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Evaluation of battery energy storage systems in the Norwegian power grid to cope with increased vehicle electrification

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Summary (English)

The Norwegian Government has set sales targets to increase the electrification of vehicles in Norway. The targets include new passenger cars to be zero-emissions vehicles by 2025. In addition, all light vans, heavy vans, 75% of the long-distance buses and 50 % of the lorries should be zero-emission vehicles by 2030. This results in an increasing demand for charging infrastructure, both updating existing stations with higher power outputs and establishing new charging stations.

New challenges arise with increased electrification. Charging station developers experience limited grid capacity, leading to high costs of reinforcing the grid. With growing charger powers, the investment in establishing stations also grows. Distribution system operators acknowledge the need of reinforcing the existing grid when charging station operators request high power grid-tie. Therefore, aspects of deviating voltages, power grid congestion, expected reduced flexibility and increased harmonic distortions, amongst others should be considered to ensure a safe grid operation.

In this thesis, the use of a battery energy storage system (BESS) has been investigated. The system was presented as one possible solution to proceed with the development of charging stations for unprofitable and time-consuming establishments. The thesis includes three methodologies: a literature review, qualitative informant interviews, and a GAP analysis. In the literature review, nine articles were included to examine the optimal way of utilising a battery energy storage system in combination with a fast charging station. Eleven informant interviews, with stakeholders from five different groups, were conducted. Charge point operators, distribution system operators, battery energy storage system providers, a funding informant, and heavy vehicle users presented a wide, informative, and adequate explanation of their experiences with the current charging infrastructure in Norway. Additionally, they noted future demands and prospects.

The literature review showed an overall interest in utilising BESS for various reasons; Reducing grid fees, helping alleviate the distribution grid, and increasing the profitability of the charging station were repeated. Several services were presented, such as grid support, frequency control services, load shifting, and energy arbitrage. According to the informants interviewed, there is a rapid demand for charging infrastructure with higher power output. However, charging operators noted fees when grid-tying at locations with low capacity and high power grid fees, leading to less profitable projects. This could result in fewer charging station installations and a failure to meet demand in the coming years. As a solution to this, implementing batteries to increase a fast charging station's profits was introduced.

According to the stakeholders of this thesis, future prospects are higher power peaks at charging stations, funding for heavy vehicles, and greater power charging output. In the GAP analysis, short- and long-term solutions with battery energy storage systems to cope with the increased demand in charging infrastructure were presented. For a short-term period, The DSO may rent BESS services for grid support and to grid-tie customers faster. CPOs may also integrate a BESS at a FCS to lower the grid fees and investment contributions. Lastly, for the short-term solution, funding was a central part to expand the heavy vehicle charging infrastructure. The long-term solution included CPOs possible increase revenue by selling services in the Norwegian reserve markets, in addition to energy arbitrage and expanding their charging station offer. Additionally, BESS operators selling services to CPOs and DSOs for increased power outputs and grid support were presented. Lastly, a proposal on funding BESSs in the distribution grid and favouring value stacking was given. Increasing the BESS operator's profitability in addition to recognising the importance of a possible flexibility resource was seen as a reasonable solution to the growing demand for charging infrastructure in Norway.

Summary (Norwegian)

Regjeringen har satt salgsmål for å øke elektrifiseringen av kjøretøy i Norge. Målene inkluderer at nye personbiler skal være nullutslippskjøretøy innen 2025. I tillegg skal alle lette varebiler, tunge varebiler, 75 % av langdistansebussene og 50 % av lastebilene være nullutslippskjøretøy innen 2030. Dette resulterer i en økende etterspørsel etter ladeinfrastruktur, både oppdateringer av eksisterende ladestasjoner, for å øke effektuttak og etablering av nye stasjoner.

Nye utfordringer oppstår med økt elektrifisering. Utbyggere av ladestasjoner opplever begrenset nettkapasitet, noe som fører til høye kostnader for å forsterke nettet. Med økende ladeeffekt øker også investeringene i å etablere ladestasjoner. Nettselskap erkjenner behovet for å forsterke det eksisterende nettet når ladestasjonsoperatører ber om høy effekttilkobling til nettet. Derfor bør blant annet aspekter som avvikende spenninger, overbelastning av strømnettet, forventet redusert fleksibilitet og økte overharmoniske spenninger vurderes for å sikre en sikker nettdrift.

I denne avhandlingen har et batterilagringssystem (BESS) blitt undersøkt. Systemet ble presentert som en mulig løsning for å fortsette utviklingen av ladestasjoner som var ulønnsomme eller tidkrevende prosjekter. Avhandlingen bruker tre metoder: et litteratursøk, kvalitative informantintervjuer og en GAP-analyse. I litteraturgjennomgangen ble ni artikler inkludert for å undersøke den optimale måten å utnytte et batterilagringssystem på i kombinasjon med en hurtigladestasjon. Det ble gjennomført elleve informantintervjuer med aktører fra fem ulike grupper. Ladeoperatører, nettselskaper, leverandører av batterilagringssystemer, støtteordingsinformanten og store kjøretøybrukere ga en bred, informativ og tilstrekkelig forklaring av deres opplevelse av den nåværende situasjonen for ladeinfrastruktur i Norge. I tillegg bidro de til å belyse fremtidige krav og forventinger.

Litteratursøket viste en generell interesse for å bruke batteri av ulike grunner. Noen

av grunnene var å redusere nettleie, bidra til å avlaste distribusjonsnettet og øke lønnsomheten til ladestasjonen. Flere tjenester ble presentert, for eksempel nettstøtte, frekvenskontrolltjenester, lastflytting og energiarbitrasje. Ifølge informantene som ble intervjuet, er det en stor etterspørsel etter ladeinfrastruktur med høyere effekt. Ladeoperatørene bemerket avgifter ved nettilknytning på steder med lav kapasitet og høy nettleie, noe som førte til mindre lønnsomme prosjekter. Dette kan også føre til færre installasjoner av ladestasjoner og manglende evne til å møte etterspørselen i årene som kommer. Som en løsning på dette ble det innført batterier for å øke hurtigladestasjonenes fortjeneste.

Ifølge aktørene i denne avhandlingen er høyere effekttopper på ladestasjoner, finansiering for tunge kjøretøy og større ladeeffekt noe de forventer mer av i fremtiden. I GAP-analysen ble det presentert kortsiktige og langsiktige løsninger med batterilagringssystemer for å takle den økte etterspørselen etter ladeinfrastruktur. I en kortsiktig periode kan nettselskap kjøpe batteritjenester for å støtte nettet og for å knytte kunder raskere til nettet. Nettselskapene kan også integrere et batteri på en hurtigladestasjon for å redusere nettavgiftene og anleggsbidragene. Til slutt, for den kortsiktige løsning, var støtteordninger en sentral del for å utvide ladeinfrastrukturen for tunge kjøretøy. Den langsiktige løsningen inkluderte ladeoperatører som kunne øke fortjenster ved å selge tjenester i de norske reservemarkedene, i tillegg til energiarbitrasje og utvidelse av ladestasjonstilbudet. I tillegg ble det presentert at batterioperatører kunne selge tjenester til ladeoperatører og nettselskap for økt effektuttak og nettstøtte. Det ble også gitt et forslag om finansiering av batteri i distribusjonsnettet hvor verdistabling ble prioritert. Å øke batterioperatørens lønnsomhet, i tillegg til å anerkjenne betydningen av en mulig fleksibilitetsressurs, ble sett på som en løsning på den økende etterspørselen etter ladeinfrastruktur når elbilandelen i Norge øker.

Preface

The thesis was prepared at NMBU REALTEK at the Norwegian University of life science for the requirements for acquiring an M.Sc. in Environmental Physics and Renewable Energy.

Energy physics is a vast and fascinating subject, so focusing on one aspect of it was an excellent way to gain more in-depth knowledge. I considered my thesis to be highly current, which encouraged me to include the most recent research and information on the subject.

The thesis deals with a GAP analysis which envisions the current state of barriers to charging infrastructure with a focus on the Norwegian power grid. Furthermore, the analysis presents future prospects of charging infrastructure demands. Lastly, proposals on how to fill the gap both in the short- and long-term are given. Throughout the analysis, a battery energy storage system in combination with a fast charging station is the main target area on how to meet the demand for charging at public fast charging stations in Norway.

Acknowledgements

The past five months had not been possible without the support and guidance of numerous people. Therefore, several people should be thanked.

First and foremost, I want to express my gratitude to my inspiring and engaged main supervisor, associate professor Heidi S. Nygård. Whenever I needed advice you responded quickly with helpful recommendations throughout the thesis period. The advantages of having a structured and organised supervisor cannot be overstated.

I would also like to thank my co-supervisor, Petter Lunde, for his help, interesting and fulfilling notes, and thorough guidance.

Furthermore, I would like to thank PhD student Åshild Grøtan for clarifying several theory and methodology aspects.

I would like to thank all of the informants who contributed to the interview process by answering my questions and explaining any technological terms. The engaged, prompt, and attentive dialogue greatly improved the outcome of this thesis.

It is important to emphasise the benefits of the opportunity to write my thesis in a room full of friends I have grown to know well over the last five years. This semester would not be the same without our relaxing lunches and breaks, as well as our motivating talks.

Finally, I would like to thank my partner and my family for their always-present support. It has been extremely rewarding to be able to discuss the topic during this process.

And to Angelica: Thank you.

Nomenclature

The table below presents the abbreviations of this thesis.

Abbrevation	**Meaning**
aFFR	automatic Fast frequency reserves
BESS	Battery energy storage system
BMS	Battery management system
DSO	Distribution system operator
EA	Energy arbitrage
EU	European Union
EV	Electric vehicle
FCR	Frequency containment reserves
FCS	Fast charging station
FFR	Frequency Restoration Reserve
HEV	Heavy electric vehicle
IEA	International Energy Agency
kV	kiloVoltage
kW	kiloWatt
kWh	kiloWatthour
LEV	Light electric vehicle
HVU	Heavy vehicle user
mFFR	manual Fast frequency reserves
MW	MegaWatt
NVE	The Norwegian Water Resources and Energy Directorate
NVE-RME	The Norwegian Energy Regulatory Authority
SAE	Society of Automotive Engineers
TSO	Transmission system operator

Contents

Chapter 1

Introduction

1.1 Background inspiration

In 2015, United Nations members adopted 17 Sustainable Development Goals (SDGs). SDG 7 is to secure "Affordable and Clean Energy" for all and holds several targets [1, 2]. SDG 7 Target 7.A states that all countries should encourage investment in energy infrastructure and clean energy technology [2].

Norway had the highest market share of electric new registered cars in Europe at 88% in 2022 [3]. So far in 2023, 83% of new cars have been electric in Norway, leading to a total number of nearly 600.000 electric passenger cars [4, 5]. The Norwegian Government has made sales targets to reach a goal of zero-emission vehicles by 2030 in a national transport plan [6]. Relevant goals for the electrification of the transport sector include:

- New passenger cars and light vans shall be zero-emissions vehicles from 2025
- New heavy vans shall be zero-emissions vehicles from 2030
- 75% of new long-distance buses and 50% of new lorries shall use zero-emission technology by 2030

If these targets are met, there will be a significant increase in electric vehicles[1] as

[1]Numbers of 2022 are given from Statistics Norway, except electric long-distance buses with

shown in Figure 1.1

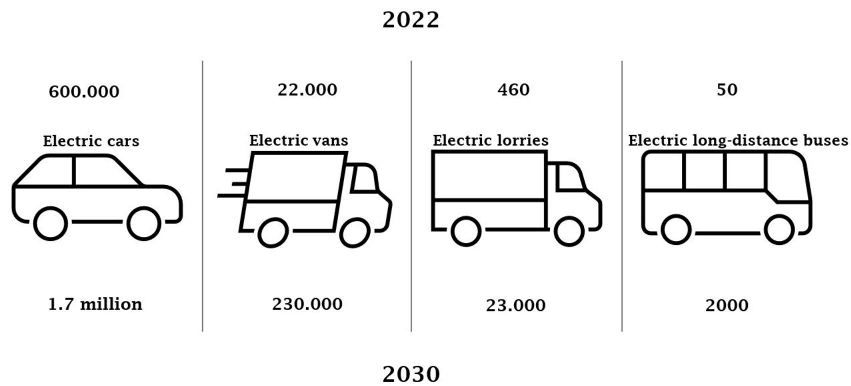

Figure 1.1: Numbers increase of electric vehicles if Norwegian Government sales targets made in the national transport plan are met [6, 7] [1]. Future prospect numbers are given by the Norwegian Environment Agency and the Norwegian Public Roads Administration [7]

In addition to the national transport plan, the Norwegian Government has created a national charging strategy to facilitate the electrification of vehicles [8]. Per 25.02.2022, there were approximately 8600[2] public fast chargers, and 1050 charging stations in Norway [10, 11]. Furthermore, the International Energy Agency (IEA) states that Norway has a high reliance on home charging. However, there will be an increased reliance on public charging as well [3]. According to the Norwegian Environment Agency and the Norwegian Public Roads Administration, there may be a demand for 10-14 000 fast chargers in 2030 if the increase of EVs is to reach numbers as predicted [7]. Of these, 1500 - 2500 fast chargers are estimated for heavy vehicles[3] usage [7]. It is critical to accelerate the development of fast charging points for heavy vehicles with high charging power in order to meet the goal of increasing the share of electric vehicles in heavy vehicle sales [7].

IEA state that the Norwegian network capacities might be robust to the increase in EV charging [3]. However, The Norwegian Water Resources and Energy Directorate (NVE) anticipates a significant increase in Norway's power consumption by 2040 [12]. Furthermore, NVE predicted that from 2021 to 2030, power consumption would increase faster than production. Arnesen et al. for NVE stated that the increase in consumption includes the electrification of transportation, which is one of the most certain trends [12]. Even if the expected amount of power is predicted to be positive in 2040, it may be barriers such as grid power congestion in the Norwegian

number from 2021, given from the Norwegian Environment Agency and Norwegian Public Roads Administration [7]

[2]8600 public fast chargers include CCS, CHAdeMO and Combo where power outputs over 50 kW are included due to this being categorised as fast chargers [9]

[3]Heavy vehicles refer to lorries, buses and similar

power grid. Barriers regarding charging infrastructure are stated in the transition from traditional combustion engines to electric vehicles. Even though there might be a high existing capacity in the Norwegian grid, deploying fast charging stations could end in costly upgrades [3]. Other possible barriers are sufficient capacity in the grid, high connection fees, grid fees and the possibility of power peaks coinciding with existing power peaks from other consumers [7, 11]. Finally, Statnett, the Norwegian transmission system operator, predicts an increase in grid flexibility shortages through 2040 [13].

Despite barriers, all charge point operators (CPOs) contributing to a study conducted by Norconsult had plans of expanding their charging infrastructure in Norway, by either developing new locations, upgrading their existing chargers or establishing greater charging spots [11]. Even though the study stated that there may be a sufficient amount of chargers in Norway, this is if the chargers' power output is increased. Nevertheless, the importance of looking at potential barriers to EV charging is being stressed [11]. CPOs are relatively new customers for distribution system operators (DSOs) with different business models and consumption patterns than traditional customers [7].

In 2022, the average electricity price reached an all-time high. In comparison to 2021, the price increased by 32%, excluding Norwegian government electricity subsidies. The electricity price increase stated was for private households. As a result of the lack of granted subsidies, industrial customers' expenditures would be even higher [14]. Additionally, a new Norwegian grid fee threshold value of 100.000 kWh was announced in 2022. Consumption of more than 100.000 kWh results in an additional fee based on the maximum peak power [7, 15]. Further, the varying electricity prices in Norway are noteworthy, with the highest peaks occurring between 8-9 a.m. and 5-6 p.m. on weekdays, motivating less usage during these hours [16].

The cost of batteries has fallen drastically and seems to continue to decrease [17]. In some cases, battery energy storage systems (BESSs) could be more cost-effective than reinforcing the grid when new power loads as fast charging stations are established [17]. Bowitz, E. for Norconsult states that batteries may not be economically profitable today, but incentives could lead to eliminating expected changes in the charging demand over time. However, the subject of batteries is changing rapidly with increased popularity, and rapid technological advancements and higher electricity prices may motivate investments [14, 18].

Norway has come far in the electrification of the transport sector, and therefore contributing to meeting SDG 7. However, there are still barriers to overcome to reach the goal of a green, zero-emission transition of transportation. A BESS in combination with a fast charging station (FCS) will be investigated in this thesis. The current situation and future prospects of charging stations in Norway will be included to present how a BESS potentially can contribute in the vehicle transition. The objective of this thesis is stated below.

1.2 Objective

This thesis investigates the following main research questions:

How can integrating battery energy storage systems in the power grid contribute to Norway's vehicle electrification?

To answer this, the following specific research questions are investigated:

- What are the reasons for establishing a BESS in combination with a FCS in Norway?
- What are the optimal ways of utilising a BESS in combination FCS in Norway?

The presented questions will be answered by the methodologies: literature review, informant interviews, and finally a GAP analysis.

Limitations

Due to the extent of this thesis, there are some limitations:

- This thesis does not include a socio-economic analysis, calculations regarding technical or economic aspects
- Only long-distance electric vehicles are investigated, meaning excavators, tractors, city buses, and other similar vehicles are excluded
- This thesis does not examine the increased production of solar and wind power's impact on the grid and its effect on flexibility

1.3 Structure

Chapter 1 is the introduction of this thesis. In this section, the background inspiration, objective and limitations of the thesis are given.

Chapter 2 includes the organisation and utilisation of the Norwegian power grid system. Additionally, a section on electric vehicles and charging is presented.

Chapter 3 presents the basics of battery implementation in the power grid. In this section, the relevant knowledge of a battery energy storage system with its characteristics, services and implementation in the power grid is included.

Chapter 4 presents the methods used: literature review, qualitative informant interviews and GAP analysis.

Chapter 5 includes the findings of the literature review and a discussion of the findings.

Chapter 6 includes relevant aspect of the informants' interviews.

Chapter 7 presents the GAP analysis. First, the current situation is introduced, then future prospects are given, and lastly, short- and long-term proposals on how to fill the gap are presented.

Chapter 8 presents the discussion of the chosen methodology in this thesis: literature review, informant interviews and GAP analysis.

Chapter 9 presents the conclusions and recommended future work.

Chapter 2

The Norwegian power grid system

In this chapter, the Norwegian power grid organisation with regulations and stakeholders are presented. Understanding BESS implementation necessitates knowledge of the power grid, both in terms of organisation and use. When requesting grid-tie, CPOs pay grid fees and have various arrangements with a DSO which are important to clearify in this section. Hereafter, the utilisation of the system is included to equip the reader with a basic understanding of the power grid divisions, operation and challenges. Lastly, a section on electric vehicles, charging and the grid impact when transitioning from traditional to electric vehicles is presented.

2.1 Norwegian power grid organisation

The Norwegian power grid is a national system that transports electricity from generators to consumers over extensive, interconnected synchronous alternating current (AC) grids [19, 20]. The power grid is a monopoly that is subject to government regulation, with the Norwegian Water Resources and Energy Directorate (NVE) serving as the regulating body. One of NVE's primary objectives is to promote efficient energy use [19]. The power grid system performs three functions: production, transmission, and trade of energy [21].

The Norwegian power grid holds three levels: The transmission grid, regional grid and distribution grid. The Norwegian Transmission System Operator (TSO), Statnett, manage the transmission grid. As a TSO, the monopoly Statnett has several responsibilities, including regulating the frequency and instantaneous imbalance of power and utilising the power supply system [21]. The TSO has the ultimate responsibility (by law) to keep the system in balance [22]. The distribution and regional grid are divided among approximately 130 Distribution System Operators (DSOs[1]) in Norway [19, 21]. The TSO and DSOs construct power lines, substations and other electrical components. For this to be pursued, NVE - RME regulates the operators [19].

Legislation

The Norwegian Power grid is regulated by the legislation in the Energy law §1-2, supervised and enforced by the regulatory authority NVE [19, 23]. An English translation of the law's purpose is given below:

"...secure that production, converting, transfer, revenues, distribution and consumption of energy is happening on a societal rational way, hereunder it shall be taken into account that general and private interests are affected "[23]

A simplified figure of the Norwegian power system organisation is presented in Figure 2.1. The Norwegian Energy Regulatory Authority (NVE - RME) is one division within NVE, regulating the DSOs [24]. DSOs make sure the quality of supply, both voltage quality and reliability of the power supply, is as it should be. If there are deviations in frequency or voltage, actions are taken. The amount of revenue, income, and grid tariffs that DSOs can get is limited by NVE. This restricts what the DSO can invest in, preventing it from competing with other DSOs. Both TSOs and DSOs are required by law to provide grid connections to all customers who request them [19].

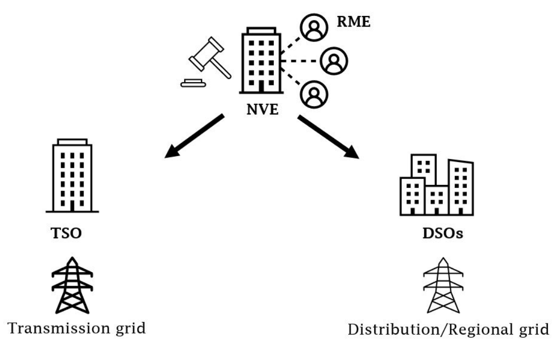

Figure 2.1: The Norwegian power system's organising. The transmission system operator and distribution system operator both follow NVE regulations and laws, of which a DSO is regulated by NVE-REM [19, 24].

[1]DSOs is in this thesis is equivalent with grid company

Additionally, DSOs are responsible for legal unbundling, which entails that they cannot be owned by or own entities involved in electricity production or trading, meaning they can not store energy [21]. However, other customers, may grid-tie and store energy in all parts of the power grid.

Grid fees

Customers who connect to the grid and consume energy will receive an electricity bill. The electricity bill contains three parts. In Figure 2.2 the three divisions are visualised: electricity delivery, grid fee, and governmental fees. The price of electricity delivery is the price paid for the power delivered. Governmental fees contribute to, among others, state enterprise and electricity fees [25]. For large industrial customers, such as charge point operators (CPOs), the grid tariff practice is either a capacity-based grid tariff or a power-based grid tariff dependent on the consumption amount of electricity in one year. The different tariffs are decided on the threshold value of 100.000 kWh per year [25]. In the case of usage over 100.000 kWh the power-based grid tariff applies. This is divided into three: fixed link, power link, and energy link as seen in Figure 2.2. The fixed link is due to grid operation and the energy link is a small rental payment per kWh usage [15]. The power link is often estimated by the maximum registered power outtake in one hour per month [19, 25]. Each DSO has its unique grid fee scheme, however, most of them are comparable [19, 26].

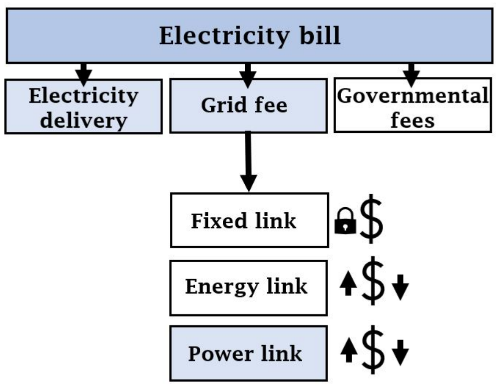

Figure 2.2: The Norwegian electricity bill is divided into three parts: Electricity delivery, grid fees and governmental fees. If the grid tariff is power-based, the power link refers to the maximum output of power in one hour in the given month [25]. The light blue colour indicates where the most cost savings in an electricity bill can be realised: less electricity delivery or lower costs due to a lower maximum power within an hour in the power link.

NVE mandated the power-based grid tariff model beginning in July 2022 in order to stabilise consumption while keeping costs low. The new laws contribute to incentives to allocate electricity use. When a large number of users utilise power at the same time, new grid reinforcements are required. The rate of electrification accelerates, causing power stresses in the grid as well as rising electricity consumption. Customers' grid tariff may be reduced by allocating consumption and using power when capacity is available. Electrification leads to capacity shortages in the power grid, and the new power tariff incentives to distribute power consumption so customers minimise their electricity consumption [26].

Lowering overall energy consumption lowers the electricity bill. If this is not possible, the electricity bill can be reduced by reducing the maximum consumption of power within an hour. This can be accomplished by utilising a flexible source to store energy at times when electricity prices are lower and extract energy at times with higher electricity prices. This results in a reduction of the power link in the power-based grid tariff, as visualised in Figure 2.2.

Connection with terms of disconnection and investment contribution

Large industrial customers often demand significant power loads. Therefore, special conditions are considered. Connection with terms of disconnection or reduced supply, often called conditional attachment, is a solution where new loads can grid-tie with an agreement of disconnection or reduced power supply [27, 28]. This solution allows developers to connect, but with a restriction in order to yield flexibility to the particular DSO. For example, when capacity reaches low levels, the developer is disconnected and production or consumption is reduced to ease the strain on the grid [29]. As a result, the DSO can postpone grid reinforcements or avoid further reinforcements, grid-tie customers more quickly and lower the investment contribution [27].

If however, the customer trigger reinforcements of the grid, they often pay an investment contribution. Investment contribution is expenses due to reinforcements of the grid. The DSO determines the costs the developers need to pay in order to develop the new network. The customer pays for either all or part of the upgrades. The part of the investment contribution that the customer does not pay, leads to increased grid fees for the DSOs customers [30]. There are three cases applicable: a customer is connecting to a grid, increase in capacity demand or improving the energy quality [28].

2.2 Power grid utilisation

The three different grid levels carry AC currents at the same frequency [19, 20]. The main grid, the transmission grid is linked to a regional grid, which is then connected to the last grid: the distribution grid. The distribution grid supplies the end-user [21]. Figure 2.3 visualises a simplified grid whereas step-up and step-down refer to transformed voltages given in Table 2.1, hence up or down voltages in-between different parts of the grid. The generation represents power production and loads represent the consumption of power.

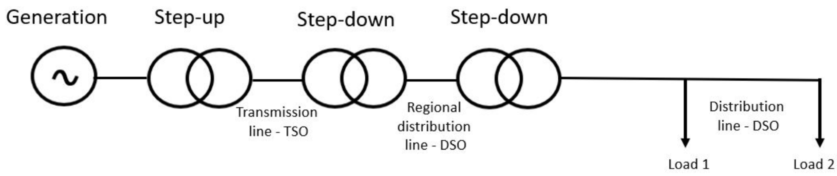

Figure 2.3: Simplified figure of the Norwegian power grid showing loads (Load 1 and Load 2) at the distribution grid level[31, 32]. Step-up and step-down refer to transformation between different grid voltages as shown in Table 2.1.

Table 2.1: The Norwegian Power grid levels Transmission grid, regional grid and distribution grid with their respective voltages [33].

Grid level	Voltage
Transmission grid	132 kV - 420 kV
Regional grid	66 kV - 132 kV
Distribution grid	230 V - 22 kV

The distribution grid is divided into two segments: low voltage and high voltage, where low voltage is 230-400V and high voltage is above 1kV [31]. The low voltage segment feeds private housings, charging for electric vehicles (EVs), etc. Normally, CPOs connect to a low-voltage distribution grid substation, hence 400V. This knowledge was learnt during the interview process (interview 6).

Imbalances and flexibility

As stated, the TSO is responsible for maintaining a stable frequency in the power grid at 50±2% Hz [21, 34]. Imbalances in the Norwegian power grid occur frequently when deviations from the actual production or consumption occur, hence a decline or incline in frequency [34]. When these events occur and the frequency is under/above 50Hz there is a risk of power system collapse. To prevent this, the TSO procures frequency control services from the reserve markets [34]. Different stakeholders in the reserve market contribute on different levels given by the activation period or energy amount their technology can contribute. Reserves are either production or consumption stakeholders who help to maintain power demand equilibrium [34].

There are four categories of reserve products[2]: Fast frequency reserve (FFR), frequency containment reserves (FCR (-N/-D)) divided into either normal or disturbance reserve, automatic - frequency restoration reserves (aFRR) and manual - frequency restoration reserves (mFRR). Figure 2.4 illustrates the different activation periods in Norway: FFR, FCR, aFFR and mFRR. The various reserves contribute

[2]In this thesis, reserve markets are also addressed as flexibility markets and frequency markets

in different ways: after 1 second of imbalance the FFR reacts to slow down the unstable frequency, second, within 30 s the FCR(-N/-D) stops the frequency and stabilises a new frequency level, third, after 2 minutes the aFFR brings the frequency between 49.9 and 50.1 Hz and finally, the mFFR replace aFFR and maintains the balance until a new equilibrium is established in the energy market. Participation in either category necessitates a minimum volume of 1MW [34].

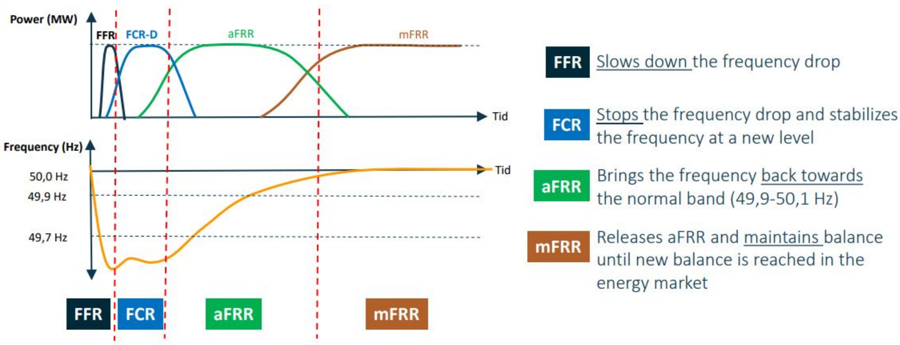

Figure 2.4: Illustration of activation and response time for the different reserve markets divisions when deviations in the power grid frequency occur. Reprinted with permission from Statnett [34].

To avoid imbalances in the grid, flexible resources can be implemented. Flexibility, in regard to reserve markets, is the ability of either production or consumption to adjust its energy supply or demand. The flexible resource, batteries, serve both as a consumer and a producer of energy [13]. The Norwegian Centre for Intelligent Electricity Distribution's (CINELDI) definition of flexibility is:

"... a stakeholder's (consumer or producer) ability and willingness to adapt production and/or consumption of electricity to offer a service to the power grid to for example maintain a good voltage value. Flexible resources can be energy production (from renewable energy sources), energy storage (batteries, EV...) or consumption of power" [35].

TSO or DSOs may use flexibility, for instance, to control congestion in the short term or to develop the grid in the long run. Both TSO and DSOs purchase energy from flexible sources to handle grid congestion at their respective levels. Grid congestion occurs at the intersection between surplus energy production in one grid area and high demand for energy in another part of the grid [36]. Distribution grid congestion is projected to increase during the next decades partially as a result of the electrification of the transportation sector, resulting in voltage deviations and overload [35]. Another aspect leading to voltage drops is power net loss. These losses are the deviation between the energy transported in the grid and the actual energy consumed by customers [37]. To stabilise voltages, the reactive power is operated to ensure the correct grid voltages as presented in Table 2.1. DSOs can utilise flexibility resources to solve voltage deviations, power grid congestion and capacity challenges. Further, the flexibility resources can be used to smooth the load curves of customers leading to less strain on the power grid [27]. The stated challenges lead to a weaker distribution grid. Weak distribution grids have high resistance, with voltages being greatly affected by load changes. Additionally, there are greater voltage drops and loss in weak distribution grids [38]. Strong distribution grids are the polar opposite of weak distribution grids. Another important aspect of imbalances to mention is harmonic distortions. These results in deviations of the sinus curve of the AC grid and are often due to power supplies to various electronic devices [38].

Figure 2.5 visualises how a flexible source owner, in this thesis, a charge point operator (CPO) or BESS provider, can use technical solutions[3] to offer a flexible resource for a TSO or DSO to purchase frequency control services or grid stability flexibility services.

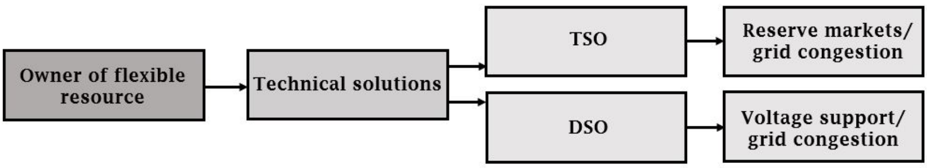

Figure 2.5: Illustration of how a flexible source can be utilised and bought by either a TSO for using flexibility resources in reserve markets or handling grid congestion. A DSO may utilise flexibility for voltage support and handling grid congestion. Third-party purchasers/sellers of flexibility services are referred to as the technical solution.

Peak Shaving/Load Shifting

Load curves vary between various consumers. Often, there are peaks in the load curve; typically, load peaks are between 8–9 a.m. and 5–6 p.m., which are normal peaks for households. Load peaks refer to higher consumption of energy, whereas load troughs refer to less consumed energy [16]. Higher consumption of energy often reflects in higher electricity prices to help alleviate the grid by incentives customers to allocate their consumption. A simplified load curve is presented in Figure 2.6. To avoid energy peaks, peak shaving can be used. Peak shaving can be defined as a strategy for managing power demand in a power system. This type of flexibility aims to reduce the maximum demand on the system, either across the entire balancing area or on a specific subsystem, by limiting or shifting the timing of energy consumption. Further, peak shaving improves the reliability and stability of the power system by reducing the need for expensive peak generation resources and infrastructure, which can also help to lower the overall cost of electricity for consumers [39]. This strategy can be achieved through various means, such as load shifting and energy storage, or other measures that reduce or shift energy consumption during

[3]The technological aspects include an additional market for purchasing/selling energy, and will not be further explained due to this thesis scope.

peak periods. As presented in Figure 2.6, the load curve, visualised as a black line shifts to blue when load shifting is conducted.

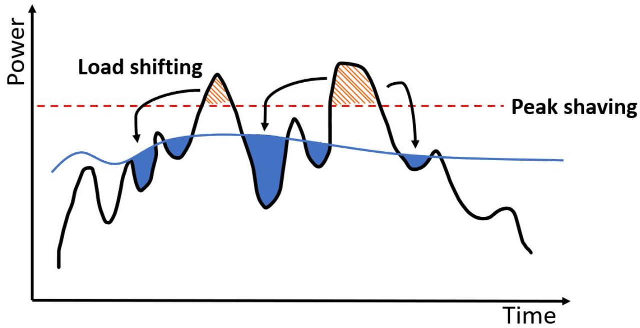

Figure 2.6: Visualisation of the peak shaving concept, including the aspect of load shifting. The load curve before load shifting (black) and after load shifting (blue) represents the flexible resource ability to provide energy during load peaks, instead of consuming energy from the local grid. The energy is shifted to other hours to minimise the maximum peaks, but the overall consumption is the same [39].

2.3 Electric vehicles and charging

In this section, electric vehicles will be presented. Additionally, the concept of EV charging will be explained, and the impact of this on the power grid.

Electric vehicles

Electric vehicles (EVs) utilise electric energy from a rechargeable battery [40]. Although fuel cell-powered EVs are becoming more popular, battery-powered EVs are the most common today; additionally, it is more technically mature. There are several battery types, dependent on the material of constituents. The most common EV battery types are within the lithium-ion family [41].

Electric passenger cars' power outputs and capacity have increased in the last few years. As presented in Figure 2.7, the vehicles' performance has increased significantly. The capacity [kWh] of an electric vehicle refers to the amount of energy stored [20]. Nissan LEAF, was the most sold car with a capacity of 40 kWh and 50 kW charging, in 2018 [42, 43]. In 2020, Audi E-Tron topped the charts of cars sold with a capacity of 84 kWh and 150 kW charging speed [44, 45]. In 2022, the Tesla Model Y with a capacity of 75kWh and power of 250 kW were the most-sold passenger car in Norway [46, 47]. As visualised in Figure 2.7, the capacity from 2018's most-sold electric car to 2022's most-sold electric car has decreased, resulting in less driving range. However, the cars' power inputs have increased, leading to a shorter charging session.

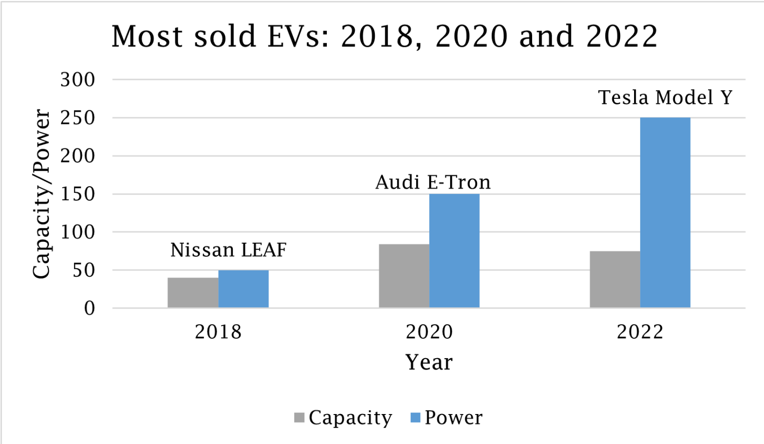

Figure 2.7: Graphics over the most sold electric passenger cars in 2018, 2020 and 2022 [43, 45, 47, 42, 44, 46]. The vertical axis represents both the capacity and power of the presented passenger cars.

Electric vehicles charging

There are three charging technologies applicable for EVs: conductive, inductive and battery swapping [41]. The most used and mature charging technology is conductive charging. Therefore, this charging solution is examined in this thesis. A charging station is connected to the power grid, hence the electrical power is generated in real-time while charging an EV, leading to variations of the dynamic stability of the power grid. Conductive charging opens up scalability and availability at various power levels [41].

Electric vehicle batteries can be charged both by alternating current (AC) and direct current (DC). Typically, the power grid provides AC while the EV battery requires DC. This difference requires a power converter that converts power from AC to DC. In addition, the interfacing converter regulates the voltage and current to match the charging profile of the battery while ensuring a safe operation [41]. The complete charging setup comes with a charger and a battery management system (BMS). The setup can be divided into two different charging methods: onboard and off-board chargers. A simplified schematic figure of these two is shown in Figure 2.8. Additionally, the figure presents how AC and DC chargers are implemented in the low-voltage distribution grid [9, 48]. The onboard charger is a combination of a power converter and a BMS. Therefore, EVs with onboard chargers can be plugged directly into the power grid. But the onboard chargers have some limitations such as the EV's weight and cost leading to limitations regarding the charging power level. On the contrary, there is the off-board charger. This charging version refers to a charger outside of the EV. Due to the power converter installed outside of the EV, the charger can be built to handle increased power levels. Hence, almost all high-power EV chargers come as off-board chargers [41]. In this thesis, off-board chargers are examined further due to probable strains in the grid [30].

The Society of Automotive Engineers (SAE) has classified EV chargers into three levels: 1,2 and 3 based on the power levels. All levels hold both AC and DC[41]. AC chargers have power up to 22kW, whereas DC chargers have a power greater than 50 kW [9]. Overall, AC charging is slower than DC charging due to lower power outputs, making it suitable for overnight charging. Level 3 in SAEs classification of DC charging holds values up to 240 kW leading to shorter charging time. The technology is rapidly changing with 400 kW chargers entering the market [41].

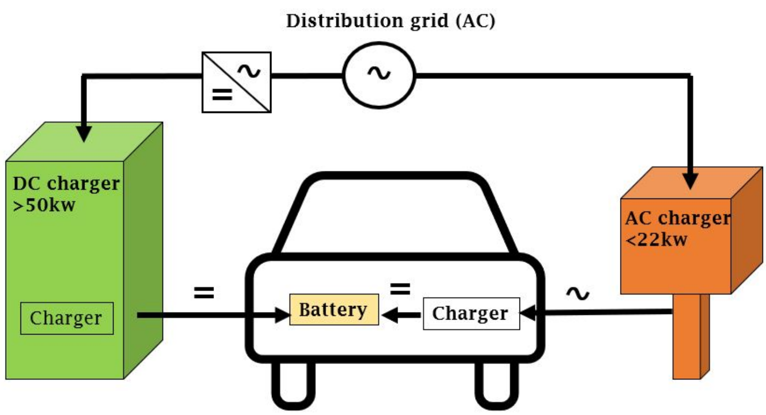

Figure 2.8: Alternating (orange) and direct (green) current chargers. Figure inspiration from the Norwegian electric vehicle organisation [49]. AC is supplied by the distribution grid. This is converted into a DC charger, which powers the vehicle battery, whereas the AC charger powers the vehicle battery through an internal converter in the EV [21, 41, 49]

DC chargers are often separated into different groups: superchargers, ultra-fast chargers and fast chargers. These separations are different for each charge point operator. Nevertheless, all DC chargers deliver power above 50 kW [30].

Charge point operators facilitate AC chargers and DC chargers in all of Norway. Often, the AC chargers do not lead to capacity difficulties in the power grid, due to their low power outages [41]. DC chargers are moreover located by the highways and demand more power than AC charging due to their higher power consumption. Locations with fast charging, so-called fast charging stations (FCS) are examined in this thesis, due to their high power outputs, hence their higher impact on the local grid compared to AC chargers. Charging infrastructure has been identified as a crucial element to facilitate the widespread adoption of electric lorries. However, the high initial cost of such infrastructure poses a significant barrier. Moreover, the large-scale penetration of EVs can create imbalances in demand and supply on the grid [41].

Grid impact of electric vehicle charging

As mentioned, fast chargers have power outputs over 50 kW [30]. Totally, there are nearly 8600 public fast chargers with an output over 50 kW in Norway [10]. As presented in Figure 2.9 there were 6000 chargers in Norway with an output up to or greater than 150 kW in 2022 [50].

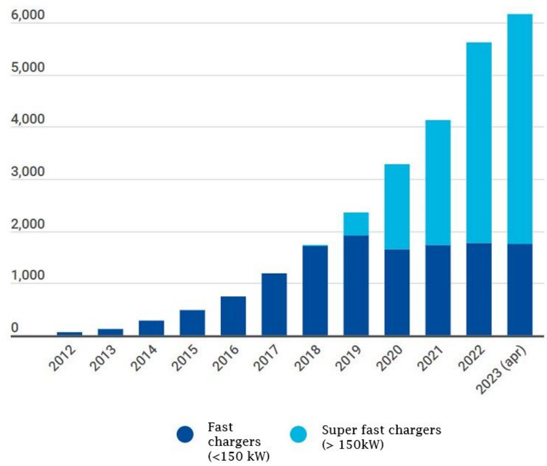

Figure 2.9: The number of fast chargers and super fast chargers [50]. As visualised, the amount of fast chargers and super fast chargers has significantly inceased the last ten years. The usage of the figure was given consent by the Norwegian electric vehicle organisation.

Development of a fast charger station often requires upgrades in the existing grid [30]. It can be challenging to set a certain price for the reinforcements of the grid due to the differences in the dimensions of the local grid [30]. According to one stakeholder, investment contributions have varied, with prices ten times higher than others for the same size of FCS, but in different locations [30]. When the power outtake from a DC charger increase, it is likely to assume that the investment contribution increases as well. The increase of power for electric bus vehicle charging will most probably lead to reinforcements of the grid with related investment contributions in Norway [30]. It is reasonable to imagine the same for cars, vans and lorries.

FCSs experience different challenges compared to traditional fuel stations [41]. Traditional fuel stations store fossil fuels in tanks, and there is a buffer to decouple demand and supply dynamics. It takes time for an imbalance to form when there is a sudden change in demand and/or supply. A FCS does not inhabit this flexibility.

This is due to the generation and delivery of electric energy in real-time. If a FCS suddenly draws a significant amount of power from the grid, it creates momentary imbalances between the supply and the demand. In uncontrolled EV charging, at a FCS, the EV immediately receives power from the grid when connected to it. The charging process continues until the battery is fully charged or the user ends the session. This method directly exposes the grid. Because the generator controller is not aware of the change, power generation remains unchanged, leading to an imbalance in the demand and supply resulting in the generator slowing down and grid frequency decreasing. Depending on the load added to the grid, the recovery time and frequency dip vary, and in extreme cases, they can exceed the limits resulting in grid instability [41]. Lastly, there is often demand for voltage regulations due to transport electrification [51].

Chapter 3

Battery Energy Storage Systems (BESS)

In this chapter, the relevant basics and services of battery energy storage systems (BESSs) integrated into the power grid will be presented. BESS[1] is an electrochemical energy-based system that includes batteries, inverters, and a battery management system (BMS) [52]. Within current research, BESS has gained popularity. This is due, among other things, to their high energy density, quality of service, and quick response time [18, 51]. Stationary batteries with monitoring and control can be one solution to reach the goal of the future grid [53]. Some aspects of batteries are mentioned in Chapter 2.3 such as capacity and charging. Batteries can be used for portable energy deliverance, as for an EV or mobile FCS, or a stationary solution where electricity demand and supply are not equivalent [54].

In 2020, lithium-ion batteries dominated the market and had a storage efficiency as high as 80-90%. These batteries can typically be recharged at least 1000 times or more [20, 52]. Battery costs dropped dramatically from 2010-2019, with a price drop of approximately one-tenth. It is expected that the price will continue to fall [52]. However, it is important to note that these costs do not include the cost of the operational services and other necessary technology for implementation [55].

[1] In this thesis, BESS in coherence the power grid, will also be addressed as a battery

3.1 Implementation

A BESS can be installed in a variety of locations and provide several services of all grid levels in the Norwegian power grid [52]. Figure 3.1 visualises a BESS with regard to the distribution, regional and transmission grid. A fast charger is visualised to represent the fast charging station. The figure does not include inverters [2]. However, it is critical to understand that every BESS contains inverters and power conversion systems [52].

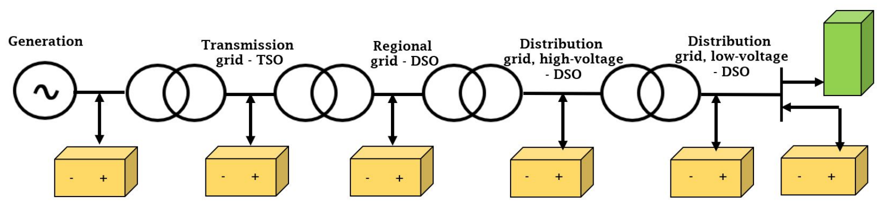

Figure 3.1: Simplified figure of the Norwegian power grid with BESSs (yellow) possible implementation in the grid [31, 52]. The BESS has various possible implementations, whereas it can serve different services both for grid support or economical value.

3.2 Services

Some services that are relevant to this thesis are presented in Figure 3.2. The services will be further explained, whereas stacking of different services are possible [52]. This is due to the battery's occasional idling time. Idling time refers to periods when a battery is not performing any services.

[2]The BESS is simplified to consist of a battery package and an inverter/converter. For the rest of the thesis, the terms converter and inverter will be used interchangeably

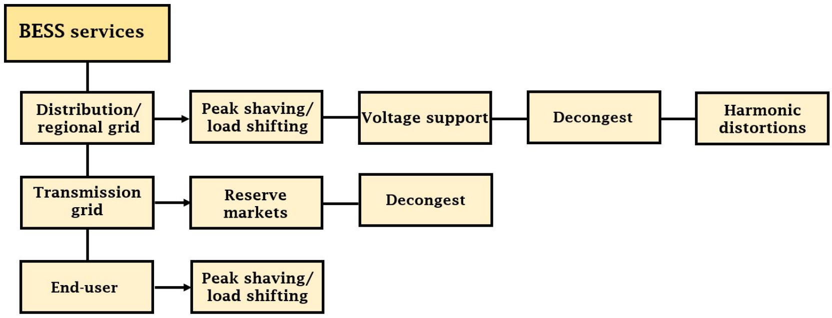

Figure 3.2: Visualisation of a BESS's services in the power grid levels. The vertical boxes refer to BESS services applicable for either the *distribution, regional, transmission grid* or an *end-user* [55].

Grid support

Høiem et al. stated that batteries can be implemented in low-voltage grids to supplement voltage support [27]. Voltage regulation is performed by the BESS's converter. By pulling reactive power when the voltage is high, or delivering reactive power when the voltage is low the battery prevents the local voltage from deviating. It can also avoid harmonic distortions [51]. A DSO may use the battery for some hours per year to relieve the grid and for example, improve the voltage quality of the lines and transformers [27, 56]. In this case, the DSO pays for its use on an hourly basis to the BESS operator [56].

BESS can also shift generation when needed, which leads to a smoothing of the power fluctuations, hence a smoother load curve [39, 51]. Furthermore, by cutting peaks and filling troughs on the network, BESS can provide an efficient solution to supply and demand imbalances and power quality problems [18].

As seen in Figure 3.2, both the DSO and TSO may utilise BESS to avoid or reduce grid congestion in the power grid by load shifting. This may lead to postponing reinforcements of the grids due to the longer lifetime of the power grid components. Regarding the distribution grid, decongesting services may result in a significant idling time, leading to hours where the BESS can be enhanced for other services. For the regional/transmission grid, several batteries combined by a third party can lead to a more efficient decongestion [51].

Reserve markets

Batteries have an adequate ramp rate which is mitigating fast changes in load/production changes [52]. Hence the most relevant products are FFR and FCR, due to the battery's fast response [51]. The BESS receives the down-regulation price for each

MWh of absorbed energy and the up-regulation price for each MWh of delivered energy to the FFR/FCR market. Revenues are made by helping to decrease or increase the frequency of the power grid to keep the equilibrium, by selling output energy or selling available storage for energy input [52, 56]. The batteries can both be several small units combined as a bigger package or one battery contributing on its own [51].

Decrease maximum load of power by load shifting

For this type of service, the customer pays a grid fee as seen in Figure 2.2. Due to high peaks (above 100.000 kWh), the power-based tariff structure is utilised. The battery has an efficient ramp rate which is mitigating fast changes in load/production [52]. Therefore, the BESS is charged during low electricity prices, often at night, and is discharged during high electricity prices, during day time [56, 16]. The reasoning for this service is to utilise a BESS to prevent higher power-based tariffs or avoid investment contributions [52, 56]. The goal of peak shaving regarding a BESS is to control it to reduce the peak load of the circuit to minimise the grid fee and power-based tariff for the CPO [39].

Energy arbitrage/Price arbitrage

Energy arbitrage, also called price arbitrage, is used to utilise the price differences for electric energy. The customer can buy energy during electricity troughs, often nighttime, and sell or use that energy during electricity peaks, often during daytime [16, 52].

Implementation for various BESS services

When the BESS supports the voltage at a FCS, the battery must be implemented with the FCS located after the power grid intersection. If the BESS is to assist with additional load, it may be installed parallel to the FCS[3]. The DSO may purchase flexibility services from a BESS operator behind the intersection, where the technical solutions regarding buying/selling of energy are handled between the DSO and the customer or a third party [55]. Similarly, when a battery is implemented before the intersection of the customer, in for example the low-or high-voltage distribution grid, the DSOs buy flexibility services from the BESS operator directly or a third party. These locations are also applicable for TSO purchasing flexibility services [51].

[3]This was discovered during the interview process.

Chapter 4

Method

In this chapter, the method of this thesis will be explained. To answer the research question, three methods were used: A literature review, informant interviews and a GAP analysis to envision the differences in the current situation and future aspects, described in Section 4.2, 4.3 and 4.4.

Firstly, the reasoning for the choice of methodology is given in section 4.1, followed by the structure of the literature review. Then, a description of informant interviews and selected stakeholders are presented. Lastly, the definition of a GAP analysis will be presented. An overview of the method used in this thesis is presented in Figure 4.1. The overall structure of the method is given in Figure 4.2 to visualise the chosen methodologies of this thesis.

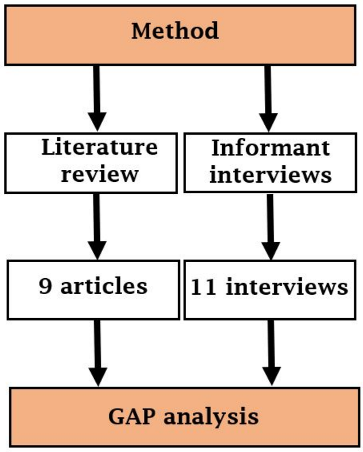

Figure 4.1: An overview of the methodology used in this thesis: Literature review and informant interviews leading to a GAP analysis.

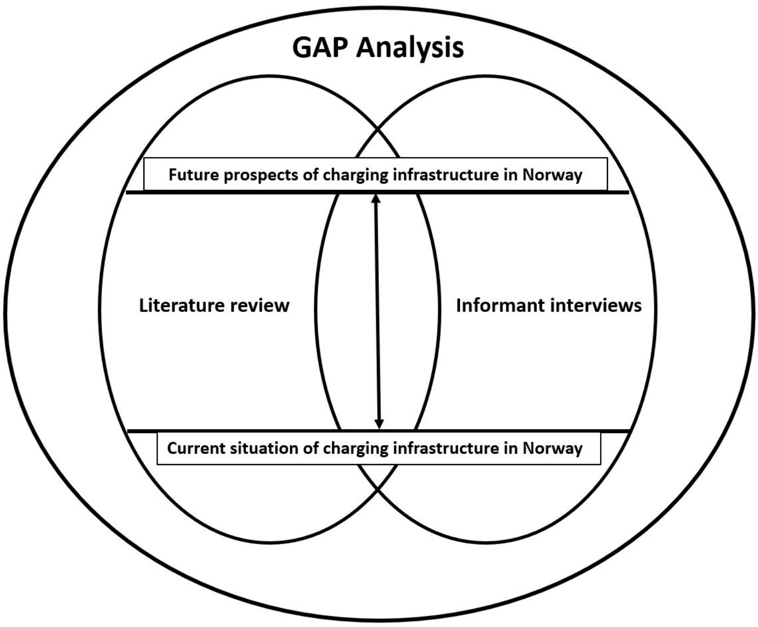

Figure 4.2: Visualisation of the GAP analysis. A literature review and informant interviews are conducted, in addition to theoretical aspects, to present the current and future situation on charging infrastructure in Norway. Then, short- and long-term proposals for filling the gap are presented in the GAP analysis. Reprinted with permission by Alexandra Østreng, but with modifications [57]

4.1 Choice of methodology

Literature review

In this thesis, it was decided to conduct a literature review. A literature review was regarded as an academic method of assessing the validity of the informant interviews and improving the various outcomes of the research questions. While interviews would yield up-to-date perspectives and prospects regarding this thesis topic, a literature review could verify or deny their statements with research. Furthermore, it was critical to understand what articles discussed in regard to the research question.

Informant interviews

There are often two ways of collecting data during an interview: quantitative and qualitative methods. These methods are used to evaluate different perspectives and are linked to for example production or consumption of energy in this case. The quantitative method is used for measurable values and is applied to a large number of people. The surveys often hold consistent and specific questions [58]. Examples are: "How many charging stations are there in Norway?", and "How many electric vehicles are there in Norway?". The purpose is often to check whether reality coincides with obtained data [58].

A smaller sample of people is used in the qualitative method. The purpose of this method is to get a better understanding and insight into a consumer or prosecutor's perspective and experiences on the selected field of study. Information is found through observations, interviews, or texts. The method is often described as flexible due to new knowledge gained throughout the study. This can lead to changes in the layout. Flexibility is often an advantage of the method that results in adaptation in the study conducted [58]. Another advantage of qualitative research is its transparency due to no rules for a survey of interviews based upon non-standardised qualitative interviews [59]. A decision was made in this thesis to utilise the qualitative approach. The reason for this was the necessity of an in-depth understanding which a quantitative method could not yield.

Additionally, in qualitative research, it is important to verify with regard to viability and validity [59]. Viability refers to the reliability of the results, and validity refers to whether the interview examines what was predetermined. An important question to ask is how many interviews one should conduct. In this thesis, the answer to this was the number of interviews that would yield the information sought after to help answer the research question [59].

GAP analysis

To answer the research questions, a GAP analysis was decided to be a reasonable method. The GAP identifies the differences in where the research question is regarding today and future prospects. The analysis was considered appropriate due to its structure to enlighten the research questions. A GAP analysis, in addition to a literature review and informant interviews, was used to conduct a structural examination of the research topic of this thesis.

4.2 Literature Review

In the literature review, the aim was to focus on the three sub-questions of the main research question. Hence, answering to what extent BESS-assisted FCS are developed, what different services and operations BESS is utilised for and what research has yielded. The main focus was to search for BESS and FCS in combination to shed light on situations inhabiting both aspects.

There are two different methods to eliminate and extract important literature for a literature review; one method is to do a broad and general search, while the other is to conduct a more particular and detailed investigation. Both of these methods were used in the search conducted in the Science Direct database.

Scopus was considered an adequate database with directions to publications to other databases for example IEEE (Institute of Electrical and Electronics Engineers) and Science Direct. The parent company, Elsevier, stated: "*Chosen by leading academic, business, and government institutions since 2004, Scopus brings together the superior quality and coverage of Scopus data, as well as advanced analytics and technology in one solution.*" [60]. Therefore, this database was considered sufficient due to the possibility of referring to other databases and the high standards of peer-reviewing.

The literature review focused on articles published within the last three years: 2020-2023. Different words and combinations were defined before the search was completed. Overall, articles including BESS and EV fast charging stations were sought after as these were seen as the most relevant to help answer the research question. Additionally, publications regarding BESS' various service possibilities were prioritised due to new insight gained during the interviews.

The literature research aimed at looking at literature including both a BESS integration and a FCS. Finally, the two search strings listed below were found to be fulfilling:

- 1. BESS charging station, Countries/Territory: All
- 2. Battery grid charging station, Country: Norway

Within the first search string (BESS and charging station), all the literature titles were examined and if they appeared relevant the abstract was read. The article was then read in its entirety, and if it was still relevant, the literature was added to the review. In addition, the article from the second search string (battery grid charging station "Norway") also included a BESS-assisted FCS.

4.3 Informant interviews

In this thesis, the purpose of the interview was to get relevant information from the informant. Informant interviews were used to carry out the qualitative method and gain a thorough understanding of the chosen subject. A survey was conducted to determine whether and how battery energy storage systems integrated into the distribution grid could assist in overcoming barriers associated with the increased use of electric vehicles. Informant interviews refer to interviews with individuals who possess comprehensive knowledge of the topic being explored [61]. The person was chosen as a representative of the stakeholder's values, prospects, and ideas. This statement suggests that informant interviews are characterised by the informant being the primary speaker, the interviewer being the least talkative, and the exchange not taking the form of a debate. The main focus was for the interviewer to get new information on the topic or to disclaim any uncertainties.

To increase the comparability of the semi-structural interviews, a coherent and organised guide for all interviews was developed. Questions were prepared ahead of the interviews, to ensure that informants from the same target group would be asked the same questions, and follow-up questions depending on the answers given. During qualitative research, there will arise new knowledge and in-depth understanding. A dilemma emerges whether to stick to the first interview guide and renounce further learning or improve the interview guide where the new dimensions and understanding are taken into account [59]. The latter was chosen for this thesis because of the importance of additional learning and insights.

Audio recordings

The interviews were conducted online with audio recordings to retain the nuances of the answers. All informants gave consent on contributing to the interview and the usage of audio recording. The audio recordings were subsequently transcribed to facilitate further analysis. All informants got the possibility of a quote check. It should be noted that audio recordings may compel informants to provide contradictory responses. Because the topic of this thesis is more focused on the implementation of technological equipment, the stated problem was kept to a minimum. The problem, on the other hand, was deemed critical to identify.

The informants' private information had to be retained due to contact information. Therefore, the thesis was reported to Norwegian Agency for Shared Services in Education. The agency gave consent upon the retention of the personal data as long as the implementation was conducted as stated.

Analytical tool - Nvivo

Apart from conducting interviews, the thesis employed the analytical tool Nvivo to facilitate the investigation of similarities in the obtained responses and to organise the collected qualitative data [59]. Nvivo is a computer software package produced by Lumivero, to enhance researchers' qualitative analysis [62]. The use of computer tools allowed for coding, analysis, and graphical representations. Nvivo enabled the categorisation of data acquired from the interviews, with relevant sections being coded to streamline the process of comparison. If different stakeholders provided responses to similar questions or topics, their data could easily be compared within Nvivo [59]. Stakeholder aspects of charging infrastructure or grid capacity were grouped together in the same section to systemise the informant's sayings.

Selection of stakeholders

Stakeholders were selected based on the information required. Eleven interviews were conducted, with semi-structural interviews proving to be the most appropriate for this thesis research question. The stakeholders were divided into five groups as a way to organise the qualitative research method. As visualised in Figure 4.3, the chosen stakeholders represent one link in the path from establishing a BESS in the power grid and a FCS to supply electricity for EV users.

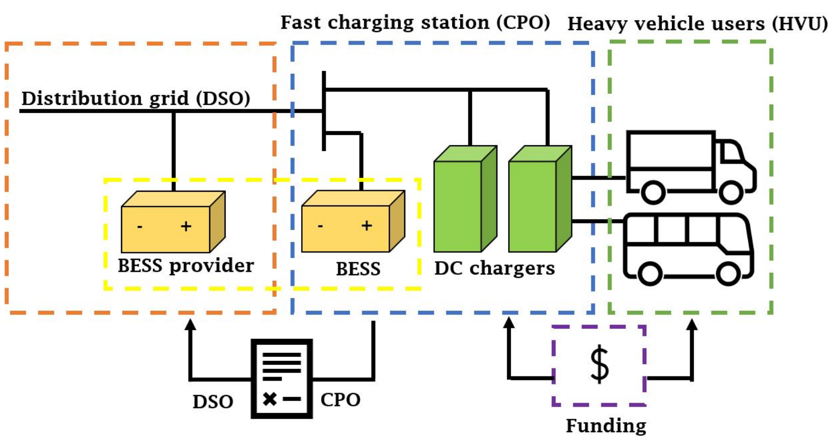

Figure 4.3: Connections between stakeholder groups. The dotted lines represent the target area of the various stakeholders. The yellow boxes visualise the BESS and green represents DC fast chargers. The fast chargers are utilised by electric vehicles. The scheme between the CPO and DSO presents the grid-tie request. Funding may be given to vehicles, charging stations and batteries.

Within the five stakeholder groups, it was decided to interview different informants. CPOs, DSOs, BESS suppliers, funding and heavy vehicle users. These have different aspects. Therefore, their answers could be summarised and discussed in cohesion with the literature review in the GAP analysis section. Each stakeholder represents different perspectives on the research questions. Further, the groups of stakeholders will be examined, in the order as presented in Table 4.1.

Table 4.1: Stakeholder interviews with three charge point operators, two distribution system operators, three battery energy storage system providers, one funding informant and two heavy vehicle user informants, resulting in five stakeholder groups.The informant numbers are used when referring to the respective informant within the given group.

Informant numbers within stakeholder groups
1 – Charge point operator
2 – Charge point operator
3 – Charge point operator
1 – Distribution system operator
2 – Distribution system operator
1 – Batter energy storage system providers
2 – Batter energy storage system providers
3 – Batter energy storage system providers
1 – Funding
1 – Heavy vehicle user
2 – Heavy vehicle user

Charge point operators

Three different charge point operators (CPOs) were interviewed. It was concluded that a difference in interests and business models was favourable. This led to CPOs targeting different areas: fuel stations, Norwegian-based charging stations, international charging infrastructure and/or separated from energy supply companies. The various interests in the distribution of CPOs were decided to enlighten several perspectives.

Distribution system operators

Two distribution system operators (DSOs) were interviewed. These two were chosen due to their broad distribution network, hence their size compared to other DSOs. To maintain size anonymity, the number of candidates was limited to two. Furthermore, the DSOs' various locations were considered important to enlighten different aspects of Norway. Following the interviews, the two stakeholders were considered relevant and retained for further discussion and analysis.

Battery energy storage system providers

Three battery energy storage system (BESS) providers were interviewed. The three stakeholders were considered different in the aspects of distribution, interests and sizing of batteries. The battery capacity ranged from 5 kWh to 1 MWh, providing a broad understanding of what different batteries could perform. The stakeholders also had different business models. They either provided BESS services and/or BESS equipment. All stakeholders were Norwegian-based, which was deemed significant due to Norway's BESS implementation being the most relevant for this thesis. More information was obtained during the interview process about BESS services and solutions. It could be argued whether a better representation of stakeholders within this group that contained either a supply of services or equipment should have been included, not both. However, to the best of this author's knowledge, the three BESS providers chosen provided adequate coverage to enlighten the aspects of a BESS system in combination with a fast charging station (FCS).

Funding

Only one Norwegian enterprise funding organisation was interviewed. The funding was to shed light on current and future funding making projects economically feasible. Because there were few relevant funding organisations found for this thesis topic, it was determined that one interview could provide a visualisation of funding while maintaining anonymity.

Heavy vehicle user informants

Two stakeholders were interviewed to get information regarding the vehicle user's interests. The two stakeholders were dissimilar: one was an organisation and the other was a company. Both of them had knowledge about the electrification of buses and heavy transportation but with different perspectives. The organisation provided a spokesperson for a working group. The company could only shed light on their demands and subjective prospects. Despite differences in stakeholder perspectives, it was determined that this would provide a better understanding of the transportation sector's demands. It was decided that the heavy vehicle users would represent all vehicle users, including passenger cars and vans.

It is important to mention the lack of an electric passenger cars stakeholder. Due to the significant increase in electric cars, it was concluded that these informants most probably would envision aspects that were similar to heavy vehicle stakeholders [5]. Because there has been a slower increase in heavy electric users such as buses and heavy transport they were prioritised.

Interview guide

This thesis employed various interview guides to investigate specific stakeholders more closely, conducting a total of eleven interviews. A total of eight interview guides were used, with informants within the same stakeholder group receiving the same interview guide due to similar interests. Due to enhanced knowledge, the interview guides were improved and more detailed-oriented throughout the qualitative research period. Furthermore, information from specific questions was compared to explore any differences within each group. The interview guides are included in the Appendix A in English, translated from the Norwegian versions that stakeholders received.

Throughout the interview period, the importance of keeping the information objective and technological aspects so that the informant's personal meaning did not affect the answer was stressed.

4.4 GAP analysis

A translated definition of GAP analysis by the Great Norwegian Encyclopedia is: "*a model looking at the gap between expectations and actual results*" [63]. Because of the thesis's research question, this method was deemed adequate to both enlighten what stakeholders think regarding charging infrastructure and future prospects, and also to envision a possible path of how to meet the demand.

The analysis answers three questions: In this thesis, only the technical aspects will be examined. A gap analysis could also include human factors, but due to the research questions of this thesis, this was not considered necessary. There are three technical levels for each question. An overview is presented in Table 4.2.

Table 4.2: GAP analysis questions and level of technology

Questions	**Technical level**
What is the current situation?	Identification, summary and consideration of the current situation
Where do we want to be?	Identification of future prospects of a battery energy storage system to help increase public fast charging station infrastructure
What does it take to tighten the gap?	Proposals on how to close the gap, with a BESS, to meet the future prospects of charging infrastructure

The main parts are defined as three major questions that a GAP analysis should answer. As visualised in Figure 4.2, and the first question in Table 4.2, both a literature review and informant interviews are to identify the current situation. Question two includes the future prospects of charging infrastructure. In addition, future prospects on transport electrification, power grid challenges and BESS were included to present an overview of the system. Lastly, question three in Table 4.2 considers ways to fill the gap between the current situation and future prospects, as visualised in Figure 4.2.

Chapter 5

Literature Review

This section poses the first part of the methodology: a literature review. As mentioned in Chapter 4 a literature review's task is to elucidate the current situation of the research question of this thesis. The purpose of this thesis is to use a literature review to learn about the current research within BESS-assisted FCS. This includes articles from around the world on various charging methods, optimisation problems, and the best ways to integrate and utilise BESS with a FCS. The findings from the literature review will further be used to identify realistic future solutions in Chapter 7. Additionally, the review will present possible solutions to close the gap between the current situation and future prospects of charging infrastructure, with a main focus on BESS.

5.1 Literature analysis

The first search results of "BESS charging station" returned publications with the yearly distribution of publishing dates as shown in Figure 5.1. Based on a wish for only new data solely, literature published after the year 2020, inclusive, was examined. Additionally, one article from the second search string "battery grid charging station" was chosen. The nine chosen articles are presented in Table 5.1.

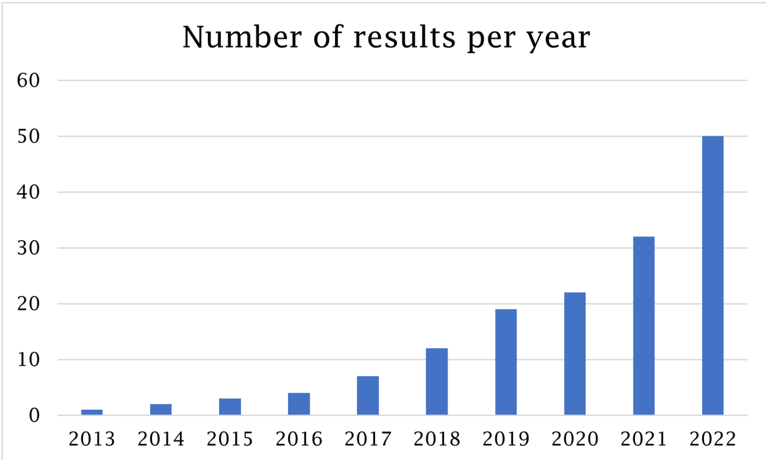

Figure 5.1: Number of results in the search string "BESS charging station" from 2013 to 2022. There has been a significant increase in the number of published articles on this topic in the Scopus database.

Table 5.1: Articles alphabetically ordered with their respective number and country of origin.

Article	Title	Country of Origin	Authors
1	Accelerating electric vehicle adoption: techno-economic assessment to modify existing fuel stations with fast charging infrastructure	India/United Kingdom/Sweden	Ghosh et al. [64]
2	Battery Energy Storage System (BESS) Sizing Analysis of Bess-Assisted Fast-Charge Station Based on Double-Layer optimization Method	China	Wu, D. et al. [65]
3	BESS Optimal Sizing and Scheduling for Energy Arbitrage and Frequency Containment Reserve via Dual-Loop Optimization	Denmark	Kurniawan et al. [66]
4	Deep reinforcement learning-based operation of fast charging stations coupled with energy storage system	United States/South Korea/Canada	Hussain et al. [67]
5	Distribution Side Optimal Operation and Control of Coupled FCS and BESS	China	Wu, G. et al. [68]
6	Optimal battery energy storage system sizing for demand charge management in EV fast charging stations	Netherlands	Koolman et al. [69]
7	Optimisation model with degradation for a battery energy storage system at an EV fast charging station	Norway	Haugen et al. [70]
8	Study of Optimally Located Electric Vehicle Charging Stations for Frequency Control Service in Distribution Network	India	Hasan et al. [71]
9	Utilizing local flexibility resources to mitigate grid challenges at electric vehicle charging stations	Norway	Ilieva et al. [72]

Another parameter deemed relevant in the literature search was the country of publication. The first search string returned 111 publications from 2020-2023 across 38 different countries, as displayed in Figure 5.2. In 2022, the global market for new EVs sold was 14% [3]. However, the country distribution of these sales is different in the countries visualised in Figure 5.2. China has half of the world's electric cars in 2022. The United States' new EV share of 2022 held 8% and India had only 1.5% market share of new EVs sold in 2022. However, India's numbers tripled compared to 2021 [3]. The respective number of publications in the first search string of these countries were 20, 11 and 30. This demonstrates that the increased EV sales may be one reason to investigate the grid impact, and technological solutions such as batteries to meet higher EV load demands.

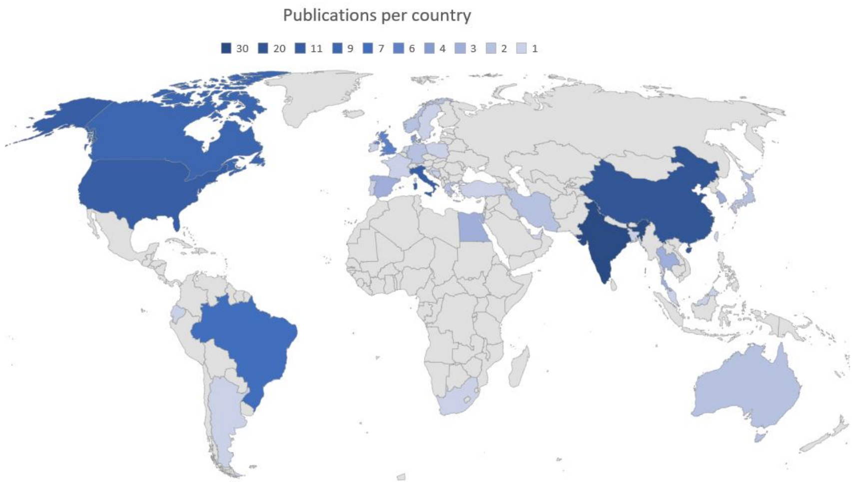

Figure 5.2: Publications per country conducted from the first search string "BESS charging station" which resulted in 111 publications

There were no restrictions considering geographical locations and citations of literature. Due to the importance of selecting recently published articles, it was deemed necessary to include all countries in order to extract more literature, and not just countries with similar EV sales and power grid setup/capabilities as the Norwegian. Furhtermore, because the articles were new, citations were not evaluated, resulting in few citations from others. All Scandinavian countries are represented, which is considered positive due to grid connections between Norway and Sweden, resulting in a common synchronous area [36].

All the chosen articles discuss EVs; in this thesis, EVs include electric vehicles that travel long distances. This is not the case with the chosen publications. In many cases, EVs are only considered passenger cars and not buses or lorries. However, because all vehicles may use the same charges and powers, the results with regard to all vehicles are interesting.

Analysis of literature composition

Eight of the 111 publications of the first search string were determined to be relevant to this thesis. In addition, because of its Norwegian case study, one article found through the second search string was included. A comprehensive evaluation of the articles in the second search string is not yielded. This is due to all articles being published in Norway since the location filter was set to "Norway", and the greater number of articles chosen were from first search string. The nine chosen publications' geographical area is presented in Table 5.1.

Furthermore, there were different stakeholders in the nine chosen publications, as shown in Figure 5.3. The figure demonstrates that universities are the most generous contributors, followed by search institutes. The variety of stakeholders was concluded to be a satisfactory indicator due to stakeholders' different perspectives. Additionally, the figure presents articles with several contributors within each article, providing a broader perspective on the results.

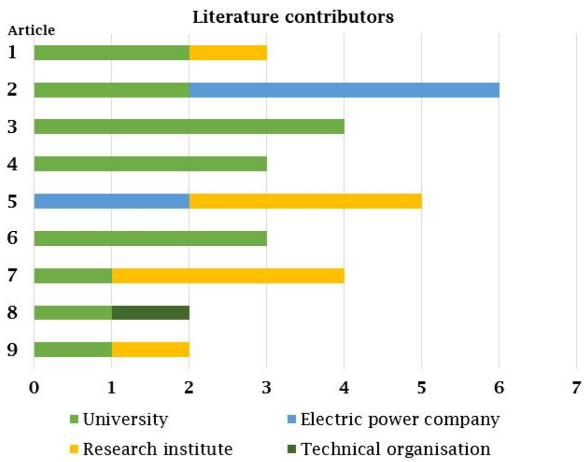

Figure 5.3: Number of contributors per article. The number of articles refers to the chosen articles as presented in Table 5.1. As visualised by the graphs, universities contribute the most and are included in all articles except Article 5. Article 8 is the only article including a technical organisation.

It was decided that articles concluding on various aspects that a BESS could contribute to a FCS would be chosen for the selection of literature. All articles meet these criteria, and to the best of this thesis author's knowledge, these articles are considered comprehensive in terms of the topic.

5.2 Specialisation of chosen articles

In alphabetical order, this section summarises each chosen literature for further understanding. Table 5.1 shows an overview of the article numbers, titles, countries of origin, and authors. It should be noted that only relevant information is included.

1. Accelerating electric vehicle adoption: techno-economic assessment to modify existing fuel stations with fast charging infrastructure

Ghosh et al. are members of the Royal Institute of Technology in Sweden, the University of Oxford, and the Council of Energy in New Delhi, India [64]. The article includes a case study of integration with/without photovoltaic panels and with/without a BESS. Gosh et al. state that FCS can be a problem for weak distribution grids and the purpose of the study was to study if BESS could reduce the grid connection costs.

In the case study presented, a battery capacity of 180 kWh was implemented on an existing fuel station. The results showed that the implementation of BESS increased the upfront costs, leading to the annual revenue generated from the system not being sufficient to compensate for the increased upfront costs. On the other hand, if the daily hours of operation were increased the system could become economically viable with a highly positive net income. The repayment time would be less than ten years for the two proposed scenarios: both with a total of 200 kW charging power outputs operating for either six or eight hours. Finally, the authors state that using a BESS-assisted FCS will help reduce connection costs, earn more revenue in the future by participating in local energy markets, and enable the use of cheaper time-of-use flexible tariffs while limiting the impact on the electricity network.

2. Battery Energy Storage System (BESS) Sizing Analysis of Bess-Assisted Fast Charge Station Based on Double-Layer Optimization Method

Members of Shanghai Jiao Tong University and the State Grid Shanghai Municipal Electric Power Company collaborated on this paper by Wu, D. et al [65]. According to the authors, a BESS could potentially help the distribution network alleviate the strike from a significant charging load. The paper conducts a method to find the optimal BESS size, including capacity, power, and service years of BESS. In addition, the model sought to minimise the annual present value of cost.

The results presented showed that BESS implementation in FCS was considered economically feasible. The BESS discharged during peak electricity price at 08.00-11.00 and 18.00-21.00 and charged at the valley electricity price during 22.00-06.00. Illustrations presented that BESS almost satisfied EV load during peak hours, which could help prevent grid peak load pressure. Finalising, the model proposed determined the optimal BESS size of 2700 kWh/540 kW which made BESS for a FCS in Shanghai profitable.

3. BESS Optimal Sizing and Scheduling for Energy Arbitrage and Frequency Containment Reserve Dual-Loop Optimization

Kurniawan et al. from the Technical University of Denmark wrote Article 3 [66]. The paper proposes that capital costs and lifetime operating expenditures are minimised by using a BESS in grid services. The implementation of a BESS system will compensate for the high peak power produced by the FCS. The FCS will then be less reliant on grid power consumption as a result of the BESS implementation. In addition, Kurniawan et al. state that the volatile electric prices in Denmark motivate BESS usage. Opposite, the BESS discharges during high EV charging demand and minimises peak load by peak shaving. A BESS charge during periods of low EV charging demand and low prices results in increased grid capacity. During high EV demand the BESS discharges, hence minimising peak load by load shifting. Potential profit can be extracted if the BESS is discharged during high electricity prices, utilising EA and grid provision. The article considers the optimal sizing and scheduling of BESS-assisted FCS for this cause. In addition, the potential energy arbitrage (EA) (Chapter 3.2) and Danish FCR-N services are included.

According to Kurniawan et al. a BESS participating in EA and utilising peak shaving only makes a small profit. Therefore, batteries should be exploited to provide FCR in addition to EA. In Eastern Denmark, a deviation of ±0.1Hz from the nominal frequency activates the FCR service. Energinet, Denmark's TSO, required 0.3MW in FCR-N. The main concern of Article 3 was FCR-N where units are activated when the frequency deviates from ±0.1Hz within 150s. This was due to the more valuable profit of this service compared to other frequency services.

The authors presented the optimal BESS power scheduling based on FCR-N provision and EA, in addition to the BESS's capacity and power ratings that would minimise the cost function. The BESS-assisted FCS was divided into two modes within 24 hours, whereas the first mode was performing FCR-N from 00.00-08.00 and the second mode from 08.00-23.00 to participate in EA. According to the authors, the most profitable BESS, in this case, was 2 MWh/4 MW. Revenue could be earned from FCR-N while also providing energy dispatch for EA for EV charging.

4. Deep reinforcement learning-based operation of fast charging stations coupled with energy storage system

Article 4 is written by three different departments from three different universities in Canada, South Korea, and the United States [67]. Hussain et al. state that BESS does not only reduce the system peak load by charging EVs during peak intervals but can also be used for providing other services to the grid during idling time. These services will increase the profit of the operator, discuss Hussain et al.

The article introduces a model to operate FCSs with a BESS under uncertainties such as EV arrival/departure and electricity prices. The model includes minimising the difference in net demand of the FCS with BESS, charging the BESS during low price intervals, and discharging the BESS during peak price intervals. The model was tested for a residential apartment complex with shared parking space, but it can be improved for any type of building with a FCS and on-site energy storage system, according to the authors.

A battery capacity of 400kWh was used. The results showed that BESS charged during off-peak (01.00-06.00) and shoulder peak (07.00-10.00) intervals on a weekday. Therefore, the FCS load increased during these time intervals. BESS was discharged during peak intervals to reduce the peak load of the FCS. Conclusively, the simulation led to a minimised peak load of the FCS.

5. Distribution Side Optimal Operation and Control of Coupled FCS and BESS

This article, by Wu, G. et al. is written by members of several departments within the Chinese state grid [68]. The article introduces the problem caused by the unpredictable charging behaviour of EVs. A method is proposed to compensate for the effect of EV charging behaviour by lowering the cost of a FCS with a BESS, and it is tested on a real-world distribution system topology using FCS data. The regulation strategy was examined from the perspective of the power grid and power station operation economy.

From the distribution line's perspective, where most FCS are connected, increased EV charging load could potentially change the former load curve. The loads could cause voltage deviations, increased power system net loss, harmonic pollution and affect the stable operation of the grid. Wu, G. et al. state that with the guidance of the orderly charging of EVs, peak power load could be cut and valleys filled, network loss potentially reduced, energy efficiency improved and the impact of load on the distribution network decreased.

Large industrial users implement the two-part electricity price system. This refers to a system where an electric price charge is collected by the power supply company that includes a basic price charge and a power price charge. The primary electricity charge was calculated according to the maximum power demand.

The results presented showed that the control of a 250 kWh BESS's charge/discharge strategy led to the output and network loss of the upper power grid slightly increasing, but the electricity cost significantly decreased. However, Wu, G. et al. proved that the presented method applied to a real-world distribution system could significantly reduce the charging cost and improve the power grid economy. The load curve was smoothed, and the impact of EV charging on the power grid was reduced. Lastly, the system could ensure the safe operation of the distribution system.

6. Optimal Battery Energy Storage System Sizing for Demand Charge

Management in EV Fast Charging Stations

Article 6, written by Delft University of Technology members Koolman et al., introduces an approach for optimal BESS and grid-tie sizing in FCS designs [69]. The authors stated that there are two main reasons for concern when installing FCS: location issues and demand charges, which in this article refer to fees based on the highest measured peak power (kW) during one month. These demand charges can be up to 90% of a CPO's electricity bill, hence weakening the economic feasibility of a FCS if peak power is high. According to Koolman et al. CPOs are motivated under these circumstances to limit their peak power by implementing a BESS.

The case study in this article included four chargers with a total power of 450kW, a peak demand of 384kW. As input for the FCS, a worst-case scenario (a period around the Christmas holidays) was chosen to ensure usage throughout the year. Further, the model included demand tariffs from Switzerland, the Netherlands, and New York City. The task of the model was to get the BESS to perform peak shaving on demand in order to limit grid-tied power, thereby reducing the station's demand chargers.

The demand tariff analysis showed that BESS costs were too high for the Netherlands. For Switzerland, a battery of 135 kWh/ 100 kW, a 40-60% cost reduction could be achieved, depending on the accepted delays in charging sessions. For New York City, with a battery of 600 kWh/ 155 kW, a 60-70% reduction was obtained. Finally, Koolman et al. demonstrated that BESS could be advantageous in regions with high demand tariffs if the proper size ratio between grid-tie and BESS was chosen.

7. Optimisation model with degradation for a battery energy storage system at an EV fast charging station

Article 7, by Haugen et al., is written by members of SINTEF (Norwegian search organisation) and the Norwegian University of Science and Technology [70]. Haugen et al. mention that FCS for EVs can lead to a significant load to the power grid system, potentially several MWs varying throughout the day. Further, the authors state that a BESS implemented at a FCS could avoid power grid congestion in the power system.

The article proposes an optimisation model for BESS-assisted FCSs in Norway that minimises operational costs. A BESS of 225 kWh/300 kW was utilised with a grid capacity of 1250 kW. The results showed that by installing a BESS, the peak power was reduced by 19% during the months with the highest load demand. The total cost difference between reinforcing the grid and installing the BESS was 906 kNOK, with the main differences being in investment and power-based tariff costs. Hence, the savings from the grid fees when installing BESS could not fully finance the installation costs. On the contrary, with decreasing BESS investment costs, it might become profitable; discuss Haugen et al.

Moreover, with increasing grid tariffs, there would be increased profitable revenue from installing a BESS compared with grid reinforcement. However, greater power-based tariff costs will reduce the number of profitable projects, stated the authors. Therefore, the DSO should be aware of the balance between new projects and incentives for increased flexibility.

8. Study of Optimally Located Electric Vehicle Charging Stations for Frequency Control Service in Distribution Network

This article, written by Hasan et al., members of the discipline of electrical engineering at IIT Gandhinagar, presents a BESS-integrated FCS to avoid instability to the grid during fast charging [71]. The FCS can affect the stability of the grid as it consumes power at a very high rate. The strategy is implemented on an IEEE 13 bus test system[1]. According to the authors, a BESS has created a new opportunity to provide frequency control services as well as manage fast charging. Therefore, coordination is needed to maintain the regulation of frequency control services and EV charging. If a CPO implements BESS for the convenience of its operation, it can also contribute to mitigating the unstable situation of the grid. This means that the FCS has the potential to provide frequency control services in addition to maintaining a stable grid due to its fast response system. Additionally, the ramp rate (Chapter 3.2) of BESS is suitable for the smooth operation of frequency control services.

The article includes a photovoltaic system, but the principle of storing energy, whether from the grid or solar cells, is considered similar. The authors state that BESS in this case was absolutely effective in utilising frequency control services.

9. Utilizing Local Flexibility Resources to Mitigate Grid Challenges at Electric Vehicle Charging Stations

The final article, by Iilieva et al. is written by members of Smart Innovation Norway and one member of Computer Science and Computational Engineering at The Arctic University of Norway [72]. The article's goal was to produce a concept that provided good opportunities to reduce the load on the local electricity grid. Additionally, the cost of operation and investment were considered important. The authors present the optimal mix of flexible resources at the INSPIRA charging station, located in Norway, to avoid costly grid infrastructure expansion. Charging EVs on a large scale can cause problems for grid operation. Increased capacity needs in relation to fast charging and unpredictable EV drivers' behaviour can create operational challenges for DSOs. Ilieva et al. refer to power loss, grid imbalance, reduction in transformers' lifetime, voltage profile, and harmonic distortions as problems caused by uncontrolled EV charging. Therefore, the article discussed how an optimal com-

[1]The IEEE 13 bus feeder is a small system that is used to test distribution systems

bination of local resources can help prevent increased grid challenges.

The INSPIRIA charging station aims to have one super fast charger of 300 kW and 32 chargers of either 22 kW or 50 kW. Different scenarios were conducted, resulting in the visitor's number, and a 300 kW fast charger kept the power output below the maximum grid limit of 500 kW. If more than one supercharger was to be installed, the chances of exceeding the limit would increase, causing major challenges to the grid's operation.

In the aspects of BESS, two solutions were considered. The first one was "opportunity" charging, and the other was "depot" charging. "Opportunity" charging referred to a battery being charged at the first available opportunity, which required a smaller energy capacity. "Depot" charging referred to a larger battery with sufficient capacity to provide load reduction for an entire day before charging. The advantage of this type of charging was that it reduced the number of charging cycles significantly when compared to "opportunity" charging. For "depot" charging, the battery could typically be charged during non-normal office hours when demand was low. Charging during high demand leads to a significant reduction in battery life and a change in the requirements for the payback period. This would lead to higher annual costs. Iilieva et al. concluded that a battery with a lower capacity and more daily discharges was less attractive. The importance of a long lifetime and the respective payback periods of the investments were stressed. For the case of INSPIRIA, "depot" charging was chosen as the most relevant technology to alleviate peak loads.

The results included calculations of the capacity based tariffs, whereas a BESS could help minimise the capacity-tariff-associated costs. For the capacity tariffs, cost data from the local DSO was used. Based on previous price drops, Iilieva et al. believe that a suitable battery for the FCS, in this case, could cost less than half the price of batteries in 2020 in the coming years. The loads over hours should be reduced or eliminated in order to achieve a grid capacity tariff (grid fee) gain. The investment cost must be less than or equal to the monthly tariff gain that can be realised with such an investment. Further, the paper showed that a battery capacity of 200–325 kWh could be defended economically with the unit costs of batteries in 2020.

5.3 Comparison of chosen literature and the findings

The nine chosen articles had different results and reasoning for utilising BESS. Therefore, in this section, a comparison and evaluation will be presented.

Table 5.2 presents the different locations of the charging stations. Articles 7 and

9 were both located in Norway. Because of the locations, these appeared to be highly relevant to this thesis topic. Additionally, an existing fuel station in the United Kingdom was included. As one of the charge point operators chosen as an informant implemented fast chargers at fuel stations, this seemed appropriate. Articles 2 and 4 include charging stations far from Norway: Shanghai and South Korea. This may have led to including barriers that are not applicable to Europe, or more specifically, Norway. All countries have their own power systems, leading to different challenges. However, the articles were included as they shed light on interesting topics.

Table 5.2: A representation of the nine chosen articles' various locations of FCSs.

Article	**Location**
1	Fuel station as FCS, United Kingdom
2	FCS, Shanghai
3	FCS, Eastern Denmark
4	Residential apartment complex with FC, South Korea
5	FCS, real-world distribution system
6	FCS, Netherlands
7	FCS, Norway
8	FCS, IEEE 13 bus system
9	FCS, Norway

The authors of the nine different articles were thought to have similar reasoning for choosing a BESS. The overview is presented in Table 5.3. Article 1 described a BESS solution as a way to help a weak distribution grid as well as reduce the grid connection cost. This was evaluated in comparison to Norwegian grid-tariff costs and deemed relevant. Articles 2, 5, and 9 implemented BESS as a way to help the distribution network alleviate charging. This was to contribute to a more stable distribution grid. Furthermore, Article 3 presented BESS as a solution to handle high peak power during the charging of EVs but this was considered the same as helping the distribution network alleviate charging. Articles 4, 6, and 7 were motivated to utilise BESS as a way to reduce the system peak load from EV charging. This leads to a possible decrease in grid fees, as described in Chapter 2, Section 2.1. Article 8 stated that BESS could help to avoid grid instability. As previously stated, the papers are produced by a diverse range of stakeholders and nationalities; however, to the best of the author of this thesis's knowledge, the motivation for BESS is fairly consistent. There is either a focus on load shifting to alleviate the distribution grid, decrease grid fee costs, earn additional revenues or a combination of these. Hence, there is an overall interest in making a charging station more economically feasible or profitable while also keeping the distribution grid stable.

Table 5.3: A presentation of the authors' various reasoning of BESS utilisation. The *Other services* column includes additional services provided by BESS that are not related to improving the FCS charging offer.

Article	Authors' reasoning for BESS utilisation	Other services
1	Weak distribution grid, reduction of grid connection costs	Additional photovoltaic system
2	Help the distribution network alleviate charging	None
3	Help the distribution network alleviate charging	Grid services, EA and Danish FCR-N market
4	Reduce system peak load, increase revenue by avoiding grid congestion/peak demand charges	None
5	Help the distribution network alleviate charging	Improve power grid economy
6	Reduce system peak load	None
7	Reduce system peak load, substitute to reinforcing the grid	None
8	Avoid instability of the grid	Grid service (frequency control services)
9	Help the distribution network alleviate charging	None

Four articles include additional services for BESS to contribute to other than making a better charging option for customers. These are articles 1, 3, 5, and 8, as presented in Table 5.3. Article 1 included an additional photovoltaic system with the BESS. However, the article still seemed relevant due to sections where a BESS-assisted FCS was considered, without the photovoltaic system. Both articles 3 and 8 present BESS for grid services. These grid services are either energy arbitrage (EA) or frequency control services. These techniques are presented in order to make the BESS more economically viable. Article 3 combines services such as energy arbitrage (EA) and frequency containment reserve (FCR) in addition to the charging of EVs. Article 8, on the other hand, mentions frequency control services but does not mention to what level of reserve products batteries can contribute. This article included an IEEE bus' system, whose location is unknown. The small model system is regarded as unimportant due to its size and non-real load data. However, it is important to note that the frequency control service can be used to make a BESS more economically profitable, according to the authors. Further, Article 5 introduces BESS to improve the power grid economy from the distribution side, while the other articles discuss a BESS from the perspective of a potential CPO.

Several articles include technological aspects that should be compared to the Norwegian power system. Article 3 had a FCS located in Eastern Denmark, as shown in Table 5.2. In this article, the BESS is introduced to the Danish FCR-N market. Compared to the Norwegian FCR-N, these two flexibility reserves seemed different. In Denmark, a deviation of 0.1 Hz from equilibrium activates FCRs within 150 seconds. As stated in Chapter 2, Section 2.2 and Figure 2.4, FCR in Norway is activated after 30 seconds of grid imbalance. The Norwegian market aFFR activating after 2 minutes–120 seconds may be more coherent with the Danish market of FCR-N. Additionally, aFFR brings the frequency back towards the normal band with a deviation of 0.1 Hz [34]. Denmark's TSO, Energinet, required a power of 0.3 MW, which is different from the Norwegian volume value of 1 MW stated by Statnett [34]. These two markets, Danish FCR-N and Norwegian aFFR, are considered similar in the aspects of functions and time, even though the amount of power input is different. Another consideration was Article 8, which also included frequency control services. The overall goal of frequency control services is to stabilise the frequency during grid imbalances. The frequency control services are considered comparable to the Norwegian frequency control services described in Chapter 2.2 even though activation time or volume are not stated. The article was included due to the interesting aspects of BESS being a reserve product.

Several articles used various grid tariffs based on consumption and location. Article 1 discussed British time-of-use flexible tariffs. This tariff is to offer customers cheaper electricity prices when demand and energy prices are low. According to the Energy Saving Trust, this is to *"help customers reduce their bills by using energy at off-peak times, relieve pressure on the grid by balancing demand"* [73]. Compared to the Norwegian grid fee, it is deemed similar in aspects of the varying electricity prices, and the power link incentives to allocate load [16, 25]. Article 6 includes demand charges. This referred to fees based on the highest measured power during one month. This is considered similar to the Norwegian power-based tariff, as mentioned in Chapter 2, Section 2.1. This is due to the Norwegian power link, which refers to the highest consumption within an hour in a month. Article 9 refers to the Norwegian capacity base grid tariff. This tariff applies for consumption under 100.000 kWh and does not include a power link. The capacity link, on the other hand, refers to the average of three peak consumption days [25]. Even though these are different, the reasoning for utilising BESS is to reduce the grid tariff by load shifting.

The outcomes of the various articles differ due to the different methods, and reasoning for utilising BESS, as shown in Table 5.3. As presented in Table 5.4, there were different conclusions. In addition, the results varied depending on whether a BESS implemented by a FCS was economically feasible. Article 7 results showed that when BESS was integrated, it was not economically viable compared to reinforcing the grid. Article 9 also concluded that with today's prices, a BESS-assisted FCS was not profitable, but it could be in the coming years if battery prices continued decreasing. Additionally, Article 1 showed a reduction in grid fees, but the investment in BESS increased the upfront costs, leading to a non-profitable system unless it operated for over eight hours a day. However, Articles 2, 3, and 6 resulted in a profitable solution with BESS. In areas with high demand tariffs, BESS was considered advantageous, as stated in Article 6. The BESS-assisted FCS in Article 2 led to an economically viable service system due to the decreased peak loads. In Article 3, BESS was utilised for Danish FCR-N and EA for EV charging, which led to increased revenues and, hence, a more profitable FCS for EV charging. However, Kurniawan et al. mentioned volatile electricity prices in Denmark motivating for EA, which may not be the case for Norway today. But, in a report by Kringstad et al. for Statnett, the spot price of power will be more volatile in Norway. According to the authors, this will result in increased revenues for utilising new or existing flexible sources [13].

Table 5.4: Table presenting the results of the chosen literature. The reasoning's for BESS utilisation differed, leading to various results.

Article	Result
1	BESS increased upfront costs and helped reduced grid-tie costs in some cases
2	BESS-assisted FCS was economically feasible, decreased peak loads
3	BESS in combination with a FCS could contribute to FCR-N, EA and charge EVs
4	BESS-assisted FCS led to decreased peak loads
5	The method significantly reduced the charging fees, improved the power grid economy, reduced the impact of EV on the grid and network loss increased
6	BESS can be advantageous in regions with high demand tariffs
7	BESS was not economically feasible compared to reinforcements of the grid
8	Effective execution of frequency control service
9	The FCS is fit to better cover the demand in the future with a "depot" battery to reduce power by utilising peak shaving

The articles used various battery sizes, with varying power loads and methods leading to a number of results. This was thought to be a good aspect to shed light on various scenarios and was an overall goal during the literature search period. The total charging station power output varied between 54 kW - 2000 kW, as seen in Table 5.5. There was a significant difference in loads, but the BESS services were also different. In some cases, such as in Articles 4, 5, and 7, the charging station power output was only given by the peak load in the given load data, which could allow for potentially higher power outputs. In Articles 1, 2, 6, 8 and 9 the charging station power had various DC chargers implemented with power of 22 kW, 50 kW, 300 kW or others. Only Article 9 had implemented AC charging of 22 kW. 22 kW is not considered fast charging, as stated in Chapter 2, Subsection 2.3 [9]. However, because these chargers are combined with other chargers, such as 150 kW, the station is classified as a fast charging station (FCS). Article 4 had a peak power load of 54 kW. The authors do not specify the charger combination used at the location, but given that it is a fast charging station, it is possible that the chargers were one 22 kW and one 50 kW, but they were not fully utilised, resulting in the low peak power.

There are different BESS power outages and capacities depending on the articles' chosen battery specifications. The grid power is affected by current and voltage. This aspect will not be taken into account in this thesis. Articles 2, 4, and 9 used peak shaving to decrease maximum loads; see Table 5.4. These articles had very varying charging station powers of 600 kW, 54 kW, and 2000 kW. The corresponding battery capacities were 2700 kWh, 400 kWh, and 325 kWh. Hence, different loads with different battery capacities can be implemented for decreasing the maximum loads of the FCS. Article 8 implemented a battery with a capacity of 3.3 kWh in a small model system, this is not deemed usable for a real charging station due to the low capacity.

Article 7 considered reduced grid fees from battery services compared to an investment contribution. A battery of 225 kWh at a 1600 kW FCS reduced the grid fees. However, the results presented an increased upfront cost due to the battery's investment price. In this Norwegian case study, the annual revenue generated from the BESS could not compensate for the traditional reinforcements of the grid.

Table 5.5: Results of the articles' charging stations' total power outputs, with the capacity and power outputs of the batteries implemented. *Charging station power* refers to the total power output or maximum peaks of the FCS. *Capacity/Power output* refers to the battery's specifications and operation is how BESS is utilised

Article	Charging station power	Capacity/Power output
1	200 kW	180 kWh
2	600 kW	540 kW/2700 kWh
3	-	2MWh/4MW
4	Peak at 54 kW	400 kWh
5	∼900 kW peak load	250 kWh
6	450 kW, peak demand of ∼380 kW	max ∼800kWh/∼300kW, NYC: 600kWh/155kW, Swiss: 135kWh/100kW max
7	Peak at ∼1600 kW	225kWh/300kW
8	600 kW	3.3 kWh
9	2000kW	200-325 kWh

The nine chosen articles are different with respect to battery sizes, reasoning for utilising BESS-assisted FCS, and results. However, after a thorough examination of the articles, it is considered that they use peak shaving/load shifting to help alleviate loads of EV charging, contribute to services such as frequency control and improvement of power grid economy, and reduce EV charging costs.

CHAPTER 6

Informant interviews

In this chapter, the informant interviews are presented. The informants chosen are presented in Chapter 4. Informant interviews were conducted to shed light on the current situation of electrification in the transport sector and BESS in combination with a FCS in Norway. For the interested reader, a more comprehensive citation outline is presented in Appendix B. The following structure is presented as shown in Table 4.1. Because maintaining the validity of the interviews is critical, the results were translated citations from the interviews and quotes checked by the informants. Additionally, the interviews are presented in the order they were held within each stakeholder group.

The interviews are presented as figures, with only the most relevant aspects of quotes included. The representation depicts the aspect to which the informants are referring (vertical boxes) and what they said about these (horizontal boxes). The stakeholder group's figures are colour coded as in Figure 4.3.

The main points examined during the informant interviews were:

- What challenges do CPOs meet during the development of FCS with capacity limitations?
- Is BESS a viable option at FCSs?
- What is the optimal way of utilising a BESS at a FCS?
- What are the future prospects of BESS integrated into the distribution grid, and specifically at FCS?
- What are future prospects regarding funding and charging stations demand?

Charge point operators

The main citations from CPOs are visualised in Figure 6.1, 6.2 and 6.3. *Capacity shortage projects* refers to the CPO's experience on this, *BESS-assisted FCSs* includes their thoughts and prospect of utilising BESS at a FCS and lastly, *Charging infrastructure* includes the informant's beliefs of charging in the coming years. When discussing capacity shortage projects, the CPOs mentioned the long period of time from project decision to project completion, known as lead time, as well as investment contributions [74]. When discussing BESS-assisted FCS, one of the main motivators for implementation was the reduction of grid charges. Utilising load shifting where a battery charges during low electricity prices and discharges during higher electricity prices, would also lead to a lower power link in the power-based grid tariff. Further, future prospects on charging infrastructure showed an expectation of higher power charging and peak power, Norway following EU regulations and a fast expansion of charging stations.

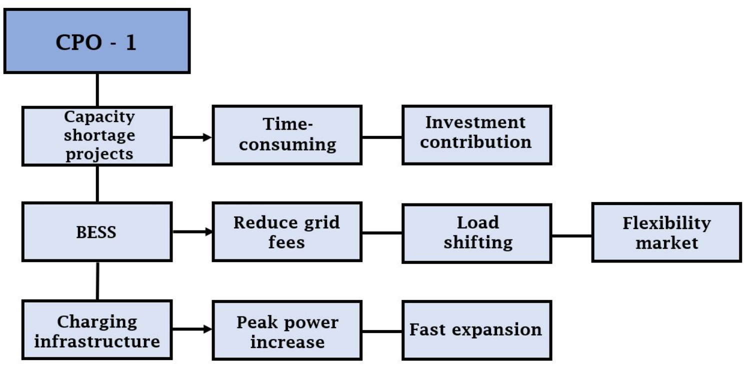

Figure 6.1: Visualisation of charge point operator 1's relevant aspects of citations.

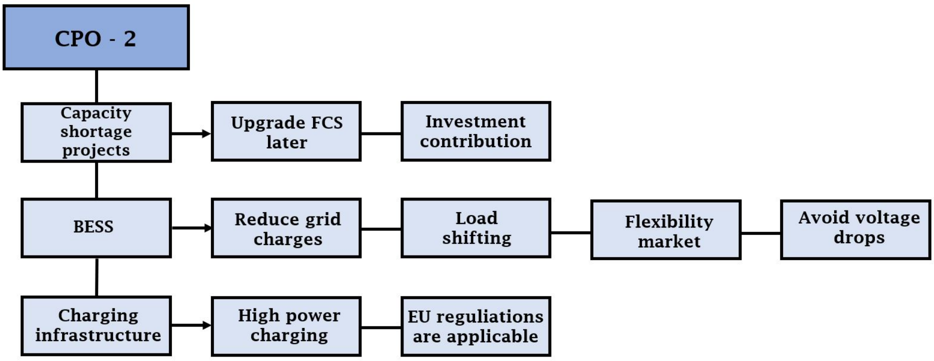

Figure 6.2: Visualisation of charge point operator 2's relevant aspects of citations.

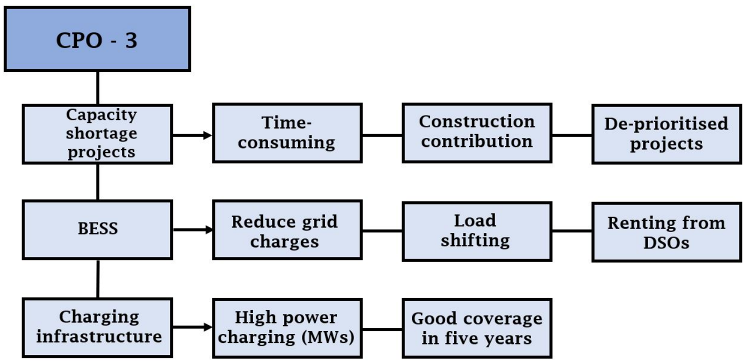

Figure 6.3: Visualisation of charge point operator 3's relevant aspects of citations.

Distribution system operators

The main mentioned aspects from both DSOs are presented in Figures 6.4 and 6.5. As visualised, they mentioned investment contribution, conditional attachments and grid fees. These aspects are described in Chapter 2. The box *Grid capacity shortage* includes what the DSO did when seeing a demand for greater grid capacity, *BESS* includes what the DSOs think of BESS both from their perspective and a customer's perspective. Lastly, *Charging infrastructure* presents the DSOs aspects of charging infrastructure in the coming years. Regarding grid capacity shortages, DSO 1 and 2 both reinforced or upgraded the grid. Further, DSO 1 and 2 noted the long lead time of grid-tying projects, which could take several years. According to DSO 2 CPOs applied for grid power below 850 kW due to costly installations if this threshold value was exceeded. Both had seen batteries used for preventing voltage drops. DSO 2 mentioned that BESS would be useful in charging stations with significant load peaks. Moreover, charging infrastructure could be faster implemented by conditional attachment and BESS utilised for either smaller or larger sites.

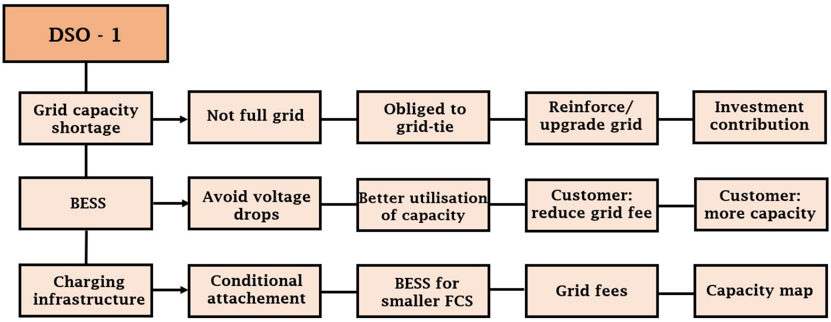

Figure 6.4: Visualisation of distribution system operator 1's relevant aspects of citations.

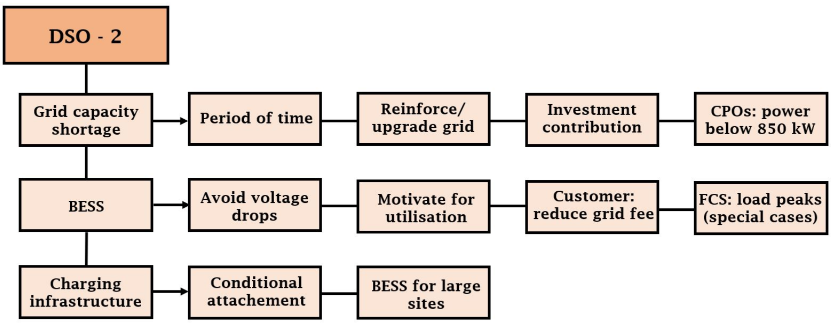

Figure 6.5: Visualisation of distribution system operator 1's relevant aspects of citations.

Battery energy storage system providers

Figures 6.6, 6.7 and 6.8 inhabit the aspects of the interviewed BESS providers mentioned. *Customers* refer to the interest customers have for BESS. The *CPO* box refers to what CPOs have shown interest in, and the *Coming years* box refers to what the BESS provider believes regarding future prospects of BESS. The overall interest for BESS operation was load shifting, according to the BESS providers. Regarding the capacity of the BESS-assisted FCS, there were differences: BESS provider 1 stated power outputs over 1 MW for economic sources such as frequency control services. BESS provider 2 stated that they had provided 300 kW/300 kWh at a FCS, while BESS provider 3 stated that they had only seen interest in 0.5 MW from CPOs, whereas a greater capacity than 0.5 MWh would be advantageous in this case. BESS providers' dialogue with CPOs revealed an interest in reducing grid fees and avoiding investment contributions. In the future, BESS were expected to be utilised at FCSs, and DSOs renting BESS services for voltage deviations. Additionally, BESS provider 3 expected an increase in BESS service in both the low- and high-voltage distribution grid.

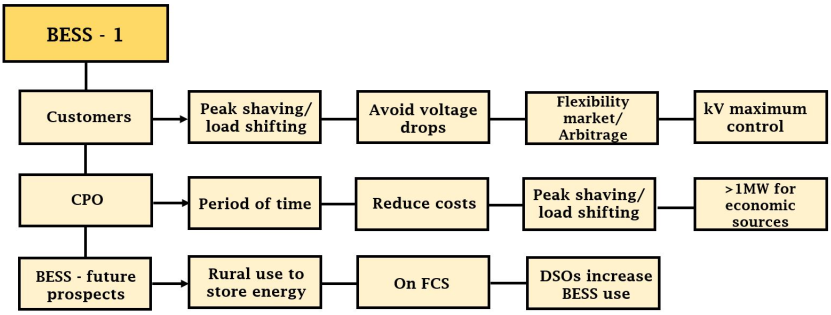

Figure 6.6: Visualisation of battery energy storage system provider 1's relevant aspects of citations.

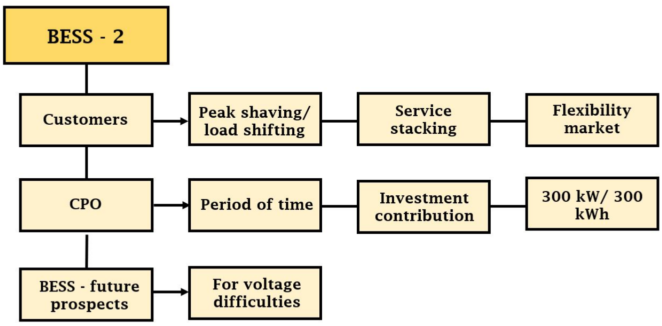

Figure 6.7: Visualisation of battery energy storage system provider 2's relevant aspects of citations.

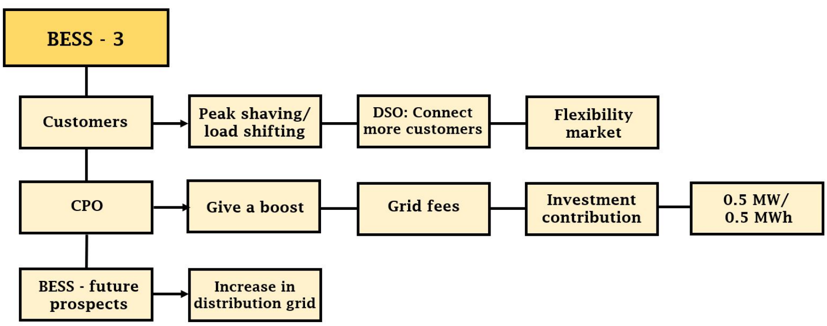

Figure 6.8: Visualisation of battery energy storage system provider 3's relevant aspects of citations.

Funding

The funding stakeholder's relevant citations are presented in Figure 6.9. *Light electric vehicle (LEV)*[1] *charging infrastructure* refers to the informant's aspects of light electric vehicles infrastructure, *Heavy electric vehicles (HEV) charging infrastructure* refers to heavy electric vehicles charging infrastructure, and lastly, *BESS* includes aspects on funding regarding battery energy storage systems. Today, HEV charging infrastructure is competitively based where the most cost-effective projects are funded. Moreover, BESS can be funded as operational support at mobile FCS for electric vehicles at construction sites. In 2023, funding for public heavy vehicle charging infrastructure of this organisation will be launched.

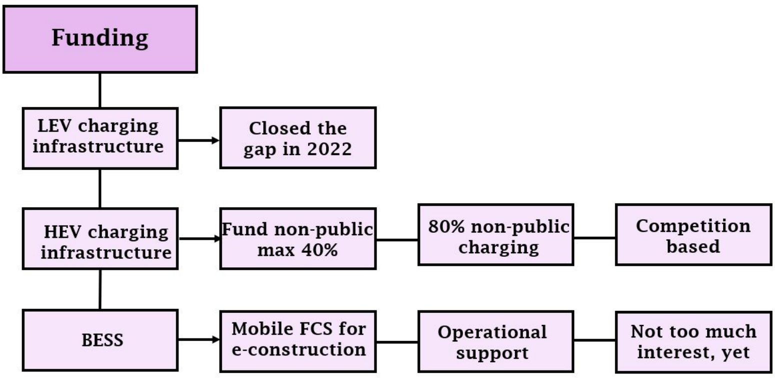

Figure 6.9: Visualisation of the funding informants aspects of citations.

[1] Light electric vehicles refer to passenger cars

Heavy vehicle user informants

Lastly, the two different stakeholders within the heavy vehicle users group are presented. Figures 6.10 and 6.11 include the main topics within *Charging infrastructure* demand and *Vehicles* in the coming years. HVU 1 referred to EU directives on charging infrastructure regarding HEV. The two informants agreed on the need for many chargers for heavy vehicles, as well as the need for high power at FCSs for shorter charging sessions.

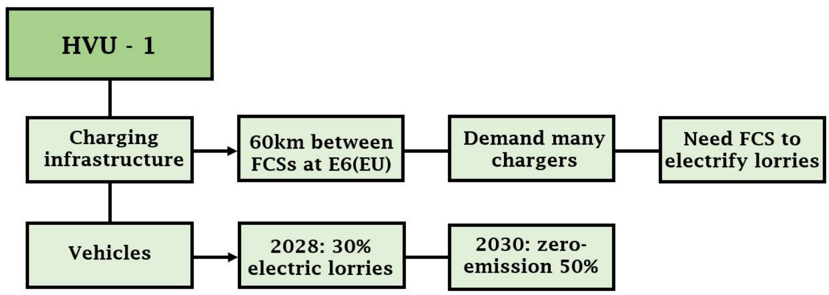

Figure 6.10: Visualisation of the heavy vehicle user informant 1's relevant aspects of citations.

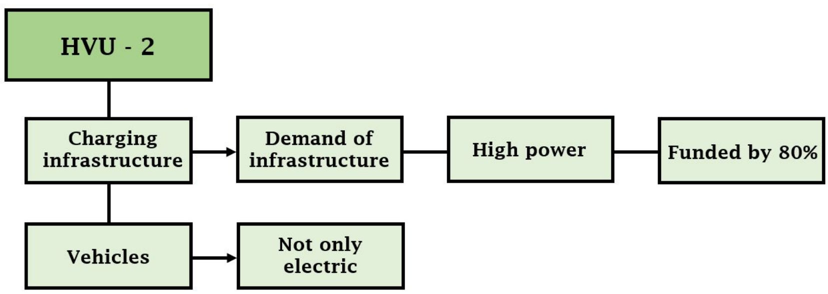

Figure 6.11: Visualisation of heavy vehicle user informant 2's relevant aspects of citations.

Chapter 7

GAP analysis - BESS integrated in the power grid to increase electrification of transport

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This chapter supplies answers to the GAP analysis. The structure of the GAP analysis will be as presented in Section 4.4 and is divided into three sections; First, the current situation will be presented in Section 7.1. Then, the future prospects of BESS in combination with a FCS to meet the increased demand of charging infrastructure in Section 7.2 is examined. Lastly, aspects of ways to tighten the gap are considered in Section 7.3. The main findings from the literature review are given in Chapter 5 and interviews are given in Chapter 6. These results, with additional information given in the chapters Introduction (Chapter 1), the Norwegian power grid system (Chapter 2) and Battery energy storage systems (Chapter 3) are used in this synthesis. The articles will be referred to as either article numeration or authors name as presented in Table 5.1. This also applies to the interviews that will be presented by stakeholders' number, which can be found in Chapter 4, Section 4.3.

7.1 Synthesis of current situation

In this section, a summation of today's current situation is given. The section is divided into electric vehicles, charging infrastructure, BESS and economic aspects. These are deemed important to comprehend a valid current situation.

Electric vehicles

In 2022, 83.4% of all new cars registered in Norway were electric [4]. There are 600.000 electric cars out of a total of 3.0 million cars [5]. Regarding, lorries, HVU 1 stated that 7-8% of new registrations in Norway were electric in 2022. Totally, there are 0.7% electric lorries. Lastly, short- and long-distance electric buses, comprehends 6% of the Norwegian market. Long-distance vehicles such as cars, light vans, lorries and buses have had an increase in electric vehicles from 2021-2022 [5].

Charging infrastructure

Today, there is uncertainty about whether the charging infrastructure for light electric vehicles (LEV) demand is met. The funding informant mentioned LEV charging infrastructure being close to market demand in Norway, with funding finalised in 2022. Bowitz, E. for Norconsult also stated that LEV charging demand where met if the existing Norwegian 50 kW DC chargers are replaced with 150 kW DC chargers [11]. However, all CPOs interviewed in this thesis stated they were expanding and developing new locations or upgrading old ones. In the study conducted by Bowitz, E. for Norconsult, all CPOs interviewed had equivalent plans [11]. Heavy electric vehicles (HEV) charging infrastructure operators may receive competitive funding, at least from the funding organisation chosen for this thesis. The funding informant stated that they have seen increased interest in HEV charging infrastructure, but cited a study that found that 80% of HEV charging will take place at non-public charging stations. Both of the heavy vehicle users' stakeholders stated that there is a need for large EV public charging infrastructure applicable for only lorries/buses today to ensure safe and fast charging sessions.

Today the technical aspects of capacity shortages in the grid are spread worldwide, as discussed in Chapter 5. Topics such as weak distribution grids and the implementation of batteries to ensure EV charging are discussed. Høiem et al. addressed fast chargers for both bus and light vehicles as new grid loads challenges, which would frequently lead to grid reinforcements [27]. When DSOs detect a demand for more power, they frequently reinforce or upgrade the power grid, according to the DSOs interviewed in this thesis. From the DSOs' interviews, conditional attachment and investment contribution are referred to as temporary solutions to meet the demand for increased power establishments from CPOs. However, the grid-ties are often time-consuming and costly at locations with limiting capacity both for CPOs and DSOs. Conditional attachment may lead to CPOs' inability to establish larger sites. The increase in electric vehicles, as presented in Figure 1.1, and the expected increase in demand for charging infrastructure both for light and heavy electric vehicles motivates for seizing barriers and technological possibilities [7].

NVE predicted that power consumption had a greater increase than power production from 2021 to 2030. This may lead to challenges such as power grid congestion [12]. All CPOs stated that they had experienced projects with limited capacity, whereas investment contributions were mentioned. Today, this frequently results in an increased aspect of time, de-prioritised or ignored projects. According to DSO 2, CPOs often request a grid power output below 850 kW. Power outputs greater than this requires further installations which leads to further costs for the CPO. CPO 2 stated there is a possibility of developing some chargers and upgrading the station's power output later. Furthermore, DSO 2's customer dialogues revealed that project de-prioritisation is due to costly investment contributions and the issue of time in regard to grid reinforcement, if necessary. However, DSO 1 stated: the grid is not full, referring to limited grid capacity. In a feasibility study, conducted by Energi Norge and CINELDI in 2021, the included DSOs stated that the Norwegian grid is well- or over-dimensions in specific areas [27]. As mentioned in Section 2.1, DSOs are obliged by law to grid-tie every customer, but the cost may vary referring to investment contribution, stated both DSO 1 and Skotland et al. [19, 30]. According to DSO 1 and CPO 3, the reason for CPOs' costly investment contributions today is due to them being the triggering customer demanding increased grid capacity. Skotland et al. state that the development of a FCS often requires upgrades in the existing grid [30]. The existing grid may be well-distributed in some areas but is not adequate for FCS requiring up to several MWs of power output.

Battery energy storage system

In Article 1, Gosh et al. motivations for examining BESS were to investigate possibilities for reducing grid connection costs at a weak distribution grid, as shown in Figure 5.3. Additionally, they stated that FCSs can be a potential problem for weak distribution grids [64]. Article 2, by Wu, D. et al. stated that BESS may alleviate significant charging load in the distribution network [65]. Kurniawan et al, in Article 3, also stated the potential in BESS by handling high peak power and leading to a less grid-dependent FCS [66]. Reducing system peak load was also supported by Hussain et al. in Article 4 [67]. Furthermore, Figure 5.3 showed a motivation for BESS to either help the distribution network alleviate EV charging, reduce system peak loads, avoid instability of the grid, avoid power grid congestion, or reduce peak demand chargers. The services and motivation for implementing BESS were often stacked to increase revenues and benefits for the operator and DSO. The chosen articles in the literature are considered to coincide with the interview object statements regarding limited capacity due to increasing demand for power, weak distribution grids and cost-cutting measures.

Given the interviews, the CPOs have investigated the use of BESS as a service to increase the charging offer for customers. Decreasing the maximum load in one hour is mentioned as one of the lowest-hanging fruits by CPO 1. By load shifting the peak power hours to hours with lower electricity prices, the power link in the power-based grid tariff would be reduced. This would also reduce the total cost of electricity consumption. CPO 2 and CPO 3 were also motivated by reducing peak loads during high electricity prices to make locations more economically profitable. This was also supported by Article 4 [67]. Today, if there is no significant EV charging during the week but high peaks on weekends, CPOs pay high power link prices for a charging offer that is not fully utilised. Additionally, CPO 1 stated that the high peaks of EV charging today often coincide with the high peaks of electricity prices. This also motivates for peak shaving, and load shifting the FCSs energy to times with lower electricity prices, leading to a lower grid tariff. CPO 3 stated that BESS is of interest at locations with shortages of capacities. CPO 2 also said voltage deviations motivated BESS service implementation.

Both DSOs interviewed in this thesis had experience with implementing a BESS. The integration of a battery was as a flexible resource to remain a steady voltage in the power grid. DSO 1 referred to a battery solution that targeted the voltage, adapted to this and provided the grid with voltage support. DSO 2 on the other hand, had experience with a BESS-assisted FCS. Further, the interview object gave an example of a CPO demanding either 2 MW or 500kW, whereas the second one would have a battery implemented due to limited capacity. According to the informant, implementing the lower power output was easier than the higher one. This was due to the DSO's opportunity to grid-tie faster because of decreased maximum load and the ability to postpone reinforcements of the grid. In turn, the customer would be provided with a lower investment contribution.

Battery energy storage system (BESS) providers have noticed a growing interest in the past few years as presented in Chapter 6. BESS provider 3 mentioned DSOs' need for connecting several customers as one BESS service. BESS provider 1 had seen increased interest for DSOs interest in implementing batteries for unstable distribution grids. BESS providers 1 and 2 referred to increased interest in value stacking and stated the motivation was to make the solutions more economically profitable. However, BESS provider 2 stated this was not yet widely used in practice. The funding informant had not seen a significant interest in BESS-assisted FCS. As of today, the funding organisation does not fund projects specifically due to the implementation of BESS. The BESS must be cost-effective, and if so it may be a part of non-public heavy vehicle charging stations. Projects including BESS are funded in innovative projects as an operational support and several stakeholders with private BESS-assisted HEV FCS have applied for funding. However, they were not the most cost-effective projects and did not win the competitive bidding.

Economic aspects

As of today, the informants refer to BESS implementation as being costly. Article 1, by Gosh et al. stated that the BESS increased the upfront costs at an existing fuel station. Even though the annual revenue generated from the system was examined, the solution was not sufficient. If the hours of operation time increased, the BESS could potentially be repaid by ten years [64]. However, CPO 3 stated that investing in batteries with a ten-year perspective would not be profitable, from their perspective. In Article 2, Wu, D et al. presented a battery capacity of 2700 kWh. The implementation led to an economically feasible BESS-assisted FCS in Shanghai, when charged during off-peak hours and discharged during peak load hours [65]. However, this battery was implemented at a 600 kW charging station, leading to fewer expenses in the charging infrastructure. This power output is also considered small in the aspects of heavy vehicle FCS that demand more power output to shorten the charging session.

7.2 Future prospects for BESS-assisted FCS

This section's structure is similar to the previous section's. However, future prospects of the same aspects will be presented.

Electric vehicles

In 2030, there might be 1.7 million electric cars in Norway if sales follow the Norwegian government's prospects [5, 7]. Additionally, if the assumptions are precise, there will be a significant increase in electric long-distance transportation as presented in Figure 1.1 [7]. However, HVU 1 stated that signals from the market implied that these criteria would not be met, referring to an expectation of 30% of new lorries being electric in 2028. Furthermore, the trend of EV power consumption appears to be increasing in the coming years, as visualised in Figure 2.7. This results in shorter charging sessions, but also higher FCS power outputs to accommodate these advancements.

Charging infrastructure

With the increasing EV share, charging stations are demanded. In the coming years, there may be a demand for 1000 - 14.000 fast chargers, whereas 1500-2500 fast chargers are meant for heavy vehicles [7]. One of the European Union's goals for alternative fuels includes a requirement of 60 km between charging stations in both directions for LEV [8]. Regarding HEV, HVU 1 stated that for lorry transportation to electrify, there is a need for a significantly larger charging infrastructure compared to today. The informant referred to distances of 60 km between each charging station on parts of Highway E6 towards 2030. According to the Norwegian Ministry of Transport, HEV adoption is still in its early stages, and a public fast-charging network is lacking. Furthermore, the Government wants the establishment and operation of charging stations for HEV to happen in commercial conditions, without public funding. The final strategy on national charging strategy, conducted by the Norwegian Public Roads Administration, will be presented in July of 2023 [8]. According to HVU 1, charging lorries will mainly be for "top-up" charging. As a result, the charging demand for lorries may be concentrated at private charging stations rather than public ones operated by CPOs. However, if 50% of new lorries in 2030 are electric or zero-emission vehicles, the increase in demand for charging infrastructure will continue [6]. HVU 2 stated that establishing charging stations is expensive, adding that the current funding covers 80% of the cost for those developing bus charging stations. Lastly, the power of charging lorries should be MW charging for rapid charging of lorries or buses.

Skotland et al. estimated that with the increased power output of the fast charging stations, there will be an increase in the investment contribution for the developers, such as CPOs [30]. Regarding funding, the funding informant stated that they will launch funding for public heavy vehicle charging infrastructure in the summer of 2023. If batteries are cost-effective in these projects, they may be included. According to the informant, stakeholders are waiting for funding programmes to be launched before developing charging stations. The result of this is that there may be a significant increase in HEV FCS after the funding is released. Funding is often time-limited: for example, a maximum of one year must elapse between the approval of the CPO's application and the completion of the facility. Therefore, solutions contributing to a more rapid grid-tie, avoiding reinforcements of the grid, may be preferable for developers.

CPO 1 stated that peak power at FCS would most likely increase in the coming years. CPO 2 had future prospects of higher power charging and stated that Norway most probably has to follow EUs devise on charging infrastructure, similar to HVU 1. CPO 3 confirmed the future prospects of higher power charging, stating that MW charging for HEVs would most likely be available within the next five years. This results in higher peak powers leading to greater expenses in grid power tariffs and investment contributions. CPO 1, on the other hand, stated that there would most likely be adequate coverage of fast chargers. DSO 1 and DSO 2 stated that conditional attachment was one way of meeting future demand for the establishment of FCS in strained areas. Conditional attachments result in a faster grid-tie, but the CPO's charging offer would vary and, in worst-case scenarios, be non-existent. Further, DSO 1 expressed BESS might be implemented for smaller FCSs while DSO 2 proclaimed BESS being applicable for larger FCSs in the coming years. Høiem et al. stated that DSOs in their study expected increased implementation of batteries by customers in the coming years. This would make flexibility more accessible to DSOs by 2030/2040. Several DSOs in Høiem et al.s study also addressed the ability to provide and consume power in the grid by utilising flexibility resources [27].

DSO 2 expressed that customers rejecting a conditional attachment could potentially be grid-tied in 2027, four years from now. The CPOs' comment on this aspect was validated as subjective, and therefore not included. Grid reinforcement results in greater lead time, especially if the regional grid is affected. If locations with limited capacities were to be de-prioritised and fully implemented in 2028 it could be difficult to meet the demand for fast charging, especially related to HEVs. Larger vehicles, such as lorries and long-distance buses, most probably will require a separate market from LEV. Additionally, it is important to stress the demand for higher power outputs resulting in shorter charging sessions. This may lead to higher investment contributions for potential CPOs.

Battery energy storage system

Regarding the future prospects of BESS in Norway, BESS provider 1 estimated an increase in the use of BESS-assisted FCS for cost savings and DSOs utilising BESS for unstable distribution grids. This was supported by BESS provider 2. BESS provider 3 stated that there would most probably be an increase of BESS implemented in both the low- and high-voltage power grid. Flexibility challenges may arise in new locations in the future. However, it may be difficult to identify potential power grid congestion in the grid, making it difficult to determine the need for flexibility. On the other hand, due to the batteries' readily availability, they can solve flexibility challenges [27]. But, some DSOs contributing to the feasibility study by Høiem et al. stated that they do not see the value of accessible flexibility. If, in this case, an operator of BESS systems, implement a flexible resource at a location with adequate capacity, the system has no value for the DSO. Additionally, the study expressed that some customers have an exaggerated expectation of what a DSO will pay for available flexibility resources services [27]. Nevertheless, capacity difficulties in the high-voltage distribution grid and regional grid leading to power grid congestion are expected to increase. This also applies to the transmission grid. Voltage deviations in the low-voltage distribution grid are also noted to increase [27].

The importance of mentioning a battery's impact on the grid is stressed. In Article 5 the results presented that there was an increase in the network loss of the upper grid[1] when a battery was implemented compared to pre-establishments. However, when considering the EV charging load without a BESS, the network losses would be greater. However, the overall power grid economy increased and the charging costs were reduced due to utilising the BESS service load shifting [68]. According to Montoya et al., a BESS decreases potential distribution-side challenges with reactive power. The reactive power capability of batteries can improve DSO profits due to less demand for reactive power compensation for voltage support from traditional methods [75]. Results presented by Montoya et al. showed that including batteries in the grid reduced the daily operational cost of the network compared to the current classical approach [75].

Economic aspects

The economic aspect of BESS establishments is of importance. For CPOs or DSOs

[1] Upper grid is assumed to be equivalent to the Norwegian distribution grid

to utilise BESS, the service should prove to gain revenues and be a more profitable solution compared to other technologies. As previously stated, several informants refer to BESS being an expensive investment and often not profitable in 2022. But future prospects may change this. Battery prices have been falling between 2010-2019 and are expected to continue [52]. The world's largest battery producer, CATL, is developing a new battery. This battery is made up of non-limited resource sodium rather than the widely used lithium-ion. Sodium costs 1-3% of lithium, leading to a significantly affordable battery. In the future, this could be used for larger battery packs as well as electric vehicles, as CATL intends. Furthermore, the batteries are stated to have less energy density, leading to heavier batteries than the normal lithium-ions [76]. Hence, they may be applicable for FCSs due to fewer area constraints.

7.3 How to tighten the GAP between the current situation and desired future prospects

In this section, the aspects of closing the gap between the current situation and the desired situation are presented. The desired situation is to meet the demand for charging stations due to the increased transport electrification in Norway. The main focus will be on how a BESS can help meet the increased demand for public FCS and present the optimal way of services. Two proposals will be presented: one short term referring to a one-year period, and one long-term, referring to a five-year time.

In the short term, many aspects will remain equivalent as of today. Regarding the long term, there is taken the liberty of assuming a rapid advancement in battery technology leading to better utilisation of service stacking, as mentioned. Additionally, it is assumed that battery investment costs will follow past tendencies. Flexibility demand is expected to grow as previously stated. Proposals for closing the gap short- and long-term regarding capacity shortages at FCSs, challenges of implementing EVs in an unstable grid, and increased demand for charging infrastructure due to transportation electrification are presented.

Before presenting the short- and long-term solutions, some additional aspects seemed relevant to mention. Enhanced dialogue between CPOs and DSOs on all aspects of grid-tying should be encouraged. Regarding conditional attachment, DSOs mention this as a way of grid-tying more customers. Some CPOs of this project meant there were other ways of meeting capacity shortages. A discussion on where grid capacity is low and high is also encouraged. This would lead to CPOs' possibility of either discarding projects faster or looking into batteries as a way of meeting the low capacity and enabling voltage stability. Finally, it is important to note that not all FCS establishments experiences challenges, as for example low grid capacity.

How to close the gap: Short-term solution

During the interview period, knowledge of the current state of BESS was accomplished. Only CPO 1 had implemented BESS at a FCS. The other two had investigated the technology but had not yet implemented a stationary BESS. The BESS providers had been in contact with CPOs or DSOs, who showed interest in utilising BESS services. However, it was only referred to two FCSs with BESS throughout the interview period, showing the early phase of BESS-assisted FCSs. In this section, a short-term solution for utilising BESS to increase the implementation of FCS is presented.

1. DSOs purchasing mobile BESS services
2. CPOs purchasing BESSs of under 600 kWh, at locations over 850 kW grid power output
3. Funding for heavy vehicle infrastructure

1. DSOs purchasing mobile BESS services

There have been cases of DSOs renting BESS services in the distribution grid. In one Norwegian case, the utilisation of BESS was to increase the grid capacity and grid-tie customers faster [77]. This project was funded. If such applications demonstrate the potential of a battery, resulting in both social and economic benefits, there may be an increase in the coming years. Traditional reinforcements of the grid are costly and lead to discarded projects or establishments several years after initial thought. This may lead to shortages in charging infrastructure, especially for heavy vehicles such as lorries and buses with high power demands. By renting BESS services, DSOs maintain a stable voltage and grid-tie customers which profits both parties. According to Wu, G et al. in Article 5 a BESS also improved the power grid economy and the impact of EV charging was reduced [68]. Because most cases of voltage instability occur locally, the BESS is implemented where these events occur [35]. In a study conducted by Energi Norge and CINELDI, some DSOs stated that challenges with power grid congestion often coincide with areas in need of grid reinforcements [27]. In these areas, a battery could both prevent grid power congestion and postpone grid reinforcements, and lead to faster implementation of FCSs.

Pilot projects, such as those mentioned, show that DSOs are interested in using batteries to improve flexibility, which may be seen more in the coming year. Additionally, DSO 1 stated that the battery targeted the grid voltage, hence providing the grid with local voltage support. Integrating BESS is favourable for DSOs by leading to fewer expenses to stabilise the voltage compared to traditional methods [75]. In addition, the DSO can postpone grid upgrades, leading to a more favourable grid tariff for all customers in that area. The fact that this solution employs a mobile BESS is stressed because the BESS can be moved to other strained areas after potentially necessary reinforcements have been completed. CPO 3 stated that this would be a beneficial service as they could grid-tie faster. By grid-tying faster, the establishment of charging stations is more rapid due to shorter lead time. In this case, the DSO will most likely need to change its business model to view the BESS as a flexible resource that enables grid stability, rapid grid connections, and postponing grid reinforcements, resulting in increased utility company revenues.

2. CPOs purchasing BESSs of under 600 kWh, at locations over 850 kW grid power output

Batteries should be purchased by CPOs in areas where a need for over 850 kW is preferable. As DSO 2 stated, installations over this threshold often result in even higher connection fees. This leads to several CPOs applying for power output below 850 kW. Higher power outputs are expected to increase due to existing FCS being upgraded with higher power outputs and new HEV establishments being built. The aspect of increased investment contributions with higher power outputs is, may therefore, motivating BESS utilisation [30]. Moreover, the CPOs should consider evaluating whether a location will have high EV load charging peaks coinciding with high electricity prices, leading to significantly high power links in the grid tariff. According to Achin et al., there were positive investment costs for BESS as of 2019 when compared to a higher power-based tariff without BESS utilisation [56]. Therefore, as one way to close the gap, CPOs are advised to invest in BESS to utilise low electricity price periods to load shift. A "depot" battery, as presented in Article 9, would be beneficial due to its ability to charge at low electricity prices. The battery should load shift over several hours to gain grid fee reductions. A "depot" battery would also have a longer lifespan and a shorter payback time than batteries that are charged at every opportunity [72].

The choice of a battery size under 600 kWh was motivated by the current costs of battery technology. During the interview process, several stakeholders claimed that BESS prices increased with size. In addition, the literature presented various battery capacities, whereas Article 6 concluded on a battery capacity between 135 kWh-600 kWh in high-demand tariff areas. Additionally, BESS provider 2 had provided 300 kWh batteries for a FCS. However, BESS provider 3 noted that a battery with over 500 kWh would be preferable for several FCSs. Articles 7 and 9, were both Norwegian case studies. Both cases presented similar EV load peaks of 1600-2000 kW and battery capacity between 200-325 kWh. While Article 7 resulted in an economically infeasible solution compared to reinforcements of the grid, it may be beneficial with BESS if the investment contribution is higher than the one presented in the article. Additionally, if power-based tariffs also are unfavourably high, a battery will make the FCS profitable. As of the results presented in Articles 6, 7, and 9, a capacity of less than 600 kWh appeared reasonable. But, the challenge, and inaccuracy, of deciding on one optimal BESS capacity are stressed due to various EV charging, power grid services, business models etc. Lastly, when the BESS operator feeds electricity into the grid, their position at the local DSO will change. As a result, they will not only pay grid fees but also an additional feed-in tariff [78]. This is not considered in this thesis' scope.

For BESS-assisted FCSs to be cost-efficient, there must be significant peaks, leading to the BESS making up for the high power-based tariffs. In the case of low grid capacity, the reinforcements of the power grid fees, hence a CPO's investment contribution, should be higher than the investment of BESS. A dialogue between the DSO and CPO is encouraged to get further insights into the investment contribution fee and what tariff the specific location most probably will hold. Furthermore, a BESS would benefit CPOs by avoiding the need to wait for grid reinforcements, which, according to DSO 1, can take up to ten years if the transmission line is affected. This would result in the rapid implementation of charging infrastructure, which would benefit vehicle electrification.

3. Funding for heavy vehicle infrastructure

A third way to close the gap is funding. One funding for heavy vehicle charging infrastructure will be announced in the summer of 2023. This will help developers establish charging stations even though the projects are not cost-efficient today. In such funding projects, batteries may be implemented. In the case of heavy vehicle charging it is important to stress that higher power chargers may lead to higher investment contribution fees, and implementing a battery is one way to contribute to lower grid-tie fees [30]. Funding for BESS-assisted FCS projects would also be beneficial to prevent grid challenges for DSOs.

How to close the gap: Long-term solution

The long-term aspect is five years from now, in 2027 and further. In addition to ways of closing the gap long-term, the previously stated proposals regarding short-term are also favourable looking at a five-year perspective. Additionally, proposals for further ensuring the meeting of the growing charging infrastructure with BESS are presented.

1. CPOs buying batteries with power outputs over 1MW
2. BESS providers renting out services to both DSOs and CPOs
3. Funding of BESS in the distribution grid

1. CPOs buying batteries with power outputs over 1MW

Power balancing as a frequency control service was the most profitable BESS service used in the Norwegian distribution grid in 2019, according to Ahcin et al. [56]. In this GAP analysis, this service was chosen as one way of closing the gap long-term. Utilising BESS for frequency control services is considered to be in the early stages but may be a reasonable solution in a five-year time with expectations of less flexibility in the Norwegian power grid [13, 52]. The reduced grid flexibility may result in higher revenues from FFR/FCR markets when a higher demand for such services by the TSO is reached. In Article 3, Kurniawan et al. chose the Danish equivalent of the Norwegian aFFR market. The results presented a 2 MWh /4 MW battery which made a profitable solution for FCS owners [66]. In Norway, FFR/FCR markets are deemed more relevant for batteries as of today, by both CPOs and BESS providers. Batteries with power over 1MW can directly contribute to the reserve markets in Norway, without third-party stakeholders [34].

Further, EA services may be utilised by the BESS operator. Article 3 is based in Denmark where the electricity prices are more volatile compared to Norwegian electricity prices [79]. However Norwegian spot prices are expected to become more volatile, leading to increased revenues in EA applications [13]. Reduced flexibility and increased power congestion, resulting in voltage deviations, may encourage DSOs to purchase BESS services to compensate for such challenges.

By value stacking and utilising the battery's idling time, the CPO may sell frequency control services to the TSO and flexibility services to prevent for example power grid congestion to a DSO. This implies that DSOs have an increased demand for voltage stability and avoiding power congestion in the power grid. As of today, this is not the case. But, due to the expected increase in power grid congestion over decades, and reduced flexibility [35] buying BESS services may be favoured to grid-tie customers faster, postpone reinforcements and increase the power grid economy. The location for frequency control services is less important compared to stabilising local voltage deviations. Hence, the location must be favourable for both uses. Lastly, it is important to note that for such services to be established in five years, several systems need to interact for the CPO to provide charging, frequency control services and grid support. As CPO 3 noted, the CPO's systems of today are not developed for all battery services.

Battery prices are expected to fall, and if companies like CATL develop new, less expensive technology, it is reasonable to believe that investing in BESS will be more profitable in five years. Moreover, because of the ability to prevent further grid reinforcements, the CPO may avoid high investment contributions. However, CPOs selling services to the TSO's frequency control will lead to roles other than simply providing energy to EV users. Nevertheless, as presented in the interviews, two CPOs showed interest in other services motivated by increased revenues.

2. BESS providers renting out services to both DSOs and CPOs

Thirdly, BESS providers may rent out services to both CPOs and DSOs to cope with grid instability and higher capacity demand. In this case, the price of renting services should be favourable over choosing reinforcements of the grid or implementing fewer charging stations to avoid high investment contribution fees. Furthermore, if the BESS provider, or other third-party owners, rent out the service to more customers, the rent will decrease and benefit customers of such services. This service would be beneficial in areas of voltage deviations in a low-voltage grid or high-voltage distribution grid coping with power grid congestion. Hence, a dialogue between the DSO, CPO and BESS service providers is necessary to meet the flexibility demand for all stakeholders.

3. Funding of BESS in the distribution grid

The third way of closing the gap between the current situation and the future is funding for value-stacked batteries. This would lead to greater knowledge of BESS's possible services: maximise revenues by reducing power-based grid tariffs, increase revenues by selling BESS's services during idling time, and postpone or discard grid capacity shortage upgrades due to flexibility enhancement. For this to be realised, a social benefit, and not only economic, values must be valued.

Chapter 8

Methodology discussion

In this chapter, the methods applied in this thesis will be discussed. Firstly, the literature review method will be presented in Section 8.1, and then the interview method in Section 8.2. Finally, the GAP analysis method will be discussed in Section 8.3.

8.1 Literature review

The literature review section includes discussions regarding constraints in the literature search, differences in perspectives and countries of origin.

Constraints

The literature review was conducted with constraints as described in Chapter 4, Section 4.2. The review was mainly conducted with a focus on finding literature including both BESS and FCS. It is highly likely that there is more relevant literature on both subjects separately, but due to the research question of this thesis, it was decided to prioritise the literature including both subjects. The uncertainty of whether the chosen final literature is representative selection is regarded as important to note. This is due to the limitations within the chosen constraints. If the literature did not include "BESS" or "charging station" in the title or abstract, it would have been neglected. The search string was decided to be a broad search string. Several search strings were tested before settling on adequate ones. By using a broad search rather than a specific one, the chances of overlooking relevant literature were reduced. However, this led to numerous articles, making it challenging to choose the most relevant ones. On the other hand, the literature review was carried out with the goal of locating relevant articles. When the relevant information sought was deemed to be covered, it was decided to conclude the literature search. The chosen search strings and the combination of them were concluded to be the most relevant. As a result, it was assumed that the selected publications would cover the subject of this thesis in depth.

It was important to look at the year the literature was published. As mentioned in Chapter 4, Section 4.2, this was one of the criteria of the literature review. The reasoning for this was to conduct the most relevant and new studies. The subject is undergoing rapid increase as shown in Figure 5.1, which could lead to former literature from previous years becoming irrelevant and outdated. However, this may result in uncited articles that are not validated by the current search environment on this topic. Three of the nine articles lacked citations.. The three articles may be considered inconclusive or lacking important aspects. Regardless of this, the articles with zero citations were included, and to the best of this author's knowledge, they were adequate and valid.

Lastly, it is important to note that fast chargers in the literature review include all DC chargers with power outputs over 50 kW. As presented in Chapter 2, Section 2.3 there is an increase in power outputs up to 150 kW, and EVs demand higher power outputs to shorten the charging sessions. In retrospect, a constraint on evaluating super-fast chargers could improve future prospects.

Perspectives

The differences in perspectives, stakeholders, and scenarios, as well as the different targets, made comparing the different articles demanding. Some of the articles, such as Articles 1 and 7, had a specific real-world case study. All articles, except Article 8, used actual data from a FCS which also presented an algorithm for a small model system. Hence, the validity of the results can be discussed. It was decided that the methods used in each article would not be compared or validated. This could lead to results that differ depending on the methods or algorithms used. The various results, on the other hand, provided a broader understanding of the topic and what the search field considers to be suitable services for a BESS in combination with a FCS.

Countries of origin

The chosen articles had fast charging stations located in different countries. This is presented in Table 5.2. The different countries may have led to aspects of BESS utilising that are not applicable to Norway. This could for example be differences in flexibility, imbalances, power grid voltages, and division of grid levels, etc. These were not validated and compared to the Norwegian system. However, two of the chosen articles, Articles 7 and 9 were Norwegian. These articles discussed BESS as a substitute for reinforcement of the grid or a more stable grid when a charging station was expanded. These motivations were also stated in other articles, such as Articles 1 and 5. Therefore, the reasoning for utilising BESS was deemed similar. Hence, the difference in countries of origin was thought to be rewarding and not hindering for the GAP analysis.

Models

The articles chosen for this thesis included models, algorithms and case studies. Hence, this can be future prospects of what will happen with BESS-assisted FCS in Norway in the coming years. Further, none of the articles of the literature review included actual BESS implementation, only modelling, calculations, and what-if scenarios. However, the interest in research and interviews were concluded to show a growing potential for BESS-assisted FCS.

8.2 Informant interviews

The stakeholder selection and informant interview methods will be presented and discussed in this section.

Choosing stakeholders

When choosing stakeholders for the informant interview, the importance of a broad selection was stressed. When an adequate group were considered found, it was not reevaluated in the interview process. Regarding the CPOs, the reason was to include their different future prospects and insights they had on capacity shortages and battery utilisation. From the results of interviews, presented in Chapter 6, broad and interesting perspectives were sought after and successfully contained. The reason for the two DSOs was to envision barriers in different grid locations. The reasoning for choosing three BESS suppliers was due to the different targets, different battery capacities and business models. This made it demanding to compare, and withdraw the most vital citations. On the other hand, the suppliers shared many similar thoughts regarding increased usage of batteries in the grid both at low- and high-voltage distribution levels and utilising BESS for frequency control services. Regarding the heavy vehicle user stakeholders, they were regarded differently in the aspect of business models. HVU 1 presented an organisation, while HVU 2 was a company. Regardless of the differences in business models, the stakeholders got similar questions. The results were concluded as adequate regarding charging infrastructure future demands and increase in transport electrification. One funding stakeholder was included. This led to no comparisons with others. This could lead to insufficient information on funding in Norway. However, when looking for funding organisations, not many were found, so one was chosen and anonymity was maintained.

Choosing informant for interviews

Weaknesses of choosing informant interviews should be mentioned. Firstly, every stakeholder was given an interview guide in advance of the interview. This may prompt the informant to respond based on the upcoming questions and the author's research question. The purpose of sending out interview guides was to allow informants to gather information about the topic and prepare for the interview. As a result, the stated issue was difficult to avoid. However, due to different responses, all interviews received a variety of follow-up questions. Secondly, when creating the interview guide, the aspects of visualisations in the result and discussion parts were not taken into account. In retrospect, it could be discussed whether the interview guide should have included questions leading to answers that could be visualised. Third, the job position or background knowledge of the informant was never requested. It can be debated whether interviewing people with similar job duties or backgrounds would have made the answers more viable and comparable. Due to stakeholder group differences, this was deemed difficult to withdraw and thus was not considered. Fourth, it is possible that the interviews were subjective when providing information about their company or organisation's viewpoints. In some cases, personal thoughts expressed during interviews were stated and referred to as such and thus were not included in the summary. Fifth, a lot of new information was gained during the interview period. As a result, changes were made to the interview guides to make the questions more relevant to the informants. This could lead to more relevance in some interviews compared to others. After extracting the important and relevant citations from all interviews, there was no discernible effect on the overall result. Finally, it should be noted that all stakeholders will have a vested interest in the interview. They may not be aware of other stakeholders' regulations and legislation when they discuss various options.

8.3 GAP analysis

A GAP analysis was chosen to be a sufficient way to answer the research questions. This was due to the significance of the current state of technology, what future demands might be in the coming years, and eventually how the gap could be closed.

The different chosen articles discussed different aspects and reasoning for utilising BESS services leading to various methods of closing the gap. Additionally, the informants discussed various numbers of reasons and motivations for utilising BESS services, or not being interested in batteries integrated into the distribution grid. The various aspects made a GAP analysis demanding. In the end, it is this thesis author that has evaluated the possible way of utilising a BESS to meet the demand for increased charging infrastructure. An aspect that could have been important to note was what share of CPOs projects either lack capacity or were de-prioritised due to not being a favourable amount of power at a FCS. This could have shed light on the importance of utilising a BESS. A question to ask was how much capacity is actually lacking in Norway in the coming years, percentage vice, visualising the importance of either stressing the development of BESS or maybe postponing integrating it. This aspect was not included, other than stating that there most probably will be an increase in limited grid capacity in Norway. Finally, to the best of this author's knowledge, the possible ways of closing the gap, both short and long-term, are based on insight into perspectives, knowledge, and assumptions from the background inspiration, theory, literature review and interviews, all of which are included in the GAP analysis.

Chapter 9

Conclusion

A literature review with nine articles and eleven informant interviews was conducted to enlighten the current situation and the future prospects of the charging infrastructure in Norway. The main purpose was to gain knowledge on BESS in combination with a FCS. A thorough process to choose the most recent and adequate literature was presented. Two search strings were chosen and determined to present relevant articles, with the first search string yielding eight relevant articles and the second yielding one Norwegian case study. The literature review showed a worldwide interest in BESS utilisation and successfully comprehended what an ideal installation could be. The literature review also presented a wide stakeholder group, showing the interest of BESS in various means. The selection of interviewees was also carefully considered, in order to shed light on the relevant stakeholders of this thesis topic. The stakeholders included three CPOs, two DSOs, three BESS providers, one funding informant, and two heavy vehicle users informants. The five different stakeholder groups presented various experiences and thoughts on the topic. The current situation was based on stakeholders' knowledge in addition to the literature review and background information. A synthesis and comparable discussion of the informant interviews, as well as an adequate current situation vision, were presented.

The CPOs had plans on expanding their network to meet the demand for fast charging stations. In some cases, they expressed the need for BESS due to limited grid capacity, high power-based tariffs, and investment contributions. CPOs ideally desired increased revenues in order to establish projects that may appear unprofitable at first. DSOs on their behalf, had various ways to meet the increasing demand for higher power outputs in the distribution grid. Conditional attachment and reinforcement were noted as ways to meet the CPOs' grid-tie terms. Both CPOs and DSOs mentioned the time-consuming grid reinforcements, which in some cases led to projects being de-prioritised or rejected. Both the lorry and bus stakeholders expressed an urgent need for charging infrastructure for them to transition to electric vehicles. The obvious need for high-power charging was a necessity to streamline the drivers' working hours. Therefore, it was concluded that for vehicle electrification to cope with the higher demand for power, the grid must be stable and in many cases reinforced. Regarding the current situation of batteries, the BESS providers had seen an increase in interest in battery services, whereas both CPOs and DSOs were mentioned as customers. The chosen funding organisation currently had no funding for public vehicle charging infrastructure. However, heavy vehicle funding will be launched in the summer of 2023. This demonstrates that there is unquestionably a demand for such.

Future prospects on charging infrastructure with the main focus on BESS in combination with a FCS were presented. Two CPOs showed an interest in utilising BESS for other services than improving their charging offer. Contribution in the reserve markets FFR/FCR, and voltage support was pointed out by both. This coincided with the literature where frequency control services, voltage support, and helping the grid alleviate charging were introduced. The results varied due to different reasons for utilising BESS. In some of the articles, BESS implementation was economically feasible. This was for articles with FCS located at high-demand tariff areas and value stacking of BESS services. The optimal size of BESS was also investigated. However, the author of this thesis concluded that determining an optimal BESS size was difficult. The stakeholders' interest in implementing batteries varied, indicating the early stages of such services or inefficiency compared to traditional methods. On their side, the DSOs stated that they had investigated BESS, but that it would typically be implemented for market services for a battery operator, rather than grid support.

In the GAP analysis, short- and long-term proposals were presented. The proposals included how a BESS could be implemented in the power grid to increase charging infrastructure. Both proposals had three specific suggestions, with the short-term expected to be similar to the current situation with BESS and EV charging. Therefore, DSOs were advised to rent battery services to grid-tie customers faster and cope with voltage deviations. Secondly, the CPOs were recommended to purchase batteries at locations demanding high power outputs and high power-based grid fees. This suggestion provided a battery capacity based on the articles and informants' considerations. Lastly, for the short-term period, funding was acknowledged as a central part of increasing investment of BESS at heavy vehicle fast charging stations. For the long-term period, several assumptions were taken for the proposals to be feasible. The CPO could purchase batteries to help the TSO with frequency control and rent grid support services to the local DSO. Otherwise, a BESS operator could rent out services to a CPO and DSO as a way to utilise the BESS idling time.

Finally, a funding proposal for BESS integrated into the power grid with a focus on value stacking was presented.

For BESS to contribute to vehicle electrification in Norway, several aspects must coincide. There is uncertainty on whether proposals on BESS for future prospects are economically viable, which is the driving force for implementation. However, integrating BESS-assisted FCS will most definitely accelerate the charging infrastructure, especially at locations with limited capacity and high investment contributions. Heavy vehicles are clearly in need of a wider charging network to transition from traditional to electric vehicles. Overall neither stakeholders nor the literature argues against the utilisation of BESS, not only alone as a grid support service, but also in combination with FCS. However, the practicalities of the implementation need to be sorted, possibly incentivised by funding.

9.1 Future work

In this thesis, the potential for BESS in the Norwegian power grid to contribute to the expansion of public FCSs has been presented. The current situation and future prospects regarding transport electrification, and charging infrastructure with BESS were established. However, further analysis is important.

During the interview period, the increasing interest in mobile FCS was introduced. Mobile FCSs for transport electrification on construction sites could be investigated to enlighten the importance of this sector less-oil independent. One CPO mentioned the benefits of establishing a BESS-assisted FCS on a construction site. FCS in regards to construction sites should avoid grid reinforcements due to the short period of time utilising the power grid for charging construction vehicles. For this purpose, it is important to note that the charging should be short, hence high power outputs are demanded.

A qualitative method where a real-world system is examined would be most rewarding when looking at BESS-assisted FCSs in Norway. Therefore, interviewing a stakeholder with both charge point operations and BESS services should be included to highlight the experiences of such. The last proposed analysis would be to examine Norwegian private FCSs for lorries or buses, and the interest in integrating renewable energy sources such as solar or wind power. This introduces an additional value-stacking where the energy produced could be consumed during peak demand hours. Such implementations were widely introduced in the literature review and are considered highly relevant for further work.

Appendix A

Informant interview guides

The interview guides are translated from the Norwegian interview guides sent to the different stakeholders.

Charge Point Operator - interview guide 1

- What is your maximum charging power on a DC-charger?
- Where is the highest charging consumption located?
- What is your relationship to lorry and van charging?
- Has capacity issues in the power grid caused you to leave a project? Why?
- What are your main obstacles in terms of project planning regarding capacity shortage?
- Have you investigated the use of BESS (Battery Energy Storage System) in combination with a DC-charging station?
  - If yes:
    * Why have you investigated the use of BESS?
    * What did your investigation conclude? (profitability, investment, technical challenges)
    * Have you investigated either buying or renting batteries? Why?
    * How large battery capacity is needed in such an implementation?

- If already built:
  * What was the reason for implementing BESS?
  * What was the purpose of BESS?
  * Can you give an example of the price?
  * Has it been profitable?

- How large is the share of electric lorries/vans/buses in five years?
- What will the charging infrastructure look like in five years?

Charge Point Operator - interview guide 2

- What is your relationship to the lorry and van charging?
- Have there been projects you had to leave/end early?
- What are your main obstacles in terms of project planning regarding capacity shortage?
- Have you investigated the use of BESS (Battery Energy Storage System) in combination with a DC-charging station?
  - If yes:
    * Why have you investigated the use of BESS?
    * What did your investigation conclude? (profitability, investment, technical challenges)
    * In your opinion, what is the optimum way of implementing BESS?
    * Have you investigated either buying or renting batteries? Why?
    * How large battery capacity have you investigated?
    * What are the technical/financial challenges with BESS?
    * What is stopping you from implementing BESS?
    * What factors need to be in place for you to implement BESS, in cases where it is needed?
  - If already built:
    * What was the reason for implementing BESS?
    * What was the purpose of BESS?
    * Can you give an example of the price?
    * Has it been profitable?
- How large is the share of electric lorries/vans/buses in five years?
- What will the charging infrastructure look like in five years?

DSO - interview guide 1

- What is the biggest challenge in increasing the capacity of the power grid?
- What methods are considered for increasing the capacity of the power grid?
- In which areas can BESS contribute?
- Have you declined the construction/implementation of BESS in the power grid?
  - What was the context of BESS?
  - Why?
- What have been the consequences of a BESS implemented in the power grid for you?
  - technical (positive, negative, challenges)
  - financial (positive, negative)
- Have you turned down an application for the construction of a fast charging station? If yes: Why?
- What kind of solutions can contribute to the increased construction of charging infrastructure in Norway?
- Have you been asked about implementing BESS adjacent to a fast charging station? Why?
- Have there been an increased interest in BESS in the power grid?
  - If yes:
    * What was the main reason for the implementation of BESS?
    * Have there also been increased interest for BESS adjacent to fast charging stations?

DSO - interview guide 2

- Which methods are you considering to overcome the lack of capacity existing in the power grid?
- Have you utilised services from a BESS provider?
  - If yes:
    * Why?
    * Which services did you use?
    * What was the result of this? (Technical, financial)
  - If no:
    * Is this something you could be interested in?

- Have you had to decline the development of a fast charging station? If yes: Why?
- What kind of solutions can contribute to increased development of charging infrastructure in Norway? Why?
- Have you seen an increase in interest in the implementation of BESS in the power grid?
  - If yes:
    * What was the main reason for BESS to be implemented?
    * Has there also been increased interest for BESS adjacent to fast charging stations?

Battery energy storage system provider - interview guide 1

- What capacity-/power level do your batteries have?
- Where is it the most interest within battery storage solutions?
- Do you have batteries for renting or for sale?
  - Why do you rent/sell?
  - Do you have an example of a price?
- Have you provided a battery storage solution adjacent to a fast charging station (DC)?
- What capacity and power should a battery storage solution adjacent to a fast charging station have?
- What technical challenges have you met in the implementation of batteries in the power grid?
  - If the challenges have been in the power grid- Where in the grid have the challenges been?
  - Any challenges related to the charging station?
- Has there been an increased interest in BESS implementations in the power grid in Norway in the last two years?
  - If yes: Why has there been an increased interest?
- In Norway in five years, how large is the usage of BESS in the power grid? What about in combination with a charging station?
- What do you think can contribute to the increased development of the charging infrastructure in Norway?

Funding - interview guide 1

- Have you given/do you give financial support to charging stations/charging infrastructure for electric vehicles or electric lorries? If yes:
  - What do you finance?
  - Why have you chosen to finance this?
  - How large is the financial support given?
  - Have you seen an increased interest in this kind of support? Why do you think that is?
- Have you given/do you give financial support to battery implementations in the power/distribution grid? If yes:
  - In what context are the batteries used? What do you support?
  - What do you finance?
  - Why have you chosen to finance this?
  - Have you seen an increased interest in this kind of support? Why do you think that is?
- What will the charging infrastructure look like in five years?
- What are the technical challenges in increasing the usage of electric vehicles?
- How do you think financial aid can contribute to increasing the usage of electric vehicles?

Heavy Vehicle User - Lorries

- What are the main, technical difficulties of converting to electric vehicles?
- What kind of charging infrastructure is needed for the increased use of electric lorries?
- In your opinion, are there any technical obstacles in the electrification of lorries services? If yes, what?
- How large is the share of electric lorries in five years?
- What will the charging infrastructure for electric lorries look like in five years?

Heavy Vehicle User - Long-distance Buses

- What are the main, technical, difficulties of converting to electric vehicles?

- What kind of charging infrastructure is needed for the increased use of electric buses?
- In your opinion, are there any technical obstacles in the electrification of bus services? If yes, what?
- How large is the share of electric buses in five years?
- What will the charging infrastructure for electric buses look like in five years?

Appendix B

Informant interviews - relevant citations

This appendix includes relevant citations of the chosen stakeholders.

CPO - 1

- When capacity is limited, it may take some time to connect to the grid. Connecting will be prohibitively expensive, or there will be a lengthy wait for increased grid capacity. Then, as an alternative to the grid, batteries can be used. The investment in a battery can partially compensate for the lack of an investment contribution, but the service life is shorter than that of a grid connection, so the calculation may be invalid when it comes time to reinvest.
- All sites are assumed to be profitable before establishment. Battery implementation will not occur if the batteries make the site unprofitable. As a result, installing a battery must have a substantial positive impact. Furthermore, batteries necessitate more systems around them, increasing the cost and making them less future-proof.
- Fast charging is closely related to the cost of electricity. Peaks of charging often coincide with higher electricity prices. During low charging, the electricity price is often lower as well. If you have battery capacity, you can move your electricity consumption away from the peak and optimise on the spot price. This will save us a significant amount of money. We have a power link on the power grid tariff in Norway. This is perhaps the lowest-hanging fruit. If you

can shift an entire hour, or a significant portion of it, away from the peak you save a lot of money quickly by spreading it out as much as possible.

- We are developing a concept in which our charging points include some battery capacity, allowing you to apply for the smallest grid possible while maximising the arbitrage on the electricity you purchase.

- First of all, the BESS is to improve our own charging offer. However, as we have seen, using BESS for selling flexibility services is the make-or-break factor for battery investment by participating in the fastest markets (FFR, FCR). This solution leads to a relatively short payback period. Even if we do that (use BESS) today partially, the idea is that we should benefit from the fact that we have a battery for operating as a CPO. If we buy batteries for those locations, we will have a competitive advantage against those who buy batteries only for grid services. Then we will not be as vulnerable to a reduction in the market price for flexibility or a reduction in the deviation between high and low electricity prices. For the battery to be profitable, we need to have a variety of uses.

- We still have a long way to go before the battery is fully integrated into our overall concept. We use it, but not entirely. It has to be used in some places where it can only be used as an alternative to the grid (-tie).

- We have a large professional customer base which we are attempting to expand. For this to happen, we must expand (the charging offer) to include lorries. The batteries may become increasingly important. It does not take a very large battery to build a truck charging site.

- Our charging infrastructure is rapidly growing. Peak power per site and charger unit power will most likely increase. The cars still have some catching up to do to catch up with the chargers. There are not many cars that fully utilise (DC power) chargers yet.

CPO - 2

- If there is insufficient grid capacity, you can either develop some (to utilise the available power) and wait for further upgrades at a higher grid level, or you can choose a location with sufficient capacity. It is costly if grid capacity is limited, and you must pay the investment contribution to the DSO in charge of that location.

- We have investigated BESS for profitability. Avoid investment contribution and voltage drops (by using BESS). It is difficult to operate if you are far out of the grid. With batteries, you look after the voltage. Also, the grid fee motivates BESS usage.

- We have investigated BESS for reserve markets to contribute to flexibility markets. This can increase revenues for the operator. This makes batteries less expensive.
- We operate charging stations that are dedicated to commercial transport. We try to design many of our charging points to be accessible for larger electric vehicles.
- Regarding charging infrastructure, we need to develop much more and focus on high-power charging, which will result in shorter charging sessions for EVs. We (Norway) are too small to enact our own rules. What the EU devises will be applicable in Norway.

CPO - 3

- Several projects have failed to meet capacity requirements and have been cancelled. To add more chargers, the network infrastructure as a whole must be expanded. It is expensive to expand the distribution grid. Economic feasibility issues cause problems. The costs or the time required (are the main difficulties with projects with capacity shortages). Projects are not necessarily ignored but are de-prioritised for a while. In some cases, we are a triggering customer and receive the entire investment contribution.
- There are two main reasons for our BESS interest: a shortage of capacity and whether it is a purely economic solution that can stand on its own. Here (with BESS), we need less power in (to the FCS). Alternatively, we have also investigated power modulation to avoid peak loads and avoid higher power based tariffs on the electricity bill. Peak shaving. It is not profitable to invest in batteries and look at ten years' perspectives, maybe more.
- Ideally, we have looked at locations where the substation's rest capacity can be used without paying too much investment contribution and where the rest capacity is large enough that we experience a good enough turn-over on that FCS.
- Difficulties with renting BESS services are that there are not too many (BESS suppliers) that rent out the small modules that we seek. The reason (for the larger BESS) is that the capacity is also for other targets that do not benefit us (economically or technologically).
- The price and technical integration hinder the implementation of BESS. Several systems need to interact, and currently, there are several systems that are out-of-the-box functionalities for battery solutions.
- It is possible that a DSO will provide a BESS connected to a substation to solve capacity issues as a temporary investment until several customers contribute to proclaim capacity. In three years, you can expect reinvestment and

development of that location. The DSO, which owns the BESS, will therefore operate it for three years until the reinvestment takes place. Furthermore, it is simpler and more ideal if they (DSOs) provide multiple BESS solutions, which can then be relocated when necessary upgrades are completed.

- There will be a good coverage rate. No one will experience range anxiety. There will always be a charging possibility within (reasonable) distance. Not so long ago, we installed 50kW chargers. Today, customers indirectly drive past these chargers since they experience that they do not have time to charge on these. In two-three years, one can imagine that 300kW chargers are what you at least would charge on. There will also be Mega Watt Charging Systems (MCS) leading to charging up to 1MW.

DSO - 1

- The grid is not full (referring to load connections). Customers are allowed to connect where they want, but it may be expensive. DSOs are required to abide by the Energy Law (Chapter 2.1).
- The main thing we do to increase capacity is to reinforce and upgrade the grid. In addition, we develop the grid in a more intelligent manner, among other things. The grid can handle more interference if it is built more powerfully (from loads). A weaker grid can function if there is less interference.
- We have had flexibility projects further out in the grid. The solutions could target the voltages and adapt and provide the grid with local voltage support. The Norwegian power grid is well-constructed. The power bottlenecks(Chapter 2.2) are distributed evenly.
- Customers typically want to implement BESS solutions in order to increase capacity or reduce grid tariffs. Additionally, customers want to utilise peak shaving to decrease the grid fee, and as a backup, if something breaks down. The interest has occurred for a number of reasons, including a significant decrease in price (of BESS) and increased availability (of BESS).
- For us, the utility values of batteries are a better capacity utilisation in the grid. This can be done by charging and discharging the grid. Other advantages are increased reactive power from the BESS inverter, phase balancing by pulling current from one phase to another, smoothing out imbalances, and frequency support to the TSO.
- There is a high reliability of supply and surprisingly low expenses and grid tariffs. A battery must take large steps (economically to be compatible with the existing structure).

- In cases of limited capacity, the grid must be upgraded, but the costs are too high it feels like a rejection (for the CPO). On one location, the grid infrastructure is weak which leads to the development of a larger line (transmission grid) that the TSO (Chapter 2, Section 2.1 and Figure 2.3) must upgrade and this can take up to ten years.
- Four solutions to enhance charging infrastructure:
  - Connection on terms of disconnection (Chapter 2, Subsection 2.1)
  - Battery behind the substations. This is for smaller FCS in weaker grid locations.
  - Capacity map to visualise where there is available capacity.
  - The new grid tariff (Chapter 2, Subsection2.1)
- The CPOs may have expected the DSOs to play a larger role in the development of charging stations. Customers can develop wherever they want and pay for the costs of the grid-tie. It is all about the proper division of labour.

DSO - 2

- Costs and the period of time are difficulties regarding limited grid capacities. All charge point operators (CPOs) under strained areas, often make a conditional attachment (Chapter 2, Subsection 2.1). CPOs often request power up to 850kW[1].
- We have tested BESS for a project with a CPO. As an example, there is a significant difference in connecting 2 MW vs 500 kW. There could be voltage drops in the grid. With the charging of a battery, there is a better utilisation of the grid (compared to normal load peaks of a charging station). When customers implement batteries, the advantages for us are that reinforcements of the grid can be postponed. In addition, if customers can decrease the maximum load, it is easier to grid-tie and there is a less expensive investment contribution. We motivate battery usage if customers want to utilise them.
- I do not think it is the investment contribution (that motivates for BESS usage) but the time frame (of reinforcing the grid). There have been cases where the customer is uninterested in grid-tying due to the investment contribution and other expenses. If the regional grid requires upgrading as a result of their connection, they are frequently unmotivated to wait the time required and withdraw the connection request. For example, we inform the customer that they potentially could be grid connected in 2027 when they do not want the

[1] 850 kW is a threshold grid-tie value. Greater values demand other installations between the DSOs transformer and customers' control panel at more than 1250 A. Customers (CPOs) want to remain beneath this value due to costly outputs over 1250 A (1250 A $\times$ 400 V = 865 kW), interviewee DSO 2

conditional attachment. Conditional attachment is a way of making our time frame suit better a customer (CPO) time frame.

- We have seen an increase in interest in batteries, but it is mostly for unique cases. The thing about batteries is that they require a peak load. You must obtain energy for later use in order to relieve the grid. Batteries are insufficient in locations where usage is evenly distributed. It is appropriate for CPOs because people do not charge (their EVs) at night, and there are peaks in the morning and evening, as well as periods with lower loads, that can be utilised (for charging the BESS) We prefer to reinforce the grid due to batteries being an operational matter that we have to control and investment in grids being a passive matter.

BESS provider - 1

- The usual customer wants to utilise smaller BESSs for peak shaving. DSOs show interest in using batteries implemented in the grid, for unstable distribution grids, for example, voltage drops. There is also interest in batteries to store local energy end use in rural areas. A BESS-assisted FCS, the battery can contribute to the frequency market (Chapter 1.1, Subsection 2.2). Batteries are an expensive investment if you only use them for peak shaving and local energy storage, but there are more options if you include frequency control services.
- For implicit flexibility[2], there are three main reasons for battery implementation. Customers want to utilise peak shaving, price arbitrage and kV maximum control. Some want to remain under a certain level in the capacity link/power link of the grid fee (Chapter 2, Subsection2.1). For explicit flexibility[3], the interest is for frequency market (Chapter 1.1, Subsection 2.2).
- We have implemented BESS coupled with FCS. The main reason was to save costs. Everyone wants local storage of energy to save costs compared to expanding the grid. The battery power should be at least 1-2 MW, as this is related to the minimum power for frequency market participation. More economic sources of income for charging stations would then be available.
- We have seen an increase in interest for BESS and believe it is due to decreasing costs, technology improvement and increasing electricity prices. However, it is somewhat costly to implement batteries, and only a few customers can afford it nowadays. The hesitation stems from the necessity of quick financial return, which is important for public traded companies, and a lack of subsidies which is important for industries with large production costs. Every power consumption usage with consumption peaks would be more profitable with a BESS, but the frequency market for BESS in Norway is not as profitable

[2] Implicit flexibility - implicit customer usage, interviewee 6
[3] Explicit usage - grid usage, interviewee 6

as Denmark and other countries with a more volatile energy market. The economic investment will become more justifiable with quicker financial return, which is dependent on the Norwegian energy market becoming more volatile.

- There is a significant probability that there is increased usage of BESS-assisted FCS in five years. The grid will probably have more battery parks implemented in the coming years, based on the market development mentioned above.

BESS provider - 2

- We have provided a BESS coupled with a FCS with a battery power of 300 kW and capacity of 300 kWh.
- For the time being, it is likely that only one application of batteries has been prioritised, but there has been increased interest in value stacking. It has, however, yet to be widely used in practice.
- Batteries in reserve markets (Chapter 2, Subsection 2.2) are currently attracting a lot of attention. You can have the primary benefit of EV charging, which aims to increase power capacity. Another favourable aspect of EV charging is that it is relatively predictable when capacity demand is expected, which means that there is also a relatively large predictability when there is no demand and you have available flexibility resources for other services. In this case, selling battery energy in reserve markets is an intriguing and beneficial additional service. The value is determined by the market which is fairly well paid in some markets, less so in Norway, but it is increasing, due to increasing demand for fast reserves in Norway.
- Regarding DSOs, there has been an interest in batteries for a long time. However, there has been a growing interest because problems regarding charging voltages are typically due to increased electric car charging and other [4]. I would say that interest in batteries is growing for dealing with voltage quality and partly due to the congestion of power, especially in some areas where DSOs do not want to make a large new investment in the grid.
- Technology and market availability for charging flexibility can contribute to profits when developing charging stations with limited capacity. In the case of batteries, they can lower the capacity barrier while also capitalising on the available flexibility, which can be sold to other stakeholders. If the capacity increase from a battery is too expensive, the flexibility may have to be rewarded in other ways.

BESS provider - 3

[4]Other, in this case, refers to partly high voltage due to more solar power, especially in areas where there is a lot of electric car charging and solar power

- We primarily have batteries of 1 MW/ 1MWh.
- We are mainly implementing batteries in the high-voltage distribution grid at 22 kV, maybe 66 kV (Chapter 2, Subsection 2.1). This is more applicable for DSOs. In the next five years, I think there is a need for BESS both in low- and high-voltage distribution grids.
- DSOs are typically interested in utilising batteries for voltage support far out in the grid. Second, some DSOs want to increase capacity to grid-tie more customers.
- We have not supplied our services for batteries coupled with charging stations. However, dialogues with Charge point operators (CPOs) has presented an interest in peak shaving/peak expansion and avoiding/reducing investment contribution (Chapter 2, Subsection2.1). When investigating battery potential at a fast charging station (FCS), the idea has been to use a battery to provide slightly more (power) than what is available from the power grid. We have seen a maximum need of 0.5 MW from CPOs. In this case, the battery should hold more than 0.5 MWh of energy. Each case is different and determined by the charging station. The charge point operators we have had a dialogue with have been interested in decreasing the power link in the power based grid fee (Chapter 2, Subsection2.1), or giving an additional power boost.
- We have looked at batteries used in reserve markets (Chapter 3, Subsection 3.2). Batteries can contribute to both FFR and FCR, and have a lot to offer. What we earn on the frequency market can lower our overall service costs by lowering capital costs.
- In five years, I believe there is a larger usage of BESS, whereas charging stations are highly relevant.

Funding

- We have had funding for charging stations for over a decade. The last funding was last year, in 2022, to close the gaps in the charging map[5] for light[6] EVs (LEVs). In 2022, we launched a time-limited support program for dedicated charging infrastructure for heavy-duty vehicles. Additionally, we work with launching funding for public heavy vehicle charging infrastructure in the summer of 2023.
- Furthermore, we have given financial support for the establishment of charging infrastructure in order to accelerate the market shift to emission-free transportation. Our role has been to help establish a critical minimum of charging infrastructure to encourage market uptake in vehicles before further expansion

[5] Charging map - map over electric car chargers in Norway, interviewee 6
[6] Light vehicle is equivalent with cars

is developed commercially by the market. Firstly, the funding was to support charging stations by the highway, then it was to meet demand where it is highly likely that no one will develop in three years.

- The support rate in both light and heavy charging is determined by competitive bidding. For light vehicle infrastructure, you could win 100% support. For heavy vehicle charging, for company chargers, the supports is maximum 40%.
- We have seen a significant interest in LEV charging stations from market participants. Additionally, there has been increased interest in heavy vehicle fast charging stations. However, it is clear that no stakeholder develops without support because it is too high uncertainty or too few lorries for the equations to add up, or to dare to take the strategic risk. It could also be that some stakeholders wait to see what support funding will come before they take a decision
- In the funding program of lorry charging, the cost of batteries can be included. In the first round, some applications did include batteries in their project, but these applications were ranked below the cut-off for this round and therefore did not receive funding.
- So far, we have not seen the most interest in battery projects. On the technical side, we have supported projects including batteries. In these projects, batteries had operational support and led to cost-effective solutions. Today, we fund mobile charging stations for electric construction vehicles in which batteries are included. When granting funding, we consider innovation and the contribution to the realisation of a project.
- Regarding prospective charging infrastructure, there are probably two markets: light and heavy vehicles. It could be that the power is shared. Several analysis done shows that approximately 80% of the charging demand will be private charging[7]

HVU - 1

- For lorries, it has been said that an EU requirement of no more than 60 kilometres between each charging point may be introduced. This will be applicable for the Norwegian highway E6. The Norwegian Public Roads Administration is developing a strategic plan for the national and European roads of Norway.
- We have many meetings with authorities and market players to find out what we need regarding the increased implementation of electric lorries. We need to have the infrastructure in place and the capacity of the infrastructure is being stressed. The capacity refers to the number of chargers, available chargers and

[7]Private charging refers to charging at a warehouse, or where heavy vehicles deliver goods

the distance between charging stations. Charging infrastructure is crucial to increase investment in electric lorry use.

- We believe that the Norwegian government will invest in some parts of the public charging stations, often in cooperation with energy suppliers. The public charging stations will mostly be for "top-up" charging. [8] Furthermore, many private stakeholders are likely to establish their own charging stations.
- We estimate that 30% of lorries will be electric by 2027-2028 assuming we have sufficient grid capacity. The goal is that 50% of all new vehicles should be electric or zero-emission by 2030.

HVU - 2

- The range of electric buses and charging options are technical challenges in bus electrification.
- A lot of power is required to charge a bus. Furthermore, you must have a charging infrastructure with sufficient electric power.
- There is very sufficient funding for creating charging points for lorris. Currently, funding covers 80% of the cost for those developing bus charging infrastructure. Establishing charging stations is very expensive, and it is likely that the public sector, municipalities or the government, will have to contribute in some way.
- Regarding the electrification of buses, it is important to stress that not all buses will be electric due to long distances

[8] "Top-up" charging is charging where the lorries fill the necessary amount of energy that satisfies the distance back to the private charging station.

Bibliography

[1] United Nations, "THE 17 GOALS | Sustainable Development." https://sdgs.un.org/goals. [Online; accessed 23. Apr. 2023].

[2] United Nations, "Energy - United Nations Sustainable Development." https://www.un.org/sustainabledevelopment/energy. [Online; accessed 23. Apr. 2023].

[3] IEA(2023), "Global ev outlook 2023," *IEA, Paris*, 2023. License: CC BY 4.0.

[4] Statens Vegvesen, "Oppdatert status på nullutslippskjøretøy." https://www.vegvesen.no/fag/fokusomrader/baerekraftig-mobilitet/nullutslippsmalene. [Online; accessed 23. Apr. 2023].

[5] Statistisk sentralbyrå, "Bilparken." https://www.ssb.no/transport-og-reiseliv/landtransport/statistikk/bilparken. [Online; accessed 25. Mar. 2023].

[6] Norwegian Ministry of Transport, "Meld. st. 20 (2020–2021) report to the storting (white paper) national transport plan 2022–2033," *Regjeringen*, 2021.

[7] Miljødirektoratet and Statens Vegvesen, "Kunnskapsgrunnlag om hurtigladeinfrastruktur for veitransport," *Regjeringen*, Mar. 2022.

[8] Samferdselsdepartementet, "Nasjonal ladestrategi," *Regjeringen*, Dec 2022.

[9] E. ON, "Hva betyr og hva er forskjellen mellom AC lading og DC lading? FAQ E.ON Drive." https://eondrive.no/faq/teknisk/hva-betyr-og-hva-er-forskjellen-mellom-ac-lading-og-dc-lading, Oct. 2021. [Online; accessed 23. Feb. 2023].

[10] L. Godbolt, "Bruk av statistikkmodul." https://info.nobil.no/statistikk. [Online; accessed 25. Apr. 2023].

[11] E. Bowitz, "Barrierer og behov ved videre utbygging av offentlig ladeinfrastruktur for elbil," *ENOVA*, Nov 2022.

[12] F. Arnesen, F. H. Aulie, H. Birkelund, I. E. Haukelig, J. Hole, S. Jelsness, and D. Spilde, "Langsiktig kraftmarkedsanalyse 2021 – 2040," *NVE*, 2021.

[13] A. Kringstad, V. Holmefjord, and J. AArstad, "Fleksibilitet i det nordiske kraftmarkedet," tech. rep., NVE, jan 2018.

[14] Statistisk sentralbyrå, "Rekordhøy strømpris i 2022 dempet av strømstøtte." `https://www.ssb.no/energi-og-industri/energi/statistikk/elektrisitetspriser/artikler/rekordhoy-strompris-i-2022--dempet-av-stromstotte`. [Online; accessed 24. Apr. 2023].

[15] Elvia, "Nettleiepriser og effekttariff for bedrifter med årsforbruk over 100.000 kWh." `https://www.elvia.no/nettleie/alt-om-nettleiepriser/nettleiepriser-og-effekttariff-for-bedrifter-med-arsforbruk-over-100000-kwh`. [Online; accessed 9. Mar. 2023].

[16] Glitre Energi, "Se når på døgnet strømmen er billigst!." `https://www.glitreenergi.no/strom/artikler/nar-er-strommen-billigst`. [Online; accessed 2. May 2023].

[17] SINTEF, "Integration of batteries in the electricity grid - SINTEF." `https://www.sintef.no/en/expertise/sintef-energy-research/integration-of-batteries-in-the-electricity-grid`. [Online; accessed 23. Apr. 2023].

[18] R. Su, G. He, S. Su, Y. Duan, J. Cheng, H. Chen, K. Wang, and C. Zhang, "Optimal placement and capacity sizing of energy storage systems via nsga-ii in active distribution network," *Frontiers in Energy Research*, vol. 10, 01 2023.

[19] NVE, "The Norwegian power system. Grid connection and licensing," *NVE*, 2018.

[20] R. L. Jaffe, *The physics of energy.* Cambridge: Cambridge University Press, 2018.

[21] N. M. of Petroleum and Energy, "The electricity grid - Energifakta Norge." `https://energifaktanorge.no/en/norsk-energiforsyning/kraftnett`, Apr. 2019. [Online; accessed 23. Feb. 2023].

[22] C. Bergaentzlé, "Energy markets: Competition, liberalization and internationalization." University Lecture, 2021.

[23] Energiloven, "Lov om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (energiloven) - Lovdata." `https://lovdata.no/dokument/NL/lov/1990-06-29-50`. [Online; accessed 25. Apr. 2023, LOV-1990-06-29-50].

[24] NVE, "Hvem er Reguleringsmyndigheten for energi? - NVE." `https://www.nve.no/reguleringsmyndigheten/om-rme/dette-er-rme/hvem-er-reguleringsmyndigheten-for-energi`. [Online; accessed 28. Apr. 2023].

[25] Norgesnett, "Nettleie næring - Norgesnett." `https://norgesnett.no/nettleie-naering`. [Online; accessed 10. Mar. 2023].

[26] NVE, "Ny nettleie (fra 1. juli 2022) - NVE." `https://www.nve.no/reguleringsmyndigheten/kunde/nett/ny-nettleie-fra-1-juli-2022`. [Online; accessed 10. Mar. 2023].

[27] K. W. Høiem, V. Mathiesen, I. B. Sperstad, and H. Sæle, "Mulighetsstudie - Bruk av fleksibilitet i nettselskap," *fornybarnorge.no*, 2021.

[28] NVE, "Anleggsbidrag - NVE." `https://www.nve.no/reguleringsmyndigheten/regulering/nettvirksomhet/anleggsbidrag`. [Online; accessed 8. Mar. 2023].

[29] NVE, "Tilknytning med vilkår om utkobling - NVE." `https://www.nve.no/reguleringsmyndigheten/regulering/nettvirksomhet/nettilknytning/leveringsplikt/tilknytning-med-vilkaar-om-utkobling`. [Online; accessed 8. Mar. 2023].

[30] C. H. Skotland, E. Eggum, and D. Spilde, "Hva betyr elbiler for strømnettet?," *NVE*, Sept. 2016.

[31] BKK, "Bli kjent med strømnettet BKK." `https://nett.bkk.no/artikkel/7f59a21f-cdbd-454e-a5c0-d13173cb6bd4`. [Online; accessed 1. Mar. 2023].

[32] A. S. Høimyr, "An analysis of electric vehicle user behaviour at a smart charging station," *Brage*, 2021.

[33] L. Mæhlum and K. A. Rosvold, "Overføringsnett." `https://snl.no/overf%C3%B8ringsnett`. [Online; accessed 1. Mar. 2023].

[34] Statnett, "Introduction to Norwegian reserve markets." `https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/systemansvaret/reservemarkeder/how-the-reserve-markets-works.pdf`. [Online; accessed 23. Mar. 2023].

[35] H. Sæle, "Når er det riktig å bruke fleksibilitet i kraftsystemet? - #SINTEF-blogg," *#SINTEFblogg*, Apr. 2021.

[36] NVE, "Hva er budområder og flaskehalser? - NVE." `https://www.nve.no/reguleringsmyndigheten/slik-fungerer-kraftsystemet/hva-er-budomrader-og-flaskehalser`. [Online; accessed 2. May 2023].

[37] K. A. Rosvold, "nettap." `https://snl.no/nettap`. [Online; accessed 3. May 2023].

[38] NVE, "Forklaring på noen begreper brukt innen spenningskvalitet." https://www.nve.no/Media/3121/definisjoner-spenningskvalitet_v2.pdf, 2015. [Online; accessed 3. May 2023].

[39] E. Reihani, S. Sepasi, L. R. Roose, and M. Matsuura, "Energy management at the distribution grid using a Battery Energy Storage System," *Int. J. Electr. Power Energy Syst.*, vol. 77, 2023.

[40] K. A. Wikse, "Elbil – Store norske leksikon." https://snl.no/elbil. [Online; accessed 23. Feb. 2023].

[41] A. Arora, A. Abkenar, A. G. Jayasinghe, and K. Tammi, *Heavy-Duty Eletric Vehicles*. Oxford: Butterworth-Heinemann, 2021.

[42] F. M. Skillebæk, "Elbil ble Norges mest solgte i 2018." https://www.elbil24.no/nyheter/elbil-ble-norges-mest-solgte-i-2018/70618205, Jan. 2019. [Online; accessed 29. Apr. 2023].

[43] Norsk elbilforening, "Nissan LEAF 40 kWh (2018)." https://elbil.no/elbiler/nissan-leaf-40-kwh-2018. [Online; accessed 29. Apr. 2023].

[44] F. M. Skillebæk, "Bilsalget i 2020: Storeslem for elbilene i 2020." https://www.elbil24.no/nyheter/storeslem-for-elbilene-i-2020/73245644. [Online; accessed 29. Apr. 2023].

[45] Norsk elbilforening, "Audi e-tron 50 / 55 quattro." https://elbil.no/elbiler/audi-e-tron-55-quattro. [Online; accessed 29. Apr. 2023].

[46] I. E. Sagedal, "Hele 10 på topp-lista er elektrisk!." https://elbil.no/hele-10-pa-topp-lista-er-elektrisk. [Online; accessed 29. Apr. 2023].

[47] Norsk elbilforening, "Tesla Model Y." https://elbil.no/elbiler/tesla-model-y-2. [Online; accessed 29. Apr. 2023].

[48] Evbox, "EV charging: the difference between AC and DC." https://blog.evbox.com/difference-between-ac-and-dc. [Online; accessed 23. Feb. 2023].

[49] Norsk elbilforening, "Slik setter du opp ladestasjon for ansatte og kunder," *Elbil.no*, Sept. 2019.

[50] O. Spaun, "Lynladerne tar en stadig større andel av ladekaka." https://elbil.no/lynladerne-tar-en-stadig-storre-andel-av-ladekaka. [Online; accessed 2. Mar 2023].

[51] J. Bjørndalen, "Batterier i distribusjonsnettet," *NVE*, Jan. 2018.

[52] K. Sand, K. Berg, A. Hammer, and K. Ingebrigtsen, "Rapport - veileder for kost/nytte-vurderinger ved integrasjon av batteri i distribusjonsnettet," *SINTEF*, Nov 2020.

[53] J. Haas, F. Cebulla, K. Cao, W. Nowak, R. Palma-Behnke, C. Rahmann, and P. Mancarella, "Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review," 2017.

[54] T. Fuller and J. Harb, *Electrochemical Engineering.* Wiley, 2018.

[55] I. Birkeland, I. Fløtre, L.-A. Bergland, and O. Skeie, "Batterier i distribusjonsnettet, Sommerprosjekt 2020," *NVE*, 2020.

[56] P. Ahcin, K. Berg, and I. Petersen, "Techno-economic analyis of battery storage for peak shaving and frequency containment reserve," in *International Conference on the European Energy Market, EEM*, vol. 2019-September, IEEE Computer Society, 9 2019.

[57] A. Østreng, "Decision support tool for procurement in the m-frr capacity market – an initial study," *Brage*, 2019.

[58] R. Streefkerk, "Qualitative vs. Quantitative Research | Differences, Examples & Methods," *Scribbr*, Jan. 2023.

[59] S. Kvale, *Det kvalitative forskningsintervju.* Gyldendal, 2006, 8 edition.

[60] Elsevier, "Importance of quality content in SCOPUS." `https://www.elsevier.com/solutions/scopus/why-choose-scopus#:~:text=Make%20your%20research%20more%20visible%20to%20a%20wider%20network&text=Unlike%20other%20databases%2C%20once%20your,data%20to%20generate%20author%20profiles`. [Online; accessed 5. May 2023].

[61] D. I. Jacobsen, "Hvordan gjennomføre undersøkelser? Basert på forelesning Kvalitative intervjuer av Tommy Tranvik." `https://www.uio.no/studier/emner/jus/afin/FINF4022/v18/index.html`, 2015.

[62] Lumivero, "NVivo - Lumivero." `https://lumivero.com/products/nvivo`. [Online; accessed 29. Apr. 2023].

[63] R. Phil and B. M. Vikøren, "gap-analyse ." `https://snl.no/gap-analyse`. [Online; accessed 7. Mar. 2023].

[64] N. Ghosh, S. Mothilal Bhagavathy, and J. Thakur, "Accelerating electric vehicle adoption: techno-economic assessment to modify existing fuel stations with fast charging infrastructure," *Clean Technologies and Environmental Policy*, vol. 24, no. 10, p. 3033 – 3046, 2022. Cited by: 1; All Open Access, Green Open Access, Hybrid Gold Open Access.

[65] D. Wu, Q. Gui, W. Zhao, J. Wang, S. Shi, and Y. Zhou, "Battery energy storage system (bess) sizing analysis of bess-assisted fast-charge station based on double-layer optimization method," *2020 IEEE Student Conference on Electric Machines and Systems, SCEMS 2020*, p. 658 – 662, 2020. Cited by: 1.

[66] R. Kurniawan Subroto, D. Gebbran, A. Barragan Moreno, and T. Dragicevic, "Bess optimal sizing and scheduling for energy arbitrage and frequency containment reserve via dual-loop optimization," *2022 IEEE Transportation Electrification Conference and Expo, ITEC 2022*, p. 941 – 946, 2022. Cited by: 0.

[67] A. Hussain, V.-H. Bui, and H.-M. Kim, "Deep reinforcement learning-based operation of fast charging stations coupled with energy storage system," *Electric Power Systems Research*, vol. 210, 2022. Cited by: 1.

[68] G. Wu, Y. Zhang, C. Ni, X. Li, and X. Jia, "Distribution side optimal operation and control of coupled fcs and bess," *Proceedings - 2021 International Conference on Intelligent Computing, Automation and Systems, ICICAS 2021*, p. 232 – 235, 2021. Cited by: 0.

[69] G. Koolman, M. Stecca, and P. Bauer, "Optimal battery energy storage system sizing for demand charge management in ev fast charging stations," *2021 IEEE Transportation Electrification Conference and Expo, ITEC 2021*, p. 588 – 594, 2021. Cited by: 3.

[70] E. Haugen, K. Berg, B. N. Torsater, and M. Korpas, "Optimisation model with degradation for a battery energy storage system at an ev fast charging station," *2021 IEEE Madrid PowerTech, PowerTech 2021 - Conference Proceedings*, 2021. Cited by: 1; All Open Access, Green Open Access.

[71] S. N. Hasan, S. K. Singh, and N. M. Pindoriya, "Study of optimally located electric vehicle charging stations for frequency control service in distribution network," *ICPS 2021 - 9th IEEE International Conference on Power Systems: Developments towards Inclusive Growth for Sustainable and Resilient Grid*, 2021. Cited by: 0.

[72] I. Ilieva and B. Bremdal, "Utilizing local flexibility resources to mitigate grid challenges at electric vehicle charging stations," *Energies*, vol. 14, no. 12, 2021. Cited by: 2; All Open Access, Gold Open Access, Green Open Access.

[73] Energy Saving Trust, "Time of use tariffs: all you need to know." `https://energysavingtrust.org.uk/time-use-tariffs-all-you-need-know`, Jan. 2022. [Online; accessed 6. May 2023].

[74] K. Martinsen, "ledetid." `https://snl.no/ledetid`, May 2023. [Online; accessed 5. May 2023].

[75] O. D. Montoya and W. Gil-González, "Dynamic active and reactive power compensation in distribution networks with batteries: A day-ahead economic dispatch approach," *Computers Electrical Engineering*, vol. 85, p. 106710, 2020.

[76] L. Dahlager, "Nu kommer kineserne med et elbilbatteri baseret på en ressource, der aldrig løber tør." `https://politiken.dk/udland/art9317796/Nu-kommer-kineserne-med-et-elbilbatteri-baseret-p%C3%A5-en-ressource-der-aldrig-l%C3%B8ber-t%C3%B8r`. [Online; accessed accessed 30. Apr 2023].

[77] Eidsiva, "Trøndelag med Norges første kommersielle nettbatteri." https://kommunikasjon.ntb.no/pressemelding/trondelag-med-norges-forste-kommersielle-nettbatteri?publisherId=17848064&releaseId=17953682. [Online; accessed 2. May 2023].

[78] NVE, "Tariffer for produksjon - NVE." https://www.nve.no/reguleringsmyndigheten/regulering/nettvirksomhet/nettleie/tariffer-for-produksjon. [Online; accessed 5. May 2023].

[79] E. Ellefsen, "Nordic peak prices strongly connected to the European market after New Year Energy Quantified Blog." https://www.energyquantified.com/blog/nordic-peak-prices-strongly-connected-to-the-european-market-after-new-year. [Online; accessed 3. May 2023].

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