 Hz. If requirements are not met it will cause severe damage to equipment. Thus, the energy system must require different components that can correct for different kinds of disturbances.

Current system is functioning based on a number of producers that place bids at the market Nord Pool. The electricity price is determined based on the cost of producing the last kwh to meet the demand at each given hour (Vattenfall, 2022). A system with a rising share of intermittent supply offers lower costs during hours that solar and wind produce. The implication of this development will cause the system's operational cost to rise during low production hours from VREs since such production causes other suppliers to produce fewer hours per year, which in turn causes their operational costs to rise (Göransson et al., 2020). Meaning that it will become more expensive for other suppliers to produce since the return on investment highly depends on the number of hours they can produce. Their operational cost will rise as their revenue from production has to meet the costs of maintaining their facility and operating their production. On the other hand, large penetration of intermittent supply results in lower system operational costs during the hours they can produce. This development is what stirs the development of amplified price fluctuations. It also pushes for lower system costs on longer timescales. However Göransson et al. (2020) claim that a larger installed capacity of intermittent supply will cause more suppliers of solar and wind to be reimbursed at a lower market price during the hours of high production from VREs. Meaning that in a future scenario with a larger share of intermittent supply, solar and wind production facilities will produce during fewer hours than thermal generation at a low profit. Such development might make investments in renewables less attractive.

To manage such development, some measures can be implemented on the consumer side(Walter, 2022). If a consumer allocates their consumption to hours with high production from VRE:s it enables an efficient use of primary energy from renewable generation. Adapting the consumption curve to peak production will create inertia toward high price fluctuations if implemented on a large scale Göransson et al. (2020). Rising demand during peak hours pushes the market price to rise. This development implies that solar and wind facilities will be reimbursed a larger profit (Walter, 2022). This allows the total operating system costs to drop since consumption is allocated to hours with peak production, enabling prices to drop during off-peak hours because of lower electricity demand at those hours. To manage consumer behavior, strategies such as Demand Side Management (DSM) can be implemented. DSM can be defined in several ways, but within the framework of this work, DSM is defined as actions taken to adapt consumer behavior based on the current supply. Transitioning into a system with more intermittent supply faces new challenges for the distribution system operators (DSO:s) to manage frequency disturbances caused by rapid variations of supply (Svenska Kraftnät, 2023). Such a transition might push for more adaptation on the consumer side and energy storage.

2.3 Electrification challenges

Another factor in this transition regards the distribution grid, e.g. how the grid is designed to facilitate the increasing electricity demand, for example due to the electrification of the transportation sector (Energimarknadsinspektionen, 2023a). According to Hartvigsson et al. (2022) investments in electric vehicles are becoming more attractive market alternatives. Because of expanded charging infrastructure, lower cost of EVS, and higher energy density in EV-batteries. Hartvigsson et al. (2022) also expect this number to rise. International Energy Agency (2022) predicts that EVS will constitute a major role in the scenario of reaching net zero emissions by 2050. Barr and Topel (2022) has created a scenario showing that it is possible that 100% of all manufactured passenger cars are electric by the year of 2030 at the Swedish market. Light duty trucks are estimated to reach a share of 80% and heavy trucks are predicted to constitute a share of 60% of all manufactured trucks. These scenarios are based on the possibility to adapt national targets of reaching net zero emissions by 2030 from new passenger cars.

Enabling an optimized charging infrastructure is a crucial step for achieving this goal. Hartvigsson et al. (2022) claims that if loads from EV-charging coincides with houshold loads at critical high load hours it can cause issues in the grid. They further claim that charging rates of EVs often are higher than houshold loads. The dimensioning factor for future investmens in new infrastructure that determines the transmission capacity is the highest peak that the transmission lines must facilitate (Energimarknadsinspektionen, 2023a). Hence, an increased electrification along with more solar and wind installations will lead to future investments in new infrastructure. Regulation for such a development should therefore be designed so that consumers receive price signals when their peak demand causes insufficient use of the grid in order to avoid unnecessary investments in new infrastructure.

2.3.1 Electrification of the construction industry

There is ongoing electrification of construction equipment in the construction sector. Mawdsley and Helbig (2021) predicts that the electrification of construction equipment will proceed by enabling market options for medium-sized equipment of around 20 tons, while heavier equipment will be electrified by the year 2025-2027. Current grid infrastructure might not be sufficient in all geographical locations, for a temporary construction site, using electricity to charge heavy equipment. Temporary connections also face logistical challenges for electrification such as limited time to charge and limited length of cables for machinery used on site. In addition, Mawdsley and Helbig (2021) describes that the Swedish Transport Administration in larger cities has introduced requirements for equipment with a lower climate impact than could be achieved with the reduction obligation. This could act as an incentive for the coming electrification of construction equipment. Another mechanism driving the development is that a major manufacturer of construction equipment has a goal of achieving climate neutrality by the year 2050, which also includes providing infrastructure solutions for the coming electrification (Mawdsley & Helbig, 2021). A further reason for an increased electrification of construction equipment is the possibility to cover the investment cost by 20 % by the Swedish Energy Agency (Energimyndigheten, 2023).

2.3.2 Power tariffs

The grid infrastructure is currently divided into geographical regions where there are different distribution system operators (DSOs) in charge of the transmission of electricity, maintenance, and management of frequency disturbances in their specific geographical region (Energimarknadsinspektionen, 2023a). Energimarknadsinspektionen (Ei) is a supervisory authority responsible for designing policy instruments to create an incentive for consumers to optimize their use of the grid (Energimarknadsinspektionen, 2023a). By the year 2027, it is decided that all distribution system operators (DSO:s) are obligated to implement power tariffs which means that consumers should receive a prize signal when their consumption leads to higher costs for the DSO:s. This cost is designed so that consumers should even out their load.

In the year 2022, 20 out of 150 DSO:s had already implemented power tariffs, and the design of the cost structure can vary a lot depending on the operational costs for each region. In Stockholm municipality, the grid owner is Ellevio AB (Nätområden, 2010). All DSO:s have natural monopolies in their geographical regions since it is not cost-optimal to provide infrastructure for parallel grids. However, they are closely monitored by Energimarknadsinspektionen to provide accurate price signals for consumer behavior (Energimarknadsinspektionen, 2023a). Another important purpose of the tariffs is to finance the infrastructure required for the increasing demand for electricity due to the electrification of several sectors. It is estimated that an investment of 700 billion SEK in by 2045 will be required to provide for the infrastructure in Sweden to manage the electrification of new sectors such as industry and transport (Ellevio, 2022).

The tariff structure is divided into two parts. One that is cost reflective, and the other one that is designed to cover future investments (Energimarknadsinspektionen, 2023a). The cost-reflective part consists of a price per kWh that is time differentiated between high load-hours and low load-hours. This means that the electricity transferred from the primary source cannot be fully utilized because of energy "losses" in the system. Such cost must be corrected for by charging a fee for the amount of electricity that has been transfered to the grid, that could not be utilized. This cost is closely correlated with spot prices (Ellevio, 2022). It also increases with more energy transferred on shorter timescales which is why the cost is time differentiated (Energimarknadsinspektionen, 2023a). The other component is designed to cover future investments and should aim to provide accurate price signals for customers to adapt their consumption behavior during high load hours. This tariff should be designed to optimize the use of the grid either as a fixed price based on the highest peak occurring each month or as a mean value of all peaks. It is up to the DSO to decide how to design the tariff structure, but it typically depends on the properties of the grid, the load, and the number of users.

In the Stockholm area, there is currently a possibility to avoid being charged for the highest peak for fuses lower than 63A (Ellevio, 2022). Hence, this cost structure further acts as an incentive for customers to even out their load (Energimarknadsinspektionen, 2023a). Peaks occurring can be evened out by either shifting energy-requiring activities in time so that peaks do not coincide or managing peaks by discharging a battery or a vehicle for example to even out the load. Such strategies will be presented more thoroughly in the following chapter.

2.4 Flexibility and variation management strategies

Due to the transition to a low-carbon economy with an increased share of renewable energy sources, flexibility services are needed to ensure enough supply (Heffron et al., 2021). Flexibility can be described to handle imbalances between supply and demand to manage fluctuations in renewable energy production. In a future energy system with more VRES, the demand for integrating more flexibility services in the system to handle these fluctuations is increasing(Bolwig et al., 2019). Variation management strategies (VMS) such as DSM and energy storage can be required to a larger extent. There are several different ways of defining flexibility and categorizing flexibility services (Göransson & Johnsson, 2018). It can be divided between managing variations and managing uncertainties(Walter, 2022). A system with high shares of VRE will require measures handling partly variability in the electricity system by VMS, and partly handling uncertainty in the system which requires ancillary services such as frequency control. Göransson and Johnsson (2018)put VMS in a broader perspective which includes the choice of strategies to be suitable for different contexts.

2.4.1 Categorization of Variation management strategies

There are different ways of categorizing VMS. This chapter will present some definitions which are most related to the study. Göransson and Johnsson (2018) has presented categorizations that can handle variability on a seasonal level, including shifting strategies, which is one focus area of this study. Shifting strategies means shifting electricity in time so that the demand can meet the production(Göransson & Johnsson, 2018). This group includes load shifting, which is a method where energy consumption can be delayed, which shapes the net load curve to be smoothed out. One way is to use a battery energy storage, and store electricity when there is an excess for later use. (Variation management) also differs between shifting- and peaking strategies. Peaking strategies can manage peaks or drops in the net load, related to short duration. The two strategies are similar in several ways. They are for example managing variations on working on short time intervals, and they provide power capacity at low costs. Shifting strategies has however a higher investment cost and lower expenses of charging and discharging batteries, and is hence appropriate to diurnal variations. Peaking strategies have instead a lower efficiency of charging and discharging and are more suitable for managing variations with high amplitudes but low recurrence.

Gellings and Smith (1989) presents 6 six different categories of DSM: Peak clipping, valley filling, load shifting, conservation, flexible load shape, and load growth. Lund et al. (2015) presents similar categorization, illustrated in Figure 2.1. There are different factors that influence the shape of the demand curve such as system reliability, energy constraint, transmission, and distribution system (Gellings & Smith, 1989). The difference between peak shaving (which could be seen as a specific strategy of peaking strategies), and load shifting (which is a technology related to shifting strategies) are in the next paragraph further clarified.

Peak shaving, load shifting, and valley filling are strategies that have the same total end-use energy consumption but change the appearance of the load curve and smooth it out (Oudalov, Cherkaoui, & Beguin, 2007). According to Gellings (1985), Peak shaving relates to peaks in electricity use. Industries can then require high amounts of energy at a limited time of the day with a duration of about 15-30 minutes. The peak demand can be much higher than the average electricity demand, which creates an incentive to reduce the peak demand. Companies are often charged by the maximum peak demand since this increases the cost of maintenance of the grid and not only the hourly consumption and can hence be the main reason for high electricity charges. Battery energy storage can be one strategy to reduce the peak, but it can also be implemented by changing consumer consumption by reducing production when demand is high. Compared to peak shaving, load shifting not only imply deductions for consumption on shorter time scales but also includes shifting the demand from on-peak to off-peak periods and not only in terms of reducing the peak. Valley filling, on the other hand, builds off-peak loads. This is most beneficial for certain parts of the year when the average electricity- price is higher than the long-run incremental cost. The average price to the consumer can then decrease when the off-peak load increases. This can for example be proceeded by thermal energy storage such as water heating instead of fossil fuels.

Strategic conservation visualizes a reduction of the whole load curve, both on and of peak. The difference between the two curves in Figure 2.1, can for example be a reduction of sales or a change of use (Gellings, 1985). It is important to first look at energy conservation that can occur before any action, to then be able to evaluate which actions that can develop from this and be the most cost-effective. Strategic Load Growth is a form that illustrates the opposite of conservation, where it instead refers to increased sales. Reasons for the growth can be, for example, fuel heating or heat pumps and increased electrification. The Flexible Load Shape describes the planned demand, which is used to study and plan the most optimal options on the supply side, where reliability is one important factor. The shape can be flexible, for example, if there are incentives for consumers to change their behavior or have choices in terms of quality. There can also be programmed flexibility with integrated energy management systems.

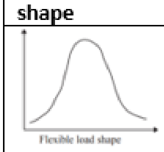
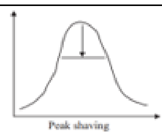
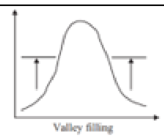
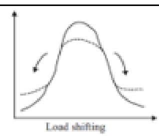
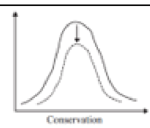
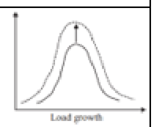
Flexible load shape	Peak shaving	Valley filling	Load shifting	Conservation	Load growth
					
	Reducing Load On-Peak	Building Load Off-Peak (increasing)	- Transfer Load from on-Peak to Off-Peak - Rescheduling energy demand, - require intermediate storage - Both increase and decrease of power need to be possible (utilization rate >100%)	On peak/Of peak reduction	

Figure 2.1: Table of DSM strategies, with inspiration from (Lund et al., 2015)
.

Another way of looking at DSM is by the definition demand response(Sandén, Karlsson, Joelsson, Johnsson, & Kjellström, 2014). One barrier for industries to engage in demand response is that a stop in production can have consequences for the business with a loss in revenue, especially for industries that are electricity- intense. In today's situation, there are also relatively low fluctuations and hence a low saving potential when changing consumption patterns. The benefits that come from increased flexibility in production need to be greater than the costs of having to shut down or change the production pattern. There are different types of demand response programs that increase the incentives for change on the demand side, which are effective on different time scales(Sandén et al., 2014). Regulating power capacity can be addressed by for example Real-time pricing (RTP), time of use (TOU) tariffs, and critical peak pricing (CPP) (Steen, Le, & Bertling, 2012).

RTP is seen to be the most effective demand response to increase the fraction of VREs(Steen et al., 2012). But to manage high peak demand locally, other demand response programs need to act as a complement. RTP means that customers behave due to changes in electricity pricing. In times of low demand such as night time, the price is often lower and thus creates incentives to change demand in relation to price fluctuations and, for example, reduce the load on the electricity system at times of high peaks. This can even out the demand curve and support a higher fraction of VREs. One challenge is when more actors increase their flexible demand since it could lead to local peak demand. Using for example day ahead prices, which has a long time delay, can also create a risk since it reflects a less exact curve of the demand and supply.

CPP can reduce the peak demand for electricity (Kii, Sakamoto, Hangai, & Doi, 2014). It also has the potential to decrease the electricity charge and creates an incentive to be flexible and get money from the grid where consumers can get credit per KW at peak occasions. Electric vehicles (EVs) can also benefit from demand response programs and has especially potential with CPP (Yusuf, Hasan, & Ula, 2021). If the EV is compatible with V2G, it can create savings for the consumers, and there is especially potential when CPP and V2G are combined. When stopping the charging EVs in buildings due to CPP, the load reduces, but the reduction is especially effective when also activating V2G.

2.4.2 Energy Storage and batteries

Using energy storage is one way of coping with the increasing intermittent supply of electricity and can be seen as a complement to renewable production (Sandén et al., 2014). One challenge, and opportunity for the industry is the shift from a centralized system to a more decentralized energy production system. For example, the spread of solar PVs creates many small of-grid producers. This creates societal challenges regarding for example laws, regulations, and norms. Battery storage systems are one example of a decentralized solution that can be used to increase the integration of intermittent supply (Vattenfall, n.d.). It can for example be used for peak shaving by minimizing the high power peaks when the demand is high. Battery Energy Storage Systems (BESS) can also be used to increase the capacity when there is a lack of access(Oudalov et al., 2007). When using a battery energy storage system, it creates the possibility to discharge at peak demand and charge at low demand.

Energy storage can then function as a source when there is limited supply from the grid since it can shift the electricity supply over time periods depending on the type of storage which depends on the type of challenge (Sandén et al., 2014).

Batteries are one type of storage technology and used in mobile applications such as vehicles. Lead acid (PbA) is a common battery in vehicles and in decentralized systems such as PV – systems and was before used as storing electricity in grids. There are some restrictions due to low energy density and risks with hazardous materials. Another group are batteries with nickel such as Nickel cadmium (NiCd), which has a higher capacity to charge and discharge. NiCd has although been replaced with metal hydride (NiMH) due to the hazardousness in cadmium, where NiMH are safer and has the same price range. A third group of batteries is Lithium ion (Li-ion) which is commonly used in phones, laptops, and electric bicycles. These batteries are characterized by high flexibility, efficiency and many cycles. One current challenge for Li-ion batteries is safety issues and that the technology is not fully established yet and therefore it has a high cost. However, it has an emerging potential for development. There are also a batteries that consists of Sodium. Sodium sulphur (NaS) has a fast response time and is beneficial for stabilizing the grid, however, high sources to keep the high temperatures are needed. There is also sodium nickel chloride (NaNiCl) which has a somewhat lower temperature requirement. It is also safer and has a higher cell voltage which is beneficial for overcharge and discharge.Sandén et al. (2014).

2.4.3 Frequency market

One opportunity for energy storage is to connect it to the frequency market as a way to get an income. Due to the increasing share of intermittent supply, the demand for system flexibility in the electricity system such as frequency- and voltage control need to increase (Lund et al., 2015). Frequency disruptions occur when there is a sudden curtailment of production or if supply fails to meet demand (Svenska Kraftnät, 2021). A system more frequently exposed to disruptions requires safety measures, which creates a demand for fast regulating capacity which can typically be provided by batteries (Ullmark, Göransson, & Johnsson, 2023). To manage this variation span Svenska Kraftnät has implemented a Frequency Containment Reserve (FCR) market (Svenska Kraftnät, 2021). The FCR market is an ancillary service which is activated upon an external signal or by local frequency measurements. Any actor participating in the FCR market will be financially compensated for the ability to regulate their production upon an external signal.

According to Mirzaei Alavijeh, Fotouhi Ghazvini, Steen, Tuan, and Carlson (2021) the current system is transitioning from a uni-directional centralized system to bi-directional decentralized system likely to act as an incentive for decentralized markets such as markets providing frequency control. Solar and wind are relatively small-scale applications and produce irregular output (Göransson et al., 2020). Electrification of the transport sector has shown to often require power levels higher than household loads Hartvigsson et al. (2022). Because of the decentralized nature of such a transition, combined with reversed power flows at certain hours, the prognosis for maintaining a stable frequency might become more complex in the future (Mirzaei Alavijeh et al., 2021). All participants in the FCR market can remedy system fragility by creating inertia towards fast frequency deviations (Ullmark et al., 2023). Participating in the frequency market could also co-finance battery storage establishment, by enabling the reserve for frequency regulation (Svenska Kraftnät, 2021).

3
Methods

The study has been conducted in two parts. One that was collecting qualitative data through semi-structured interviews. This aimed to map and analyze the future electrification challenges of an equipment rental business, by reaching out to various actors related to a rental business company. The other part of the method included quantitative data collection to evaluate the potential of flexibility measures as a way of reducing power peaks at a construction site. Furthermore, scenarios for a future construction site were modeled, with increased electrification for a future electricity system that includes more renewable energy sources.

3.1 Interview study

The purpose of the interviews was partly to get a better understanding of the organization and the Rental business role in the energy transition from different perspectives. The data has been used to map possible challenges that construction sites face in a future electricity system and find trends and ongoing processes that counteract or reinforce the development. Data from interviews were also used to strengthen assumptions that were made when creating scenarios in the quantitative part of this study. The interviews have been conducted by using a semi-structured approach where multiple questions have been prepared. However, the questions have been adapted based on the respondent's awareness of the subject and their area of expertise.

3.1.1 Selection of interviews

Respondents have been selected either through first contact where the contact already was established at the Rental business, or through further recommendations (snowball sampling). Possible interviewees were recommended through supervisors at the rental business. The interviewees were further selected based on their area of expertise to include a wide range of competence from different perspectives. In addition, interviewees with insight into operations throughout the supply chain (customers, employees, and suppliers) have been selected to reach an understanding of possible barriers to implementing flexibility services at construction sites. The purpose was also to investigate whether there are aligning visions and strategies among the respondents. Snowball sampling was later used in the process to get additional recommendations for further interviews. Due to the lack of time, some of the recommendations from the interviews have mainly been held as more casual meetings where more specific questions have been asked. Brief phone calls or emails have been sent to obtain additional technical information required to create the model. Table 3.1 shows the interviewees' different roles in the study and table 3.2 shows the participants' roles obtained through meeting and email contact.

Table 3.1: Table of role for the interviews, identification number and selection method

Role/area	Identification number	Selection method
Executive	I1	Recommendation
Executive	I2	First contact
District manager	I3	Recommendation
Fleet manager	I4	First contact
Project manager	I5	Recommendation
Business developer (client)	I6	Recommendation
Sales	I7	First contact
Sustainability	I8	First contact
Area manager	I9	Recommendation
Supplier	I10	Recommendation
Supplier	I11	Recommendation
SVK (external)	I12	Snowball sampling
Energy engineer	I13	Recommendation

Table 3.2: Additional personal communication structured as a meeting

Role/area	Identification number	Selection method
Product manager cranes	A1	First contact
Project engineer	A2	snoball sampeling
Product Manager	A3	First contact

3.1.2 Questions and procedure of interviews

The interview study was conducted in order to gain insights into challenges and possible solutions for different time scales. The interviews began with a brief introduction of the study, where the level of detail has been dependent of the respondent's awareness of the subject. The respondent was firstly asked to briefly present themselves. After that, the questions have then been divided into two parts, general questions, and specific questions. The general questions have been asked to all respondents at the company. The general questions have been selected with a backcasting methodology as a starting point (see 2.1.1), where questions are related to a vision, challenges, and strategies for the organization. For the interviewees outside the rental business, questions about the challenge of the energy transition have been asked. All interviewees were also asked to reflect on the potential of implementing flexibility services and adaptable behaviors at a construction site. The questions asked are collected in Appendix A, however, the questions differed somewhat depending on how the participant answered the questions.

After that, more specific questions were asked, which are summarized in Appendix A. They have been selected and differentiated among respondents based on their backgrounds. Follow-up questions were asked and some questions that were irrelevant in the context and redundant were not asked. This has been used for mapping a rental business and the different phases that construction projects undergo. Moreover, qualitative data collection has been used for making assumptions when modeling scenarios to investigate the technical potential to use flexibility services. Questions asked to the respondents are attached in Appendix A.

The interviews have been held either online through teams-meeting or in person and have been recorded after the approval of each respondent. The interviews held online were recorded and transcribed by team's own function. The transcriptions were later corrected due to errors in the transcript as it was difficult to understand. After that, the interviews were summarized and collected under different themes, including the important parts to answer the research questions. The on-site interviews were recorded via a mobile phone and later transcribed by hand. Irrelevant information of-topic was not transcribed in detail. Results from the interviews were compiled in an Excel sheet with the interviewees in different columns and different themes on each row, where relevant information from each interview was filled in for each person. The different themes were later compared between all interviews with similarities, differences, and aligning trends. Based on this, all interviews in the report were presented under various themes as headlines. The most important findings from the interviews were also summarized in Tables 4.1 and 4.2 to provide an overview.

3.1.3 Mapping of the rental business

Mapping was done of the rental business through interviews and was further supplemented with emails. The aim has been to compare the power requirement in the current state with a future scenario with more electrical equipment on site. Scenarios were created to illustrate how behavioral consumption patterns affect the load curve. Moreover, the potential of implementing flexibility measures was investigated related to the different scenarios observed. Lastly, technical data from the interview study was used as a foundation for mapping the case project to find common characteristics of how projects proceed (see 3.2).

A general mapping of a construction site was done to identify different phases of a construction project. The categorization was furthermore conducted by identifying the share of fossil-fueled machines, battery-powered equipment, and equipment with direct grid connection. This was used to identify different phases of a project and investigate the load allocation throughout the phases. In addition, different groups of equipment have been evaluated based on how electrification in a future scenario is likely to proceed and what the most critical loads will be.

3.2 Modelling of the Case

A case study was created in order to gain a quantitative analysis of the technical potential of using flexibility services. It has later on been used to draw some general conclusions about the potential of using battery storage combined with flexibility services at a construction site and what the most cost-efficient strategies would be to reduce peaks. The case consists of a smaller project where a preschool is being built. Information was collected from the interviews about different phases of the project, how the equipment is used and what the electricity demand looks like in each phase. Information from the interview results and meetings was used as a basis for assumptions when data was lacking. This was used to identify where in the project, and for what equipment there is technical potential to have a flexible load curve. The cases were also used to create a general methodology which could be implemented for other construction projects. For example what information that is needed to be mapped in order to determine suitable flexibility services. Moreover, modelling the case aim to provide an understanding of what data is crucial to obtain in order to evaluate different flexibility measures.

3.2.1 The model

The possibility of using a stationary battery has been analyzed in order to determine the technical potential to use battery storage as a flexibility service. This has been investigated looking at different electricity prices for different time periods which is illustrated in table 3.3. Electricity prices for the same time period as the observation of the project have been used and additionally prices from before 2020 have been used to examine the potential before the increase in electricity prices compared to previous years. In addition, future scenarios have been modeled with estimated electricity prices for 2045 when the electricity system in Europe has had a net phase-out of fossil fuels in the energy system. One scenario with a higher proportion of intermittent supply with an expansion of wind power (spot price VRE), and one with a larger share of baseload from nuclear power (spot price Baseload) were used. Electricity spot prices have been conducted from Energi data service for historical data Energinet (n.d.). For the future scenarios, electricity prices have been obtained through previous research at Chalmers (Göransson, 2023).

Table 3.3: Presentation of the different electricity prices investigated in this study.

Electricity/spot price	Electricity system	source
2018-2019	Historical data	Energinet (n.d.)
2022-2023	Historical data	Energinet (n.d.)
2045	Future scenario of more baseload (nuclear)	(Göransson, 2023)
2045	Future scenario of more VRE (wind)	(Göransson, 2023)

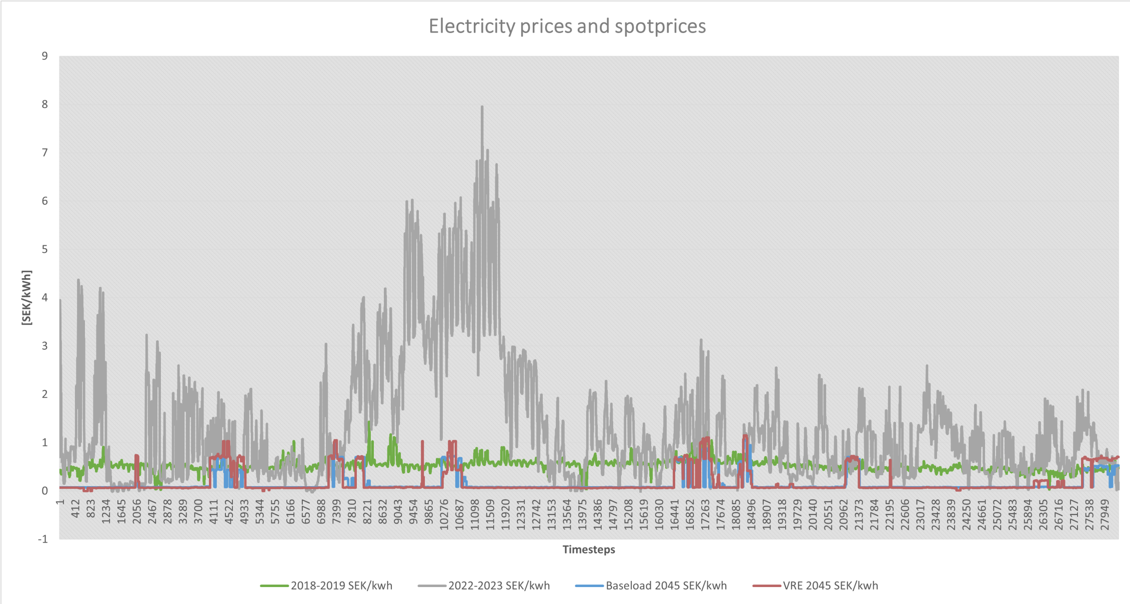


Figure 3.1: Plot of spotprices over the project time period for year 2018-2019, 2022-2023 and 2045

The fuse in the project observed was 125 A, which exceeds the charge of hedging subscriptions, and hence a peak charge for the highest peak occurring each month was selected according to (Ellevio, 2022). The total grid cost was chosen including a variable cost for transmission losses in the system which was time differiented between high- respectively low load time. The prices marked in red in Figure 3.1 has been assumed when creating the model.

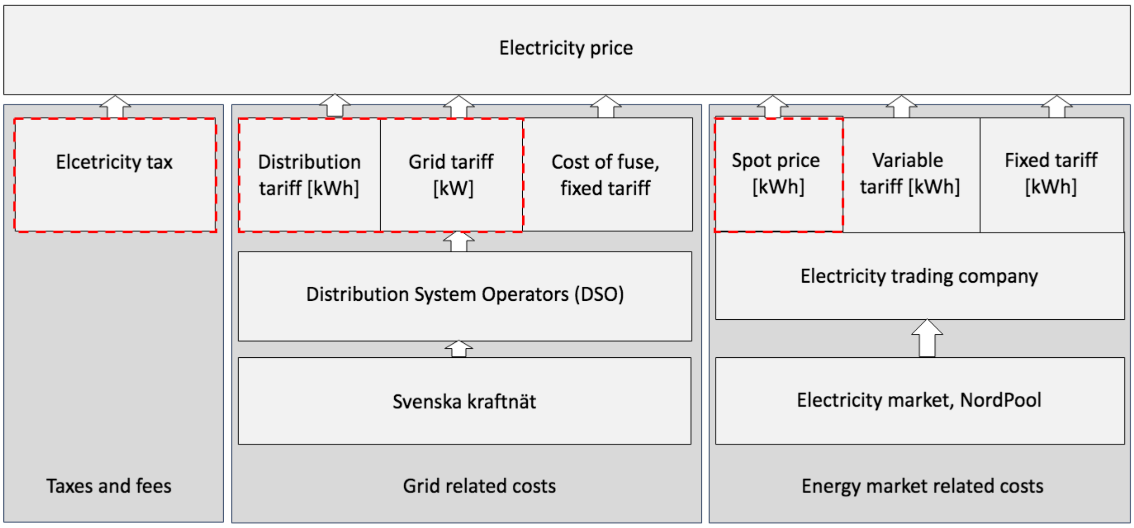


Figure 3.2: Illustration of how prices and fees have been selected

The variation management strategies used in the model for cost optimization are a combination of shifting strategies and peak shaving since these are mostly related to battery storage which is in the scope of the thesis. The potential of using a stationary battery has been analyzed in the model, to examine whether the most cost-efficient option is to charge directly from the grid or to use a battery as a complement. The model selects the lowest total electricity cost by iterating the objective function given the constraints of equations (3.4,3.5,3.8 3.9). Additional equations (3.2, 3.3, 3.6 3.7) describes the relation between each variable in the objective function. If the lowest cost is obtained by using a battery the model will select the cost optimal battery capacity for the time period observed. If the lowest total cost is obtained by only purchasing the electricity directly from the grid, the model will not select a battery for the given time-period. The model has been designed to select the most optimal charging pattern for each time-step (t) to satisfy the demand at the entire construction site, see illustration 3.2. This applies to both charging of the stationary battery from the grid $E_t^{BatCharge}$, and discharging the battery to the construction site $E_t^{BatDisch}$. It also includes using electricity directly from the grid to the project E_{Grid} which is the current way of enabling electricity in the project. Table 3.4 shows all the sets and parameters that are used in the equations.

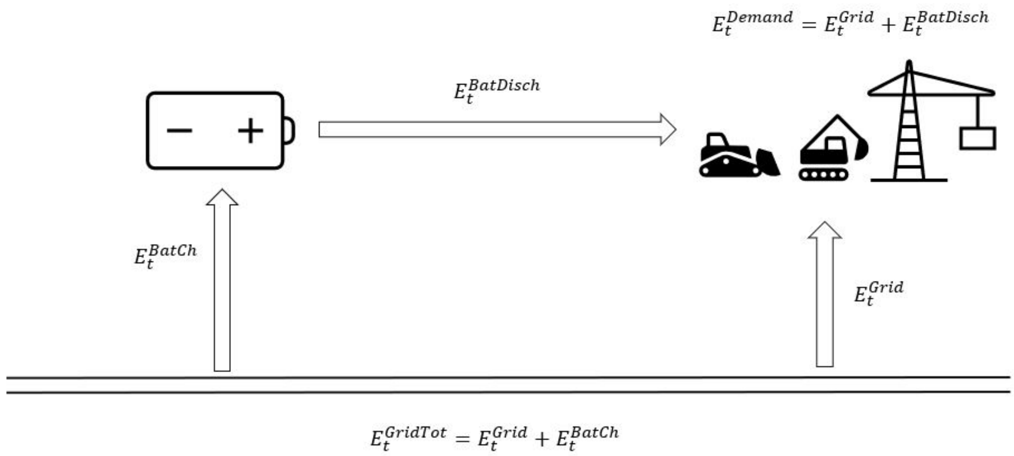


Figure 3.3: Illustration of how equations and variables are correlated

Table 3.4: List of indices, sets and parameters used in the model

Indices	Description	Unit
t	Index for time step	[h]

Parameter	Description	Unit
C_t^{Spot}	Spotprice	[SEK/kWh]
E_t^{Demand}	Demand in the project	[kWh]
$C_t^{VarGrid}$	Variable grid cost	[SEK/kWh]

Scalar	Description	Unit
C^{tot}	Total system cost	[SEK]
C^{run}	Running cost of the battery	[SEK/kW month]
C^{Bat}	Fixed cost of the battery	[SEK/kWh]
C^{TotBat}	Total battery cost	[SEK]
C^{Tax}	Tax cost	[SEK/kWh]
C^{Fixed}	Fixed cost	[SEK/month]
C^{Power}	Grid power cost	[SEK/kW]
$PV^{Annuity}$	Annuity factor battery	[Month]
CF	Capacaty factor battery	[%]
η^{Bat}	Efficiency factor for battery	[%]

Variables	Description	Unit
SOC_t	State of charge	[kWh]
$E_t^{BatCharge}$	Battery charge	[kWh]
$E_t^{BatDisch}$	Battery discharge	[kWh]
P^{Max}	Maximum power peak	[kW]
E_t^{Grid}	Energy consumption from grid	[kWh]
$E_t^{GridTot}$	Total energy consumption from grid	[kWh]
i	Investment in Batteries	[kWh]

The objective function (3.1) calculates the total cost for the time period observed (one month), which includes investment cost and a variable cost for the battery, and the cost of electricity, illustrated in Figure 3.1 where the red lines mark the prices used in the model. The case spans over 25290 timesteps, i.e. approximately six months. But each month is run and optimised separately in the model. All values used in the model are therefore per month inclusive C^{run} and $PV_{Annuity}$ which were converted to the time frame in the project by multiplying with a factor (1/12) since they were stated per year originally.

.

$$C^{tot} = C^{TotBat}\times i + \sum_{t=1}^{25290} \mathrm{E}_t^{GridTot}\times(\mathrm{C}_t^{Spot} + C_t^{GridVar} + C^{Tax}) + C^{Power}\times\mathrm{P}^{max} + C^{Fixed} \tag{3.1}$$

$$C^{TotBat} = C^{run} + C^{Bat}\times\mathrm{PV}^{Annuity} \tag{3.2}$$

Equation 3.3 is state of charge, hence evaluating how much the stationary battery can be charged in the system for each time step (t).

$$SOC_{t+1} = SOC_t + \eta^{Bat} \times E_t^{BatCh} - E_t^{BatDisch} \tag{3.3}$$

Equation 3.4 and 3.5 describes a limitation in charge and discharge which is constrained by the battery capacity and the capacity factor.

$$E_t^{BatCh} \leq i \times CF \tag{3.4}$$

$$E_t^{BatDisch} \leq i \times CF \tag{3.5}$$

Equation 3.6 describes that the electricity collected from the grid correspond to the electricity used in the project and the electricity to charge up the battery. Equation 3.7 describes the connection that the demand in the project is equal to electricity from the grid and electricity discharged from the battery.

$$E_t^{GridTot} = E_t^{Grid} + E_t^{BatCh} \tag{3.6}$$

$$E_t^{Demand} = E_t^{Grid} + E_t^{BatDisch} \tag{3.7}$$

Equation 3.8 describes that the state of charge must be lower or equal to the battery capacity, and 3.9 limits that the electricity from the grid must be lower or equal to the capacity of the power grid. Note that $P_t^{GridTot}$ was converted to energy in the model. Since the data from the project was retrieved with an interval of 10 minutes between each data point, the model was converted so that each variable would contain the energy requirement of each time step. 1 kW transferred over a time span of 10 minutes would give that the energy transferred over each time step corresponds to 1kW x (1/6)h = (1/6)kWh. This conversion factor has been used for converting $E_t^{GridTot}$ to $P_t^{GridTot}$ by stating that $E_t^{GridTot}$ is (1/6) of $P_t^{GridTot}$ in each time step.

$$SOC_t \leq i \tag{3.8}$$

$$P_t^{GridTot} \leq P^{max} \tag{3.9}$$

A future scenario for a power curve was created where fossil based construction equipment was converted into electric equipment. Data on diesel consumption was provided from the project on a monthly basis. The following assumptions and calculations were made to convert diesel consumption into electricity consumption for equipment with a battery. The equations are used to calculate how much electricity the equipment is going to use based on the current diesel consumption.

Table 3.5: Presentation of parameters assumed in the calculation of electricity consumption including source.

Constant	Value of constant	source
η_{diesel}	$0,4$	Taljegard et al. (2019)
$\eta_{Electricengine}$	$0,9$	Taljegard et al. (2019)
$\eta_{Battery}$	$0,88$	Taljegard et al. (2019)
1 L diesel	$9,9633kWh$	Statistiska centralbyrån (2008)

The fuel consumption E_{Diesel} was converted into average electricity consumption in kWh in a battery per day, which is described in equation 3.10. It was based on the monthly consumption of diesel ($V_{Monthly,consumption}$) consumed in the project multiplied by a conversion factor.

$$E_{Diesel} = V_{Monthly,consumption} \times 9,9633 \tag{3.10}$$

Equation 3.11-3.12 shows the calculation of the energy consumption for the electric heavy equipment for one month. $E_{battery}$ shows the energy content in the battery and $\eta_{battery}$ describes the efficiency of the battery. E_{diesel} and η_{diesel} show the energy content and efficiency in the diesel engine. $\eta_{Electricengine}$ is the efficiency of the electric engine.

$$E_{battery} \times \eta_{battery} \times \eta_{Electricengine} = E_{diesel} \times \eta_{diesel} \tag{3.11}$$

$$E_{Battery} = \frac{E_{Diesel} \times \eta_{diesel}}{\eta_{battery} \times \eta_{Electricengine}} \tag{3.12}$$

Equation 3.13-3.14 describes the calculation of the crane which does not have a battery. $E_{Electricengine}$ shows the energy required to run an electric engine.

$$E_{Electricengine} \times \eta_{Electricengine} = E_{diesel} \times \eta_{diesel} \tag{3.13}$$

$$E_{Electricengine} = \frac{E_{Diesel} \times \eta_{diesel}}{\eta_{Electricengine}} \tag{3.14}$$

Equation 3.14 shows the average electricity use for one day. Once the average consumption in kWh was determined a machine with a capacity close to the daily demand was selected for the purpose of understanding the charging pattern of the vehicle.

$$E_{Average,machineuse} = \frac{E_{battery}}{Numberofworkdays} \tag{3.15}$$

3.2.2 The created scenarios

The case in this study has been analyzed by four different electricity price periods together with four different load curves which are named scenarios 1-4. Each scenario is analyzed with each electricity price periods, which creates a total of 16 different cases of which 12 are investigated, since it was considered not to be relevant to look at a future demand curve for the current electricity prices. The selection of the time range for the scenarios was based on the date when all power sources were connected to the grid in the project (17/10 2022), until the day of observation (10/4 2023). All the collected spotprices were restructured to match the data points from the project at 10-minute intervals. This leads to a time interval in the model from t=0 to t=x. The model is simulated for each month during this period, in order to optimize a solution for each month. Prices from this period are plotted in Figure 3.1 for the period 2018-2019, 2022-2023, and 2045. Table 3.6 gives an overview of all the different scenarios.

Table 3.6: Presentation of the different scenarios investigated in the case.

	Spot price 2018 – 2019	Spot price 2022 – 2023	Spot price VRE 2045	Spot price Baseload 2045
Scenario (1)	✓	✓		
Scenario (2)	✓	✓		
Scenario (3)	✓	✓	✓	✓
Scenario (4)	✓	✓	✓	✓

The interview study was used to categorize different phases of a project to understand what type of equipment has been used during different time periods and how they are used. This was complemented by a planning scheme for the whole project which was used to understand how construction progressed and what events could be possible causes of power peaks. Furthermore, a general time schedule for a typical working day was based on the interview with (I3) to estimate a possible charging schedule, which is illustrated in Figure 3.4. Note that phase 3 runs for a longer period of time than shown in the figure.

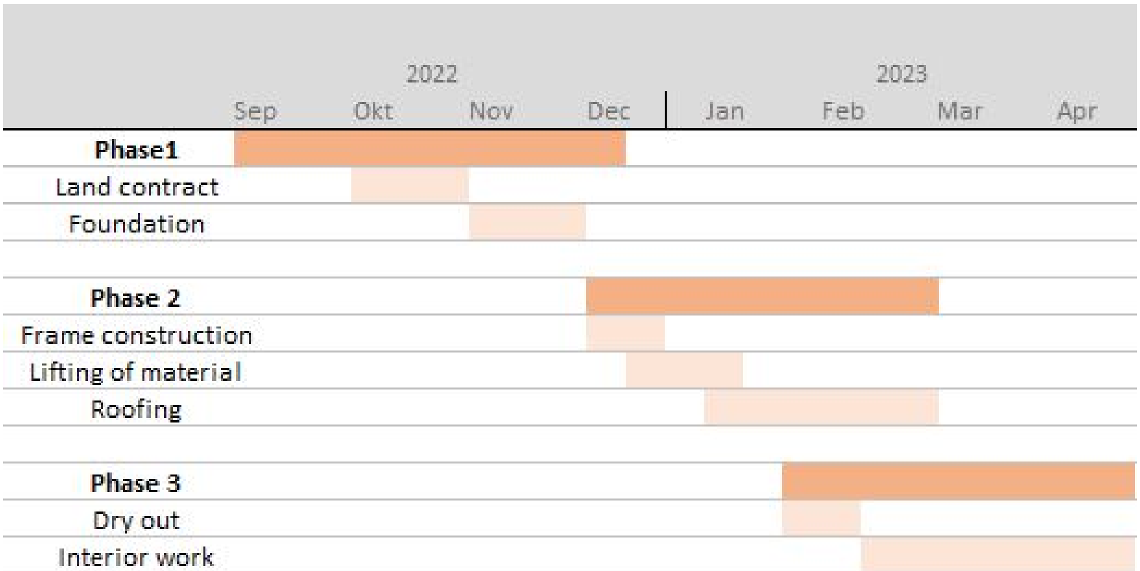


Figure 3.4: Simplified schedule for an overview of the phases and tasks in the project during the observed time period.

Table 3.7: Presentation of the time schedule that is assumed to determine the charging schedule.

Time	Activity
6.30 – 7.00	Morning meeting
6.30 – 9.00	Work
9.00 – 9.30	Break
9.30 – 12.00	Work
12.00 – 13.00	Lunch break
13.00 – 16.00	End of workday

The first load curve analyzed is named Scenario 1, where data from the project were collected and construed. The data was separated between construction current, container, and shed where the power curves are illustrated in Figure 3.5. All the small equipment is charged in the container, and the shed is used for workers during breaks, for example, drying clothes or warming up food. The construction current is used for all further use of equipment. The total demand for these sources added is investigated in Scenario 1. Scenario 1 is illustrated in Figure 3.6 and shows the total power demand for the three sources summarized.

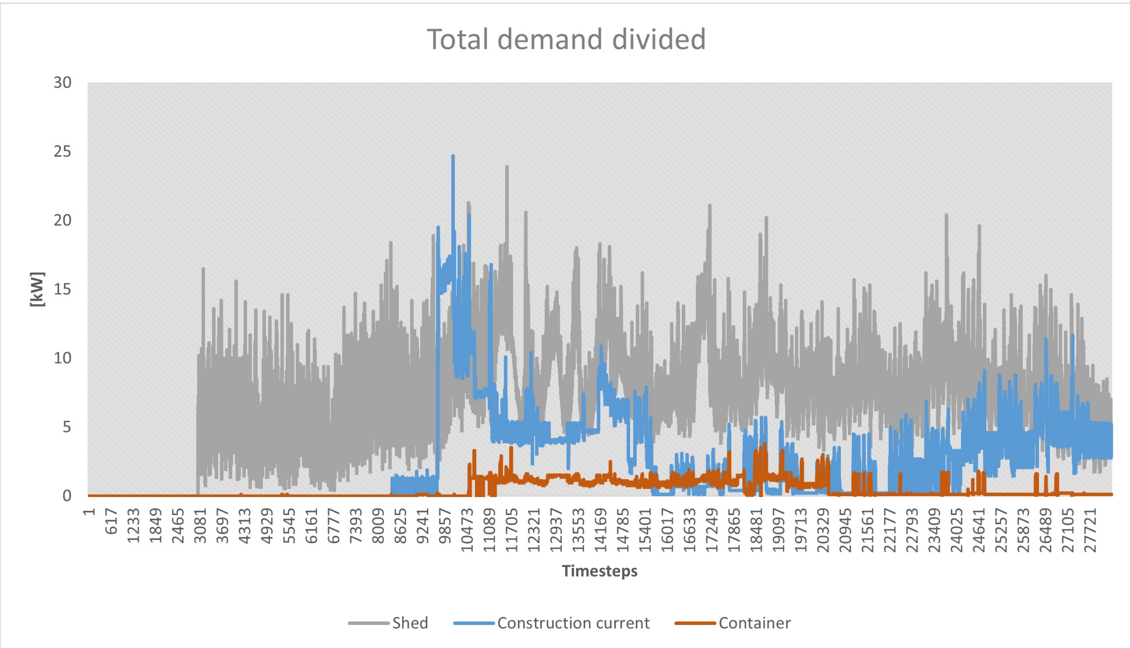


Figure 3.5: Total demand from the project divided between shed, construction current, and container. One timestep equals 10 minutes.

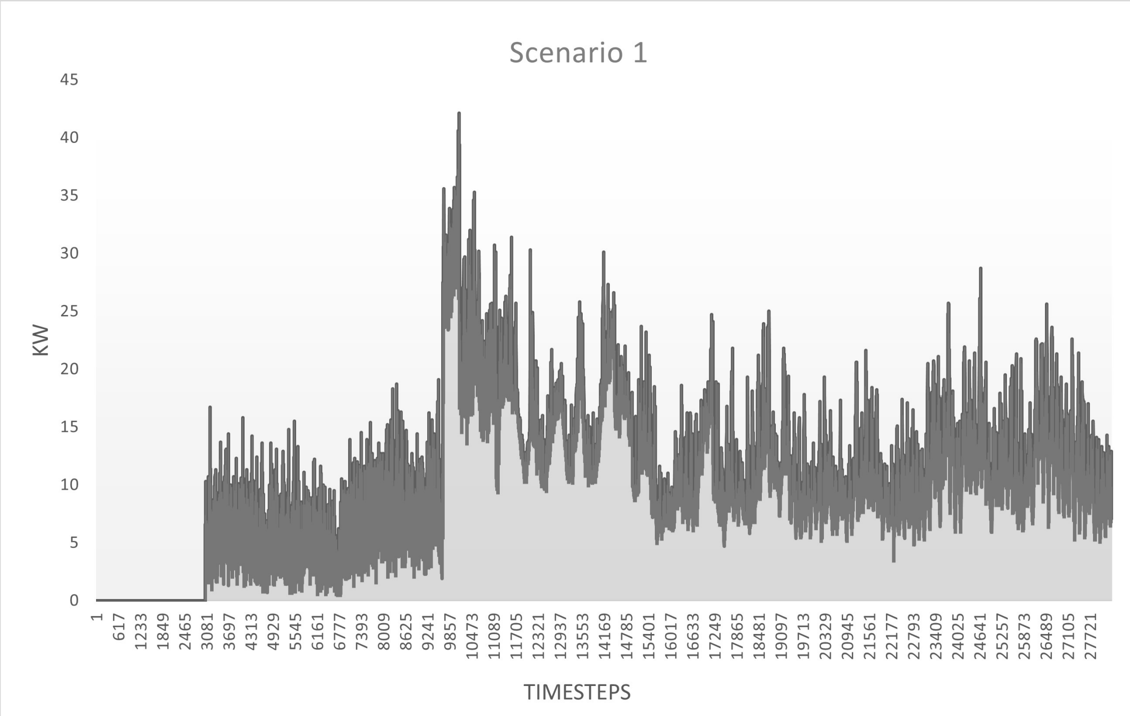


Figure 3.6: Total power for scenario 1. One timestep equals 10 minutes.

In the three other scenarios, a future demand was investigated where more equipment is electrified. The additional demand was added to the current electricity demand. In scenario 2, the electricity demand of an electric mobile crane was added to this curve. The power demand is illustrated in 3.7 The power curve for the crane was created by looking at the dimensioning power peak when lifting an item to get an understanding of the magnitude of consumption related to other peaks. This happens when all engines are operating at its maximum simultaneously (from interview with A1). This result was furthermore matched with the phase of constructing the construction frame of the building assuming that the heavier lifts occurred throughout this phase. In order to create the power curve, additional respondents at the rental business have been asked to provide information on typical consumption patterns of mobile cranes. However, since a wide range of different parameters are possible causes of power peaks this scenario was created as a worst-case scenario. The aim was to run the model to see how such an outcome will affect the cost and the demand of the battery. Furthermore, the profile was analyzed by comparing the frequency of occurrence of power peaks, duration of peaks, the magnitude of peaks, time range at which they occur, how they coincide with other peaks in the project, and moreover what could be possible causes of such peaks.

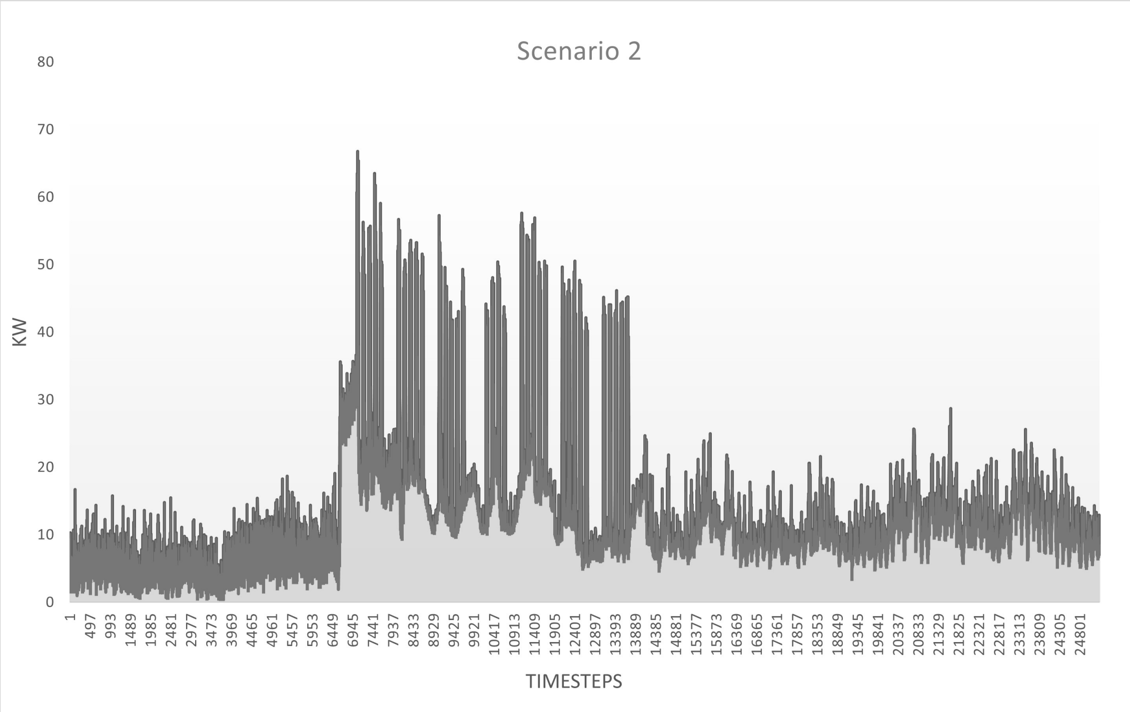


Figure 3.7: Total power for scenario 2. One timestep equals 10 minutes

The following assumptions have been made for the calculation of the electricity demand for the crane:

- The crane can use its maximum speed when lifting an item
- The crane can not use more than its maximum capacity when lifting up an item which for MK-88 is 33kW. For a worst-case scenario, the lifting uses 50% of the consumption for one lift.
- Unloading the item is assumed not to use any electricity.
- The The crane is used continuously for seven weeks as it is rented out in the project, from week 49 2022 – week 3 2023 (A2)).
- The crane has been used 40 hours/week with approximately 280 lifts total during the period (personal communication, A2). An assumption is made that the crane has made 40 lifts per week and 8 lifts per day, which is on average 1 lift every hour.
- A sensitivity analysis was conducted where possible scenarios of using the crane were estimated to see if that affected the result.

The project observed is a relatively small project, where a mobile diesel crane (100 tons) has been used. To create a future power curve, The size of this mobile crane can be compared to an MK88 mobile crane that runs on electricity (personal communication, A1). This crane has a maximal capacity of 33 kW which can be separated between three different directions. A maximal capacity vertically of 24 kW with a maximal speed of 75 m/min, slewing at 5 kW, and "trolley travel" at 4 kW (LIEB-

HERR, 2015). The crane does only use its max capacity if all these operations the crane uses all these three operations at the same time, which happens seldom at maximum power (Personal communication, A1). Full speed is rarely used, except when there is no load in the crane. This happens in no more than 50 % of the lifts that are made. It is also very dependent on the weather and the load that is added to the trolley. The number of lifts needed and the time for each lift is also dependent on the specific process and circumstances. For example, sometimes objects need to be turned around before lifting. Following specific approximations have been made, assuming that the crane does one lift over an hour where each step is ten minutes. Figure 3.8 shows the load distribution for one lift.

1. Connect load - no energy required
2. Turn around load - 15 % of the energy required
3. Lifting the item - 50 % of the total energy demand
4. Lifting or lowering the item - 50 % of the energy required for lifting the item
5. Standing still - no energy required
6. Back - remaining energy

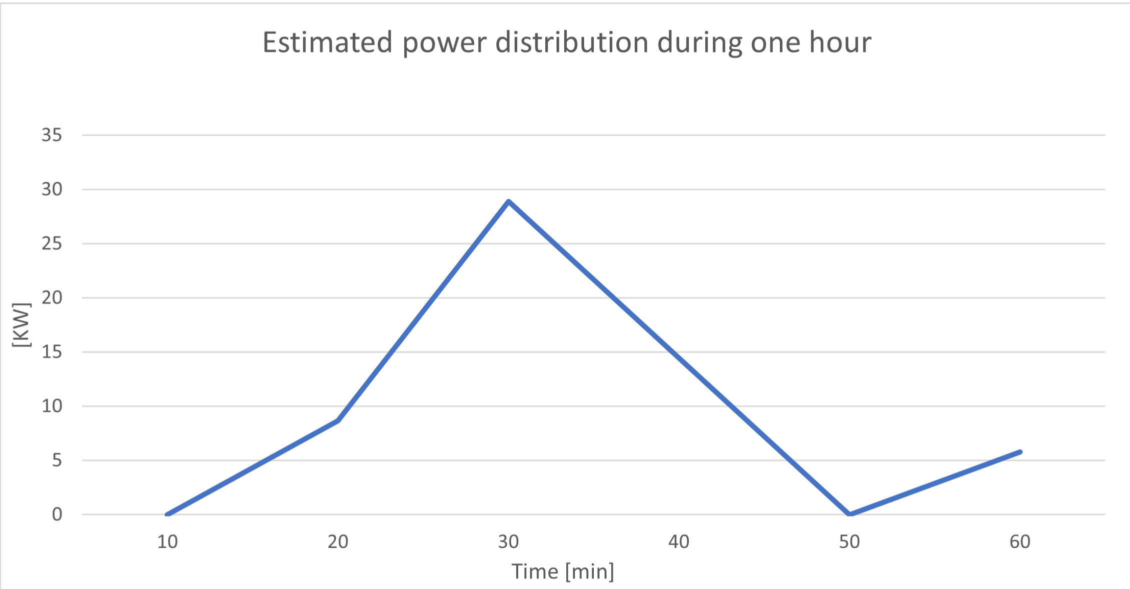


Figure 3.8: Load distribution over an hour for using an electric crane

Two different scenarios for charging the wheel loader were conducted to satisfy the electricity requirements. Figure 3.9illustrates the electricity requirement that is converted from diesel consumption, which is the electricity that needs to be charged during the day. Two different strategies to fulfill this has been accomplished in the study, an optimal charging behavior and a worst-case charging behavior.

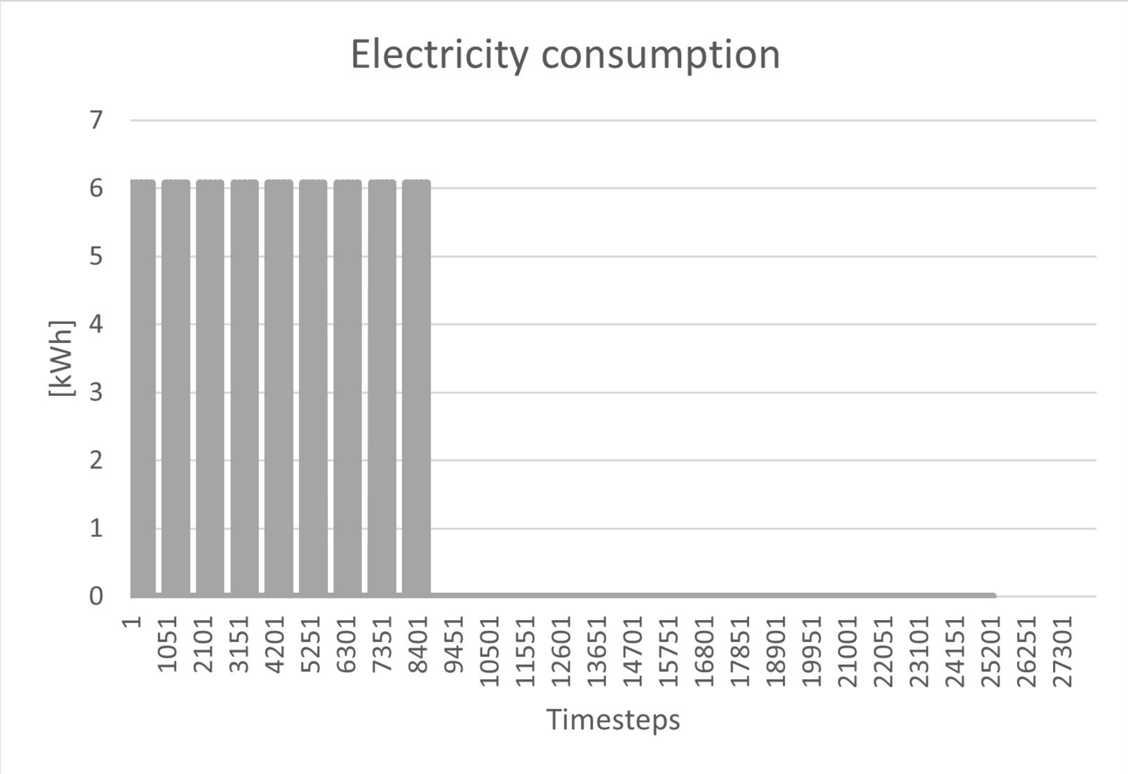


Figure 3.9: Electricity consumption for the wheel loader during the project period (Phase 1). One timestep equals 10 minutes.

In scenario 3, the wheel loader was charged in an optimized way distributed between two breaks during the day. The demand is illustrated in Figure 3.10 It is charged in order to fulfill the assignments during the day and have a minimum SOC of 5 % at the end of the day. The wheel loader is also charged on nights and weekends with minimum capacity and reaches 100% SOC by the start of the working day. The battery capacity was selected to 240 kWh and the average daily consumption was set to 291 kWh/day assuming it has been in operation for 20 days a month. To fulfill these conditions, the wheel loader was calculated to be charged with 64 Kw throughout two breaks and 22 Kw throughout the night.

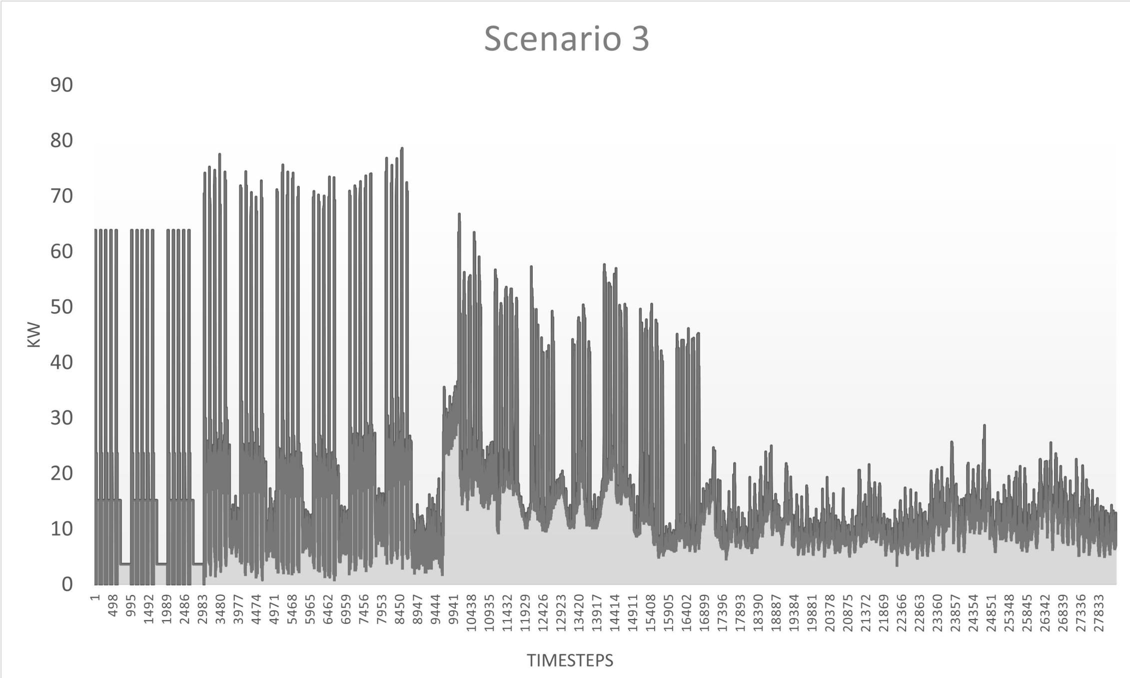


Figure 3.10: Optimal charging of electric wheel loader (Scenario 3). One timestep equals 10 minutes.

In scenario 4, the vehicle was "fast charged" at high capacity (150 kW) during lunch and at lower capacity (22 kW) after the working day. The demand is illustrated in Figure 3.11 This scenario is based on a "worst case scenario" with a charging pattern based on the assumption that the driver wants to overestimate the charging capacity during the day. In the created case, this is fulfilled by only having to charge during one break. This was based on the results from the interviews as well as comparing data from a log measuring machine use of an electric dumpster from another project provided by the interview with (I6). The same data on energy consumption has been used in both cases, however, the distribution of charge has been differentiated between scenarios.

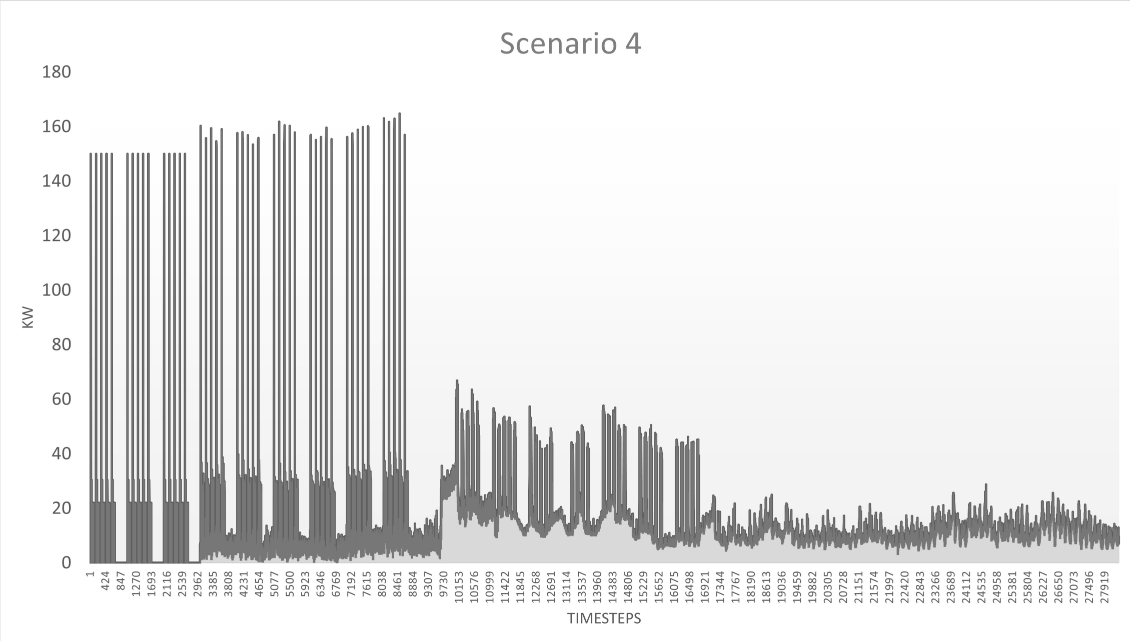


Figure 3.11: Optimal charging of electric wheel loader (scenario 4) One timestep equals 10 minutes.

In order to calculate how much the battery can contribute to minimizing the system cost in its present state, another test was simulated without the power peak cost by constraining the main fuse to 63A. This test was done for scenarios 3 and 4. This assumption has been made based on one interview where it has been suggested to save costs by having a hedging subscription in place instead of a power subscription (I9). The model was hence forced to select a battery if the peaks were higher than the maximum allowed peak. The cap was based on constraining the main fuse to a hedging subscription of 63A allowing the highest peak to reach (63A x 3 x 230V)/1000 =43kW. Any peak exceeding the maximum allowed peak was "peak shaved" to a minimum level of 43kW. One additional equation was added, replacing eq(3.9) where C_{Tax} as well as C_{Power} was set to zero in the objective function (3.1) for this particular case.

$$P_{Grid,tot} \leq \frac{63 \times 3 \times 230}{1000} \tag{3.16}$$

4
Results

In this chapter the interview results and results from the case will be presented.

4.1 Interview results qualitative data collection

Five different themes stood out from the interviews which were considered to be most important to answer the research questions. The first theme focuses on theequipment rental business' role in achieving their goals and visions. The next theme brings up the challenges that the current situation face regarding the goals, related to the scope of this study. The third theme summarizes in broad terms possible strategies to fill out the gap between the current state and the vision. The next theme is the potential for flexibility which focuses specifically on the challenge and possibilities to have a flexible load curve. The last theme summarizes a mapping to determine the power demand at a construction site as well as the development in flexibility and electrification related to different phases and different kinds of construction projects.

4.1.1 Vision and a equipment rental business part in the transition

There is a common goal within the business to achieve climate neutrality until 2045 and a 50 % reduction of CO_2 emissions until 2030 (I8). There is also a goal brought up by (I1), that the equipment rental business has a role in providing climate-neutral projects to the costumers until 2030 (I1). However, this goal was also questioned due to its credibility, where (I2) sees that the equipment rental business "can push for providing solutions that can enable the development of climate-neutral production sites". A better way to describe the goal could according to (I2) be that the company could provide locally emission-free sites until 2030. (I8) also believe that the goal needs to be reformulated, where the aim could instead strive for climate-optimized construction sites, and that the equipment rental business should enable solutions to minimize the carbon footprint. (I4) sees that the aim for the company is to have a fleet that provides the customer with as energy-efficient and green options as possible that minimize the climate impact. There is also a common vision within the equipment rental business brought up by (I1), to "be an effective, proactive and sustainable company".

When asking the respondents about the equipment rental business part in the sustainability- and energy transition, several participants concurred that they have a role in creating possibilities for the customers (I1, I2, I4 I5, I6 I7, I8). According to (I6), the organization can be seen as a key player in all projects to achieve climate neutrality until 2045. (I5) and (I6) see that the equipment rental business has a double role, partly by providing electrified equipment, and partly by the competence around the infrastructure. The biggest contribution is according to (I8) to enable the whole picture, for example, that the charging infrastructure works for electric equipment. (I7) points out that the equipment rental business has a role in anticipating what the customer needs and has a great responsibility to inform about possible sustainability alternatives. From a customer point of view, the equipment rental business has a part of mapping the use of the equipment and enabling electricity solutions together with grid operators (I5). Battery storage was brought up by (I1) and (I6) as an infrastructure solution that could enable electrification at the construction site. Another aspect brought up during the interviews was that the equipment rental business' part in the transition could also become more significant in the future (I2, I6, I7). Another respondent added that they experience that customers tend to shift their focus upwards in the value chain towards purchase and production (I2).

4.1.2 Challenges to fulfill the goals

One challenge that several corespondents have addressed is the controversy of combining sustainability and profitability (I1, I2 I4, I5, I6, I7, I13). (I6) means that a major opposition against the sustainably transition is power and money. (I13) sees that there is a tendency of making short-term profitable investments, and rather perceive the real challenge to accept the cost and to chose the least expensive sustainable option. "Right now, it is a lot more expensive to have a net zero-emission project. Before any technology is well established, it is costly"(I13). Furthermore, (I5) believes that there is a need for customers to be prepared to bear the cost. Moreover, (I5) believes that the investment cost for batteries is likely to drop in the future. Hence, it is important to accept the threshold cost now, although better market alternatives may arise in the future. Another challenge brought up by (I5) and (I6) is that it can be difficult to make use of existing investments in batteries and construction equipment when the next generation enters the market. Two of the interviewees (I1, I2) did however highlight that sustainability and profitability can complement each other. “From being very separate parts a few years back, my scouting is that sustainability and profitability are merged together, closely interrelated” (I1).

Another common challenge that was brought up during the interviews was that the equipment rental business is dependent on the entire supply chain. The equipment rental business´ sustainability goals depend on what suppliers and the entire market can develop and deliver (I1, I3, I4, I5, I6, I7, I8). For example, there are currently only a few market options today to provide an electric vehicle fleet (I6). (I3) also believes that a single company is not enough to drive the development since they exist in an interconnected system. "The entire industry needs to transition, including competitors, supplies, and customers" (I3). (I7) points out that it is central to get the equipment rental business´ customers to rethink. (I8) also agrees that it can be hard to get the customer to be interested in the new solutions.

One additional problematic area from the interviews was the challenge of keeping the big picture together. (I3) claims that electric equipment lack purpose if the grid infrastructure on-site fails to provide sufficient power. (I8) stresses the importance of not only talking about machine-specific emissions but to consider the entire constriction site. The respondent further means that the role of renewable technologies are emphasized, but as an example, little attention has been paid to using equipment efficiently.

Lastly, a theme that was brought up was the development of the electricity system. More intermittent supply could according to (I4) make the construction process more unreliable (I4). Some of the interviewees concurred that there must be a continuous balance between production and consumption (I10, I11, I12, I13). Another recurrent tangible challenge from the interviews was power shortage (I6, I7, I9, I11, I12, I13). (I11) means that it can be problematic that the electrification proceeds much faster than the pace of reinforcing the infrastructure (I11). (I13) agrees that solving the distribution and the accumulation of electricity to the construction site is one of the main difficulties. (I12) points out that there are bottlenecks where there are not enough grid capacity, especially in large cities (I12). (I9) explains a scenario at lunch when all equipment is charging, the power requirements might correspond to multiple residential areas (I9). (I6) and (I3) agrees that it is not a challenge right now, but possible in the future.

4.1.3 Strategies forward for the equipment rental business

One recurrent strategy for the equipment rental business was to not only focus on one solution, but be open to different options, both short and long term (I2, I3, I4). (I2) states that the equipment rental business is working on different kinds of solutions where electrification can handle local GHG-emissions which can be managed with today's technology. (I2) and (I4) means that it is also important to be open to different options apart from electrification, such as for example hydrogen. (13) stresses that hydrogen could have potential in the future (I13). (I13) does also see the importance of looking more long term in investments and finding new business models which can prove profitability. (I6) believes that renting of for example equipment and energy storage is going to be more common, which enables depreciation in a shorter time. However, it is still important to be profitable within a number of years.

Another strategy that appeared during the interviews is to continuously find better sustainability options for the customers (I2, I4, I7, I8). Additionally, one strategy is to be proactive and try new options as soon as they enter the market (I4, I7). (I4), mean that it is hence important to make a close market analysis, and have a continuous dialogue with suppliers. It seems according to (I2), (I6), (I7) and (13), that there is a hesitant behavior towards testing new products with low profitability prospects in the organization. One development could be not to wait to invest until the product is commercial (I2). (17) stresses the importance of contacting the client early to influence the entire building process in the right direction and hence make the customer more open to new possibilities. One example brought up by (I7) was showing calculations and explaining the benefits.

The majority of the participants agree that battery storage is a strategy forward at construction sites in the future. It is an area which the equipment rental business can collect competence around and support the costumer with (I1, I2, I6, I7). Today, the demand is highest at infrastructure projects which are dependent on diesel generators to produce power (I5). In order to map the demand and to be able to dimension the battery storage, it is important to understand what kind of project it is and what type of equipment is available as well as what are the requirements for the electricity demand (I1). It is important for the equipment rental business to have competence around what kind of battery solutions that is suitable for a specific project (I1). "This depends on what equipment is in place for it to be possible to dimension the battery storage. We can help with this sort of calculations and provide different options" (I1).

One related recurrent strategy was to develop the contribution and knowledge around holistic solutions. (I8) stresses the importance of not only focusing on emissions for a specific machine but more around the entire construction site. (I7) sees that one important contribution of the equipment rental business is to map the customer's consumption and come up with alternative infrastructure solutions. It is important to map what the equipment rental business can provide to the customer and everything that uses electricity (I1, I7). There is already a large competence, but the ability not to over-dimension can be improved, which will require more knowledge (I1, I7). It will also be important to educate the equipment rental business to show the contribution to the customer regarding sustainability and batteries (I1). One example is understanding of the use of a battery (I1, I2, I7). "It is important to have an understanding of how the product is going to be used. Everyone sees it as a component for the product to work, but not all projects understand why, and then you lose some people...(I2)."

Table 4.1: The result from the interviews summarized for the three first themes which focus on the broad challenge of achieving goals.

Vision	Challenges	Strategies
Achieve climate neutrality until 2045	• Challenges with new technology • The infrastructure development has not caught up with the electrification development	• Look at different kinds of options both short and long term • Be first with sustainable innovations
Provide a climate-neutral construction site	• The Rental business is expected to have competence around new solutions • Uncertainties of future development of electricity system and power demand	• Foreseeing what the customer need and provide sustainable options • Map the prerequisites and demand at the construction site and provide optimized solutions for the specific project. • Have a holistic view and increase the talk around the whole construction site
First moover in the maket	• Uncertainties of future development of electricity system and power demand	• Be proactive and have a constant analysis of developments and new developments of technology.

4.1.4 Potential for flexibility

All respondents related to the equipment rental business were asked if it is possible to adapt any equipment or specific operations to manage power peaks. Aligning thoughts among respondents is that doing so cannot inhibit the productivity of a project. (I2) furthermore believes that in a case of not accessing sufficient power, or in a case of saving costs consumers are forced to optimize their consumption. However, the interviewee believes that optimization will not be achieved as a result of behavioral change, without an incentive. (I2) furthermore believes that such a development will have to reach an equilibrium where the invested planning time will be worth the cost saving. The construction industry is known to be innovative and entrepreneurial and to manage changed conditions since that is a part of their daily tasks (I2). If a situation occurs that requires behavioral adaptation, (I2) is assured that it is possible to solve, but that it will become a long journey.

Interviewees were further asked about the causes of power peaks in construction projects and how flexible different operations are to reduce peaks in projects. Several respondents brought up that the reason for high power peaks occurring in a project is when large equipment does its most energy intense job simultaneously as other loads occur (I3, I4, I6, I9). Hence, the power requirement fluctuates a lot (I3). (I6) identifies a homogeneous behavior as a possible cause of power peaks, and believes that some activities can be shifted in time. On the contrary (I3) believes that is is difficult to predict when power peaks for different equipment coincide. (I1) and (I3) believes that it is not an option to run equipment at a lower capacity if it means delaying the project. However short delays on a minute basis will not be significant, rather it is about what could be followed up on a workday (I3). Construction equipment that is not used continuously has more potential to be flexible such as using the crane at lower capacity during certain hours (I3). Rollers and packing equipment could also have the potential to be flexible since they are not constantly in use (I3). Additionally, (I3) mean that implementing flexibility services must not inhibit the conditions for the workers since they must be able to perform their tasks efficiently.

Another topic discussed among respondents regards the role of the equipment rental business, to provide insights into flexibility measures in construction projects. (I7) means that it is difficult for an equipment rental business to intervene in the construction process since the projects themselves must learn what their fluctuations are caused by (I7). It is not impossible, and the equipment rental business can inspire and give suggestions (I7). However, the customers are mainly driven by the construction process. There are a lot of different aspects affecting the pace of construction and the equipment rental business´ customers are in turn driven by the requests and deadlines of their clients. (I1) sees that it is possible to change behavior and spread out the peaks to some extent. The industry can most likely learn to plan these kind of peaks but expects suppliers to provide efficient solutions (I1). This, in turn, makes an equipment rental business´ role to provide efficient solutions that are not compromising the productivity of a project. (I6) thinks that in a perfect project with no delays it could be possible to plan for the coming power peaks, but projects must ensure enough power capacity if an unexpected event occur.

During some of the interviews, charging behaviour of electric equipment was discussed. (I3) is involved in a project where they have tested electric construction equipment. (I3) and (I5) further stresses the importance to deviate from homogeneous charging behaviours. Currently it is enough to charge the vehicles during the breaks, but in a case of 100% electric vehicles on site the interviewee believes that it would require behavioural adaptation (I3). The electric vehicles currently used are fully charged during night-time and charged to the extent possible during the breaks. The breaks are usually 30min which makes it difficult to fully charge the vehicles. (I3) Depending on the types of tasks that will be performed and the temperature outside, the energy requirements will vary (I3, 15). (I3) believes that it is not impossible to rethink how breaks are allocated as a way of implementing flexibility, and to reduce the power peaks. However, (I3) proceed by reflecting about further challenges that the project manager will face in order to manage the tasks for all employees. Another respondent agrees that simultaneous charging can cause difficulties of ensuring enough capacity (I6). The interviewee also suggests that in a future scenario with increased electrification, there would be an incentive to plan for the charging of equipment to ensure that the energy-requiring events will not take place at the same time (I6)."The problem will occur when several equipment is simultaneously charging while the project next door also requires more electricity. How will the DSO:s manage such a scenario?" (I6).

Two of the respondents brought up the topic of using load balancing to manage power peaks. (I9) suggests that a possible solution for managing the charging of heavy equipment would be to implement some sort of load balancing charging equipment or a timer, since the grid is affected once the machine is charging. This often occur after 16.00 but will typically coincide with the time many people come home from work when electricity demand is high (I9). (I10) gives an example of a construction project, where a load balancing of charging has been tested by postponing charging of different equipment. The respondent furthermore consider this a simple way to save costs by time differentiating charging since the cost savings related to the investment are predominant.

Another flexibility strategy that can even out the power curve is to use battery energy storage, which was discussed among the interviewees. One area of potential identified among respondents is to use battery storage when several equipment need to be charged at the same time to avoid peaks (I1, I3, I7). Another purpose that (I9) discuss is to use batteries to enable temporary power connections with lower main fuses. Instead of choosing a large main fuse of 63A it might be enough to have a main fuse of 32A since the energy in the battery is consumed at the peak (I9).

Further potential of flexibility identified is the possibility to consume less electricity, where some of the interviewees provided practical examples. (I2) highlights that there is a tendency on the consumer side to choose a large machine to ensure that the machine will manage the task that it is designed for, which could result in a higher electricity consumption than necessary. The respondent believes that an equipment rental business´ role is to guide the costumers in choosing a smaller equipment that is more optimized for its purpose. Another aspect of this is that there are smarter market options that utilizes the energy in a more efficient way (I2). According to an additional respondent such example is the development of cranes (Personal communication A1). The older versions were less efficient as they were consuming equally as much energy when lifting as well as when lowering equipment. Modern frequency-controlled cranes store a certain amount of energy on the way down meaning that the frequency inverter generates less power(A1). Such a development has caused the electricity consumption to drop (A1).

Another flexibility measure that has been discussed with a few of the respondents is vehicle to grid (V2G). The potential for an equipment rental business to, in a future scenario, use rental equipment to discharge to the grid, as a way of implementing load balancing at the construction site. (I13) believes that it is important to consider the purpose of which the machine is designed for. (I13) further claims that the battery in the machines are designed for high performance which requires high energy density that results in fewer cycles, and they are typically more expensive than stationary batteries. Stationary batteries on the other hand are designed to provide high power output, have many cycles, and are designed to activate frequently (I13). The interviewee furthermore believes that it is a better profit to use the machines for its primary purpose. Another aspect that (I13) brings up is that it might be logistically challenging to discharge the vehicle. (I13) and (15) highlight that once the machine is not in use it needs to be charged to ensure enough capacity throughout the workday. Such a solution could be technically feasible but will probably not become an attractive market option (I13). However (I10) means that all types of measurements are going to be needed in the future, and that there could be a possibility to use V2G in a case of power shortage since vehicles may be required to be used to minimize the cost in the future (I10).

The potential of using batteries for frequency regulation has been discussed with a number of respondents. (I13) believes that frequency regulation serves an important societal function that might co-finance the establishment of battery storage and stabilizing the electricity system. However, the pre-qualification in order to participate in the market is known to be a long and costly process (I13). (I13) furthermore highlights the uncertainty of pre-qualifying construction sites. Since frequency regulation serves a function of maintaining the level of security in the electricity system, it can be an issue that construction sites are temporary which makes them less reliable, it is easier to invest in a house property that has a time frame of 10 years (I13). In summary, the respondent sees the potential of providing frequency regulation, but sees challenges of connecting the service to a temporary battery establishment at a construction site. One of the suppliers that were interviewed further agrees that the potential of frequency regulation is interesting to look at on a short-term basis but describes the current pricing on frequency services as unsustainable to sustain on a long-term basis (I10), and further expects the refund to drop. (I11) and (I12) hope to see a larger acceptance of temporary storage alternatives functioning as frequency regulation, such as for electric vehicles or temporary storages.

Table 4.2: The result from the interviews summarized focusing on flexibility, which possible ways there are to use flexibility in different time scales, what challenges it implies and what potential could be.

	Possible flexibility solutions	Challenges	Potential
Short term implementation	Batteries as energy storage	• High investment cost for new technology • Barriers with knowledge of the possibilities and needs • Uncertainties about future demand	• Do not intervene in the construction process • New business models for the customer increase the demand for renting batteries • Batteries can contribute to the customer in different ways which the Rental business can explain and educate about • The demand for using batteries for peak shaving will increase in all types of projects
	Frequency reserves	• The battery cannot be present to the market when it is used for peak shaving	• Frequency reserves can be a possibility for payback on the investment short term. The potential can however decrease with time. • A possibility to contribute with stability to the electricity system
	Load balance for charging equipment		• Could be an easy way to save cost
Medium to long term implementation	Learn to plan and avoid certain peaks by for example: • Running equipment on lower capacity • spread out break times and think beyond the current time schedule • Optimize the electricity demand	• A lower electricity bill cannot compromise with the productivity of the project. • Hard to change behavior and intervene in the construction process.	• Low potential now but could have potential in the future when there is a higher incentive to be flexible. • Equipment that is not used continuously during the working day has more potential of being flexible • The Rental business could inspire and teach wich could be one part in a long process.
Long term implementation	Vehicle to grid (V2G)	• Is not yet an option on the market •Sceptisism around using the battery for something else than the primary use, since it wears on the battery • All available electricity in the vehicle will most likely be required during the day • Logistical challenges with discharging the vehicle during the day	• Can minimize costs in the future • All measures are needed in the future, the incentive for using the batteries in the vehicles will most likely increase

4.1.5 Mapping the power demand at a construction site

When looking at rental equipment a large share of the vehicle fleet is already electric (I4). Indoor equipment is to a large extent already electric, whereas larger equipment such as heavy equipment is typically fueled by gasoline and diesel (I4). Moreover, Tower cranes have been electric for many years and are directly connected to the grid through a cable, but there are also alternative options such as mobile cranes which are typically fueled by gasoline or diesel, suitable for projects < 14 weeks (A1). The most fuel consuming equipment is currently heavy machines (I4). However, there are a few electric heavy machines that currently exists on the market today such as an electric excavator and a few electric loaders as well as a number of lifts (I4).

There are different types of projects that require different kinds of machine use. Typically construction residential projects could be categorized into three different phases. The first phase consists of constructing the foundation. Machines that are used in this phase is piling machines and sheet piling, depending on the seasonal conditions (I3). Excavators are used when creating the foundation but in infrastructure projects, and are used continuously throughout the entire project (I3). Depending on what project that is to be carried out there could be a need of drilling in rocks, but to characterize this phase it is typically dominated by heavy machines (I3). It is noticeable that heavy equipment is dominating throughout the first phase by studying the consumption curve of diesel and HVO100 (I3). At the finalizing stage it is common that there are fewer machines at the construction site, which also could be seen when studying the consumption curve of diesel and gasoline (I3).

The second phase of construction of housing could be dominated by heavy lift by cranes which are powered by direct electricity. This phase typically has a more tangible effect on the electricity system since heavy lifts of building blocks are installed once the foundation is finalized (I3). This is also a phase where more diesel and gasoline fueled vehicles are phased out and replaced by machines with electric engines such as cranes and building hoists. According to some of the respondents, peaks can occur when building hoists are simultaneously used as the cranes are doing heavy lifts (I3, I9). This is typically a phase where the building start reaching height (I9, I4).

The last phase is dominated by smaller equipment that is mostly used to finalize the interior work. This is a phase that is dominated by electric equipment and has been electric for many years (I3). One of the main reasons for this is the requirement of a clean-air indoor environment. Hence, a large share of the equipment has an internal battery which is charged in a container at the construction site mainly at night or during breaks (Personal communication, A3).

The majority of interviewees agrees that the nature of projects looks very different depending on the request of the clients. (12) stresses the importance of perceiving the industry as a diverse set of actors, since it includes companies with just a few number of employees, to major companies. There are no clear distinctions that can be made among the projects discussed, however characterizing factors could be investigated in order to find common trends. To distinguish the types of projects, these phases typically characterise construction of residential buildings. Infrastructure projects are dominated by the use of fossil fueled heavy machines that have a rather continuous machine use throughout the entire project (I3). According to (I5) road constructions sometimes lack accessibility to the grid. Hence, diesel aggregates are currently used for off grid applications. Sometimes, kilometer long power connections must be used to supply with electricity which is costly for the costumers (I5).

Table 4.3: The result from the interviews summarized focusing on flexibility, which possible ways there are to use flexibility in different time scales, what challenges it implies and what potential could be.

	Phase 1: Foundation	Phase 2: Frame construction	Phase 3: Finalised exterior
Dominating equipment	A large fraction of heavy equipment runs on fossil fuel or HVO100, such as excavators and wheel loaders. There are only a few electric options on the market.	Dominated by cranes, building hoists and additional loads	Fewer heavy equipment on site and a larger fraction of smaller electric equipment
Affect on the grid	Currently low stress on the grid due to low fraction electrification. High fuel consumption.	Direct load on the grid and has a more tangible effect on the grid. Likely that the peak coincides with other loads.	Load on the grid at charging occasion from smaller equipment
Machine use	High duration of machine use throughout the workday	Cranes has lower duration of use compared to heavy equipment.	Charging at night and breaks
Electrification development	The electrification of medium-sized equipment is currently increasing Heavier equipment is harder to electrify Can have a large effect in a future electrification, for example when the several heavy will be charged at breaks.	Mobile cranes has been electric several years. Mobile cranes which are suitable for projects < 14 weeks are still on fossil fuels	Already a high fraction of electrfication due to indoor health requirements
Potential for flexibility	Excavators etc. has low potential for flexibility since they need to be used constantly. Equipment that is not constantly in use has higher potential	Cranes can have the possibility to run on low capacity during periods since it is not needed continuously	

Table 4.4: Key points from mapping different types of projects

Infrastructure project (off- grid)	Residential building
Unpredictable network connection, especially for road construction	More predictable network connection, but can be challenges with providing enough power output, especially in central parts.
High demand for energy storage to substitute long cable connections and diesel generators to support the project	Increasing demand for battery storage to cut power peaks. Will be more attractive when a larger fraction of heavier equipment gets electrified.
Larger fraction of heavy equipment, phase 1 and 2, sometimes only phase 1	Can be divided into three phases

4.2 Results and analysis from case "preschool"

In this chapter, the result from modeling the case "preschool" is presented where the use of a battery has been simulated for different scenarios. The results from the model give the cost-optimal battery capacity for each scenario which will be differentiated between months. Furthermore, the charging behavior and peak shaving behavior of the battery will be presented and analyzed.

4.2.1 Results and interpretation from the scenarios

In this section, the results and analysis for the different scenarios will be presented. Figure 4.1 is a compilation of all scenarios illustrated in one graph, where the colors represent how the power curve was built up for each scenario.

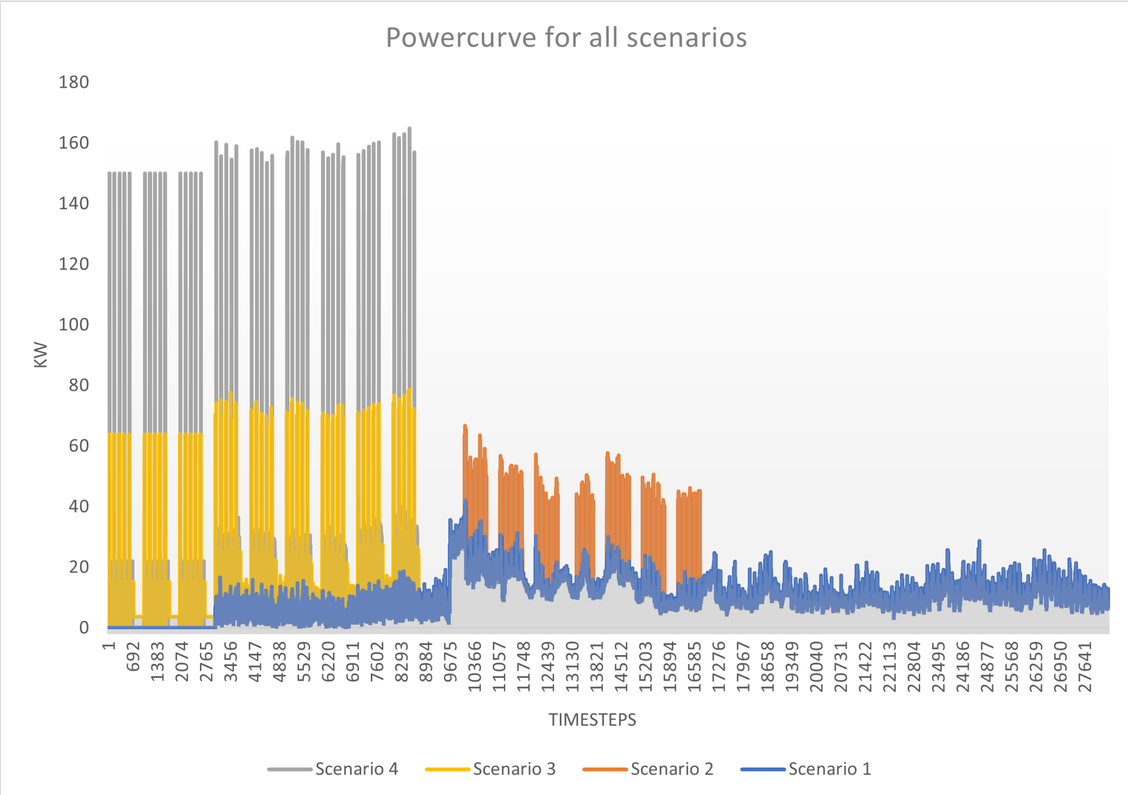


Figure 4.1: Powercurve of all scenarios. The grey area represents the transferred electricity for scenario 1 and one timestep equals 10 minutes.

Figure 3.5 or the blue graph in Figure 4.1 shows the electricity demand before additional demand is added. The shed establishment was the first current connected to the grid while the container and construction current was connected in December. Due to electric heating in the sheds, the peaks are temperature correlated where the highest peaks occur at the lowest temperatures which can be seen in Figure 4.2. Furthermore, the highest peak occurred in December (40 kW) when the construction current, as well as the container, was connected see Figure 4.1. This would correspond to the second phase of construction. According to multiple respondents, the highest peaks are likely to occur throughout this phase due to frame construction. However, the highest peak is likely a result of connecting all power sources, further because of low outside temperatures.

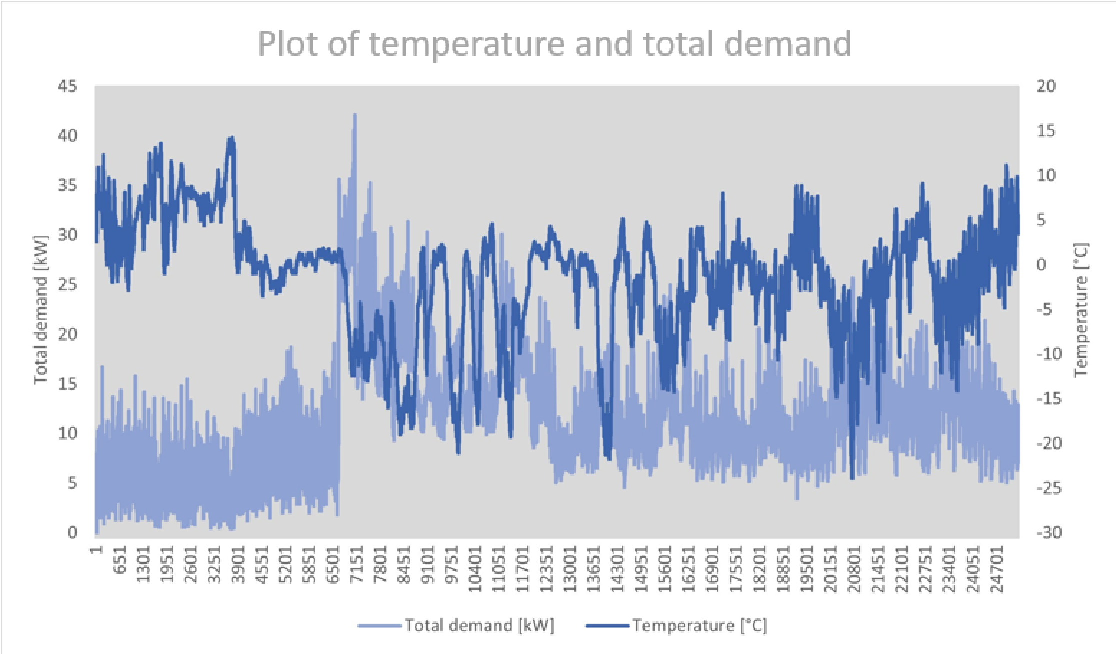


Figure 4.2: Total power demand and outside temperature. One timestep equals 10 minutes.

In scenario 2, represented by the blue and the orange graph in Figure 4.1, the power demand for an electric construction crane was added during the frame construction of the project (5/12-20/1) where the rest of the period remains unchanged. This leads to recurrent power peaks during this period, where the maximum peak reaches 65 kW. As could be seen in this scenario the construction of the frame would coincide with the connection of the construction current as well as the container. It can also be assumed that the peaks from the frame construction will coincide with power peaks from smaller equipment for finalizing exterior work, and coincide and fans that are used to dry out the building damp and such.

The third scenario in (Figure 4.1) represented by the blue, orange and yellow power curves combined shows the result of adding an electric wheel loader. In this scenario, an optimal charging pattern was implemented which is a result of implementing some behavioral changes at the construction site. The result gives that the main fuse is enough to provide sufficient power (125 ampere) and that it is not necessary to use a battery to manage these peaks. However, as seen in Chapter 4.2.2, it was still cost-optimal to use a battery. This case resulted in a maximum peak of about 80 kW in phase 1 which is about five times higher compared to the maximum peak in the same phase in scenarios 1 and 2.

The last scenario (4) shows a charging behavior of an overestimation of charge to ensure enough capacity during the day. This could be seen in Figure 4.1 where the blue, orange and gray graphs forms scenario 4. The curve illustrates the power demand when fast charging the wheel loader with a capacity of 150 kW. When charging according to this behavior, the highest peaks become about eight times as high as before adding any additional load, and the peak gets about twice as high compared to the optimal charging pattern. Hence, it is a challenge to fast charge during the day for equipment of that size in this magnitude of project. The main fuse in this project is at 125 A and is connected to the low-voltage grid which enables the highest power peak to reach a maximum of 90 kW. By looking at the results from the graph this charging pattern would not be possible to obtain without having a battery in place or ensuring a higher main fuse. Most likely, it will not be profitable to charge equipment of this size for this magnitude of project as the connection needs to be determined based on the wheel loader.

4.2.2 Result of battery use

In this section, the result and analysis for battery use is presented. Figure 4.5 from the variable Battery capacity (i) in the model is presented in the first column, together with the highest peak that the battery has "peak shaved" down to and lastly the main fuse that has been chosen. The area marked with grey is considered irrelevant to simulate since it is unlikely that the power curve will look the same in 2045. Note that the table was created based on the assumption that the power subscription has a fixed cost per kW that is valid for all sizes of Fuses. Generally, large battery capacity correlates with high electricity prices, with a larger capacity being chosen in 2022-2023 during the period when electricity prices were rather high and fluctuating. The capacity was much lower in 2018-2019 where prices compared to 2022 were very low. For the case of 2045, the capacity was larger compared to 2018 but smaller than 2022, which can be explained by larger price fluctuations compared to 2018, lower total electricity prices than 2022 and lower investment cost of the battery than 2022 and 2018. The size of the battery is also related to different phases in the construction process, which will be further analyzed in this section.

Table 4.5: The result from the model for the optimal capacity of a battery each month for the different scenarios.

		Spot price 2018-2019			Spot price 2022-2023			Spot price VRE 2045			Spot price Baseload 2045		
		Battery capacity [kWh]	Highest peak [kW]	Fuse [A]	Battery capacity [kWh]	Highest peak [kW]	Fuse [A]	Battery capacity [kWh]	Highest peak [kW]	Fuse [A]	Battery capacity [kWh]	Highest peak [kW]	Fuse [A]
Scenario 1	okt	9	8	16	11	8	16						
	nov	19	26	50	100	22	35						
	dec	24	32	50	289	60	100						
	jan	12	22	35	100	23	35						
	feb	34	16	25	44	15	25						
	mar	23	18	35	38	19	35						
Scenario 2	okt	9	8	16	11	8	16						
	nov	19	26	50	100	22	35						
	dec	74	32	50	364	71	125						
	jan	61	25	50	128	27	50						
	feb	34	16	25	44	15	25						
	mar	23	18	35	38	19	35						
Scenario 3	okt	59	18	35	73	27	50	59	18	35	59	18	35
	nov	54	24	50	120	34	50	54	24	50	54	24	50
	dec	74	32	50	364	71	125	105	31	50	106	31	50
	jan	61	25	50	128	27	50	123	23	35	121	24	35
	feb	34	16	25	44	15	25	49	14	25	49	14	25
	mar	23	18	35	38	19	35	34	17	25	32	17	25
Scenario 4	okt	144	18	35	134	28	50	144	18	35	144	18	35
	nov	137	28	50	135	30	50	141	24	35	141	24	35
	dec	74	32	50	364	71	125	105	31	50	106	31	50
	jan	61	25	50	128	27	50	123	23	35	121	24	35
	feb	34	16	25	44	15	25	49	14	25	49	14	25
	mar	23	18	35	38	19	35	34	17	25	32	17	25

In phase 1 (Oct-Nov) scenario 1 and 2 does not differ since no load is yet added. But the battery capacity increases between scenarios 2 and 3, and from scenarios 3 to 4. It seems hence like the demand for peak shaving increases in relation to the extra load of charging heavy equipment. This means that it seems like the charging pattern for the heavy equipment affects the investment cost for the battery. In this case, there was only one heavy equipment added, but for a case with several equipment that need to charge, it is likely that a much larger battery is needed in this phase. That increases the incentive to look for charging strategies. For electricity prices in 2018-2019 and 2045, the largest battery was chosen in this phase (October) in scenario 4, but for all other cases, the largest battery was found in December.

In phase 2 (Dec-Jan), the highest capacity of the battery was found, which occurred in December 364 kWh when observing the prices in 2022-2023. This is the same for scenarios 2, 3, and 4 since the load from the crane does not overlap with charging the wheel loader. The highest fuse was also found in these scenarios and was the only ones that reached over 63 A. This correlates with the highest peak which is found in December, which partly can explain the result. One noticeable result from the table is that the battery has cut the peak more in scenario 4 compared to scenario 3 related to prices 2022-2023 although there is a higher load in scenario 4. This peak shaving pattern is illustrated further down in Figure 4.10. Another noticeable aspect is that it is not necessary for the project to use a battery in this phase since the main fuse is enough. But due to the assumed battery- and grid cost, this is the most cost-efficient solution.

In phase 3, there are no differences between the phases regarding the size of the battery since there is no added load. The only difference is that it changes between the selected spot prices. In this phase, the model has chosen the smallest battery capacity compared to phases 1 and 2. This can partly be explained by the usage of smaller equipment in phase 3 which appear to constitute a relatively low load on the grid. It can also be affected by electricity prices, which will be analyzed further in the following sections.

One possibility for selecting the largest battery capacity in December can be explained by the amplitudes of price fluctuations in 2022-2023 see Appendix B.1. The big difference in prices could cause the model to charge at low prices and discharge at high prices, which enables more electricity to be provided from the battery when the difference between price peaks is large. Another factor possibly affecting the selection of battery is the total amount transferred electricity. The total amount of consumed electricity at the construction site in phase 1 was 18800 kWh and the total amount of consumed electricity in phase 2 was 21600 kWh which gives that slightly more energy has been transferred in phase 2. On the contrary, looking at Scenario 4 with 2018 and 2045:s prices that are lower, it appears that the selection of largest selection of battery capacity occurred in November. Suggesting that in the case of running the model with lower prices, the dimensioning factor appears to be the highest peak in the project, rather than the total electricity transferred.

Since the largest battery was selected for December with prices 2022, it also becomes relevant to look into the charge and discharge capacity as factors characterizing each phase. The peaks are higher with lower recurrence and lower duration than in phase 2 which makes the cost-optimal design a selection of higher discharge capacity [kW], but lower capacity to store energy (battery capacity [kWh]). This could be seen when comparing the charge and discharge graphs 4.3 and 4.4 for phases 1 and 2 with spot prices for 2022.

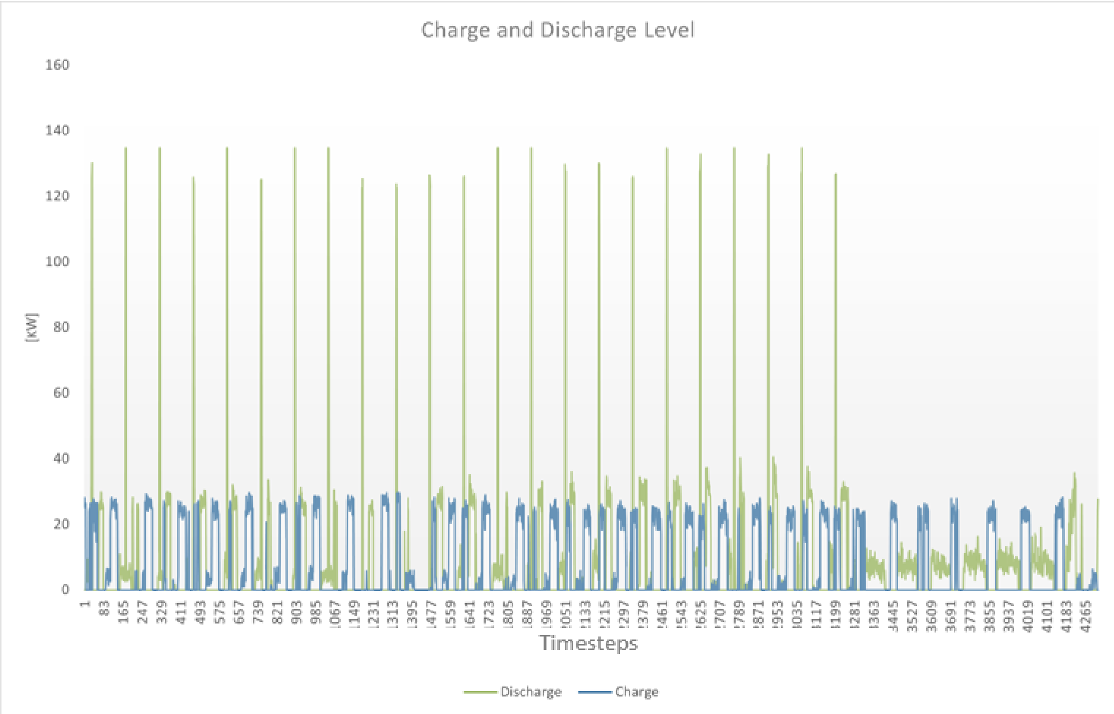


Figure 4.3: Charge and discharge levels looking at scenario 4 (Phase 1) using spot prices for 2022. One timestep equals 10 minutes.

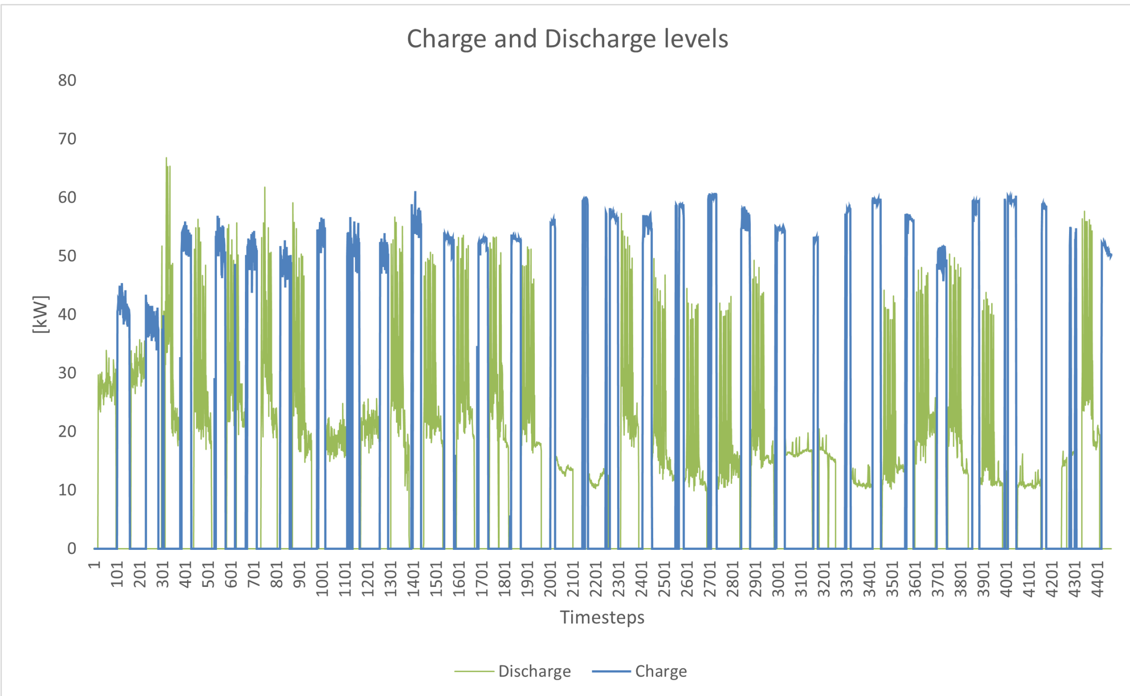


Figure 4.4: Charge and discharge levels looking at scenario 4 (Phase 2) using spot prices for 2022. One timestep equals 10 minutes.

The graphs 4.3 and 4.4 shows how the model has selected the optimal charge and discharge pattern in phase 1 using spot prices for 2022. It can be seen from the graph that the optimal discharge level is higher in November than in December. This is due to the fact that the wheel loader is charged at full capacity in scenario 4 which results in high peaks. In December the discharge level is lower which is the phase where the construction crane was used. This pattern can be observed when looking at Table 4.10 where the wheel loader was charging. In scenarios 3 and 4 where the wheel loader is used, the highest optimal discharge level is lower in November compared to December which suggests that the battery has discharged at higher capacity in November.

4.2.3 Charging behavior of the battery

In this section, the pattern for how the battery is charged and discharged is presented in relation to the demand for the different phases and scenarios of the project. Figure 4.5 shows an overview of the state of charge for parts of phase 1 - 2 (15 Nov-15 Dec) for electricity prices 2022-2023 in relation to the demand.

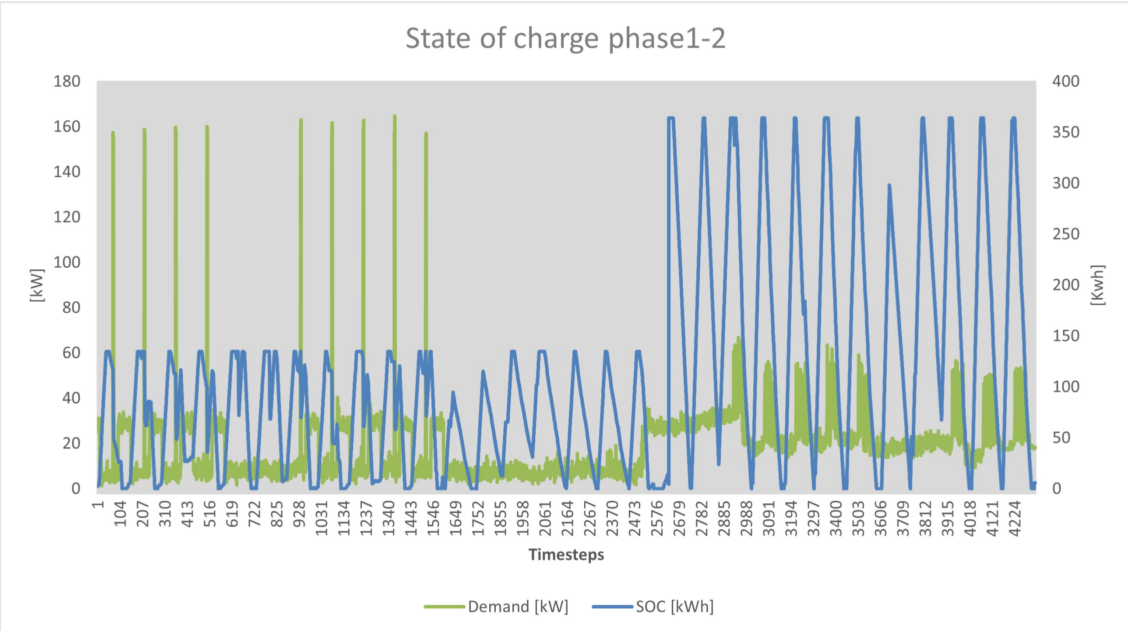


Figure 4.5: State of charge for scenario 4 zoomed in during phase 1-2 in relation to the demand for year 2022-2023 electricity prices. One timestep equals 10 minutes.

A more zoomed-in image of the first phase of the project is illustrated in Figure 4.6 for case 4. It can be seen that state charge is the highest before the peak demand when the wheel loader is fast-charged during the lunch break. The lower peaks illustrate the charging during the night (22kW) until the battery is full. The battery starts to charge during the night when generally prices are low (see Figure 4.8), whereas the battery is fully charged in the morning. The battery is discharging somewhat before the fast charging occasion but starts to discharge fast when the wheel loader is charged during the lunch break. After that, the discharging pattern differs between the days, which could be explained by the fluctuations in electricity prices. For example, the state of charge becomes constant on some occasions where the charging stops. The correlation between the state of charge and the demand is seen more clearly in Figure 4.6.

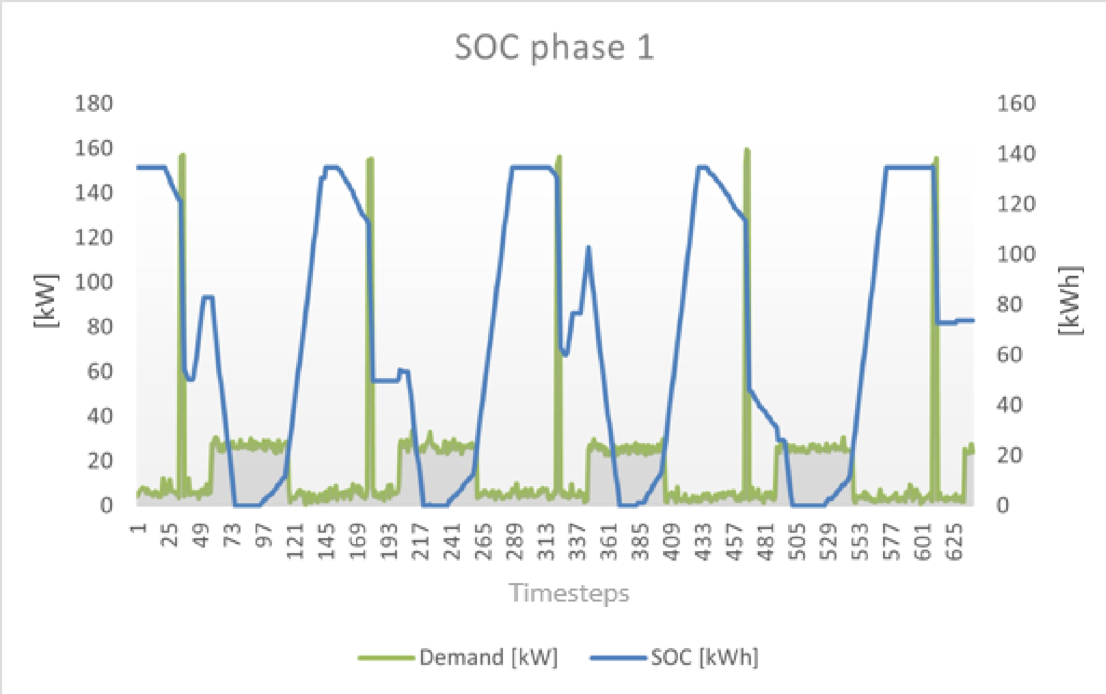


Figure 4.6: State of charge for scenario 4 zoomed during phase 1 in relation to the demand for year 2022-2023 electricity prices. The gray area represents the total demand in kWh during phase 1 and one timestep equals 10 minutes.

Figure 4.7 illustrates the charging behavior zoomed in from 5th to 9th of December in phase 2 when the crane is added, which looks the same for scenarios 2-4. The high peaks occur during the day when the crane is in use, where each peak represents a lift. The battery is charging when the demand is lowest and is fully charged before the working day starts (6.30). The state of charge is also constant for a short time before it is starting to discharge at the beginning of the working day (6.30) when the use of the crane starts until fully discharged at the end of the working day. The charging pattern seems hence to correlate with the demand. It also appears that the battery has been charged throughout the night when peaks are low from the project. It can be seen in comparison to phase 1 that peaks occur more frequently in phase 2. It also appears that the battery has not charged or barely charged in between the peaks in phase 2. In phase 1 the battery has been charged in the afternoon in between the break and the end of the workday during some days. Moreover, looking at phase 2 it has a rather continuous discharge rate. This might also suggest that the frequency of occurrence could be a determining factor for the selection of battery capacity.

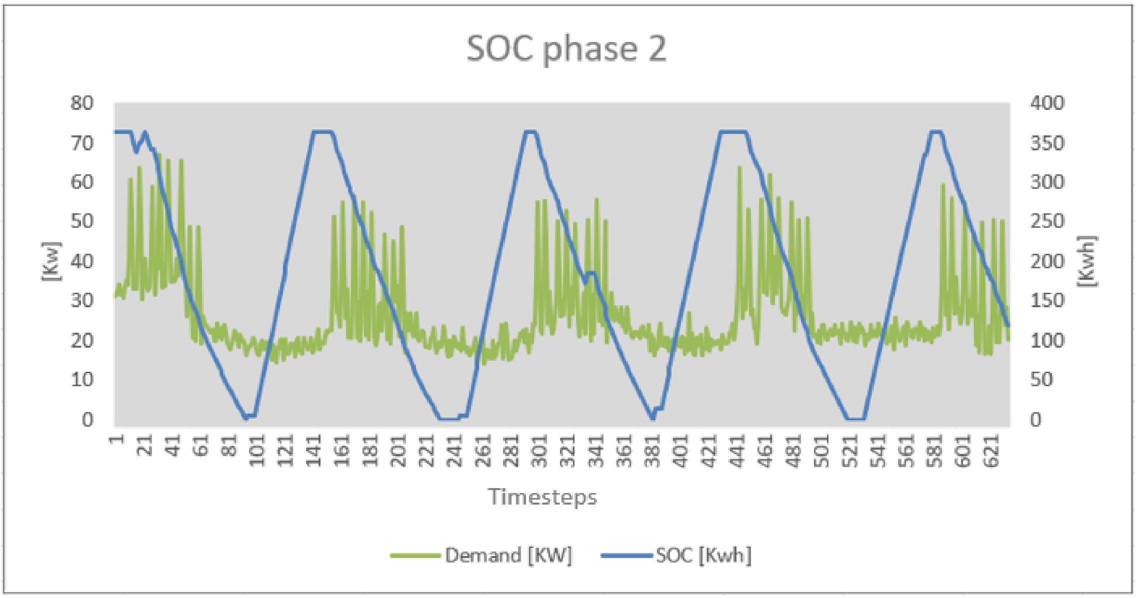


Figure 4.7: State of charge for scenario 4 in-zoomed during phase 2 in relation to the demand for the year 2022-2023 electricity prices. One timestep equals 10 minutes.

Figure 4.8, shows a section of State of Charge in scenario 4 together with spot prices, where it can be seen that the charging pattern partly can be explained by how the electricity prices fluctuate. The figure has the same time period as for figure 4.16. It can be seen in the graph that there is a correlation where the battery is charged during low spot prices and discharged during peak prices.

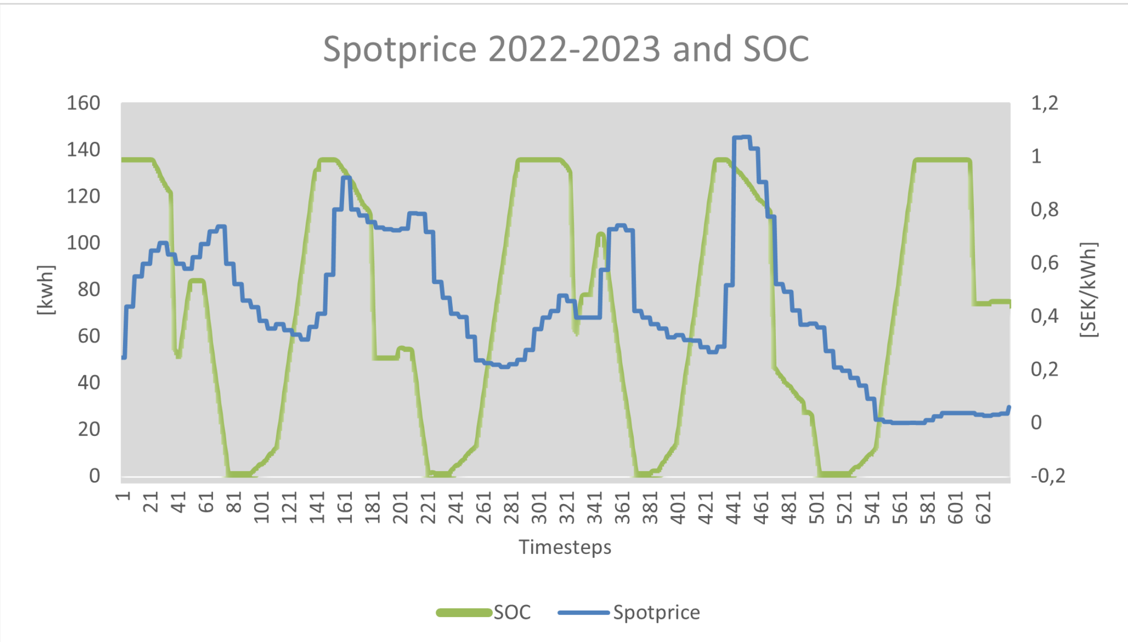


Figure 4.8: Plotted spotprices for 2022-2023 in relation to state of charge 5-9 dec, looking at scenario 4. One timesteps equals 10 minutes.

4.2.4 Purchase from the grid

This section describes the total purchase which includes the electricity purchased from the battery and the electricity purchased from the grid. This has also been compared between scenarios. Figure 4.9 shows a comparison between scenarios 1 and 2 in phase 2, hence with or without the electric crane. In scenario 1, the battery "shaves" the peaks down to 60 kW and for scenario 2 down to 70 kW. This level is the most cost-optimal level for the battery to peak shave for the different scenarios, in relation to the assumed battery cost and electricity prices. For spotprices 2018-2019, the battery shaved to the same optimal level in this phase, although the differs between scenario 3 and 4 in phase 1. This could be explained by the low price fluctuations in this time period, which decreases the incentive to use the battery and charge at low prices and discharge for high prices.

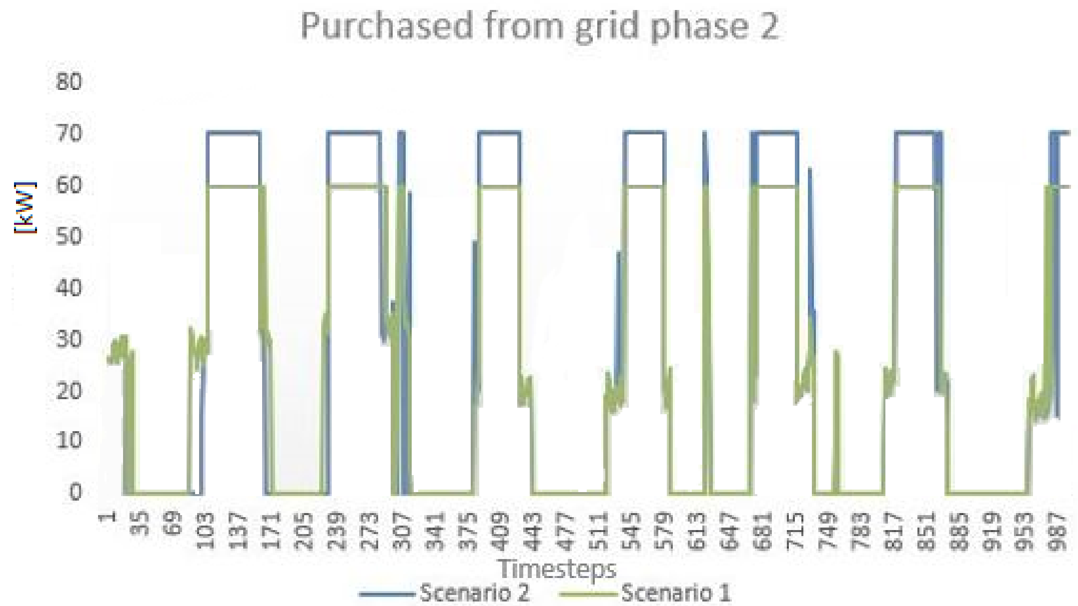


Figure 4.9: Purchased electricity from the grid in phase 2, comparison between Scenario 1 and 2 in December with electricity prices 2022. One timestep equals 10 minutes.

Figure 4.10 illustrates a comparison between the different charging patterns (scenarios 3 and 4) for spot prices 2022-2023. It can be seen that the battery has shaved more in scenario 4 compared to scenario 3. The battery has hence been used more in scenario 4. It can also be seen in Table 4.10 that the investment cost of the battery is higher in scenario 4. One explanation could be that there is a higher incentive to use the battery more when there is a high peak and make use of the high price fluctuations. Hence, for case 3, it was more efficient to purchase relatively more electricity directly from the grid. For spot prices 2018-2019 when the price fluctuations were low, the optimal level was lower for scenario 3 compared to scenario 4. In 2045, the optimal level was the same for the two scenarios where the prices fluctuated more than for 2018 and less than for 2022, which strengthens the assumption.

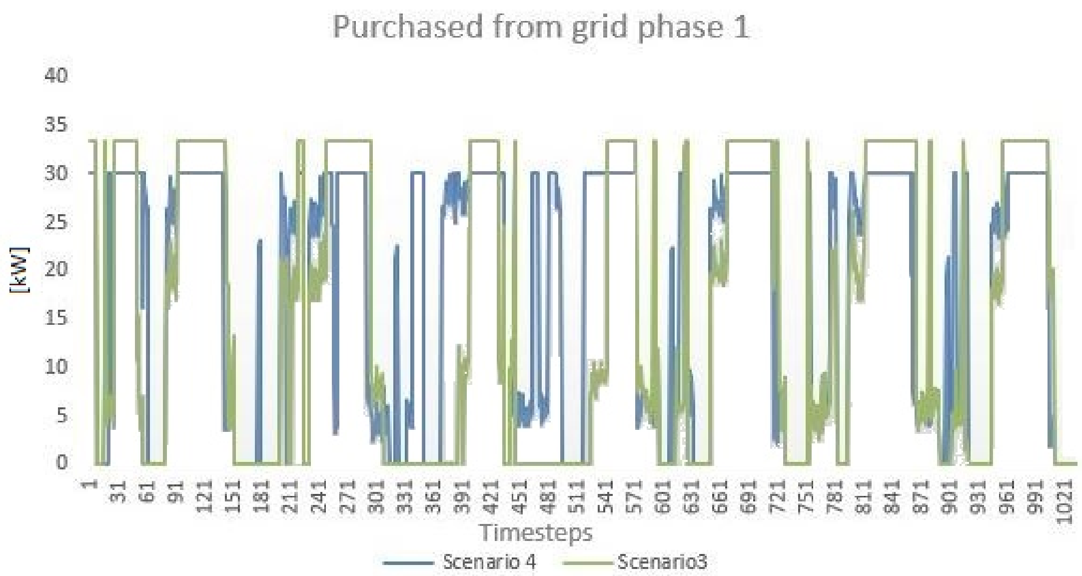


Figure 4.10: Purchased electricity from the grid in phase 1, comparison between Scenario 3 and 4 in November with electricity prices 2022. One timestep equals 10 minutes.

Figure 4.11 represents the test that was run in the model where the main fuse was constrained to 63A. Subscriptions below 63A currently are not charged a fee for the highest peak in this geographical area considered. Rather they are charged a monthly subscription cost and a variable cost for the electricity transferred, including tax, which was added in the model. For Scenario 4 (nov), the system cost was for this case 45 000 SEK using a battery with a fuse cap of 63A. Without using a battery, the cost was set to 62 000 SEK for the same period. There is hence a possibility (in short time) to save approximately 17 000 SEK in December, forcing the model to choose a fuse below 63 A by using a battery. However, this cost was based on the high prices in December 2022. Looking more long term when there is no distinction between the different subscriptions, a possibility to save cost during this month was about 10 300 SEK when comparing the system cost between with or without a battery in the model.

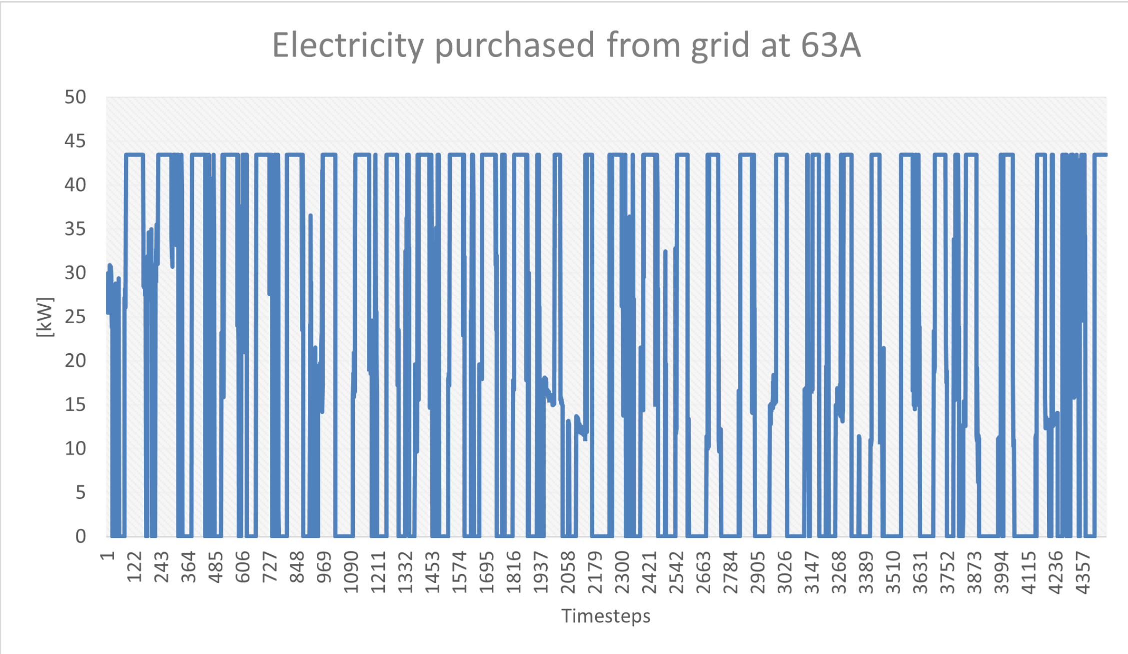


Figure 4.11: Purchased electricity from grid with a constrained main fuse of 63A in phase 2 (December) 2022 for scenario 4. One timestep equals 10 minutes.

5
Analys

In this section, the result relative to the research questions will be analyzed. There will be a combination analyzing the interview results in comparison to the case study and how this relates to relevant literature.

5.1 An Equipment Rental business part in the energy transition

This section will go further into how the Equipment Rental business can contribute to the transition related to the scope of the study. One starting point in this study was backcasting, where the aim of the study was to start with mapping the challenge and people's perspectives on the vision before examining possible solutions. The area investigated in this project is related to several new ways of thinking and organizing, where it has appeared to be barriers to implementing some of the strategies. This work can be seen as an expedition (chapter 2.1), where challenges are being explored with the goal to learn and get new perspectives, and bring important knowledge back to the organization in the long term. Current business models, routines, and behaviors can in this context be seen as a barrier in a transition such as the one observed in this thesis. Meanwhile, it is important for the organization to keep up with the business model, where there is an urge to find a way to keep up with the same effectiveness, but at the same time implement new ways of thinking.

The case in this study addresses the challenges that the Equipment Rental business faces when reaching the sustainability goals in 2030 and 2045. Predictions and calculations such as the cases in this study could provide key insights into what actions are needed to be taken in relation to the development of electrification and a changed electricity system. For example, how to proceed with the electrification and infrastructure solutions with fluctuating electricity prices, and at the same time be profitable. From several interviews, it appeared that the Equipment Rental business needs to provide holistic solutions for the construction sites, and has the role of providing solutions that can enable a future "emission-free" construction site. The Equipment Rental business has the role of providing comprehensive and optimized solutions to the project, which also could include flexibility services. Although the the Equipment Rental business can contribute with electrified heavy equipment, they key part that they could have in the transition toward "emission-free" construction sites is to provide calculations and knowledge to manage changed conditions. Future challenges are dependent on the development of electrification and in the electricity system. A way to analyze this demand is by building up possible future scenarios such as the case in this study.

5.1.1 Why is there a need to map the demand at a construction site?

One finding in the study is the importance of analyzing measurement data from the project. For the case investigated in this report, there were measurements from different sources (shed, container, and construction current) which is digitally analyzed. However, measurements like this seem to be rare at the moment and were hard to find, but are starting to emerge. One possible reason is that there has also not been an incentive to focus on this, comparing the electricity prices between 2018 and 2022. Hence, the incentive for minimizing electricity consumption and optimizing the time of consumption at the construction site has increased. The power curve that was built up in the case from the diesel consumption is one strategy to create similar analyses for when there is a lack of electricity measurement data, or when there is a need to look at future demand. However, it is possible to obtain historical data from a specific project from the DSO that is operating in the region where the project is carried out. They are according to Energimarknadsinspektionen obligated to provide electricity distribution over time by law to customers (Energimarknadsinspektionen, 2023b). Upon request of the customer, it should be possible to obtain the data if the measurement has been retrieved with an hourly resolution. Additionally, looking at power subscriptions, the data provided to the DSO must show the electricity distribution over time in order to charge for the highest peak. Hence, there is a possibility to use the model created in this project to run simulations on several other historical projects, with lower resolution of data points.

It appeared both from conducting the case and the interview study, that it is important to find the source in order to address the right solution in the context of minimizing peaks at the construction sites. Additionally, that it is important to have a broad perspective on the entire construction site. By analyzing data from different sources, it creates the possibility to see what is causing high peaks or high electricity consumption. Using flexibility services is one way to cope with minimizing the electricity cost and satisfy the demand at the construction site. There is hence a need to know what is causing the peak. For example, if the cause of the peak is due to that different tasks or charging occasions coinciding, or if the charging occasions need to be reallocated. It is then possible to answer where in the project there is potential to use flexibility services, and which peaks are possible to move.

By mapping the electricity demand at the specific project and providing the right kind of solutions for the customer, it can contribute to fulfilling the sustainability goals and at the same time making profitable investments. Battery storage seems to be a solution that participants in the interviews saw potential in, which does not compromise the productivity of the project. However, it is still important to understand the context in order to provide a suitable and cost efficient solution. For example, as (I1) mentioned in chapter 4.1.3, if the Equipment Rental business is going to provide a battery to a specific project, it is important to know the type of project, what equipment is used, and what the electricity demand is. Therefore, measuring the power demand for different connections as in case preschool, and mapping how different equipment is used, can be a way forward to keep track of the demand and provide a battery that is suitable. In addition, it appeared from the interviews that the knowledge around these kind of new solutions should increase, and that is important to understand the use of the battery. It is moreover important to make calculations and explain the benefits of an increasing cost, and get the customer to rethink. The preschool example can be seen as a possibility to increase awareness and find the most suitable solution for the customer.

5.1.2 How can the development of the electricity system and future electrification affect the role of the Equipment Rental business?

It has become apparent that a likely trajectory for the development of the energy system includes a larger share of intermittent supply, which has been shown to amplify price fluctuations but lower the long term average electricity costs. Further, because of climate targets from several industries such as construction equipment manufacturers reaching net zero emission by the year 2050 and the transportation sector reaching net zero emission by 2050 (chap 2.3.1), it is estimated that grid infrastructure will be reinforced. One of the DSO:s operating in the Stockholm region has predicted that a cost of 700 billion SEK will be invested in network infrastructure by 2045 in Sweden to provide for the sustainability transition (chap 2.3.2). It is therefore likely that peak consumption will become more expensive for single consumers since the grid must be reinforced in local regions. This development creates an incentive for construction sites to even out their load by either shift activities in time, by using a battery or a vehicle to discharge to the grid to provide peak shaving, or to reduce the overall consumption at high load hours. Since construction sites typically have temporary power connections that are replaced once the construction is finalized the tariff structure is however likely to look very different depending on the area. What could be assumed however is that there seems to be a direct correlation between electricity prices and variable network costs. All these factors combined are crucial mechanisms pushing for a more flexible behavior at construction sites and can in that way increase the Equipment Rental business contribution with flexible solutions. This will be further analyzed in the next section.

5.1.3 How can a Equipment Rental business use flexibility services to manage future demands and challenges at different time scales?

Flexibility services investigated in this study were peak shaving and load shifting by using a battery in this specific project. According to the results, there seems to be a short-term potential to use a battery to even out the demand However, an important factor from the interview study was that there is a knowledge gap where the customer needs to see the value of having a battery in place, where the Equipment Rental business can have a role of providing "black and white" examples of benefits. The actual potential for using peak shaving can according to this only be significant in combination with proving the Equipment Rental business and, in turn, the customer the benefits.

One strategy that can make the investment of a battery even more cost-efficient is to evaluate if there are other ways to even out the power curve or minimize the amplitude of peaks. The result may be that it is not necessary to use a battery or that it is possible to invest in lower capacity. Therefore, it is important to map all peaks and evaluate if it would be possible to move any load. For example, plan not to have multiple tasks simultaneously that require high power. This is however an area where the Equipment Equipment Rental business could have limited potential to change since it is about the construction process, but could still have one role in the process by education and providing examples. There is a risk to disturb the productivity of the project. The main goal for the project is to be as effective as possible, and in some projects, there is no incentive to change the mindset and value other aspects more such as valuing lowering the electricity bill. In the future, with a higher peak demand due to more electrified equipment, the incentive to keep the electricity bill down will increase as it will constitute a higher fraction of the total cost for the project. A conclusion from the interviews is that flexibility solutions that limit the productivity in the project only have the potential to be implemented long-term. It is however difficult to predict the time range since it is most likely a continuous process. According to the interviews, solutions that do not intervene with the productivity of the project could instead be seen as having higher potential to be implemented short term such as batteries, smart charging during the night, or small delayments on a minute basis.

There are however different factors that can steer what the potential will look like in the future. We are in a dynamic system in constant change, and it is important to keep track of different developments and have a long-term approach. For example, changes in electricity prices can change the demand for flexibility services at different time scales, both short and long-term. Due to the research used in the case, the energy system costs in 2045 will decrease. In shorter time scales, it is more uncertain whether the prices will increase or not. Another factor that can change the demand is the development of frequency reserves in the market, which could be steered by the development of electricity prices. The demand for using battery storage is likely to increase, both on a small- and large scale, and there is uncertainty about how the demand will develop. Another important factor is to consider different scales of projects. It is likely that large projects are less price sensitive since they have larger budgets, while small-scale projects are more vulnerable to rising electricity costs.

6 Discussion

In this study, an investigation of challenges for a Rental business and construction sites have been analyzed in the context of reaching sustainability goals and managing a development of the electricity system. It have been seen that there is a lot of development potential in the area of investigation where the thesis can be seen as a suggestion to manage these challenges. In this chapter, the results will be put in a broader context of the sustainability- and energy transition in the entire industry, in connection to parallel developments. Furthermore, the chosen method will be critically evaluated.

6.1 Strengths and weaknesses of the study

In this section, methodology choices, limitations, and further research will be discussed.

6.1.1 Methodology choices impact

The methods used in this study were a combination of a quantitative part when studying the technical potential of load shifting and peak shaving at a construction site in combination with an interview study to get insight into the organization and the industry. This provides a broad understanding of the need for looking at the potential for flexibility services. There is a lack of research in the area of investigation for this particular study, which motivates the choice of having a broad starting point and looking at the challenge from different perspectives. This study can be seen more as a way of creating a possible methodology for how to manage situations of power shortage, expensive tariffs and increased electrification. By collecting data from projects of different magnitude through DSO:s it could be possible to draw more general conclusion about the potential of using a battery.

A limitation of the study was that only one case was investigated. In order to get a result that can be applied to different projects with different prerequisites, it would have been beneficial to look at several different kinds of projects. The result would most likely turn out differently if a larger project was analyzed. For example a case where a larger tower crane has been used, it could have led to much higher power peaks. Additionally, if studying project with several heavy equipment running on electricity, the conclusion made for future challenges in this study would be more nuanced. A larger project would also have a different budget and price sensitivity and a longer time frame. Another aspect that would give more weight into the result and conclusions, would be to look at projects in different local areas which have different structures around the electricity cost and different local challenges.

Several assumptions affected the result of the study. The worst case charging behavior for heavy equipment was partly based on a log and the result from the interviews where it appeared that it is important not to risk production fallout during the day. However, in reality, the breaks could have been located differently, and there could be occasions where it would not have been necessary to charge during a day with low workload. The optimal charging pattern was also optimized without considering other loads. For example if there would be a peak during the night due to low temperature, the charging could be stopped, which the model does not consider. This could create a basis for if a "smart charging" system would be efficient to invest in. The optimal charging pattern is most likely not possible to obtain in reality. It was also assumed that the wheel loader was in use for 20 days/month, hence the energy demand was overestimated. However, since the energy required for the wheel loader was calculated based on an average daily demand given by a monthly consumption of diesel, it is likely that the actual consumption will fluctuate above the mean value sporadically throughout this time period.

Another assumption that has been made is that the power peak cost is valid for all subscriptions. Currently the power subscription is only valid for fuses larger than 63A which can make the cost efficient battery capacity overestimated in this table. However, it has appeared that it is likely to change within the coming years since Energimarknadsinspektionen has commissioned all DSO:s to implement a new tariff structure by the year of 2027 (see chap 2.3.2). Meaning that subscriptions with lower main fuses than 63A might have to pay for their highest peaks, but the design of the tariff will vary depending on the geographical area. However it is also reasonable to assume this value to be lower for lower subscriptions.

The assumptions made for creating the power curve for the crane were based on a "worst case". It was estimated that 50% of the energy consumed by the crane is allocated on a timespan of 10 minutes. In order for the maximum peak to reach 150kw which the wheel loader was charged with the total energy consumed in the crane would have to be distributed over a time span of four minutes which was deemed unreasonable for this case, since one lift has been estimated to take one hour which includes connecting, turning, lifting and lowering the load. Hence fast charging the wheel loader at 150kw is estimated to be the dominating peak throughout this project. Hence the power output that the battery requires will be determined by the highest load if the battery is used for the entire project.

6.2 The results in a broader context

In this section, the result from the interview and the case study will be discussed outside the limitations of this study, where the results will be discussed in a broader context.

6.2.1 The case up-scaled

It became apparent from this study that the use of heavy-fueled vehicles will constitute to a significant load on the grid once they are charged. The effect on the grid is varying depending on the tasks performed. Whenever the wheel loader requires more electricity than what could be consumed from the battery in the machine (i.e. 240kwh), it will constitute a load on the grid since the excess energy it requires must be provided by charging the vehicle. One thing that appeared from the interviews was that heavy equipment is continuously used throughout the day, which could indicate that the charging opportunity occurs during the breaks. If the total excess energy that all heavy equipment requires in a project is larger than the total battery capacity for all vehicles, the excess energy will at some point throughout the day be provided by the grid or discharged from an external battery. It can be suggested that the power curve in phase 1, when the foundation is built, will be characterized by high peaks with low duration and low recurrence throughout the workday and continuous load throughout the night.

Another factor that emerged from the interviews was that heavy vehicles require more energy during the winter seasons because of frozen conditions in the ground which makes the engines consume more energy. This data was retrieved in August which makes it reasonable to assume that if phase 1 coincides with lower temperatures the vehicles will likely consume more energy. This indicates that the critical peak loads will most likely occur during wintertime which also coincides with a more expensive tariff. Moreover, these loads are less likely to coincide with loads of the second phase when the frame is constructed since most of the heavy equipment have finalized the tasks and is returned to the equipment rental business. This suggests that a battery with a higher discharge capacity might be selected when several electric heavy vehicles are in place, see table 4.13 in chapter 4.2.2. This also suggests that the peak load from charging the electric vehicles could be spread out, in order to find a cost-optimal battery system. Further, it can be assumed that the tariff structure will change in several regions by the year 2027, and possibly act as an incentive for the use of battery systems for peak shaving.

From the result of the model, it also appeared that the combination of high amplitudes of price fluctuations and high system costs was the dimensioning factor when selecting the optimal battery capacity. On the contrary, it appeared that the implementation of more intermittent supply in the system will amplify price fluctuations, but lower the system costs in the long term. In such cases, the optimal battery capacity has been deemed lower, running the model with the spot prices of 2045, although the investment cost has been set to 41% of the investment for 2020. It also appeared that the scarcity of peak generation, which is currently dominated by fossil fuels has shown to be a driving mechanism for high system cost and high fluctuations. Assuming that the prices for 2022-2023 are static and not representing long-term development, the battery capacity in 2022-2023 might be overestimated.

In small-scale projects such as the one observed, solutions such as rethinking how breaks are allocated or deviate from a mindset of overestimating the charge might decrease the need for having an overestimated battery in place. It can be assumed that small scaled projects have tighter margins in the budget, and do not have the opportunity to overestimate the capacity of equipment, including battery storage. A larger project where several heavy equipment needs to be in place, it however increases the incentive to not charge all the equipment at the same time, since this would constitute relatively high power peaks, which will lead to increasingly high power costs. It can hence be assumed that prospectively, the incentive for looking at planning around charging schedules and breaks will be important.

The case showed that there was a large variety of battery sizes between the different phases. A suggestion for residential construction projects could therefor be to either rent different sizes of batteries for the different phases or to only rent a battery for a specific period since the battery will be oversized for the entire project. It is however important to consider what the cost-optimal option in the project would be since changing the battery size could cause additional transportation- and service costs. The important part of the project would be what in the end causes the lowest total cost and what is most effective. It is also a question however it is possible for the rental business to provide the service to change batteries frequently. In the short term, the stock of different battery sizes will be limited because of high investment costs and an uncertainty of the demand. However, in the long term, the rental business could perhaps be able to provide a range of batteries. It could although be assumed that it is not efficient to change the battery from one month to another when the optimal size for each month differs marginally since there will be a limited range of battery sizes available at the market. A possibility could, in such a case, be to offer different batteries when changing construction equipment for the different phases or tasks in the project.

6.2.2 Further investigation

It has not been thoroughly investigated in the study whether temporary power connections are likely to be rejected as a result of the expanded charging infrastructure. This is an area where there is a lack of research on whether it will be a challenge in the future. Challenges with power shortage will be a combination of external factors and developments at the construction site. For example electrification of projects nearby, more electric vehicles, possible projects nearby that also have increased electrification and trucks that will have to charge at the site when dropping off a delivery. There is hence an incentive to investigate further how the construction sector will be affected due to different developments, and also how for example vehicle charging will be affected by construction projects in the city that increases the amount of electrified equipment. A recommendation for further study is hence to investigate if and how construction sites are competing with other sectors in the city regarding power demand. There seems to be a lack of research what the role of construction sites are in sustainable cities. A possible question to investigate could be if there are any possibilities to collaborate with projects that focus on shared charging infrastructure in the city.

One possible strategy and further development of this study could be to so scale up the project. A first step could be to look at how several heavy equipments are affecting the result and evaluate this for different kinds of projects. The next step could be to scale up the development for a larger area, for example, the Stockholm area, and investigate how all the construction sites could affect the electricity system. This could furthermore be scaled up to the industry as a whole on a national level.

Another development of the case is to further investigate the potential of allocating breaks. The case together with the interview study indicates that allocation of breaks and planning of tasks can have an effect of minimizing the cost when more equipment is electrified. However, in order to examine more precisely the potential of reallocating breaks to minimize power peaks, more projects must be observed.

Lastly, one improvement of the study could be to use more exact data. There were several assumptions and estimations made to create the power curves for the crane and for the wheel loader. The result would be more specific and close to reality by tracking the fuel consumption of different equipment continuously throughout the day. It would then also be possible to find how the use of equipment affects the need for flexibility as well as the investment cost of a battery storage.

7
Conclusion

- Battery storage has the potential to lower the system cost for this magnitude of project, in the considered geographical region. The potential is likely to rise in the future when more heavy equipment is electrified. The major findings that affect the total invested capacity of a battery are the electricity prices and how peaks coincide. By implementing variation management strategies at the construction site it is possible to lower the total cost of electricity in a project.
- Solutions that can be implemented without hindering daily operations have the potential to be implemented short-term. This includes using batteries or being flexible with the load curve on a short-time basis that does not affect productivity. Measures that involve behavioral changes and adjustments in project setups will become relevant when there is a sufficient incentive for it. Examples of variation management that has potential further ahead could be to reallocate breaks, plan to avoid energy-intense operations coinciding, run equipment on lower capacity, or implement load balancing equipment on site. The potential of these strategies will vary depending on the scale of projects and local conditions.
- From the interviews, it was found that a major challenge for the Equipment Rental business is to manage the changing demands at the construction site. From the interviews aligning thoughts was that the equipment Rental business was found to have a role in the development of net zero emission- construction sites. The case in this study can be seen as a strategy that the Rental business can embrace to be able to contribute with comprehensive solutions. This means tracking and (1) analyzing sources that are contributing to the electricity demand (it is necessary that different sources are looked at separately to be able to find critical loads possible to shift in time), (2) determining if it is possible to move any peak without disturbing the productivity of the project, (3) Cost-efficient storage options can be provided to the customer that is suitable for the specific project.
- Phase 1 could become critical in the future, where many machines with high electricity demand will be electrified and charged simultaneously. This could include wheel loaders, excavators, and piling machines. It is highly likely that this phase will have an impact on the power grid, where load shifting can be used to reduce the peak by for example charging during low electricity prices or low demand in the project or using a stationary battery for this purpose.

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A

Appendix 1

Interviews have started with a brief introduction of the aim of our thesis. This is a summary of how the thesis work was presented to the interviewees, somewhat differing between setups and awareness of the subject:

The goal of our thesis is to investigate the extent to which a project has the potential to use construction equipment for flexibility services (which manage that demand meets production at all times). In a future energy system with more intermittent sources such as solar and wind, this leads to a greater demand for flexibility services to manage these fluctuations while increasing electrification. So we are looking at how flexibility services could both stabilize the grid and at the same time be beneficial for an actor like a rental business.

What we mean by flexibility services could mean shifting the power demand to times with lower loads to reduce the power peaks. It can also mean moving your consumption to times of the day where or to use a battery to cut power peaks. The aim is therefore to investigate the extent to which it is possible to be flexible against prevailing conditions such as increased electrification, increased installation of intermittent energy sources, and increased electricity and fuel prices.

A.1 General questions

General questions that are asked to everyone internally but also to customers. Mostly to get a picture of the transition and the rental business role in the energy transition and as part of the basis for mapping around factors that are important for development, and what challenges there are with flexibility. Not all questions have been asked and often it has devolved into more specific areas depending on the person's expertise/interests. Everything from this will not be included in the final report.

- In a future scenario eg 2045, how do you see a rental business role in the energy and climate transition, where do you want to be and what do you think is important?
- How do you see the current situation?
- Do you consider that you are working in the right direction or are there trends going in the "wrong" direction?

- Are the goals reasonable and are they coinciding with the ongoing development?
- What do you see as the main challenges for the transition to occur? (to achieve climate neutrality, electrification, and at the same time manage a future energy system, etc.)
- Where do you think there is potential for change?
- Which direction do you think one should take strategically in order to shift toward this transition?
- What kind of development do you see going forward in terms of strategy to be able to move toward the changeover?
- What challenges do you see with the electrification of construction equipment? Do you have any awareness/knowledge of an electrification plan?
- If it has not been answered before: What do you see as the biggest challenges in a future energy system with more intermittent sources such as solar and wind while at the same time, there is an increased electrification?
- What factors do you think are important to look at regarding this challenge?
- To what extent do you think it is possible for the construction sector, more specifically, machines used in a project, to adapt their energy consumption/-electricity consumption? (There is a lot you can do, you can take some measures or it is highly unlikely that any major changes could be made.) Why?

A.2 Questions asked for mapping a construction site (mainly project manager/product manager/machine manager)

It should be noted that not all of these questions have not been asked and the interviews have been adapted to the person and topics that have come up. A lot that was discussed has been focused on obtaining insight into the projects, what the network connection looks like, where there may be delays, etc. This is to get an idea of trends and consumption patterns as well as which time periods have the most critical consumption/will have in the future.

- What is the reason why the power peaks look the way they do?
- Do they coincide for different projects?
- How flexible do you think the load curve is? Is it possible to "shift" the peaks?
- Which machines are used during these peaks, and how do you work to avoid them?
- If it is not possible to say specific machines - can you list groups of machines?
- What kind of machines are present at a construction site? How are different machines used?
- Is there an estimate on when power is used and not for different machines?
- What opportunities do you see for flexibility? For example, that cranes can run at half speed at power peaks/high prices? Must all machines be used on this occasion?

- How flexible can the business be?
- Which loads can be flexible?
- What machines and processes cannot be flexible?
- Do projects look very different when it comes to maximum loads?
- Is there any annual energy consumption, or consumption for different stages in the construction process?
- How many machines run on batteries or have a direct connection? What are the plans for this going forward?
- How is the power requirement met today? How much and which machines run on petrol/diesel?
- What potential do you see for selling power?
- How is the equipment charged?
- When of the year do you build the most?
- Which machines are used the least?
- Is there any description of different machines and how/when they are used?
- How is the power requirement met today? (distributed to different machines?) which runs on petrol/diesel?
- How much of the equipment is battery operated and which part of the equipment?
- What time of day is the equipment used the most?
  What flexibility do you see for different machines?

A.3 Questions asked to the sales managers

- Have you seen a greater change in the demand for sustainability in construction projects?
- Do you think that sustainability and business development go hand in hand? (mainly applicable to construction projects/work machines)
- Have there been increased demands from customers?
- What demands do the customers have of themselves in turn?
- What do you think you can expect to pay more for "sustainable" services?
- What do you think is important for a marketing perspective regarding new "sustainable" solutions?
- Are you primarily guided by what the customers want, and is this in line with Skanska's need to be proactive and first on the market?
- How do you analyze what the market looks like?
- What limits development?
- What do you think mainly drives the "green" work?
- What do you think about the potential of having climate-neutral construction projects?
- Are there requirements placed on a contractor during construction to, for example, obtain a certain certification
- What different types of certification are there, if any, and do you think Skanska Rental has any use for them?
- Norway's development?
- Are there requirements to comply with?

- Do you have any input regarding investing in battery storage in projects?
- How do you view the fact that these are very large investment costs and that they may not be paid off in the next few years?
- Are you looking at new business models?
- How are the thoughts going?
- Do you have any input regarding investing in frequency services as a revenue opportunity?
- What do you see as opportunities and barriers with flexibility for a construction project?
- Does the customer always pay for their own electricity costs?

A.4 General questions about the energy system

- What challenges do you see for the energy transition in society?
- What do you see as the most important changes/development of the energy system?
- What challenges and opportunities do you see with the decentralization of the energy system?
- What do you see as the biggest challenges with electrification in society?
- Do you think there will be major challenges in the future with power shortages when many different sectors will be electrified?
- What do you think are the biggest challenges when looking at a future energy system (especially linked to construction projects)
- What does the infrastructure look like today to cope with the upcoming electrification?
- Are there specific regions in Stockholm where it is already noticeable that there is a high load on the network?
- Is it the physical dimension of the network that determines how large the transmission capacity is?

A.5 Battery storage

- What do you see as opportunities and challenges with battery/energy storage?
- What opportunities and challenges do you see in using it for construction projects?
- How do you see it as a very costly investment?
- What opportunities and challenges do you see with hydrogen storage?
- What does the market look like for energy storage?
- How much can customers expect to pay?
- Has demand increased?
- How long does it take for a battery to pay for itself?
- Do you think battery storage will become more common in larger applications (on an industrial scale) or will it be more common on a smaller scale?

- Do you see energy storage as the primary solution to the limited power challenges, or do you see other solutions as well?
- Do you see energy storage as having the greatest potential when it comes to cutting power peaks?

- What does the potential look like in the future for energy storage?
- What does technology development look like?
- Will the profitability/repayment be worse if, for example, you want to save money by charging when prices are low?
- To what extent can you be compliant with the electricity price when it comes to buying electricity?
- What potential do you see for batteries to be cheaper in the future?
- What affects battery life?
- What potential do you see in combining solar cells and energy storage?
- How do you think about choosing a battery type?
- Which battery types are most efficient?
- Who do you think might be suitable for construction projects?
- Can you be flexible in building up batteries depending on the size of the project?.
- What do you think this development looks like?
- What do you think about the development of solid state batteries?
- Thoughts about hydrogen storage?

A.6 Balance market

- What do you see as opportunities to relieve the power grid? (and at the same time be favorable for actors?)
- What opportunities do you see in participating in the balance market? Frequency regulation
- Which branch do you think might be most suitable for a construction project?
- Can you still use the battery for peakshaving?
- How do you think this would work for construction projects, do you pause the charging for a certain time? How long?
- You charge mainly during the night, will this be a problem? Alternatively breaks, so possibly not so flexible when charging.
- How do you think the balance sheet market will change in the future (will it become more attractive?)
- What are the thresholds?
- Do you have good foresight when bidding?

B
Appendix 2

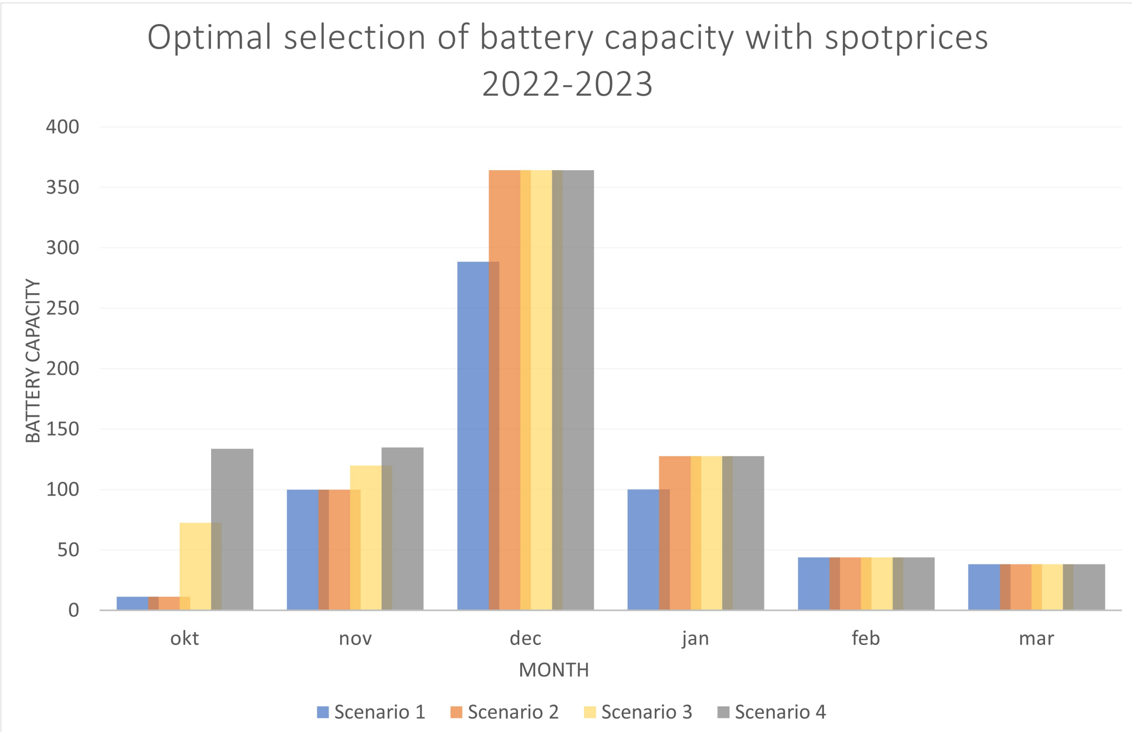

Figure B.1: Optimal selection of battery capacity over different months of the project

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