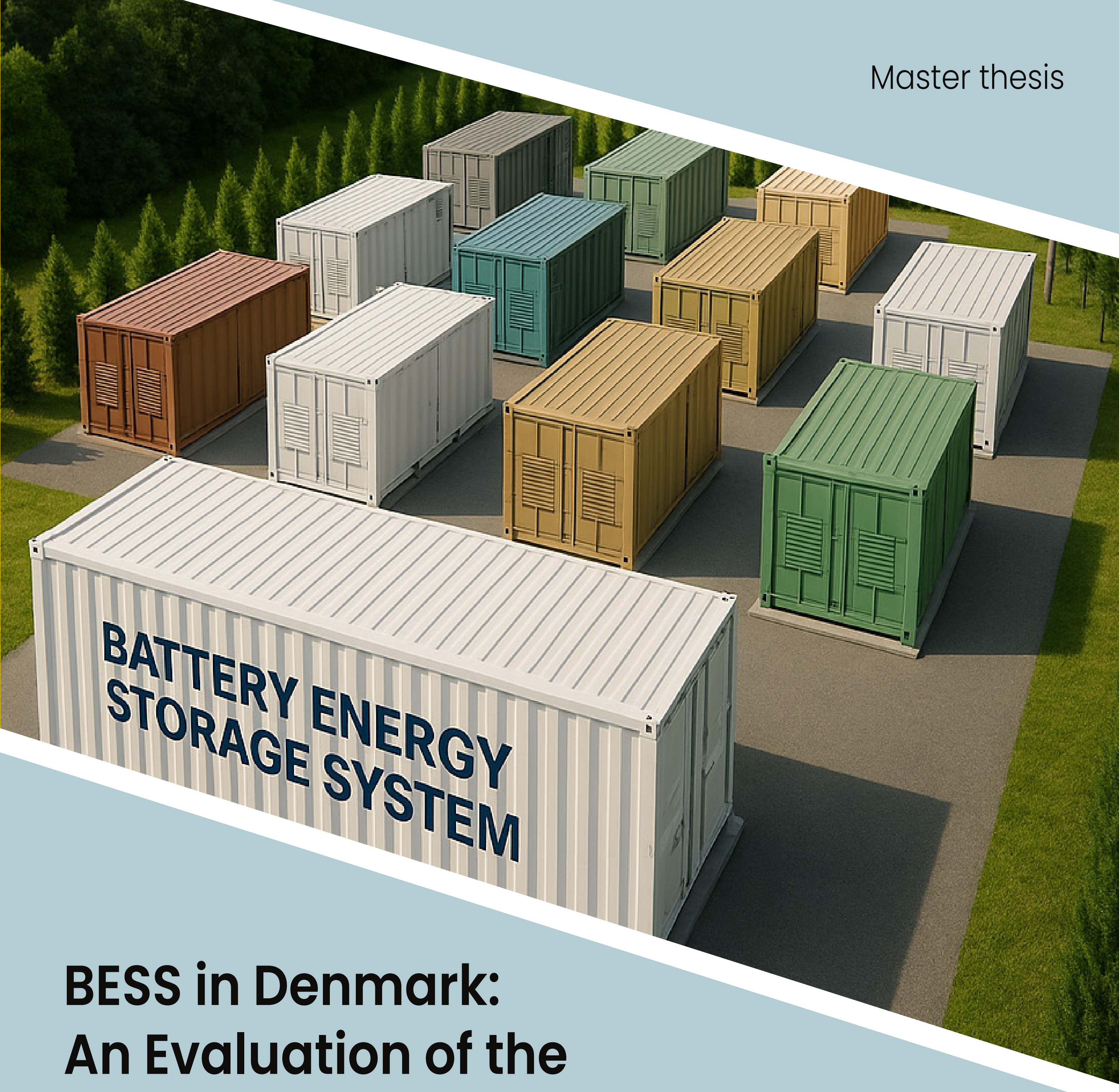
Master thesis



BESS in Denmark: An Evaluation of the Business-Economic Viability and Organisational Framework

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Abstract:

This thesis investigates the financial viability and organisational framework of stand-alone Battery Energy Storage Systems (BESS) in Denmark. It is guided by the research question: *"How do BESS's current and future business economic prospects affect its financial viability in Denmark, and how could relevant stakeholders address the challenges and opportunities related to BESS planning, regulation, and deployment?"* The thesis combines qualitative and quantitative methods, including stakeholder analysis, interviews, and techno-economic modelling of a 10 MW / 20 MWh stand-alone BESS participating in the frequency containment reserve and intraday market, in DK1 for 2024. The modelling results show that BESS can be financially viable, but the return is modest and sensitive to changes in market saturation, conditions, and investment costs. Multi-market participation is essential for achieving economic viability. The analysis also finds that local planning and authorisation processes are characterised by regulatory uncertainty and a lack of national guidance. This creates uneven conditions across municipalities and contributes to an uncertain investment environment. In conclusion, the thesis highlights both the challenges and opportunities facing BESS in Denmark. It presents insights into BESS's financial viability and organisational structure under current conditions for decision makers. It recommends providing more explicit national guidance for local planning and that BESS's future role be holistically assessed from a smart energy system perspective.

Preface

This thesis was written as part of the Master's programme in Urban, Energy and Environmental Planning at the specialisation of Sustainable Energy Planning and Management at Aalborg University, in the period from 1st of February 2025 to 28th of May 2025.

The thesis investigates BESS's current and future business economic prospects in Denmark, in DK1, as well as its organisational and planning aspects.

We want to thank the following individuals for their valuable insights, time, and participation in interviews, which have been important for the completion of this thesis:

- Mads Paabøl Jensen, Senior Lead Regulatory Advisor at Cerius Radius
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Reading guide

The references in the thesis are presented in the Harvard style, where they are formatted with the last name of the author(s) followed by the year of publication, e.g., [Last name, Year].

Executive Summary

This thesis investigates the business economic viability and organisational framework of stand-alone Battery Energy Storage Systems (BESS) in the Danish electricity system. As Denmark integrates higher shares of wind and solar power, the need for flexibility and grid-balancing technologies is increasing. BESS has emerged as a solution due to its rapid response capabilities and decreasing investment costs. However, uncertainties about its profitability, regulation, and deployment have raised questions about the technology's long-term prospects and role in Denmark's energy transition.

The central research question guiding this thesis is: *How do BESS's current and future business economic prospects affect its financial viability in Denmark, and how could relevant stakeholders address the challenges and opportunities related to BESS planning, regulation, and deployment?*

To answer this question, the thesis combines qualitative and quantitative methods, including interviews, market participation models, literature study, and business economic evaluation.

The study begins with a stakeholder analysis to identify the key stakeholders involved in the development of BESS. Through interviews and a literature study, it maps the roles, interests, and influence of both public and private stakeholders, including developers, regulators, Transmission System Operators, Distribution System Operators, and municipalities.

The second analysis examines the regulatory and local planning framework for BESS in Denmark. Interviews reveal that the absence of national planning guidance can lead to uncertainty in project approval processes. This creates challenges for municipalities and developers, delaying project timelines and increasing development costs. The analysis suggests that more precise regulation or national guidance is needed to ensure legal rights and a stable investment environment for BESS.

The third analysis of the thesis includes a techno-economic model of a 10 MW / 20 MWh stand-alone lithium-ion BESS operating in the DK1 bidding zone. The model simulates participation in the Frequency Containment Reserve and the intraday market. Results show that while BESS projects can achieve a positive financial return, the profitability is modest, with a 12.75 year payback time and an internal rate of return of 6.5 %. A sensitivity analysis reveals that the project's financial viability is sensitive to changes in market prices and investment costs. Multi-market participation is necessary to ensure stable revenue potential.

Finally, the thesis discusses BESS's broader challenges and opportunities in Denmark. While BESS has potential, it faces competition from other flexibility technologies such as electric boilers, flexible demand, and Power-to-X. Regulatory uncertainty, limited market size and profitability in the ancillary services markets, and technical constraints related to

energy capacity also pose barriers. However, opportunities do exist to combine BESS with renewable energy production and changes in market structures to better accommodate BESS.

In conclusion, stand-alone BESS is a relevant but currently uncertain investment in Denmark's electricity system. It can contribute to grid flexibility and the integration of renewable energy, but financial sustainability depends on stable regulatory frameworks, diversified revenue streams, and careful planning. This thesis provides insights to inform political, institutional, and developer decision-making about the conditions required for BESS to play a meaningful role in Denmark's future energy system, provided it is considered a valuable technology for achieving societal goals.

Abbreviations and Acronyms

aFRR Automatic frequency restoration reserve

BESS Battery Energy Storage System

BMS Battery Management System

BRP Balance Responsible Party

CAPEX Capital Expenditures

CBC COIN-OR Branch and Cut

CHP Combined Heat and Power

CIP Copenhagen Infrastructure Partners

DaCES Danish Center for Energy Storage

DEA Danish Energy Agency

DSO Distribution System Operator

EU European Union

ENTSO-E European Network of Transmission System Operators for Electricity

FCR Frequency containment reserve

FCR-D Frequency containment reserve - disturbance operation

FCR-N Frequency containment reserve - normal operation

FFR Fast frequency reserve

FRR Frequency restoration reserves (aFRR + mFRR)

KL The National Association of Local Authorities in Denmark

LER Limited Energy Reservoir

LFP Lithium Iron Phosphate

GCT Gate Closure Time

MTU Market Time Units

mFRR Manual frequency restoration reserve

NCF Net Cash Flows

NEMO Nominated Electricity Market Operator

NMC Lithium Nickel Manganese Cobalt Oxide

OPEX Operating Expenditures

O&M Operation & Management

SA Synchronous Area

SES Smart Energy Systems

SoC State of Charge

SoE State of Energy

PtX Power-to-X

PV Photo-Voltaic

RE Renewable Energy

RES Renewable Energy Sources

TMS Thermal Management System

TSO Transmission System Operator

VRE Variable Renewable Energy

VtG Vehicle-to-grid

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Introduction 1

In light of the global climate crisis, Denmark aims to reduce greenhouse gas emissions by 70 % by 2030 and achieve 100 % reduction or climate neutrality by 2050, as outlined in the Climate Act (Danish Ministry of Climate, Energy and Utilities, 2021). The current Danish government (2025) has proposed a bill to advance the year of climate neutrality to 2045 and become climate-negative in 2050 (KEFM, 2024). The energy sectors account for a significant part of Denmark's total greenhouse gas emissions, and it is essential to decarbonise these sectors to reach climate neutrality (The Danish Council on Climate Change, 2024). Denmark has made progress with renewable energy, accounting for 45.8 % of the gross energy consumption in 2023 (Danish Energy Agency, 2023). However, achieving the goals will require continuous effort. As detailed in the Climate Council's 2024 status report, electrification and greater electricity demand underscore the urgency for expanding renewable energy capacity to meet the future demand (The Danish Council on Climate Change, 2024).

Achieving a 100 % renewable energy system entails a mix of Variable renewable energy (VRE), other renewables such as biomass, alongside parallel electrification of the heating, transport, and industry sectors (Lund et al., 2022). The transition from easily storable and dispatchable fossil fuels to fluctuating renewable energy sources like wind and solar power requires several new solutions and changes across the energy system and infrastructure. High levels of fluctuating wind and solar in the generation mix result in more imbalances and volatility in the power system, increasing the requirement for ancillary services to balance consumption and production (Energinet, 2024). Thermal power plants have historically played a key role in maintaining grid balance, but with the phasing out of fossil fuels, fewer of these are anticipated in the future. As a result, ensuring future grid stability requires a large and diverse portfolio of balancing technologies (Energinet, 2024).

At the same time, electricity storage becomes more relevant for integrating the fluctuating production and accommodating the demand (Chen et al., 2019). Among the existing electric energy storage technologies, Battery Energy Storage Systems (BESS) have attracted widespread interest, with storage possibilities and decreased investment costs (IEA, 2024). It has reached a high energy efficiency, modular installation, and different appliance opportunities (Statista, 2025; Hesse et al., 2017). Batteries are also suitable for frequency regulation with their fast response time.

BESS has recently emerged as a new entrant in the Danish energy market, making it a highly relevant and timely subject for further investigation. According to recent projections by Danish Energy Agency (2024a), battery energy storage capacity in Denmark is expected to increase rapidly, with 0.75 GWh in the pipeline toward 2026. Furthermore, prevailing market trends indicate that this projection is likely to grow even further. This thesis aims to investigate BESS's business economy prospects in the Danish electricity and ancillary service market. This entails its opportunities, challenges, revenue streams, and market conditions in Denmark. Furthermore, it investigates its organisational context, including relevant stakeholders and planning framework. This is done to create a knowledge base that can inform decision-making by developers, municipalities, and policymakers, and contribute to addressing the current uncertainty about the economic viability and regulatory framework for BESS in Denmark.

Problem analysis 2

Attaining a 100 % renewable energy system requires the development of VRE producing facilities such as solar and wind power, together with a transition and integration of Renewable Energy (RE) in the electricity, heating, transport, and industry sectors. This transition entails several challenges. Section 2.1 presents the overall projected and needed changes for the Danish energy system in the transition towards climate neutrality. Section 2.2 presents some of the challenges in balancing the power grid frequency with higher shares of VRE. Large-scale batteries are a more recent market entrant and have received increased interest from developers due to the decrease in investment cost, capabilities to provide frequency regulation, and integrate VRE. With an increased commercial interest in BESS in Denmark, it is relevant to investigate its prospects. Section 2.3 unfolds the motivations behind developers' increased interest in BESS and examines the increased Danish interest. Furthermore, it presents recent studies of the business-economic and local planning prospects.

2.1 Outlook of electricity demand and production

Denmark's transition towards a renewable energy system entails increased VRE electricity production from wind and solar power. Figure 2.1 illustrates the expected development of the electricity consumption and RE capacity towards 2050. On the consumption side, a transition of the demand sectors to electricity-based solutions results in a significant increase, with electricity consumption approximately quadrupling from 2024 to 2050 (Danish Energy Agency, 2024a).

The increase in electricity consumption results from the direct electrification of heat pumps, electric boilers, and electric vehicles. For indirect electrification, Power-to-X (PtX) is expected to increase the electricity consumption significantly, constituting half of the projected gross electricity consumption in 2050 (Danish Energy Agency, 2024a). Simultaneously, a larger deployment of VRE capacity, solar, onshore wind, and offshore wind, is required, as projected in Figure 2.1. The integration of VRE requires flexibility, storage, and balancing, where the demand sectors will have a larger role through flexible consumption and utilisation of excess electricity to manage the intermittency of variable electricity production (Lund et al., 2021). The power grid adequacy will be challenged by increased electricity consumption and decentralised consumption (Danish Energy Agency, 2022b). The overall technological shift and expansion of renewable energy come with different new opportunities and challenges, and the renewable energy system requires a large coupling and interplay between multiple energy sectors and stakeholders (Lund et al., 2022).

The development of demand and supply is intertwined and dependent on each other (Lund et al., 2021). The projections in Figure 2.1 should be perceived with high uncertainty as it depends on several factors, including developments in both demand and supply, national policies, and technological advancements. As shown in Figure 2.1, PtX is expected to become the largest electricity consumer by 2050. Nevertheless, recent cancellations and delays of multiple planned PtX facilities limit the future growth in demand. This is partly due to increased investment costs, complexity in project development, a shortage of new VRE development, and insufficient off-take agreements on a long-term basis (Danish Energy Agency, 2024b). A new plan for a shorter hydrogen pipeline from Esbjerg to Germany was also published after the announcement

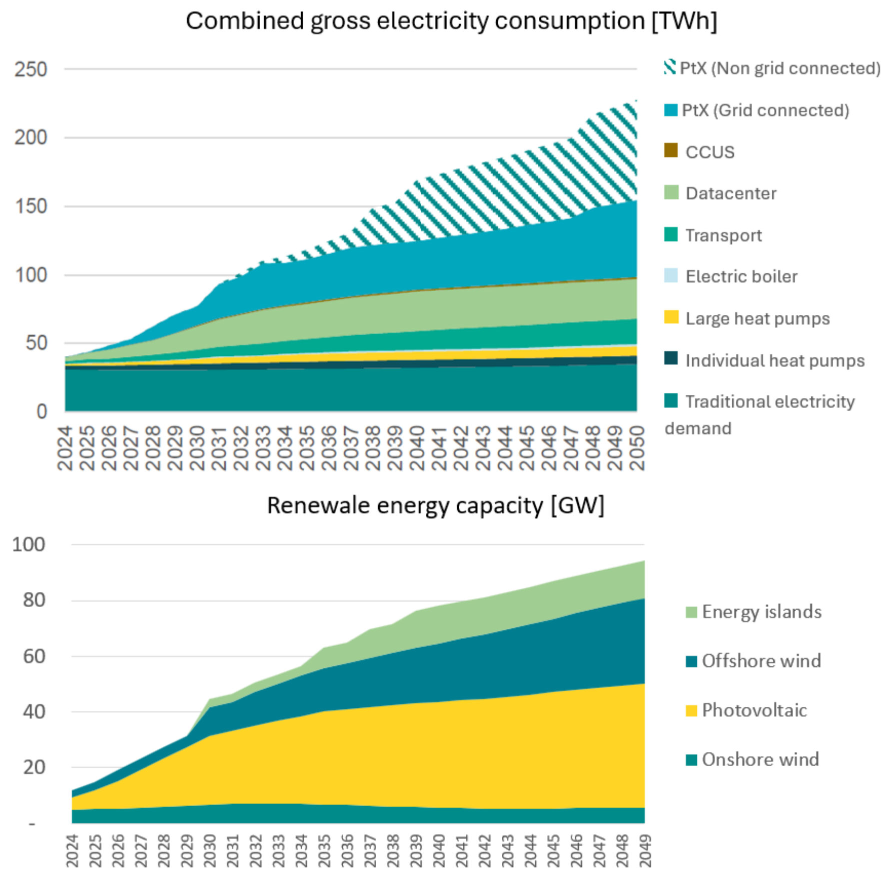


Figure 2.1. Projections of the electricity demand and renewable energy capacity towards 2050 (Danish Energy Agency, 2024a).

of the postponement of the hydrogen pipeline through the majority of Jutland (Danish Ministry of Climate, Energy and Utilities, 2025c). This results in the future demand for PtX not being as significant as expected. In addition to PtX, the electricity demand development also depends heavily on the electrification of the transport, heating, and industry sectors and the expansion of data centres.

On the production side, a recently failed offshore wind tender in 2024 for 6 GW of offshore wind has delayed the planned expansion of offshore wind; furthermore, the planning of the Energy Island Bornholm has been put on hold (Danish Ministry of Climate, Energy and Utilities, 2025c). In May 2025, a new political agreement introduced a state-subsidised scheme for 3 GW of offshore wind (Danish Ministry of Climate, Energy and Utilities, 2025b). Production is expected to grow, although the target has been revised downward from 6 GW to 3 GW, reflecting a significant reduction in planned production capacity.

The impact of renewable energy on electricity prices

The electricity spot prices in Denmark are generally determined by a market-based balancing of supply and demand. The prices are set on the principle of uniform pricing, where the price is set by the last and most expensive electricity producer needed to meet the demand for the specific hour (Nielsen et al., 2011). The balancing of supply and demand primarily takes place via the wholesale market of electricity on the day-ahead and intraday markets (Nielsen et al., 2011).

Higher shares of VRE electricity can contribute to declining wholesale electricity prices, due to the uniform pricing mechanism as explained above, where low marginal-cost renewables push higher-cost generation out of the market (Sorknæs et al., 2019). The low electricity prices incentivise the transition of the demand sectors towards electricity-based solutions(Bogdanov et al., 2021). However, saturation of VRE can also reduce revenue potential for new and existing VRE projects and discourage further investments if the demand does not increase simultaneously. As more RE generation is implemented and electricity prices decrease, existing investments worsen (Sorknæs et al., 2019). These relationships between electricity prices and implementing more VRE production can be seen in Figure 2.2.

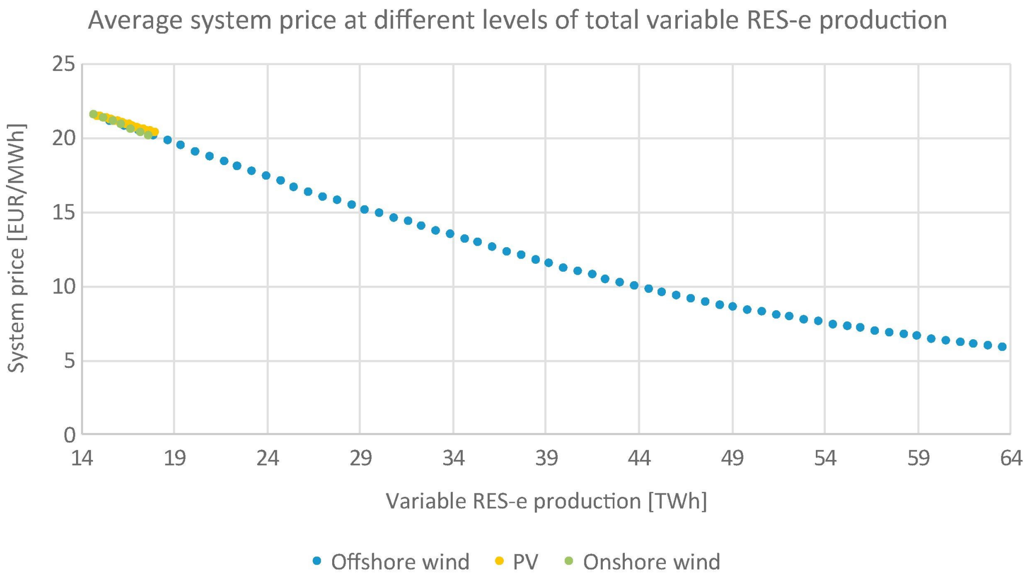


Figure 2.2. Yearly average price of electricity at different levels of electricity production from VRE (onshore wind, offshore wind and PV) (Sorknæs et al., 2019).

In the bidding area DK1 (Western Denmark), where wind power exceeds 50 % of the annual production, electricity prices fluctuate significantly based on wind conditions. When wind power production is high, prices tend to drop, sometimes turning negative (Grohnheit and Sneum, 2023). A similar trend is seen with Photo-Voltaic (PV) production, where midday peaks in PV generation, especially during the summer, coincide with low to negative prices. This volatility creates uncertainty for developers, reducing expected returns and making new investments less attractive (Szabo et al., 2024).

The electricity prices are also based on the development of the demand side (Sorknæs et al., 2019). As explained, there is an expected expansion in electricity demand from the heating and transport sectors, data centres, and PtX. With the general electricity demand increasing less than expected, delayed and reduced plans for PtX and a hydrogen pipeline, the development becomes even more uncertain. If this stagnation in expected demand continues, the saturation of the electricity market is unlikely to change in the foreseeable future. As a result, the expansion of VRE projects could slow down, creating further challenges for Denmark's energy transition.

2.2 Balancing the power grid in a renewable energy system

The European grid must have a frequency of 50 Hz, meaning that the electricity supply and demand must be equal every second. In the final stage of operation, the Transmission System Operator (TSO), Energinet, is responsible for keeping Denmark's power grid in balance (Energinet, 2024). The increased shares of VRE, and decentralised, flexible demand will increase the need for balancing (Energinet, 2020, 2024). Figure 2.3 illustrates that increasing the share of renewable energy in the grid leads to greater imbalances between production and consumption, ultimately affecting grid frequency.

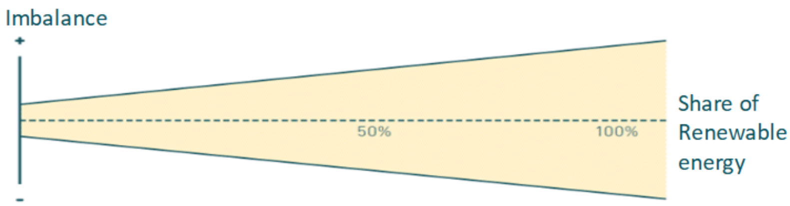


Figure 2.3. The relation between the share of RE and imbalances in the power grid. A higher share of renewable energy leads to higher imbalances. From slides provided by Pedersen and Bundesen (2025).

Figure 2.4. An example of the production profile from a PV plant for a day. From slides provided by Pedersen and Bundesen (2025).

The imbalances are caused by, among others, the intermittency and volatility in the production from wind and solar, which can change down to the second, for example, in changes from wind speed or if a cloud passes over a PV-farm (Pedersen and Bundesen, 2025). PV can create more frequent imbalances than wind turbines because of their steadier production profile (Pedersen and Bundesen, 2025). Figure 2.4 illustrates the production of a PV farm, showing the large fluctuations in production that can occur during a day, causing rapid changes in the frequency. Energinet uses ancillary service markets to maintain grid balance, where producers and consumers offer flexible production or consumption in exchange for financial compensation (Energinet, 2024a). This represents a financial opportunity for interested actors, as Energinet spent 2.35 billions DKK on ancillary services in 2023 (Energinet, 2025b).

Thermal power plants have traditionally been responsible for maintaining and regulating the frequency in situations where imbalances occur. However, many of these are decommissioned due to end-of-lifetime constraints and the need to reduce carbon emissions, necessitating other solutions, technologies, and stakeholders to manage supply and demand (Energinet, 2020). There are different types of ancillary services with different requirements for the product characteristics, such as activation time, delivery duration, activation method, and energy volume (Energinet, 2025). The ancillary services are explained in more depth in Chapter 9. The following gives an overview of the expectations of ancillary service demands and providers.

Energinet (2024) has made projections of the need for ancillary services towards 2040, and identified a significant increase in their demand. This is due to the expected higher shares of VRE and the decommissioning of thermal power plants. Figure 2.5 illustrates the overall identified procurement for ancillary services in DK1 and DK2 to balance the power system, where Energinet has indicated a significant increase of around 150 % from 2024 to 2040 (Energinet, 2024). However, there are significant differences between the development in demand of the different ancillary services towards 2040, where some are projected to remain stable for a period, and some are projected to increase. The projections also come with large margins and uncertainties. The need for ancillary services depends partly on the development of more VRE. For example, the GW-scale offshore wind tenders and changing market structures can influence the development of the future demand of ancillary services (Energinet, 2024; Pedersen and Bundesen, 2025).

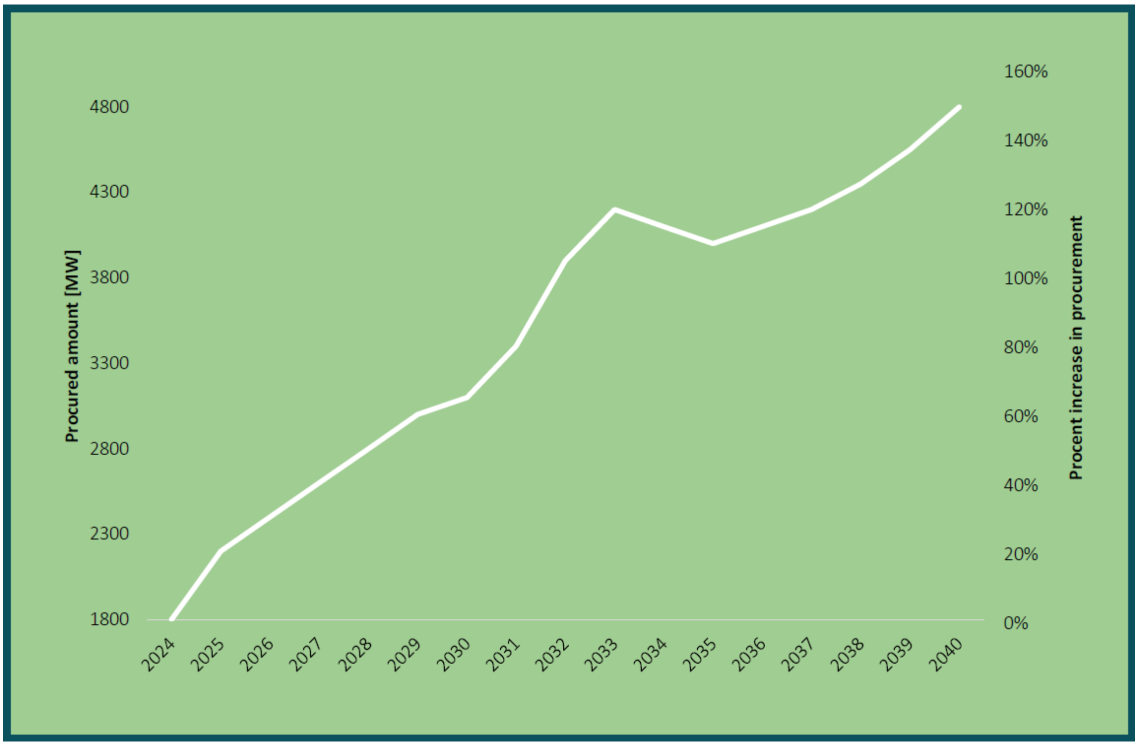


Figure 2.5. Outlook of the summed average need across all ancillary services towards 2040 in DK1 and DK2. The specific outlook for each ancillary service differs (Energinet, 2024).

Grid stability support requires diverse balancing assets (Pedersen and Bundesen, 2025). The increased demand and the prices of the ancillary services have made it attractive and created business opportunities, which have driven the supply-side interest in becoming a provider of the services. Energinet experienced rapid growth in 2024, where they prequalified 272 new units, seven times more than in 2023, and around double the capacity of units (Energinet, 2025b). The development in prequalified units is partly driven by the heating sector, which can use large-scale heat pumps and electric boilers to react quickly, provide flexibility, and ancillary services (Energinet, 2024). An increasing number of new stakeholder types are also entering the ancillary service markets to generate revenue alongside their core business. This includes technologies and actors such as garden centres, ice rinks, public swimming pools, and cooling system operators, who can adjust their electricity consumption for short periods (Energinet, 2025b). However, as interest in supplying ancillary services increases, these markets may become saturated, making it risky to rely solely on them for revenue Pedersen and Bundesen (2025).

Furthermore, the markets are constantly evolving. In October 2024, Denmark connected to PICASSO, the European energy activation market for aFFR (one of the ancillary services, introduced in Section 9.3). The PICASSO platform enabled more market participants to submit bids and facilitated cross-border activation of automatic Frequency Restoration Reserve (aFRR) by European TSOs, increasing both the number of participants and market competition (Energinet, 2024). This illustrates that various factors can influence price developments in the ancillary services markets.

Large-scale batteries can also provide ancillary services, and this potential and market opportunity has especially caused an increasing interest in BESS in Denmark. BESS can offer fast response times for up- and downregulation, which some ancillary services demand. However, they are limited in delivering energy amounts for more extended periods of larger energy quantities. (Energinet, 2023) As the electricity sector undergoes significant transformation and the demand for flexibility increases, the role of BESS in the ancillary service markets warrants further investigation, especially given the increased interest and development of BESS.

2.3 Battery Energy Storage Systems

Large-scale BESS remains a relatively new technology in Denmark within the Danish energy system. However, recent years have seen growing attention to its potential, raising new questions and areas for investigation. This section explores key perspectives related to the rising interest in BESS.

Application purposes

BESS can serve a range of applications in the energy system and the power grid. BESS can be installed at both individual building levels for local electricity storage and at a utility scale to provide services, such as frequency regulation and peak shaving (Zhao et al., 2023). Utility-scale BESS has potential for grid services such as ancillary services, as well as wholesale market participation, and VRE integration (Killer et al., 2020). VRE developers are increasingly interested and looking to add BESS to their portfolio to improve revenue from storage, bidding in different electricity and ancillary service markets (Bech and Youssef, 2025). This section goes through some of these application purposes and the incentives behind them.

Alongside other technologies, BESS can help meet the growing demand for fast ancillary services (Energinet, 2023). BESS has a rapid response time, enabling BESS to stabilise the power system through *frequency regulation* via the ancillary service market. With the ability to react within milliseconds, BESS can be utilised in the fastest primary control reserves (Zhao et al., 2023). The battery capacity is defined by both its power (MW) and energy (MWh) capacity. A 1MW / 1MWh battery can provide energy for one hour, whereas a 1MW / 2MWh battery can provide energy for two hours if fully charged without considering losses. The optimal balance between power and energy capacity depends on the specific business case and desired application. BESS has limited energy capacity makes it challenging to deliver the secondary and tertiary control reserves for frequency regulation, which have larger energy demands (Zhao et al., 2023). However, according to Pedersen and Bundesen (2025), who are responsible for the pre-qualification ancillary service providing units, BESS has the potential to deliver all types of services.

BESS can also help smooth grid fluctuations and feed-in profiles from wind and solar production, which can fluctuate quickly. See, for example, Figure 2.4, an example of intermittent production from a PV plant (Chen et al., 2020). Developers are interested in combining BESS with PV to reduce connection and internal balancing fees costs by lowering and smoothing their peak feed-in capacity and thereby connection tariff (Bech and Youssef, 2025). The intermittency of VRE production and electricity demand causes fluctuations in electricity prices at the wholesale exchange markets. As emphasised above, VRE owners are challenged by the low electricity prices during hours of high RE production, especially for PV (Albretschen, 2025).

Therefore, VRE and BESS developers are interested in BESS for *load shifting* for consumption and *peak shaving* for production, where electricity generated in hours with low electricity prices is stored and sold in hours with higher electricity prices. For example, by shifting generated electricity from PV from the middle of the day to selling in the peak consumption hours in the evening (Hoff, 2022). Due to decreasing electricity prices in peak VRE production hours, BESS can peak-shave VRE production and shift energy to hours with higher prices, thereby enabling further VRE penetration in the energy system (Zhao et al., 2023). BESS is also used for *arbitrage trading*, where electricity is bought and stored when prices are low and sold when prices are high, thereby enhancing revenues for market participants (Hesse et al., 2017).

Another ability worth mentioning about BESS is *behind-the-meter* storage, which typically refers to smaller battery systems installed for local supply and power quality purposes in commercial, industrial, or residential settings (Hesse et al., 2017). An example of this could be PV in combination with BESS for households or industrial consumers to increase self-consumption or reduce their electricity bill by saving electricity and tariff costs in peak hours (Hesse et al., 2017).

Behind-the-meter is also used for critical consumers, who are highly dependent on power quality and a stable frequency. Lastly, it can also be used for *black-starting* of distribution grids, which happens when supply failure results in planned or unplanned blackouts of the power system (Chen et al., 2020).

While BESS can be used for black starting and behind-the-meter solutions, studies indicate that globally the primary applications of BESS are frequency regulation, voltage support, load shifting, peak shaving, and energy arbitrage (Zhao et al., 2023). This thesis only focuses on utility-scale BESS, as these are utilised for challenges at the system level, such as frequency regulation and increasing the penetration of VRE. However, BESS units can contribute to some of the same purposes when aggregated.

Increased interest in BESS globally and nationally

This section examines the decreased investment costs of BESS, its global deployment, and the current national interests in Denmark. The investment costs of lithium-ion batteries have declined. They are projected to continue to decrease due to scaling, advancements of manufacturing facilities, and cell chemistry optimisation, mainly driven by the industry for electric vehicles (Danish Energy Agency, 2024c). Their capabilities and prices have improved dramatically, making them more attractive at grid-scale level (Hesse et al., 2017). Figure 2.6 shows the price development of lithium-ion batteries, which has decreased significantly worldwide by 85 % from 2013 to 2024, and is expected to decline to 70 $/kWh by 2030 (Statista, 2025).

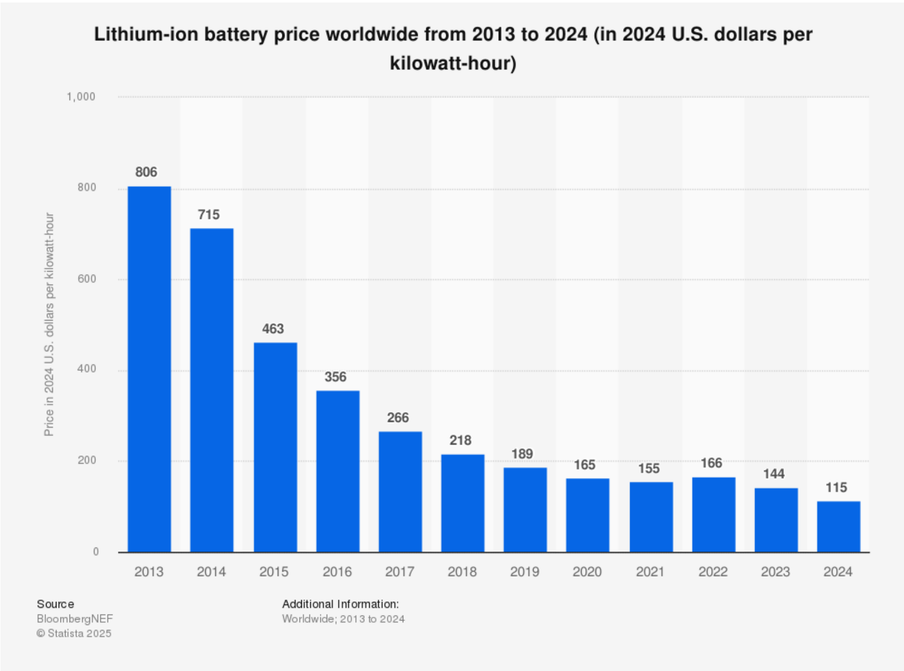


Figure 2.6. Worldwide investment cost development of lithium-ion battery from 2013 to 2024, U.S dollars pr kWh (Statista, 2025).

The capacity of installed battery storage globally is expanding rapidly, with more than 40 GW added in 2023 (IEA, 2024). The capacity consisted primarily of utility-scale projects, which accounted for 65 %, while behind-the-meter installations made up the remaining 35 %. Figure 2.7 illustrates the global increased interest in BESS development, showing annual additions of grid-scale battery storage in the power sector from 2016 to 2022. The growth has increased significantly since 2020, mainly driven by China and the United States (IEA, 2024).

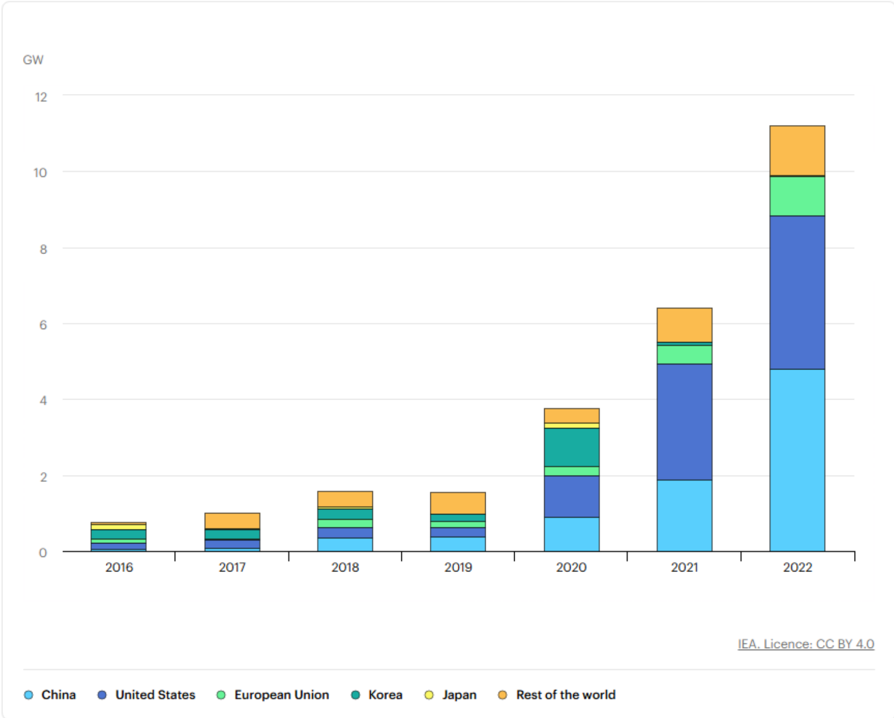


Figure 2.7. Annual additions of grid-scale battery storage in the power sector from 2016 to 2022 (IEA, 2023). The added capacity of 2023 was 40 GW (IEA, 2024).

In Denmark, the enquiry and deployment of BESS have grown in recent years, and the capacity expansion is expected to increase in the coming years. The Danish Energy Agency's (DEA) latest publication of the report *"Analytical Assumptions for Energinet 2024 - Electricity Storage"* from October 2024, projects a battery power capacity of 400 MW in 2026, based on current pipeline projects nationally (Danish Energy Agency, 2024a). The expectations for 2050 are 690 MW with an energy capacity of 1.3 GWh. This projection from 2024 was adjusted from the previous assumption in 2023 of 460 MW in 2050. This only accounts for stand-alone batteries. Batteries at the residential level, electric vehicles, and behind-the-meter in combination with RE are not included (Danish Energy Agency, 2024a).

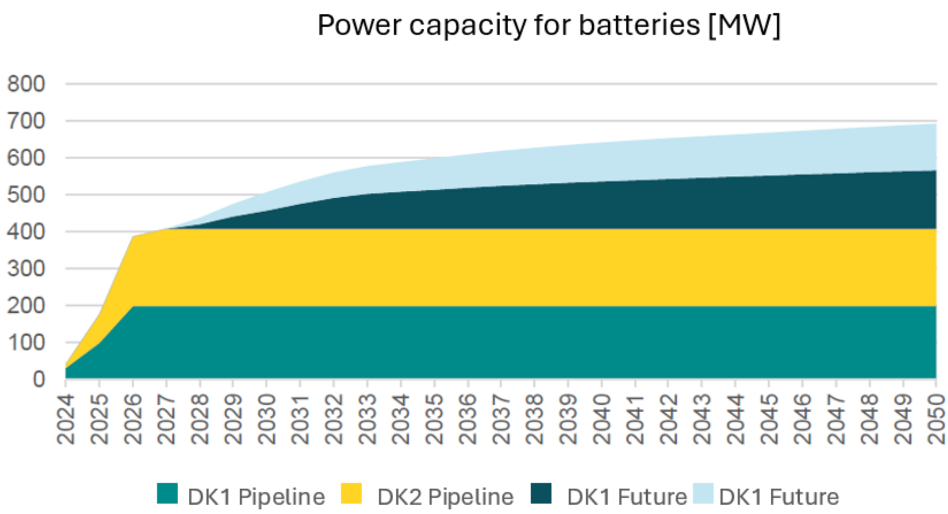


Figure 2.8. The projected development of the power capacity of stand-alone BESS in Denmark (Danish Energy Agency, 2024a).

Danish Distribution System Operators (DSO) are also experiencing a growing interest in BESS. As of November 2024, Cerius-Radius a DSO operating in DK2, had received BESS applications and screening requests totalling 1,500 MW (Jensen, 2025b). Of these, 10 projects, each ranging from 50 to 100 MW, were submitted to Energinet. By the end of 2024, Cerius-Radius had 75 MW of battery storage connected to its distribution grid. With its current rapid deployment and interest, there is a need to investigate its different prospects on a unit and system scale.

Recent studies of the business economic prospects of BESS

This section examines different studies that have investigated the business economics of BESS in various applications, as it remains one of the main challenges for BESS. Despite the expected decrease in investment costs, their growth potential is still highly challenged by high investment costs and limited cost-effectiveness (Chen et al., 2020). Killer et al. (2020) finds that the feasibility of large-scale battery projects often depends on combining multiple applications, as not all are equally economically viable.

While most studies so far have mainly focused on BESS's operational control, some also investigate the business point of view. Hameed et al. (2023) have investigated the business prospects of BESS in the Nordic ancillary services markets with historic price datasets for six years between 2015 and 2020 in DK2. The study found significant differences in revenue generation across the various ancillary service markets. Revenue from Frequency Containment Reserves (FCR) was higher than from Frequency Restoration Reserves (FRR), and the DK2 bidding zone was found to be more attractive than DK1. Finally, it was found that stacking different ancillary services gave increased revenue. The different ancillary services are explained in Section 9.3. Nevertheless, Hameed et al. (2023) and Thingvad et al. (2023) highlight that a high number of charging cycles from bidding in the FCR-N market can lead to increased degradation and reduced capacity and lifetime of the batteries, compared to bidding in the FCR-D market, which does not require the same energy amounts. This shows that different considerations need to be considered when planning market participation.

Cremoncini et al. (2024) have investigated the simultaneous participation of hybrid BESS and wind in the day-ahead and the aFRR market to evaluate the potential market revenue in the Danish bidding area DK1 with prices from 2024. The research found it advantageous to bid in both markets, in which the revenue increases of 39 % - 56 %, compared to only participating in the day-ahead market. However, the feasibility of the investment in BESS is, according to the study, not guaranteed, as the increase in revenue does not guarantee a return on the investment.

Yuan et al. (2022) has investigated bidding strategies of large-scale battery storage within the context of smart energy systems and a 100 % renewable energy system with Denmark in 2050 as a case. The bidding is only focused on energy arbitrage and not frequency regulation. This study found that only relatively small-sized batteries at medium and low-cost levels were economically feasible for energy arbitrage.

Beyond academic studies, commercial techno-economic analyses of BESS and their economic potential in trading and ancillary service markets are complex and valuable to commercial stakeholders. However, companies typically treat software, algorithms, and methodologies as proprietary knowledge, and limited data transparency restricts knowledge sharing about battery modelling and operation. This represents a knowledge gap that warrants further research into the economic feasibility of BESS.

Different studies indicate that BESS revenue potential can be significantly improved through a multi-market bidding strategy that shifts between ancillary and energy markets based on profitability (Hu et al., 2018; Thingvad et al., 2023; Cremoncini et al., 2024). Generally, the primary identified parameters to improve the economic feasibility of BESS are revenues from FCR combined with other ancillary services, peak shaving, and arbitrage trading. Findings suggest that the business viability of BESS in the ancillary service markets can be enhanced by strategically stacking services based on their availability payments, energy requirements, and activation characteristics (Hameed et al., 2023). Participating in different markets complicates bidding strategies and sets high requirements for complex market participation algorithms or models.

Looking at an energy system level perspective, BESS can contribute to the increasing demand for ancillary services and integrate more VRE into the energy system. Nevertheless, other well-known technologies and cross-sector opportunities already exist for flexibility, increasing VRE penetration, and providing frequency regulation (Lund et al., 2022; Energinet, 2024). Lund et al. (2025) examined energy storage and balancing in a future Danish climate-neutral society by comparing a sole electricity system to a fully integrated cross-sector energy system. The study finds that focusing solely on the electricity sector leads to higher balancing costs and greater curtailment, compared to a system that integrates energy, resources, and materials across sectors, enabling least-cost solutions. For example, electric boilers can contribute to frequency regulation and support higher VRE penetration by offering a more affordable form of energy storage through heat storage (Pedersen and Bundesen, 2025).

Local planning of BESS

A significant part of the development and deployment for BESS in Denmark depends on regulation, local planning, and the authorisation process. The Danish municipalities are also experiencing the increased interest in BESS, as they are responsible for local planning, according to the Planning Act (Danish Ministry of Urban, Rural and Church Affairs, 2024). They are receiving inquiries for large-scale BESS and must process the planning process of relevant permissions and screenings. According to Bech and Youssef (2025), the geographical differentiation and placement of new BESS plants depend on the differences between municipalities' approaches. There is no current regulatory framework and guidance for the general placement and local spatial planning focused on large-scale BESS, which makes it challenging for municipalities to process BESS projects (Bech and Youssef, 2025). Under Danish legislation, two different declarations and guidelines address detailed planning for local wind turbines and PV. Still, there is no specific regulation of local planning and authorisation of BESS (Balle and Tolborg, 2025). There have been administrative uncertainties about BESS concerning spatial planning and emergency management. Therefore, the planning practice has become challenged and differentiated between different municipalities (Bech and Youssef, 2025).

While research has been conducted on the planning of wind and PV from a perspective of local and spatial planning, as well as environmental impact, there is a gap in the research and knowledge of the local planning process of BESS. The researched environmental aspects of BESS are highly connected to the production phase, material, and Life Cycle Assessment (Degen et al., 2024). Other scientific literature on BESS is highly connected to its operational and economic aspects: integration in the grid, application, operation, degradation, and market conditions (Hameed et al., 2023). However, there is a gap in studies of local planning and environmental impacts. A significant area of uncertainty is the authorisation and significance of the fire brigade in case of fire, as there are no standardised requirements for the authorisation of this yet (Bech and Youssef, 2025). The lack of research, documentation, and knowledge for the municipalities to correctly process applications for BESS results in a resource-demanding task (Balle and Tolborg, 2025). This regulatory and knowledge gap leaves room for interpretation, creating uncertainty for both developers and authorities. Such uncertainty can create an unstable investment environment and may lead to suboptimal or misaligned deployment of BESS projects in Denmark. (Balle and Tolborg, 2025)

2.4 Summary of the problem analysis and problem definition

As Denmark integrates more VRE, balancing the power grid becomes even more complex. The phase-out of thermal power plants, traditionally providing ancillary services for grid stability, has opened the market for new participants, and many new technologies and stakeholders, such as electric boilers, heat pumps, flexible demands, and batteries, can contribute to the ancillary service market.

BESS is one of these new market participants entering the energy market and system in Denmark. Investment costs for BESS have decreased significantly, and many developers are now applying for grid connections for BESS, with projects with a wide range of capacities, up to 100 MW. The combination of lower investment costs in BESS, attractive prices in the ancillary service market, and saturation of VRE during production peak hours, causing low wholesale electricity prices, has driven a growing interest among developers in BESS. This interest stems from the potential to profit from ancillary services, load shifting, peak shaving, and arbitrage trading opportunities.

Given this increasing interest in BESS, it is relevant to examine the current business economic prospects for developers and assess whether these investments are feasible in the long term. Existing scientific research suggests that the economic benefits may be limited without mixed market participation. The ancillary service market is limited, yet the number of providers is increasing fast. This makes it relevant to analyse how BESS performs financially under current market conditions. At the same time, it is relevant to examine how future changes, such as declining revenues from ancillary service markets and other market parameters, could impact the economic viability of BESS.

With the increased interest in BESS development, municipalities must be able to process enquiries and applications. However, there is a lack of framework and knowledge about BESS's local and spatial planning regarding general placement, legislation, permits, environmental impact, fire safety, and spatial requirements. This regulatory and knowledge gap introduces ambiguity, causing uncertainty for both developers and authorities. As a result, investment conditions may become unstable, and the development of BESS projects across Denmark may become suboptimal, misaligned, or underregulated.

Furthermore, the existing forecasts for BESS deployment in Denmark prompt the discussion of BESS as an alternative technology and its opportunities, challenges, and impacts. The electricity and ancillary service market, as well as the energy system, are dynamic and evolving, and BESS should be assessed within these contingent changes.

3 Research Question

The problem analysis illustrated the changing energy market dynamics driven by increasing VRE penetration. This causes overall electricity prices to decline, reducing the financial attractiveness of existing electricity producers. Simultaneously, increasing VRE penetration has increased fluctuations in hourly electricity prices, increasing arbitrage opportunities. These effects, in combination with decreased BESS investment costs, have caused an increased interest in BESS development in Denmark.

In addition to these market changes, higher VRE shares and the closure of larger power plants have lowered system inertia, increasing the demand for ancillary services to maintain grid stability. This has created new revenue opportunities, drawing developers and other stakeholders into the ancillary services market. However, these markets remain limited, with multiple competing actors and technologies, raising concerns about saturation.

As stated in the problem analysis, current research argues that multiple market participation is necessary for large-scale BESS to be financially viable. Since the market for ancillary services could become saturated, it is relevant to investigate BESS's business-economic prospects under current and future market conditions and assess how changing market factors may affect the viability of large-scale BESS investments in Denmark.

As BESS is relatively new on the market, it is relevant to map and analyse the new and existing stakeholders who participate in and influence its development to understand the organisational structure surrounding it. Furthermore, there is uncertainty about BESS's regulatory and local planning framework, which affects deployment, implementation, and investment decisions. Municipalities are experiencing growing interest in BESS projects as the local planning authority, but the absence of clear regulatory guidance leads to varied local approaches. This creates uncertainty for municipalities, developers, and investors regarding spatial placement and approval processes, causing inconsistent and ineffective local planning of BESS and creating an unstable investment environment.

Finally, the increased interest in BESS prompts discussions about the current and future challenges and opportunities for BESS and how relevant actors and stakeholders could address these.

Based on this, the following research questions and sub-questions have been formulated:

How do BESS's current and future business economic prospects affect its financial viability in Denmark, and how could relevant stakeholders address the challenges and opportunities related to BESS planning, regulation, and deployment?

1. Who are the current key stakeholders in Denmark involved in BESS deployment, and what are their roles, influence, and interests?
2. How does regulatory and local planning uncertainty affect BESS planning, and which planning aspects should stakeholders consider?
3. What are the business economic prospects of BESS under current market conditions, and how would changes affect its viability?
4. What are BESS's main challenges and opportunities now and in the future, and how could relevant stakeholders address them?

The first sub-question identifies and examines the key stakeholders involved in BESS deployment. Understanding these stakeholders' interests, dynamics, and influences are essential for understanding BESS's current and future deployment. This information is also important in identifying potential barriers or opportunities. Therefore, the findings provide a foundation for the second and fourth sub-questions by clarifying the perspectives and influence of different stakeholders in the BESS development.

The second sub-question investigates how regulatory and local planning uncertainty affects the deployment of BESS in Denmark. Based on interviews and stakeholder experiences, the analysis examines the current planning and authorisation practices applied by municipalities. Since authorisation of a BESS project depends on the local interpretation of planning frameworks, these processes shape the investment environment and influence developers' decision-making. The analysis outlines the challenges and identifies the planning and environmental aspects that stakeholders must consider.

The third sub-question assesses BESS's business-economic prospects under current and future electricity, ancillary service, and other market conditions. This is done through a techno-economic analysis, including a sensitivity analysis to examine how changes in key parameters may impact project viability. Since BESS is often argued to require multiple revenue streams for financial sustainability, this analysis explores potential income sources such as arbitrage trading and participation in ancillary service markets. Understanding these financial dynamics and the effect of changes in these markets and other parameters is essential for determining whether BESS is an economically viable solution for developers and investors.

The fourth sub-question discusses some of BESS's challenges and opportunities in Denmark, both now and in the future, and how relevant actors could address them. This analysis builds on insights from findings in the analyses of the previous sub-questions, insights from interviews, and a literature study, by identifying challenges and opportunities.

3.1 Delimitations

Regarding BESS facilities, the thesis focuses on large-scale BESS, as it is a newer market entrant and technology in Denmark's energy markets and system. As outlined in Chapter 2, VRE-developers seek to include BESS as part of their asset portfolio in combination with their wind and solar facilities. While it could be relevant to investigate the effects of combining BESS with VRE facilities, this thesis focuses on stand-alone facilities. However, the potential impacts of combining VRE facilities and BESS are discussed in Chapter 11.

The temporal scope is centred on short-term conditions and decisions. The main focus is on the current regulation. Nevertheless, perspectives on how future changes can affect current investments in BESS are also discussed. The thesis analyses an investment case based on current technologies, market conditions, regulations, and historical prices. A detailed assessment of long-term national energy system transformations is outside the scope of this thesis, which focuses on the business economics of specific short-term investment cases. The techno-economic analysis does not include a complete market analysis of price forecasts, but the impact of changes on the market is discussed. Likewise, the effect of a large-scale integration of BESS from a national energy system perspective is not included.

One of the challenges and considerations of BESS as a technology is the environmental impact related to the resource consumption, production, and handling of end-of-life batteries (Danish Energy Agency, 2024c; Degen et al., 2024; Nielsen, 2025; Montana et al., 2025). The battery cells and cathode chemistries often rely on resource-intensive materials such as lithium, cobalt, nickel, and graphite, which are materials of more or less limited availability and constraints (Hoff, 2022; Montana et al., 2025). These issues are acknowledged but not explored in depth, as the thesis focuses on the business-economic and local planning aspects of BESS development in Denmark, rather than broader socio-economic considerations. However, the relevance of production-related environmental impacts is recognised and should be considered in a holistic evaluation of BESS as a technology.

Methodology framework 4

This chapter presents the scientific perspective and research design of the thesis. The scientific perspective presents the underlying paradigms of the view on markets and framework conditions for planning technologies. It expands on how the thesis is positioned within perspectives of ontology and epistemology, which refers to the study of how reality and knowledge are perceived (Egholm, 2014). The research design illustrates the approach and link between the methods and theories used to analyse the research question.

4.1 Scientific perspective and theories of science

This thesis is positioned within a constructivist, social constructivist, and post-positivist scientific perspective. The post-positivist perspective acknowledges that while objective reality exists, our understanding of it is influenced by uncertainties, limitations in data, and the complexity of systems in the real world (Phillips and Burbules, 2000). Post-positivism builds upon positivism, which assumes that objective truths can be discovered through empirical observation and logical reasoning, with a more critical and probabilistic approach to knowledge production (Phillips and Burbules, 2000). With the post-positivistic perspective, it is recognised that fields like energy markets and energy policy are dynamic, wherein absolute certainties are unattainable.

Furthermore, markets can be defined as social constructions. This comprehension claims that markets are not natural but socially constructed institutions formed by political, historical, and cultural effects (Fligstein and Calder, 2015). This perception challenges the neoclassical economic view, where markets are perceived as neutral mechanisms of supply and demand in perfect competition, consumers and producers act rationally, and no governmental intervention is needed (Keohane and Olmstead, 2016). Instead, Çalışkan and Callon (2010) argues that practices, discourses, and technologies shape markets and economic actions and that markets are constantly redefined through these processes. Fligstein and Calder (2015) extend this with the argument that markets are formed by power structures and institutions, which require governance structures to stabilise economic interactions. They argue that markets consist of fields where dominant actors cooperate and compete. Norms, rules, and interrelationships stabilise the economic interaction within market frameworks established by legal and political influences.

These perceptions lead to the scientific perspective of constructivism, where reality and knowledge are contextual, subjectively interpreted, and constructed (Egholm, 2014). Reality and knowledge are not objective, neutral, or absolute. Instead, it is shaped by individual experiences and constructed by the different methods, terms, analyses, and strategies with which it is interpreted. The perspective of this thesis falls under the branch of social constructivism, which underlines that knowledge is shaped by social interaction, communication, collaboration, and cultural aspects. Knowledge is affected by time and place, meaning that it is changeable and subjective; absolute truths are never possible to obtain. (Egholm, 2014)

Because the energy sector and market are dynamic and transitioning, it is important to recognise the time-sensitivity of the results of this thesis. This study analyses BESS within the current regulatory and market structure. However, future policy changes, technological advancements, and market developments may influence BESS's economic viability and role in renewable energy systems. As a result, the findings of this thesis should be interpreted within the context of the present conditions. By having a post-positivistic approach, it is acknowledged that this thesis's energy modelling and business economic calculations are inherently uncertain due to evolving market conditions, technological advancements, and regular regulatory changes. An example of a market change is the recent Danish entry into PICASSO; a European market of one of the ancillary services, aFRR, which has increased the market size of demand and supply, impacting the commercial competition (Energinet, 2024).

The thesis aims to investigate BESS as a storage and ancillary services technology and create a knowledge base for stakeholders' decision-making. However, as market conditions, policies, and technologies evolve, the results should be seen in the above-mentioned context: Markets are socially constructed within a broader societal framework shaped by legal, political, and institutional influences.

4.2 Research design

The research question and scientific perspective shape the research design of this thesis. Specifically, it uses a mixed-method approach, combining different methods for answering the research question. This combination ensures a comprehensive understanding of the role of BESS in Denmark, from a stakeholder, planning, and business economy perspective. The approach stems from the social constructivism perspective, where data sources are critically evaluated, as each understanding and perspective can be subjective (Brinkmann and Tanggaard, 2015). It combines different sources to critically assess BESS's present role within a complex and evolving energy system to attempt to converge towards an objective reality. It aims to develop evidence-based conclusions while still acknowledging the limitations of available information and the constantly evolving field. The use of mixed methods allows for a more comprehensive understanding where different methods can complement one another (Brinkmann and Tanggaard, 2015). For instance, interviews can serve to verify, clarify, or further explore findings in the literature. This methodological triangulation enhances the validity by combining the strengths of both quantitative and qualitative empirical knowledge and data. The analysis entails a quantitative analysis of energy modelling, business economic calculations, and qualitative data from interviews and literature studies.

The approach in this thesis and the link between the applied methods and theories used to analyse the research question are illustrated in the research design in Figure 4.1. Each round box represents a Chapter of the thesis. The sub-questions and their content are emphasised in Chapter 3, where this section emphasises the interrelations between them. As illustrated in the research design in Figure 4.1, the arrows descend from the research question. The analyses can be perceived as split into two parts.

The first part, Chapter 7 and 8 revolves around BESS's organisational, knowledge, and spatial planning perspectives. The stakeholder analysis, which addressed the first sub-question, functions as background information and understanding of the surrounding context of BESS in Denmark. This contributes to the analysis of local planning and authorisation, addressed by the second sub-question.

The second part, Chapter 9 and 10 revolves around BESS's market and business economic prospects. These analyses are both part of the third sub-question. Chapter 9 examines the electricity, ancillary services, and market conditions relevant for BESS. This functions as background information for the actual techno-economic analysis of a BESS facility in Chapter 10. The expositions of the markets are used to delimit price zones, battery capacity, and market participation in the techno-economic analysis. This delimitation is presented at the beginning of Chapter 10.

The two parts contribute to the discussion Chapter 11, which represents the answer to the fourth and last sub-question. The analyses and division derive from the constructivist scientific perspective. With this perspective, it is acknowledged that the framework conditions and markets are constructed. Therefore, it is also essential to consider the organisational surroundings when analysing the context and economy of BESS. The two parts also derive from the interpretations of the technology concepts, which are presented as the theoretical framework in Chapter 5.

The theoretical framework serves as a foundation for the whole analysis and discussion. The theories provide an understanding of the background and the dynamics that shape the development of BESS as well as the surrounding market structure and energy system. The dimensions and perspectives from the theories will be used to frame and support the discussion in Chapter 11.

The methodological framework and methods surround both the problem analysis and the analysis of the research question. Two methods, literature study and interview, were used throughout the thesis. As many of the interviews were held at an early stage of the project period, they were utilised to map and investigate different perspectives of BESS. As BESS is a new entrant in the market in Denmark, there is little literature on the practical experience of the development of BESS in Denmark. Experience and knowledge are evolving from ongoing projects, and interviews are therefore necessary for the problem analysis to explore its current status. Other methods are applied differently across the analyses and discussion depending on their respective focus.

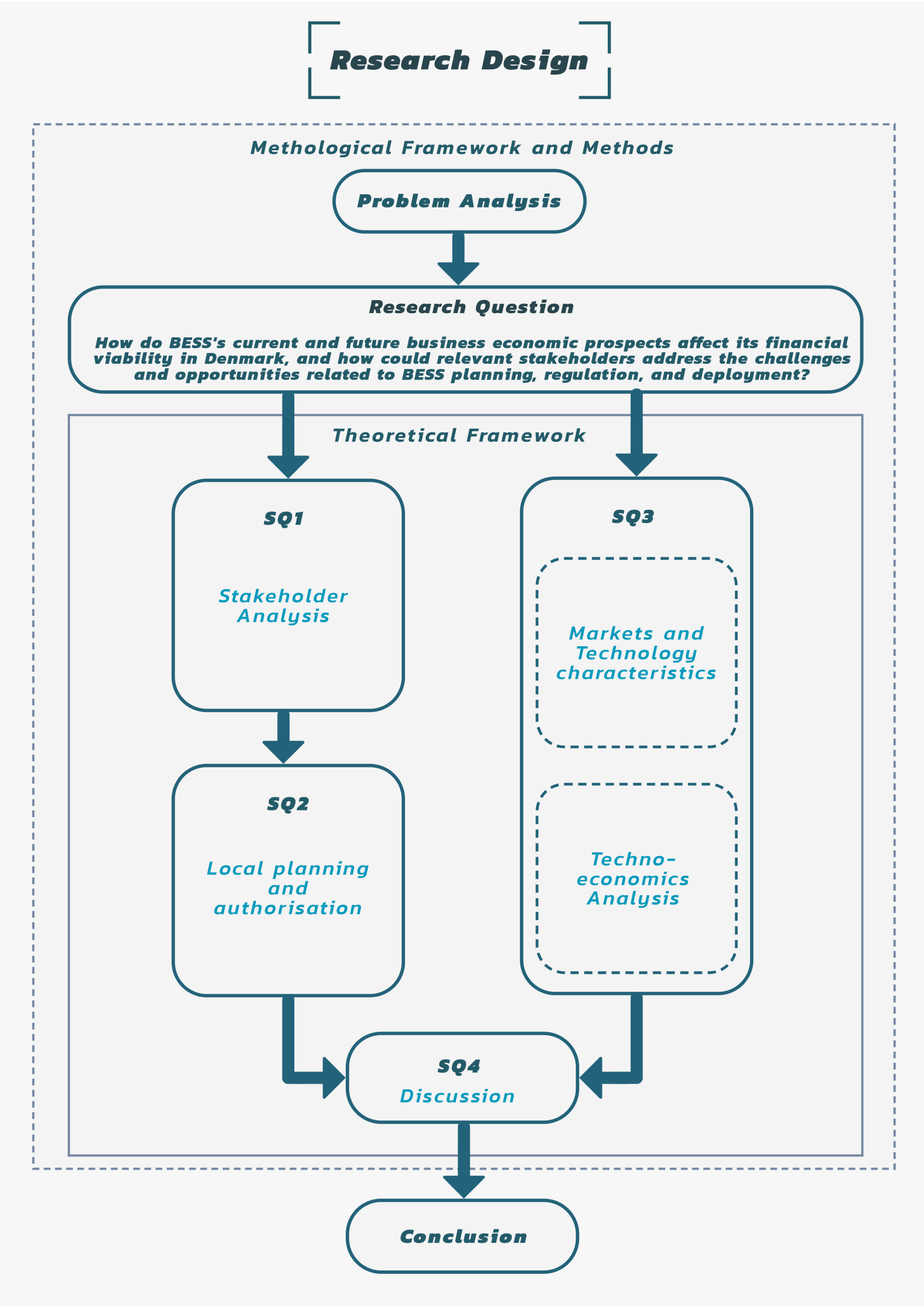


Figure 4.1. Illustration of the thesis's research design. The text in the boxes represents the headlines of the respective chapters.

Theoretical framework 5

This chapter emphasises the conceptual and theoretical framework serving as the foundation of the analyses. The theories define some key concepts and position the thesis within the fields of energy systems, technology, and market theories. Firstly, the theories are positioned in relation to each other and connected to key elements of the analysis. Hereafter, the theories are presented in the chronology: smart energy systems and Choice awareness, the Technology concept, and lastly, Game, Auction, and Market theory.

This thesis incorporates multiple theories to create a theoretical framework, as visualised in Figure 5.1. The selected theories support the thesis by offering a framework and understanding to assess the role of BESS in the Danish energy market. The larger circle that entails Smart Energy Systems serves as a fundamental perspective, highlighting the interplay between the different energy sectors; electricity, heating, cooling, transport, and industry, and how technological choices work towards this. The second circle of Choice Awareness highlights the need for an evaluation of BESS as an alternative solution to other technologies. Inside these circles is the Technology concept, which adds the five dimensions shaping a technology. Game, Auction, and Market Theories are included in the middle as they provide a theoretical foundation and a contextual understanding for the analysis of the business economic prospects of BESS. Game, Auction and Market theory theories are mostly pointed towards the dimensions "Product" and "Profit" in the Technology concept. Together, these theories form the framework for the analyses and discussions carried out in this thesis.

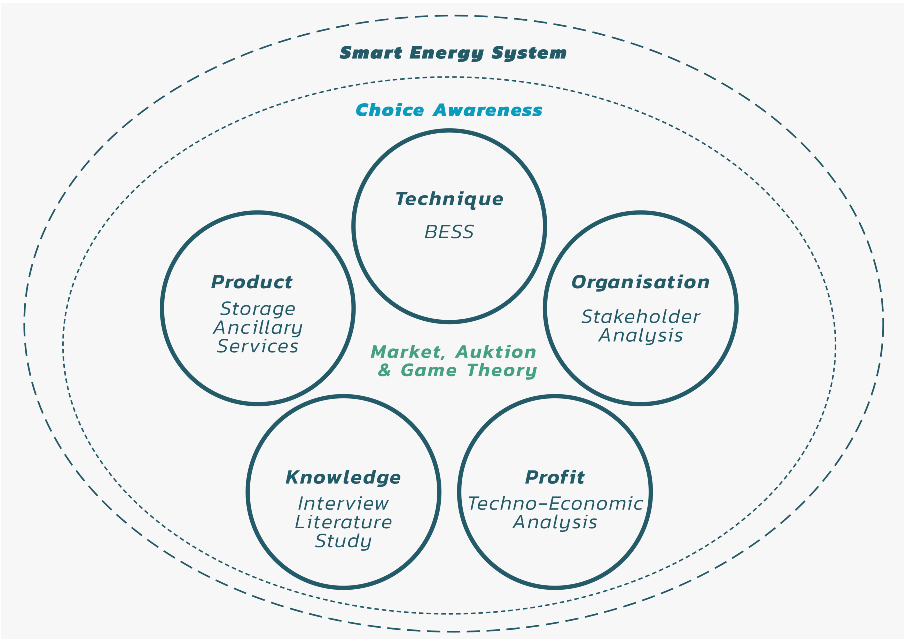


Figure 5.1. Overview of the theories used in this thesis. Different elements of the analysis and methods are placed inside the five circles of the technology concept, according to their connections to each dimension.

5.1 Smart Energy Systems

Several new concepts and definitions have emerged as the energy system transitions towards more renewable energy sources and sustainable energy systems. One of these is Smart Energy Systems (SES). The central concept of SES is to have an integrated, flexible, and coordinated planning between all energy sectors; the electricity, heating, transport, industry, and cooling sectors. This approach aims to identify optimal solutions for both the individual sectors and the overall energy system, considering both energy production, conversion, and consumption (Lund, 2024). SES aims to identify synergies across sectors, improve energy efficiency, and optimise the integration of Renewable Energy Sources (RES). Some of the key objectives are to increase flexibility in energy supply and demand, and herein include storage solutions which are especially relevant with the intermittent nature of solar and wind (Lund, 2024). It is important to consider how the energy sectors influence each other, how the whole energy system operates, and how the political context can affect this.

SES expands the concept *Smart grid*, which focuses solely on the electricity sector (Lund, 2024). SES focuses on the integration and interplay between all energy sectors and is used to understand the future energy system. This thesis investigates BESS as an option for electricity storage, integration of VRE, and frequency regulation. Nevertheless, BESS should be perceived in the context of SES, which includes the entire energy system. Different demand side units can deliver frequency regulation, such as electric boilers and heat pumps in the heating sector (Energinet, 2024). With aggregated battery storage from electric vehicles, the transport sector could also potentially deliver some of the same services via the Vehicle-to-grid (VtG) concept (Meesenburg et al., 2020).

Large-scale BESS can assist in balancing the local and national grids, peak shaving, and storing renewable electricity (Zhao et al., 2023). However, it may be expensive, less energy efficient, resource demanding, and have other environmental consequences compared to other solutions. It is relevant to consider the interaction and influence of the other sectors. The development of VRE and changes in the other sectors affect the wholesale and balance market as well as the demand and supply dynamics, which influence each other's business cases. This is further discussed in Section 11.3. This also aligns with the theory of Choice Awareness, where alternative technological solutions must be evaluated holistically.

5.2 Choice Awareness

The theory of Choice Awareness highlights the importance of recognising that alternatives exist when making decisions about technological changes (explained more in depth in Section 5.3) (Lund, 2024). This is relevant for BESS as a technology that has experienced a more recent increasing interest from actors in the energy sector. As VRE penetration increases, actors explore different options for balancing. While BESS is one of these solutions, it competes with other technologies such as PtX for energy storage and electric boilers for ancillary services. However, BESS does not necessarily exclude these other technologies; instead, it may improve existing and future investments in wind and solar energy (Kaur, 2022).

Despite the range of technological options available, the perception of no choice often limits decision-making (Lund, 2024). In some cases, actors may not recognise BESS as a viable alternative, or institutional structures may favour existing technologies. The theory of Choice Awareness emphasises that it is essential to clarify that large-scale deployment of BESS is a choice rather than an inevitability (Lund, 2024). If BESS is to be implemented widely, it could change dynamics in electricity markets, system planning, and regulatory frameworks, as all sectors are interconnected.

This thesis is primarily concerned with the second thesis of the Choice Awareness theory, which argues that raising awareness about alternative technologies is essential for informed decision-making (Lund, 2024). In the case of BESS, this entails analysing it as an alternative technology for storage and ancillary services, and ensuring that stakeholders and decision-makers are aware of its associated opportunities and challenges.

5.3 Technology concept

This thesis applies the interpretation of the technology concept by Remmen et al. (1986) and Hvelplund (2011) to create a framework for a holistic examination of BESS as an energy storage and ancillary service provider and assesses its opportunities and challenges. By investigating the dimensions of the technology concept, the thesis aims to provide an informed decision-making knowledge base.

In order to analyse the technology BESS, it is essential to conceptualise what is meant by the definition of "Technology" in order to gain knowledge about BESS as an alternative technology. For this, the technology concept provides a framework to understand the different elements shaping the technological dimensions. Technology is, by Remmen et al. (1986) defined as a combination of the four dimensions: Technique, Knowledge, Organisation, and Product. These four dimensions are not independent components but rather interconnected. The four dimensions are intertwined, meaning that a change in one will inevitably trigger changes in the other three. If a change in the other dimensions does not happen, any attempt at technological change will become abortive. (Remmen et al., 2011).

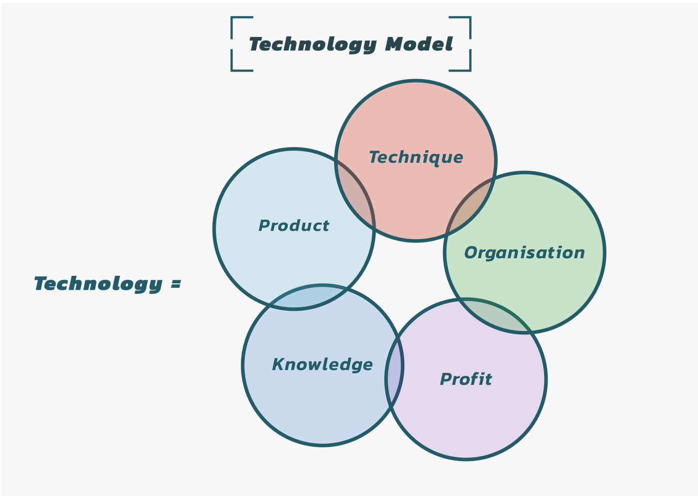


Figure 5.2. Technology concept showing the five dimensions of technology. Inspired by (Hvelplund, 2001).

The first dimension *Technique* comprises the physical tools, machinery, and infrastructure encompassing the technological processes. It is linked to human effort and production dynamics, making it a material and labour-driven process. The second dimension *Knowledge* encompasses the expertise behind technology. This includes the tacit knowledge and skills developed through practical experience and scientific understanding. Knowledge is a process that continually refines and advances technology as it evolves through learning and adaptation. The third dimension *Organisation* serves as the mechanism that couples knowledge and technique together. Effective organisation requires management, coordination and communication to ensure the smooth integration of all the processes. While not all forms of organisation include technology, every technology inherently contains an element of organisation. (Remmen et al., 1986)

These three dimensions are the productive technology. They are combined to bring forward a thing or a service. This results in the fourth dimension, the *Product*. It is an integral part of technology as it is a means to fulfil societal needs and solve problems. For BESS, the product could, for example, be storage and the delivery of ancillary services. Products often carry economic significance as they enter markets and generate value alongside their use-value. (Remmen et al., 1986)

Hvelplund (2011) proposes an additional dimension to the technology concept; *Profit*. Profit represents the economic dimension of the technology. It acknowledges that financial viability is a driver of technological implementation and that technology is not only a technical and organisational system but also an economic one. The now five dimensions can be seen in Figure 5.2. A technological change occurs when at least one of these dimensions changes. However, radical technological change is when at least two of these five dimensions are substantially changed. (Hvelplund, 2011) Such a change impacts the technology's structure and thereby reshapes its organisational frameworks, the knowledge required for its operation, the resulting products, and the economic structures.

Radical technological change can typically also result in a systemic shift within a sector (Hvelplund, 2001). In this context, BESS can be characterised as a radical technological change within the energy sector. Recent developments across multiple dimensions, most notably Profit and Technique, have accelerated the integration of BESS. Declining investment costs, combined with the attractive prices in ancillary services markets, have significantly altered the economic attractiveness of BESS, while advancements in battery technology have enhanced its technical capabilities. If large capacities of BESS are implemented, it could influence market dynamics. This thesis examines BESS as a technology shaped by the regulatory framework, economic conditions, advancements in technique, expert knowledge, and product improvements. By integrating this perspective into the Choice Awareness theory, as written above, this thesis emphasises that the development of BESS is not inevitable but rather a conscious choice among multiple pathways.

5.4 Game, auction and market theory

This section presents how game, auction, and market theory can assist in understanding these markets' conditions and how participants behave. Supply and demand dynamics, auction formats, and market participants' decision-making all influence market price formation. Game, auction, and market theories are relevant for the business-economic modelling and discussion of BESS participation in the electricity and ancillary markets.

Game theory helps to understand how markets evolve and operate (Lin and Magnago, 2017). It provides a framework to describe the behaviour and strategic interactions between auction participants whose decisions impact each other (Huang and Li, 2022). The framework of game theory can be classified in several ways, including whether the game is dynamic or static, whether players have complete or incomplete information, and the sequence of decision-making (Lin and Magnago, 2017). Games can also be cooperative or non-cooperative, where electricity markets are typically *non-cooperative*. This means that each participant acts independently to maximise their own benefit without forming binding agreements with others (Lin and Magnago, 2017). However, producers in the electricity markets compete by setting bids while considering their competitors' actions (Huang and Li, 2022). The electricity trading market is a commodity between producers, energy retailers, and consumers. The power system functions as an interconnected system of various participants, where one participant's actions affect the entire system and, therefore, require coordination (Huang and Li, 2022).

A key assumption in game theory is that the participants act rationally, meaning they try to maximise their payoff in the shape of profits or benefits by optimising bidding strategies (Lin and Magnago, 2017). Electricity producers submit bids, including the price and how much electricity they will produce at a given time. Furthermore, if a producer is aware of the bids submitted by other participants, they can strategically modify their bid (Lin and Magnago, 2017). The bidders can, for example, modify their bid in the intraday market after bidding in the day-ahead market.

Nash equilibrium is a concept in game theory that describes a situation where no participant can improve their payoff by unilaterally changing their strategy, assuming the strategies of all other participants remain fixed. It represents a stable state in which all players have chosen optimal strategies in response to one another, and thus have no incentive to deviate. (Lin and Magnago, 2017; Klemperer, 2004)

Buying and selling electricity occur in formal auction markets, where the auction format influences the seller's revenue and their bidding strategy. *Auction theory* provides a framework for the structures and rules and how different auction formats influence pricing and bidding strategies (Lin and Magnago, 2017). Electricity is auctioned as a homogeneous good, as each item is identical. Different bidders submit their bids for a quantity, and the auctioneer aggregates the bids and determines a clearing price, where the supply crosses the demand. The auction format, either a pay-as-bid or uniform pricing, determines the payment. In the pay-as-bid format, the payment is implicit: the bidder is paid the bid amount for each won unit. In the uniform price auction, the bidder is paid the clearing price for each unit. (Lin and Magnago, 2017) Under uniform pricing, Nash equilibrium suggests that generators are incentivised to bid close to their marginal cost, as bidding too high increases the risk of not being selected, while bidding too low reduces potential revenue (Klemperer, 2004). The bidding strategies in each auction format are examined in more depth later in Section 9.1.

To understand traditional economic thinking, it is relevant to consider the neoclassical perspective, which has influenced many of today's economic models (Hvelplund and Arler, 2015). The neoclassical understanding of the economy relies on the assumption that the market is always at an optimum level where independent producers and consumers act rationally to maximise their profit (Lin and Magnago, 2017). Resources are allocated optimally through supply and demand, naturally reaching an equilibrium.

However, as emphasised in the scientific perspective in Section 4.1, electricity markets are more complex than the neoclassical perspective suggests, involving strategic interactions, uncertainties, and market constraints. Hvelplund and Arler (2015) challenge the neoclassical understanding of the economy, which weights the private actor's independence with limited governmental involvement. Hvelplund (2001) presents another approach, referred to as *innovative democracy*, which acknowledges the influence of institutional framework conditions. It is argued that the market's concrete mechanisms are institutional and human-made, which extends the scientific perspective of social constructivism, and how markets are constructed (Hvelplund, 2001). Figure 5.3 illustrates Hvelplund's division of the actors and influences within energy politics and indicates the flow between boxes in the concrete planning.

Box A shows the technical scenarios with the current market conditions, trying to fulfil society's goals in box D. These market conditions are affected by different institutional conditions listed in box B. The parliament and municipalities determine the institutional market conditions in Box C. Boxes E, F, and G represent the lobbyists trying to impact the decisions made by politicians and authorities. Lastly, the market can be influenced directly or indirectly, as illustrated by the arrows I and II. (Hvelplund, 2001). The Figure illustrates how many different market conditions and actors affect the energy policy. Changing the energy policy and technical scenarios requires changes in different boxes. If the market design changes, consequently, market shares will change between stakeholders. The theory of innovative democracy argues that institutions are always politically constructed and should make room for innovation. (Hvelplund and Arler, 2015)

The shift from fossil fuels to renewable energy is a radical technological change entailing new technologies, knowledge, and organisations (Hvelplund and Arler, 2015), as written above in Section 5.3. BESS is a new entrant in the market, and integrating it requires new knowledge and organisations. The arguments by Hvelplund underline the need for an analysis of the current stakeholders and market conditions to understand the conditions and impacts of the new technology. The main focus of this thesis is not to develop new technical scenarios of the national

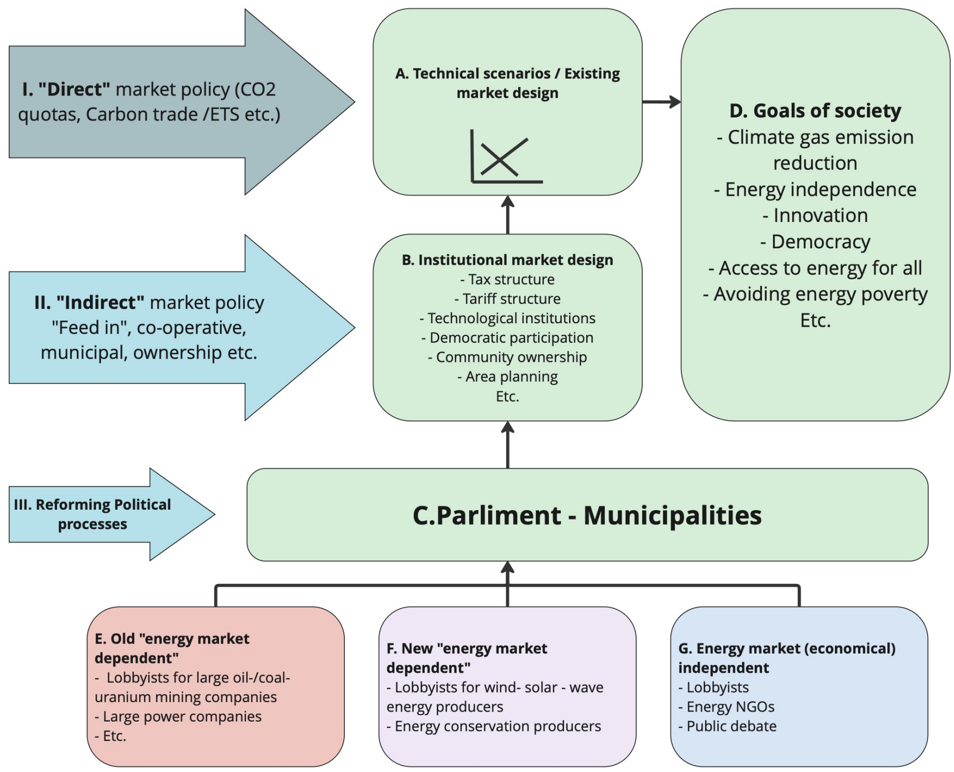


Figure 5.3. The components of energy politics. Developed by Hvelplund (2001).

or regional energy system, including BESS. It is illustrated in Figure 2.8 in Chapter 2, that BESS is already being implemented, and a large capacity is in the pipeline. As this deployment is happening at a fast pace, this thesis, therefore, aims to contribute to the knowledge and understanding of it to examine its deployment and the business case.

Methods 6

This chapter outlines the methods used. The chosen methods provide a framework for gathering data and knowledge needed to answer the research question and sub-questions. The following sections outline the concept, application and limitations of the methods: Literature study, Use of generative AI, Semi-structured interviews, Written correspondence, Stakeholder analysis, Energy modelling in Excel and Business economic evaluation.

6.1 Literature study

A literature study has been conducted throughout the chapters and analyses of this thesis. The literature study aims to understand the current knowledge and frameworks, identify gaps, and establish a theoretical context (Snyder, 2019).

In the problem analysis, literature was used to identify the initial problem and the state-of-the-art of BESS in the Danish energy system, as well as gaps in the current knowledge. In the analyses, a literature study was applied to cover the energy market structures, framework conditions, and the current legal framework of BESS. This is based on scientific reports and regulations by public institutions and stakeholders.

A semi-structured literature study of academic studies on the scope of the thesis BESS has been conducted to identify gaps in this literature. The semi-structured literature study aims to create an overview of the research area, existing research, development over time, and understanding of specific themes (Snyder, 2019). It is essential to map the literature that already addresses the scope of the thesis to avoid duplication of existing research. For academic literature, the following databases and search engines have been used: *AUB* (Aalborg University's library), *Science Direct*, *Google Scholar*, and *SciSpace*. To find relevant literature search terms such as *BESS*, *appliance*, *grid-scale*, *ancillary service*, *bidding strategy*, and more specifying words such as *Danish market*, *Lithium-ion battery frequency regulation*, *integration of renewable energy*, or *energy arbitrage* have been used.

The searches resulted in outcomes of different research articles and studies. All documents, articles, studies, and findings have been evaluated for their validity and transferability. The term validity is used for qualitative data and refers to the accuracy and to what extent the studies' findings can be generalised to this thesis (Lincoln and Guba, 1985). Various studies have examined BESS participation in energy markets and ancillary services, and these have been evaluated to determine whether these studies align with the research focus of this thesis. Transferability is used for qualitative data and refers to the degree to which the findings can be applied to other contexts (Lincoln and Guba, 1985). It is evaluated whether findings in some studies of BESS in other countries can be transferred to the context of the Danish markets and energy system.

The evaluation of the articles entailed reading the title, then the abstract, highlights (if given), conclusion, and eventually, the method and analysis of the literature were deemed relevant. The literature has been evaluated according to its time of publication, where publication within the last three to five years has been preferred, as large-scale BESS have undergone large development within this period (IEA, 2024). Furthermore, the literature has been evaluated according to the motivation behind the publication and validity for this search scope. For example, some of the studies address BESS's integration and participation in foreign countries. These have been evaluated based on their transferability to the Danish market. The critical approach to sources, authors, and messages stems from the social constructivist perspective, as emphasised in Chapter 4.2.

In addition to scientific literature from AUB and Science Direct and other databases, several reports and documents by Energinet have been used to identify challenges, possibilities, and framework conditions for integrating BESS into the Danish power system. Additionally, the *snowballing*-method has been used, where additional relevant studies have been identified by exploring the references in key articles (Wohlin, 2014). This helped to discover other pertinent literature that was not as easily found through the database search.

Limitation of the method

Limitations of the methods include selection bias, publication bias, time sensitivity, and scope limitations (Booth et al., 2012). The thesis group may have unintentionally selected studies that aligned with their idea of the relevant research area and missed relevant sources, addressing significant topics in BESS's problem analysis or research field. Publications may have a degree of bias from the author, and there has therefore been a cautious attention to potential underlying agendas from authors and stakeholders. It is important to consider the author or publisher (Booth et al., 2012). For example, project developers of BESS may be critical of the tariff structure and framework conditions of BESS, as they have an interest in profit and the deployment of BESS. However, it may not be the best societal solution, energy or resource-wise.

6.2 Use of generative AI

In this project, generative AI was used for selected tasks. Specifically, ChatGPT has been used for language-related support such as sparring and checking of text. It has further been used to clarify definitions and explanations, particularly when researching technical or economic concepts related to BESS or the electricity markets. Furthermore, ChatGPT has been used to explain formulas for energy modelling in Excel. AI was not used to generate analytical content, academic arguments, or writing parts of the project. While ChatGPT can be a helpful tool, it may occasionally respond with inaccurate or misleading information. Therefore, every time ChatGPT is used, the thesis group critically evaluates the answers, and the outputs are read through, discarded, rewritten, or cross-checked with scientific literature. In addition, ChatGPT has been used to make tables and BibTex sources using the correct LaTeX writing style.

This project has also utilised the AI-driven transcription tool Good Tape. Good Tape has been used to transcribe the interviews, reducing the manual labour required for transcription and rewriting. However, as Good Tape is AI-driven, it cannot fully guarantee the preservation of all nuances of speech in the interviews. Consequently, it is expected that there will be minor spelling errors, irregular sentence structures, and occasional inaccuracies in the transcription. The transcriptions have, however, also been reviewed for manual corrections. Good Tape is fully GDPR compliant, securing the data in the interviews for privacy. (Good Tape, 2025)

6.3 Semi-structured interview

Interviews were conducted with key stakeholders to understand the challenges and opportunities related to BESS deployment in Denmark. Key stakeholders were identified and interviewed based on their influence, involvement, and interest in BESS deployment. An effort was made to include interviewees with diverse expertise and roles within the value chain of BESS development in Denmark to ensure a comprehensive understanding of the technology.

All interviews for this thesis followed a semi-structured format, allowing for prepared questions and flexibility during the interview (Kvale and Brinkmann, 2015). The questions were tailored to each interviewee's role concerning BESS, based on background research on the company/organisation's webpages and other relevant sources. Each interview began with an introduction of the scope of this thesis, followed by general questions about the interviewee's company and their work concerning BESS. The interview then followed the questions of the interview guide. The semi-structured format enabled specifying and follow-up questions, allowing for deeper exploration of topics while still creating structure for the interview (Kvale and Brinkmann, 2015). Table 6.1 gives an overview of the held interviews.

Company/ Organisation	Interviewee	Title	Mainly covered areas	App.	Date
Cerius Radius	Mads Paabøl Jensen	Senior Lead Regulatory Advisor	Legal responsibilities, enquiries & tariffs	D	18. February 2025
Green Power Denmark	August Bech Anders Bitsch Youssef	Consultant Consultant	Potential applications, challenges & general market interest	E	19. February 2025
Energinet	Andreas Simoni Huse Pedersen Maibrit Vester Bundesen	Engineer Engineer - Prequalification	Grid challenges, Ancillary services, Providers & Outlook	F	21. February 2025
EWII	Thomas Bjerring Albrechtsen	Asset Manager	Market opportunities Their assets and experience	G	27. February 2025
Centrica Energy Trading A/S	Michael Mejdahl Ørkilde	Portfolio Manager	Current and future market structure, opportunities and strategies	H	3. March 2025
Niras	Niels Nielsen	Consultant, Engineer PhD	Technical considerations System perspective Challenges and opportunities	I	11. March 2025
Eurowind Energy	Jacob Hollerup Søndergard Gustav Damsgaard Ebbesen	Project Manager - Environment Project Manager - Local Engagement	Local planning and authorisation, Developer motivations & Environmental impact	J	13. March 2025
Sorø Municipality	Hans Henning Jensen	Planner and Landscape Manager	Local planning and authorisation & Emergency management	K	23. April 2025
Viborg Municipality	Birgit Balle Mads Tolborg	Land Surveyor RE planner	Local planning and authorisation	L	28. April 2025

Table 6.1. An overview of the respective interviews.

The interviews were recorded with the consent of the interviewees. This was done to process and utilise the interviews afterwards. All interviews were transcribed using the AI transcription program Good Tape, as written in Section 6.2. The transcriptions of the interviews are attached Appendix M. The transcriptions are kept in their original language, Danish, to ensure no meanings and expressions would become mistranslated. When utilising the insights from the interviews, they have been translated into English. AI-generated resumes of the transcription were made using Good Tape as an overview of the interview content. The resumes were read through for corrections and misunderstandings, and can be found in Appendix D - K. The interviews, their application, and their purposes are presented in the following sections in chronological order of the date of the interviews:

DSO, Cerius-Radius: Cerius and Radius are two Danish DSOs responsible for operating and developing Denmark's electricity distribution grids most of in eastern Denmark. As DSOs, they manage and are responsible for the grid stability, grid connections, and regulatory tasks of the distributive grids they operate (Radius Elnet, 2025). Senior Lead Regulatory Advisor Mads Paabøl Jensen was interviewed on the 18th of February 2025, and a resume is found in Appendix D. The interview aimed to understand how Cerius-Radius manages the growing interest in BESS, including the scale of projects and how the current grid planning handles this development. Additionally, the interview explored BESS's potential opportunities and challenges from a DSO perspective, including its impact on grid stability. The interview also focused on tariffs and grid connection fees, including whether adjustments to the current structures are being considered. Lastly, the interview provided insights into these DSOs' perspectives on the long-term role of BESS in the electricity system.

Green Power Denmark: Green Power Denmark is an industry organisation representing companies, actors, and organisations in the Danish electricity sector, including RE developers/producers, technology developers, etc. (Green Power Denmark, 2025b). Consultants August Bech and Anders Bitsch Youssef were interviewed on February 19, 2025. A resume is found in Appendix E. The interview was held at the beginning of the project period and functioned as an exploratory interview on the interests, challenges, application purposes, stakeholders, and incentives for BESS. Therefore, it was also used for the problem analysis. It focused on BESS's role in providing balancing and ancillary services, regulatory and market conditions, investment and business case uncertainties, and revenue streams. It also discussed Denmark's position relative to other countries as well as planning challenges for authorities. Finally, alternative technologies that could complement or compete with BESS and expectations for BESS's future in Denmark were discussed.

Energinet: Energinet is Denmark's TSO responsible for maintaining, building, and owning the transmission grid. They are, therefore, responsible for balancing and are the entity purchasing ancillary services from assets such as BESS. Energinet is a part of creating the frameworks and structures that affect the development of BESS, such as grid connections, ancillary services markets, pre-qualification, and tariffs. Engineers Maibrit Vester Bundesen and Andreas Simoni Huse Pedersen were interviewed on February 21, 2025. A resume is found in Appendix F. Bundesen and Pedersen work with prequalification in the Department of Ancillary Services and therefore have knowledge of challenges, ancillary services, and battery opportunities for frequency regulation. The interview focused on BESS's current and future role in providing ancillary services and grid balancing. It also discussed the growing interest in large-scale BESS and whether regulatory adjustments are needed. Additionally, the discussion addressed how BESS compares to other ancillary service providers and the risks of saturation in the ancillary services markets.

EWII: EWII is an energy concern involved in developing renewable energy and electricity infrastructure. It owns the DSO Trefor (EWII, 2025a). EWII has constructed Denmark's currently largest BESS facility on Bornholm, a 30 MW /43 MWh battery, and has additional smaller BESS projects in other locations (EWII, 2025b). They were contacted for an interview because of their experience with BESS deployment on various projects. Asset Manager Thomas Bjerring Albrechtsen was interviewed on February 27, 2025. A resume is found in Appendix G. The interview explored EWII's motivation for investing in BESS, project experiences, ancillary service market participation, and business case development. It also covered regulatory and permitting challenges, including municipal planning, safety regulations, and interactions with emergency services. Additionally, the interview discussed market dynamics, such as the importance of ancillary services in BESS profitability and the potential for future revenue streams.

Centrica Energy Trading A/S: Centrica Energy Trading A/S is an energy trading company that optimises the operation of energy production assets, participates in electricity, ancillary services, and gas markets. It trades on behalf of owners of energy production assets, including owners of BESS, and therefore knows BESS's different revenue streams and market structures. (Centrica Energy Trading, 2025) Portfolio Manager Michael Mejdahl Ørkilde was interviewed on the 3rd of March 2025, and a resume is found in Appendix H. The interview focused on how Centrica manages its BESS assets. It also covered long-term expectations for BESS in the Danish electricity market, including whether BESS is a viable long-term solution or a transitional technology, and how to compete with alternative flexibility solutions like demand response and VtG. Lastly, the interview examined the revenue potential and market strategies of the different potential revenue streams, such as ancillary services and arbitrage trading.

NIRAS A/S: Niras is a consultancy within different engineering sectors such as energy, planning, and infrastructure (NIRAS A/S, 2025). They provide technical, economic, planning, and environmental advisory services throughout the project lifecycle, assisting with everything from feasibility studies to engineering and permitting support. Engineer Niels Nielsen was interviewed on March 11th, 2025. A resume is found in Appendix I. The interview provided insight into the current challenges in local planning processes, authorisation, and the regulatory framework for BESS. Furthermore, the interview discussed the technical operation of batteries and the combination of BESS and VRE assets. Nielsen also provided knowledge of different cathode materials for Li-ion batteries and the advantages and disadvantages of each type, including fire risks.

Eurowind Energy: Eurowind is a developer of VRE and BESS. Eurowind Energy has BESS projects for existing and new VRE facilities in its pipeline. Thereby, they possess insight and experience with concrete projects. Project Managers Jacob Hollerup Søndergaard and Gustav Damsgaard Ebbesen of Environment and local engagement, respectively, were interviewed on March 13th, 2025. A resume is found in Appendix J. The interview gave knowledge of local planning, authorisation, and the environmental impact of BESS. It focused on spatial planning, visual impact, local worries, and fire risks. There was also a focus on Eurowind Energy's approach to scaling, placement, and motivation behind their projects, with an insight into the current market conditions of VRE in Denmark.

Sorø Municipality: The municipalities are the authorities responsible for granting BESS planning permission. Sorø Municipality, located in the middle of Zealand, was chosen due to its experience in making permits for the construction of BESS in rural areas. Planner and Landscape Manager Hans Henning Jensen was interviewed on April 23rd, 2025. A resume is found in Appendix K. The interview provided insights into their experience with the two BESS projects, of which they have permitted construction, as well as the general interest and inquiries they had received. The interview addressed general challenges, the municipality's considerations regarding placement, safety management, and neighbour concerns. Lastly, it was discussed whether the current national guidelines were sufficient.

Limitation of the method

While the interviews provide valuable insights into BESS development and market conditions, the method also has limitations. One limitation is the objectivity of the interviewees. Interviews reflect the perspectives of the individuals, even when they represent a company or organisation, and may be influenced by their roles, interests, or personal opinions (Kvale and Brinkmann, 2015). The questions asked were primarily neutral or open-ended, with questions such as:

- Which opportunities and challenges do you see for BESS in Denmark?
- How do you see the market development of the ancillary services market in the future?
- What are your motivations for developing BESS?

However, responses may still be subjective or influenced by personal views about BESS and its role; for example, developers might wish to change tariff structures to generate more revenue. Also, during the interviews, some framing or leading of questions may have happened unintentionally, and subtle cues from the interviewer, such as nodding or reacting to responses, may have influenced the interviewee's answers (Kvale and Brinkmann, 2015).

Another limitation is the generalisation of the responses given in the interviews (Kvale and Brinkmann, 2015). The findings are based on a limited number of interviewees and may not fully represent the broader energy sector. The opinions and responses may not be aligned with what other companies or even employees in the same company may have responded if they had been interviewed. Therefore, it has been essential to cross-check information by comparing insights from the interviews and validating them against the literature.

Despite the limitations of the interview as a method, it has been invaluable in gathering qualitative insights about BESS's development, structures, challenges, and opportunities in a Danish context that wouldn't otherwise have been available through just doing a literature study.

6.3.1 Written correspondence

In addition to the semi-structured interviews, written correspondence was also conducted with Viborg Municipality. According to the municipality's own assessment, they did not possess sufficient knowledge on BESS or enough time to participate in a full semi-structured interview. Therefore, they answered questions via written correspondence, giving Viborg Municipality more flexibility.

The written correspondence followed a structured approach with open-ended questions based on the same principles as the rest of the interviews. This provided the respondent the opportunity to reflect and offer considered answers. However, the use of written correspondence also introduced certain limitations. It restricted the opportunity for immediate follow-up questions and clarification of responses. Nevertheless, the insights obtained have been used particularly to support the analysis of local planning procedures and stakeholder cooperation. The response to the questions can be seen in Appendix L.

6.4 Stakeholder analysis

This section outlines the methodological approach used to map and analyse actors, contributing to the analysis and answering the first sub-question.

Understanding the various actors is essential for analysing the deployment of BESS as they shape the regulatory, financial, and technical conditions. As the actors hold varying levels of power and interest, it is essential to assess how they may support or challenge the development of BESS. In this way, this method also offers an insight into the dimension of the Organisation from the technology concept in Section 5.3, as it shows how the different stakeholders influence one another and the framework around BESS. The method forms the structure for the analysis in Chapter 7.

BESS is influenced by various actors, each with different interests and influences. It is important to distinguish between actors and stakeholders. Actors are directly involved in or influence the processes that shape the development of BESS. They have a direct role in determining policies, regulations, investments, and market structures. In contrast, stakeholders encompass a broader set of entities that have an interest in or are affected by the development of BESS but do not necessarily directly influence its implementation. While they may engage in discussions and shape public discourse, their role is often more indirect. (Hollebeek et al., 2020)

By systematically analysing the stakeholders and their respective positions, it is possible to identify key drivers and barriers to developing BESS. Some stakeholders may view BESS as an enabler of financial viability, while others, such as regulators, may be more cautious due to potential changes in market structures.

The stakeholder analysis in this thesis is based on the method description by Sarungu (2024), which has three phases: *Identification*, *Understanding*, and *Analysis*. These three steps help identify all relevant stakeholders, understand their interests, and analyse their influence to support the development of BESS (Sarungu, 2024).

The first phase, *Identification*, involves mapping out all relevant stakeholders that BESS may influence or affect, who are relevant in the development of BESS (Sarungu, 2024). The stakeholders are identified through reviewing literature, brainstorming, and mentions of stakeholders in the conducted interviews. Actors, such as Energinet, policymakers, and developers, hold direct power, as they are actively involved in shaping the regulatory framework and market structure that influence how BESS is integrated into the energy system and markets. Stakeholders, such as municipalities, research institutions, environmental organisations, and financial institutions, exert a more indirect influence. For example, while they are not directly involved in formal decision-making processes, they can affect the development of BESS through local planning processes, research, or by shaping investment conditions.

The second phase, *Understanding*, focuses on gaining insight into each stakeholder's positions, motivations, and potential impact. When a stakeholder is identified, the literature is examined to understand their role and how they are relevant. This includes a literature study and interviews to evaluate their power, interests, objectives, and possible areas of conflict. Understanding these dynamics is essential for gaining insight into the development of BESS. Every stakeholder will also get a score based on their power and interest in this phase. (Sarungu, 2024).

The third and final phase, *Analysis*, involves systematically evaluating each stakeholder's interests and power in the development of BESS. In this phase, the Power-Interest Grid framework is used, which categorises the stakeholders based on their level of power and interest in terms of the development of BESS in Denmark. (Sarungu, 2024)

The Power-Interest Grid

The Power-Interest Grid categorises stakeholders based on their ability to influence (Power) and their level of stake in its outcomes (Interest). The grid consists of four quadrants, as shown in Figure 6.1. The Power-Interest Grid is structured along two axes: the Y-axis represents the level of influence or power a stakeholder has over BESS deployment, and the X-axis reflects their degree of interest in the development of BESS. Interest increases from left to right, ranging from low (1) to high (5), while influence and power increase from bottom to top, following the same scale. (Sarungu, 2024) Each stakeholder is assigned a score from 1 to 5 for power and interest in the second phase. In the third phase, these scores are combined and analysed using the Power-Interest Grid.

Each quadrant represents a stakeholder category. Stakeholders with high power and high interest are categorised as *"Manage Closely"*, as they have a significant role in the policies, market conditions, and investment frameworks that determine the viability of BESS. Their involvement is essential, as their decisions can facilitate or hinder the large-scale development of BESS. (Zhu et al., 2024)

In contrast, stakeholders with high power but low interest belong to the *"Keep Satisfied"* category. While they hold substantial power over regulatory or financial conditions affecting BESS, their direct engagement with its development may be limited. They must be kept informed to enable them to make decisions on the development of BESS. They may not actively prioritise BESS unless strategic incentives align with their broader interests. (Zhu et al., 2024)

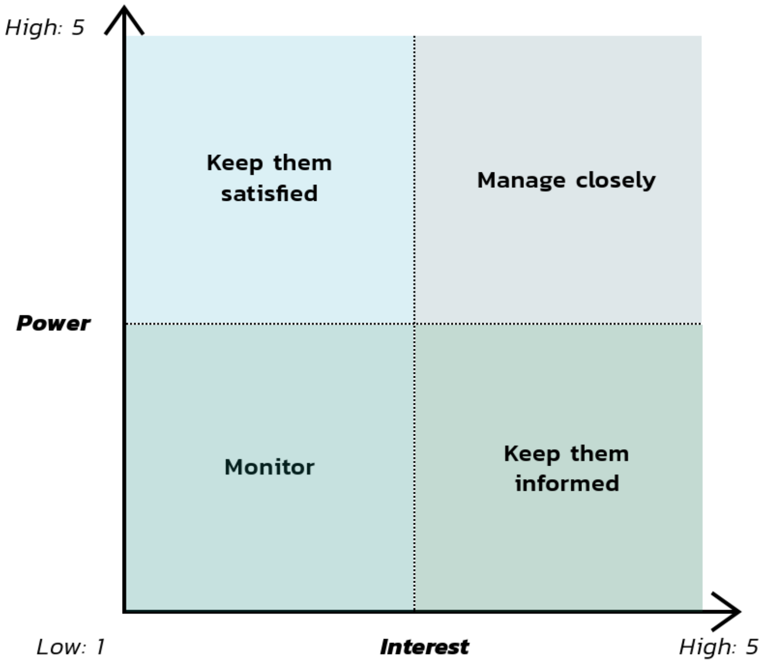


Figure 6.1. The Power-Interest Grid with the four quadrants of: "Manage Closely", "Keep Satisfied", "Keep Informed" and "Monitor" (Sarungu, 2024).

Stakeholders with low power but high interest belong to the category of *"Keep Informed"*. Although they do not directly control, for example, market conditions, they are actively engaged in discussions surrounding BESS and can influence the public and policy discourse. Maintaining transparency and collaboration with the stakeholders in this group can help build long-term support for BESS. (Zhu et al., 2024)

Lastly, the stakeholders with low power and low interest are categorised as *"Monitor"*. Their role in the development of BESS is limited, yet they may still be indirectly affected by its integration into the energy system. Their involvement remains minimal unless specific policy changes or local developments bring BESS to their attention. (Zhu et al., 2024)

Limitation of the method

While the stakeholder analysis provides a structured approach to understanding the role of different actors in the development of BESS, this method has limitations.

One limitation lies in the first identification phase, where mapping relevant stakeholder groups relies on literature studies, brainstorming, and the snowballing effect from interviews. Even when done comprehensively, this process may still lead to oversights or biases (Sarungu, 2024). Some stakeholder groups may not yet be actively engaged in the development of BESS but could become influential as market conditions change. Additionally, stakeholder groups that operate across multiple sectors may not fit neatly into the defined categories, making their roles more difficult to assess (Zhu et al., 2024). Furthermore, the selection of stakeholder groups is subjective, as it is determined by the thesis group based on available knowledge, expert input, and discussions with interviewees. This introduces a limitation in that specific relevant groups may be overlooked or undervalued in the analysis (Sarungu, 2024).

Another limitation arises in the second phase of understanding, where stakeholder motivations and objectives are evaluated. Stakeholder positions are not static, as they can shift over time due to changing regulations or technological advancements (Zhu et al., 2024). Additionally, specific stakeholders may intentionally or unintentionally provide subjective interview responses, potentially leading to misplacement of their power or interests (Kujala et al., 2022). In line with the post-positivistic approach written in Section 4.2, the assignment of scoring power and interest is based on the thesis group's interpretation of each stakeholder. Although the process is thorough, it is shaped by subjective judgments and should be viewed as an interpretation of stakeholder dynamics rather than an objective truth. Moreover, the scores are assigned at the group level, and differences likely exist between individual actors within each stakeholder group.

In the third phase, the Power-Interest Grid also has limitations. The grid simplifies complex relationships, reducing the stakeholders' power and interests to two dimensions. Many factors influence power and interests, and therefore, the grid does not account for nuanced interactions between the stakeholders. (Zhu et al., 2024).

6.5 Energy modelling in Excel

This section describes the method and calculation used to model a BESS facility in the electricity and ancillary service market. The specific case is described in the techno-economic analysis in Chapter 10.

The BESS market participation models are created in Microsoft Excel using the OpenSolver add-in to perform optimisation. OpenSolver utilises a linear programming solver method, the COIN-OR Branch and Cut (CBC) solver, which was applied in this model (Mason, 2012). The linear programming solver method finds the optimal value of a linear objective function subject to a set of linear constraints. CBC is an open-source solver designed to efficiently handle large linear and integer programming problems. The model uses historical intraday electricity price data from Nord Pool, and day-ahead prices and FCR capacity prices are from Energidataservice by Energinet.

The following subsections introduce the mathematical explanations for how the FCR, intraday, and day-ahead market participation are modelled in Appendix A.

Method for FCR participation

The participation of the BESS in the FCR market is modelled based on historical market prices and the bidding strategy described in Section 10.2. For each hour in the time $t \in \{1, ..., 8760\}$, the FCR market price P_t^{FCR} is compared to the bid prices P_t^{bid}, shown in Table 10.1. If the market price equals or exceeds the bid price, the bid is considered accepted, and the BESS is committed to providing FCR capacity in these hour. Since bids for FCR must be submitted before the gate opening of the day ahead and intraday market, FCR commitments can block day-ahead and intraday market participation, but not the other way around. The timeline of bids is illustrated in Figure 9.7.

The following parameters are used:

- $t \in \{1, ..., 8760\}$: represent each hour of the year
- $a_t \in \{0, 1\}$: binary parameter indicating FCR participation in hour t; 1 if the bid is accepted
- P_t^{FCR}: historical market price for FCR in hour t [EUR/MW]
- P_t^{bid}: bid price for FCR in hour t [EUR/MW]
- R_t^{FCR}: revenue from FCR provision in hour t [EUR]
- R^{FCR}: total revenue from FCR provision over the year [EUR]
- $P^{\max} = 10$: battery input/output capacity committed to FCR [MW]

The acceptance of a bid in FCR is represented by a binary parameter $a_t \in \{0, 1\}$, where:

$$a_t = \begin{cases} 1, & \text{if } P_t^{\text{FCR}} \geq P_t^{\text{bid}} \\ 0, & \text{otherwise} \end{cases}$$

This means that a_t is like a yes/no switch that tells the model whether it is participating in that hour or not. a_t is used in two parts of the model. First, it determines the revenue R from FCR in each hour:

$$R_t^{\text{FCR}} = a_t \cdot P_t^{\text{FCR}} \cdot P^{\max}$$

The total FCR revenue over the year is then:

$$R^{\text{FCR}} = \sum_{t=1}^{8760} a_t \cdot P_t^{\text{FCR}} \cdot P^{\max}$$

Second, a_t is used to prevent the BESS from participating in the intraday or day-ahead market in any hour where it is committed to FCR. This is implemented to define that when a_t is 0, then 10 MW is available for use in the day-ahead or intraday market, while 1 means that 0 MW is available in the particular hour. The FCR participation is an exogenous condition in the model, meaning that it is not optimised, and intraday and day-ahead will be optimised around FCR participation.

Method for intraday participation

The intraday market participation is modelled hourly and aims to maximise annual revenue through arbitrage trading while working within the BESS's operational constraints and market conditions.

As mentioned, the BESS facility can only participate in the intraday market during hours when it is not reserved for FCR, binary parameter $a_t \in \{0, 1\}$ as described above.

The following parameters are used:

- $t \in \{1, ..., 8760\}$: represent each hour of the year
- $c_t \in [0, C^{\max}]$: energy charged in hour t [MWh]
- $d_t \in [0, C^{\max}]$: energy discharged in hour t [MWh]
- $SoE_t \in [E^{\min}, E^{\max}]$: State of energy (SoE) at the end of hour t [MWh]
- η_c: charging efficiency [%]
- η_d: discharging efficiency [%]
- $E^{\min}$: minimum allowable SoE [MWh]
- $E^{\max}$: maximum allowable SoE [MWh]
- $C^{\max}$: maximum charge/discharge rate [MW]
- $P_t^{\min}$: minimum accepted price in hour t [EUR/MWh]
- $P_t^{\max}$: maximum accepted price in hour t [EUR/MWh]
- T_{ct}: tariff for electricity consumption in hour t[EUR/MWh]
- T_d: tariff for electricity fed into the grid [EUR/MWh]
- $\mathcal{T}_d \subset \{1, \ldots, 8760\}$: set of hours belonging to day d

Because the intraday market is pay-as-bid, and because of the modelling assumptions, the BESS facility is not assumed to buy consistently at the lowest or sell at the highest accepted price, which is given in the data sheet. Instead, the purchasing and selling prices are adjusted to 75 % of the minimum and maximum accepted prices. This is added to simulate a more realistic revenue stream from participating in the intraday market. These adjusted prices are denoted with a tilde to indicate that they are modified estimates rather than actual market-clearing prices:

$$\tilde{P}_t^{\text{buy}} = 0.75 \cdot P_t^{\min}, \quad \tilde{P}_t^{\text{sell}} = 0.75 \cdot P_t^{\max}$$

The SoE of the battery is updated hour by hour with the following equation:

$$SoE_t = SoE_{t-1} + c_t \cdot \eta_c - \frac{1}{\eta_d} \cdot d_t$$

Charging and discharging are only allowed when the battery is available and within technical limits. Here, c_t represents the amount of energy charged into the battery in hour t, and d_t represents the energy discharged. The charging and technical limits for the battery are thereby:

$$c_t \leq C^{\max} \cdot \eta_c, \quad d_t \leq C^{\max} \cdot \eta_d$$

$$E^{\min} \leq SoE_t \leq E^{\max}$$

As the model operates with hourly time steps, the power capacity $C^{\max}$ in MW is directly interpreted as an energy limit of $C^{\max}$ MWh per hour.

To limit battery degradation, the battery is restricted to two full charge-discharge cycles per day (2 x 20 MWh), corresponding to a maximum of 40 MWh charged and 40 MWh discharged daily. Let $\mathcal{T}_d \subset \{1, ..., 8760\}$ be the set of hours in day d. Then:

$$\sum_{t \in \mathcal{T}_d} c_t \leq 40MWh, \quad \sum_{t \in \mathcal{T}_\lceil} d_t \leq 40MWh \quad \forall d \in \{1, ..., 365\}$$

The actual revenue R_t^{ID} from intraday trading in each hour is calculated by subtracting the costs for buying (including tariffs) from the income from selling. The tariffs T_ct and T_d apply to consumption and feed-in respectively:

$$R_t^{\text{ID}} = d_t \cdot (\tilde{P}_t^{\text{sell}} - T_d) - c_t \cdot (\tilde{P}_t^{\text{buy}} + T_{ct})$$

The total intraday revenue over the year is:

$$R^{\text{ID}} = \sum_{t=1}^{8760} R_t^{\text{ID}}$$

OpenSolver operates within the above mentioned constraints to identify the optimal hourly charge and discharge strategy that maximises total annual revenue from intraday market participation. Because the Opensolver tool is used to optimise, perfect foresight is assumed.

Due to technical limitations in OpenSolver, particularly the solver's handling of large problem sizes, the model was split into two parts, each lasting six months. Although the paper: *"OpenSolver - An Open Source Add-in to Solve Linear and Integer Programs in Excel"* (Mason, 2012), suggests that OpenSolver can handle up to 70,000 variables and 76,000 constraints, the model developed in this thesis, with approximately 63,000 constraints and 16,000 variables, crashed unless it was split in two. This may therefore be due to limited computational power. As a result, certain features could not be implemented. For example, it was not feasible to implement a constraint that would prevent the BESS from charging and discharging in the same hour. Doing so would require introducing over 16,000 individual constraints. Consequently, the model in some hours both charges and discharges, which is a source of error.

Another limitation, is that the model is limited to data availability and simplification for the intraday market. The modelling is based on hourly price data, using only a minimum and maximum accepted price. In reality, the intraday market consists of numerous transactions matched in a shared Order Book, where bids can be adjusted, cancelled or resubmitted continuously throughout each hour (Energinet, 2019).

Method for day-ahead participation

Participation in the day-ahead market follows the same principles as in the intraday market. However, the day-ahead market is a uniform pricing market, meaning that all accepted bids are settled at the same market-clearing price. Therefore, the BESS is assumed to be a price taker and does not influence the market price.

The main difference between day-ahead and intraday participation is the revenue calculation. In the day-ahead market, the hourly revenue is given by the following expression:

$$R_t^{\mathrm{DA}} = d_t \cdot \left(P_t^{\mathrm{sell}} - \tau_d\right) - c_t \cdot \left(P_t^{\mathrm{buy}} + \tau_{ct}\right) \tag{6.1}$$

Unlike the intraday market, where different prices may apply to buying and selling, the day-ahead market uses a single uniform price. Therefore, the same price is applied to both charging and discharging decisions in the model and the opensolver therefore only has one price to determine to buy or sell from.

The total annual revenue from day-ahead market participation is calculated as:

$$R^{\mathrm{DA}} = \sum_{t=1}^{8760} R_t^{\mathrm{DA}} \tag{6.2}$$

6.6 Business economic evaluation

This section presents the method used to evaluate the BESS facility's economic performance. The evaluation is done from a business economic perspective, focusing on the investment's payback time and Internal Rate of Return (IRR). The primary metrics used for economic assessment in this thesis are the dynamic payback time and IRR. Dynamic payback time is the number of years required for the cumulative discounted net revenues to equal or exceed the initial investment cost, considering the time value of money. In addition, the IRR is calculated to complement the payback period, as it captures the investment's overall profitability. These metrics have been chosen because they fit with the business economic approach (Whitman and Terry, 2012). Throughout all calculations, current prices are used, which are adjusted with an inflation of 1.83 % per year based on an average of the project period from 2025 - 2040 (Danish Energy Agency, 2022a)

Dynamic payback time

The dynamic payback time is calculated by comparing the discounted, inflation-adjusted annual Net Cash Flows (NCF) to the Capital Expenditures (CAPEX). The cash flows consist of annual revenues from the FCR and intraday markets, subtracting annual Operational Expenditure (OPEX). Revenues and OPEX are calculated as current prices assumed to increase by 1,83 % per year because of inflation, described above (Danish Energy Agency, 2022a). Future cash flows are discounted using a 4.6 % annual nominal interest rate based on Statistics Denmark's data for new mortgage agreements by households with collateral in real estate. The rate is nominal, meaning it does not account for inflation (Statistics Denmark, 2025; Danmarks Nationalbank, 2023).

- t: time, the respective year
- I_0: initial investment cost
- R_t: revenue in year t
- O_t: operational expenditures in year t
- $i = 1,83\%$: annual inflation rate
- $r = 4.6\%$: annual interest rate

The inflation-adjusted and discounted NCF in year t is:

$$\text{NCF}_t = \frac{(R_0 \cdot (1+i)^{t-1}) - (O_0 \cdot (1+i)^{t-1})}{(1+r)^t}$$

The payback time is the smallest integer N such that the cumulative sum of NCF equals or exceeds the CAPEX:

$$\sum_{t=1}^{N} \text{NCF}_t \geq I_0$$

Internal rate of return

The IRR represents the annual rate of return at which the net present value (NPV) of all future cash flows equals zero. It is calculated based on inflation-adjusted annual net cash flows. Revenues and OPEX are both assumed to increase by 1.83 % per year due to inflation. Unlike the payback time calculation, no external interest rate is applied, as the IRR represents the interest rate that balances the investment.

- I_0: initial investment cost
- R_t: revenue in year t
- O_t: operational expenditures in year t
- i: annual inflation rate, 1,83%

The inflation-adjusted net cash flow in year t is given by:

$$\text{NCF}_t = (R_0 \cdot (1+i)^{t-1}) - (O_0 \cdot (1+i)^{t-1})$$

The internal rate of return r is the value that satisfies the following condition:

$$0 = -I_0 + \sum_{t=1}^{T} \frac{\text{NCF}_t}{(1+r)^t}$$

Where T is the total years in the investment period. The IRR is found numerically using this equation and reflects the average annual return generated by the investment over its lifetime.

There is no definition of an acceptable IRR, as it depends on the project's risk profile, market conditions, and investor expectations. However, the paper *"Infrastructure fund as an alternative driver in the implementation of green energy policy in European countries"* suggests that for renewable energy infrastructure projects, IRRs typically range between 6 - 15 % (Klimek et al., 2024).

These calculations are found in Appendix B.

Stakeholder analysis 7

This analysis examines the first sub-question *"Who are the current key stakeholders in Denmark involved in BESS deployment, and what are their roles, influence, and interests?"* The stakeholder analysis is conducted to understand the organisational dimension of BESS deployment in Denmark. This analysis aims to identify the stakeholders involved in BESS's deployment and implementation and examine how their roles and interactions influence the planning and deployment processes. The analysis follows the method described in Section 6.4. Stakeholders are identified according to their power and interest in BESS deployment to analyse the organisational structure of BESS. The findings contribute to a holistic understanding of the organisational situation that shapes BESS deployment and serve as a basis for discussing challenges and opportunities in this dimension of BESS as a technology.

7.1 Identification of relevant stakeholders

Phase one, Identification, involves finding all relevant stakeholders. This is done by brainstorming, using current knowledge, the snowball effect from interviews, and the literature study. Stakeholders are grouped, which means not all relevant stakeholders are identified. An example of such a grouping could be "BESS and VRE Developers." As there are many BESS developers, such as Eurowind Energy, EWII, European Energy, etc., an exhaustive list of all developers currently developing BESS would be too detailed. Table 7.1 lists relevant stakeholder groups which in some way have influence or interest over BESS development in Denmark, either directly or indirectly.

7.2 The stakeholders' power and interests

The goal of the second phase of the stakeholder analysis is to understand the stakeholders. This is done by evaluating their power and interest in BESS development in Denmark, according to the grid in Figure 6.1. Each stakeholder group is assessed regarding their power and interest, respectively, with a score ranging from 1 (low) to 5 (high). The scoring is based on literature, interviews, and webpages of some stakeholders under the stakeholder groupings. The opinions from interviewees have been used cautiously, as their perspectives could be generalised for the broader stakeholder group, which may not be entirely accurate.

The context is important when assessing stakeholders. For example, the TSO Energinet has varying levels of influence depending on BESS's role now and in the future. If BESS is used primarily for peak shaving of VRE projects, Energinet's role could be limited. However, BESS could supposedly have a significant role in providing ancillary services. In that case, the TSO becomes a key stakeholder as they are interested in BESS's services for the grid along with other technology providers.

The assessment of each actor includes a description of the actor and their role in BESS development, followed by a description of their Power and Influence, and, finally, the scoring of these two parameters. Hereafter, Section 7.3 gives an overview of the placement of the stakeholders in the Power/Interest grid, and the interaction between the stakeholders.

Stakeholder (grouping)	**Examples of stakeholders**
BESS and VRE developers	**Eurowind Energy**, **EWII**, Battman Energy, European Energy
Transmissions system operators (TSO's)	**Energinet**, European Network of Transmission System Operators for Electricity (ENTSO-E)
Distribution system operators (DSO's)	**Cerius** , **Radius Elnet** , N1, Nord Energi
Municipalities	**Viborg Municipality**, **Sorø Municipality**, KL
Government & Regulators	European Union (EU), Danish Energy Agency, Ministry of Climate, Energy, and Utilities, Danish Utility Regulator
Safety regulators	Danish Emergency Management Agency, Local fire departments
Energy traders	**Centrica Energy Trading**, Danske Commodities, Energi Danmark
Competitors	CHP & Biomass: Ørsted, Vattenfall; Pumped Hydro: Statkraft, Vattenfall; Power-to-X: Everfuel, European Energy; Aggregators: Flextools, EasyPower
Investors & financial institutions	PensionDanmark, Copenhagen Infrastructure Partners (CIP), Banks
Consultants	**NIRAS**, Sweco, Hybrid Greentech
Industry organisations	DaCES, **Green Power Denmark**, Energy Cluster Denmark
Research & academia	Technical University of Denmark, Aalborg University
Citizens	Local citizens and neighbors
Battery manufacturers	ABB, LG Energy Solutions, Samsung

Table 7.1. Key stakeholders and examples relevant to utility-scale BESS development. Stakeholders who have been interviewed are written in bold.

BESS and VRE Developers

BESS and VRE developers are central in developing BESS projects regarding planning and establishment. The primary motivation for BESS developers stems from the potential for revenue generation and optimisation, mainly through energy arbitrage, peak shaving, and participation in ancillary service markets. The interview with Eurowind Energy indicated that their focus is on integrating batteries with existing and new VRE assets, particularly solar, to improve the economic viability of their projects from electricity sales to reducing grid connection tariffs (Albretschen, 2025). Eurowind emphasised that batteries allow peak shaving of solar generation to the evening, addressing market saturation issues where midday solar production can lead to negative electricity prices (Søndergaard and Ebbesen, 2025). EWII highlighted that their business case relies on utilising BESS in ancillary and electricity markets, while their ambitions for utilising BESS in their distribution grids (as owners of the DSO Trefor) are currently restricted by regulations (Albretschen, 2025). Because of this, BESS developers are highly invested in BESS deployment as they can improve the financial situation of their current investments and generate revenue from the BESS itself. Therefore, the BESS developers' interest is scored 5 out of 5

Regarding power, BESS developers influence individual projects and make the final investment decisions, allowing them to shape the development of individual BESS projects within the constraints of the existing regulatory and market structures. BESS developers are a new market entrant. Their power is limited as they cannot directly change regulatory conditions for BESS deployment, which frames their planning or the economy of BESS. Instead, they must rely on lobbying efforts directed at the government and regulators to create more favourable business conditions for BESS deployment, such as improved tariff structures, streamlined permitting processes, and area planning (Hvelplund and Arler, 2015). Because of these considerations, the power of BESS developers is scored 4 out of 5, reflecting their central role in project development while recognising limitations.

Transmission System Operator - Energinet

The TSO, Energinet, is overall responsible for maintaining the security of supplies of the Danish electricity and gas grid (Energinet, 2025a). It is an important stakeholder as it participates in developing market structures and tariff design (Bulut, 2024). Energinet sets standards for the technical requirements and pre-qualifies assets such as BESS facilities for ancillary services. Energinet thereby influences whether and how a battery storage facility can participate in ancillary service markets. Additionally, their role in creating tariff structures affects the economic viability of BESS projects. (Pedersen and Bundesen, 2025) However, Energinet does not have full autonomy in these areas, as it must operate within the regulatory framework established by the DEA and the Ministry of Climate, Energy, and Utilities. Therefore, their power over BESS deployment is limited by political decisions and broader energy policy goals and requirements (Pedersen and Bundesen, 2025). Because of these considerations, Energinet has scored 4 in terms of its power over BESS deployment.

Energinet's interest in pushing BESS development is limited as they take a technology-neutral approach, meaning they do not favour batteries over other flexibility solutions such as demand response, thermal storage, etc. Their objective is to obtain the lowest possible electricity prices for consumers (Pedersen and Bundesen, 2025). However, Energinet recognises that BESS offers unique abilities in frequency regulation, particularly in mitigating rapid fluctuations from solar production. In the interview, Energinet representatives noted that cloud cover could cause sudden and unpredictable variations in PV output, requiring fast-response assets like BESS to stabilise the PV's injection of electricity to the grid. (Pedersen and Bundesen, 2025) Because of these considerations, their interest is scored at 3 as they recognise the potential of BESS but do not actively push its development.

Distribution System Operators

The DSOs have a role in managing the distribution grid and grid connections. Their responsibilities primarily involve ensuring grid stability, planning network expansions, and setting tariff structures (Radius Elnet, 2025; Jensen, 2025b) . Unlike the TSO, DSOs do not control system balancing markets and do not have authority over prequalification processes for ancillary services. However, DSOs can influence the regulatory framework by providing input to policymakers and regulatory bodies about the impact of BESS on the distribution grid. According to the interview with Mads Paabøl Jensen from Cerius-Radius, DSOs work with government institutions and industry organisations to create tariff and regulatory structures (Jensen, 2025b). Given this indirect role, their power score is 2.

In terms of interest, DSOs adopt a technology-neutral stance, meaning they do not actively promote any specific technological solutions and therefore do not favour BESS over other technologies. (Jensen, 2025b). Furthermore, the regulatory framework limits DSOs from directly utilising BESS to balance distribution grids, reducing their interest in BESS deployment (Albretschen, 2025). Cerius Radius underscores that DSOs cannot assume that batteries will always have a net-positive impact on grid stability; however, there might be some applications for distribution grids (Albretschen, 2025). Because of these considerations, the DSO's interest in BESS was scored at 2.

Municipalities

BESS are subject to the general regulations of rural zone regulation, local and municipal planning of the Planning Act (Danish Ministry of Urban, Rural and Church Affairs, 2024; The Danish Planning and Rural Development Agency, 2025). The municipalities are thereby responsible for the local planning, permitting, and land-use regulations, some environmental permits, and the involvement of the general public. They therefore possess a central role in deploying BESS locally. They can choose to reject or begin authorisation or planning of BESS applications based on an assessment of zoning laws, principles of spatial planning, environmental assessments, and local community concerns (Jensen, 2025a; Balle and Tolborg, 2025). This regulatory role gives municipalities a moderate power score of 3 over BESS development.

Regarding interest in the deployment of BESS as a technology, the municipalities focus on the national energy targets and goals, including renewable energy deployment, district heating, gas phase-out, etc., rather than specific support for battery storage. From a planning perspective, they must base their decisions on the purpose clause of the Planning Act, national interests, and their internal directions for local and municipal planning (Danish Ministry of Urban, Rural and Church Affairs, 2024). Balle and Tolborg (2025) from Viborg municipality highlights that the municipalities have an interest in a due process, transparency, and a fair foundation for the planning.

The municipalities' interest in BESS has been scored 2. This refers to their interest in the planning process for BESS, rather than its implementation, development, or penetration in the Danish energy system. Their roles and interests in the planning process are examined further in Chapter 8.

The National Association of Local Authorities in Denmark (KL) is a political interest organisation that represents the collective municipalities in national policy development. While KL does not have a formal regulatory role, it supports municipalities through guidance and coordination, particularly on matters related to local planning and implementation. In this way, they indirectly influence the framework for BESS by contributing to the interpretation of planning procedures and facilitating knowledge sharing between municipalities. (Kommunernes Landsforening, 2025)

Regulators and government

The Danish government, regulators, and ministries define regulatory and legal frameworks for different stakeholders and fields, and directly impact the deployment. The European Union (EU) establishes overarching directives and regulations for sectors within which the Danish government must operate. This is, for example, tax structure, tariff structure, area planning, etc. (Hvelplund and Arler, 2015)

The EU, Danish government, and regulating institutions have high power in shaping BESS development through regulation, support schemes, market design, and legal frameworks. The EU has a direct and indirect influence on Danish legislation. For example, the EU has passed the Electricity Regulation (EU) 2019/943 and Electricity Directive (EU) 2019/944, which define the fundamental principles for the energy markets (EU, 2024). The EU also defines product requirements and specifications of batteries in the Battery regulation 2023/1542, such as labelling and handling after the end of the lifetime (EU, 2023).

The Ministry of Climate, Energy, and Utilities defines long-term strategies as the purpose of developing a foundation for green transition, as well as efficient utility sectors (Danish Ministry of Climate, Energy and Utilities, 2025a). Agencies like the DEA and the Danish Utility Regulator approve grid tariffs and market participation rules (Energinet, 2025). Therefore, their decisions can both enable or restrict BESS deployment. Given the governments' and regulators' control over policy and market structures, their power score is 5.

The government and regulators are generally interested in the security of supply and a sustainable, effective energy system (Danish Ministry of Climate, Energy and Utilities, 2025a). They have published strategies or support schemes for other new or well-known technologies and infrastructures such as PtX, CCUS, offshore tender, and hydrogen pipeline (Danish Ministry of Climate, Energy and Utilities, 2025c; Danish Energy Agency, 2025b,a). Until now, the government has not published official strategies, statements, programs, or plans mentioning large-scale BESS specifically. However, battery storage can fall under the demand for advancing flexibility and solutions for integrating more renewable energy, together with other technologies (Danish Ministry of Climate, Energy and Utilities, 2023). Their position and interest in BESS can, thereby, be perceived as relatively low or uncertain. This could be because BESS is a relatively new technology, with alternative grid flexibility and storage solutions being available. A focused strategy, interest, and position in large-scale integration of BESS have not been developed (Balle and Tolborg, 2025). Nevertheless, according to the Danish Climate law, the government has a goal of becoming climate neutral (Danish Ministry of Climate, Energy and Utilities, 2021). Together with other technologies, BESS might have the capability of providing grid stability and integrating renewable energy, and the government and regulators could, therefore, be interested in being informed and updated on its impact on the Danish energy system. For these reasons, their interest in BESS deployment is scored 2.

Safety Regulators

Safety regulators ensure that BESS projects adhere to safety standards and risk management protocols. This includes fire safety, emergency response planning, and hazardous material handling. Relevant stakeholders include the Danish Emergency Management Agency and local fire and emergency departments. The Danish Emergency Management Agency (2023) has published a guidance document on fire prevention and protection of large-scale lithium-ion batteries and BESS in general. BESS is conceived as a combustible storage and can therefore be regulated by the declaration of emergency management (Danish Ministry of Defence, 2017). With the guidance document on insurance against fire, the emergency management agency can impact the physical construction design of BESS. It also concerns the treatment of wastewater and management of fire water, in case of fire (Søndergaard and Ebbesen, 2025; Bech and Youssef, 2025). According to different interviewees, the constraints differ between each municipality and local fire and emergency departments, and there are still uncertainties among these constraints (Nielsen, 2025; Søndergaard and Ebbesen, 2025; Albretschen, 2025; Bech and Youssef, 2025). These aspects of risk management and collaboration between the stakeholders are examined further in Chapter 8.

These constraints, therefore, set requirements for the developer and owner in the construction design and local planning. The distance between the containers impacts the overall spatial need and thereby the planning process (Søndergaard and Ebbesen, 2025). The developers should further acquaint themselves with the local emergency management, as these can differ locally. Given their authority to impose safety requirements that can impact a BESS project's feasibility and financial viability, they score 2 in power. However, as their involvement consists of reviewing and approving projects submitted to them, they score 1 in Interest.

Energy Traders

Energy traders play a key role in the market and commercialisation of the products of BESS (Bulut, 2024). They act as intermediaries between electricity-producing and other facilities and the energy market, including for BESS, enabling operators to monetise the products of BESS (Bech and Youssef, 2025). Energy traders such as Centrica actively manage BESS on behalf of owners while providing trading services and handling technical constraints such as state of energy management (Ørkilde, 2025). While energy traders possess a high degree of expertise in energy market participation and are essential for maximising the revenue generation of BESS. They typically engage with projects once assets are operational with no formal authority over regulations or market designs (Centrica Energy Trading, 2025). Consequently, while their active role in market participation and in procuring assets they can manage warrants a high score of 4 in Interest, they score a 2 in Power due to their limited involvement in the development of BESS.

Competitors in the electricity markets

BESS developers often compete with or complement other owners who provide flexibility or capacity to the energy system. These are, for example, operators of, Combined Heat and Power (CHP), pumped hydro storage, PtX developers, flexible demand from electricity consumers, and the heating sector (Pedersen and Bundesen, 2025). Aggregators of different technologies can also provide flexibility to the energy system by bundling resources and technologies (Meesenburg et al., 2020). While some aggregators incorporate BESS within their portfolios, they are included as a competing technology due to their engagement with these other technologies, such as freezers, electric vehicles, etc (Energinet, 2025b).

All these technologies typically operate independently from BESS projects and do not play a direct role in their development or market operation, so they are given a low score of 1 in Interest. However, they exert power by shaping market conditions as they compete for the same revenue streams in the ancillary and wholesale markets and lobbying decision-making, which gives them a score of 2 in Power.

Investors and Financial Institutions

Financial entities can provide the capital necessary for BESS's initial investment costs (Bulut, 2024). This group includes pension funds, investment firms, and banks, which evaluate projects based on risk-return profiles (Hameed et al., 2023). While investors and financial institutions are essential to enable projects for BESS through financing, their involvement in the specific project is limited. Their primary influence lies in setting investment criteria and ensuring financial viability, thereby indirectly shaping the project (Bech and Youssef, 2025). Consequently, they score a 2 in Power, reflecting their ability to approve or reject projects based on financial risks. Given that BESS only represents one of several possible technologies competing for financing, their interest is primarily guided by creating revenue from their loans or investments. Their interest in individual BESS projects is scored as a 2.

Consultants

Consultants offer technical, economic, planning, and environmental advisory services, and their involvement may range from feasibility studies to engineering and permitting support. Consultants can be relevant for developing BESS facilities, as they may follow the process closely depending on their role and involvement in the different stages. They can contact other stakeholders on behalf of and in cooperation with the customer (Nielsen, 2025). Consultants are interested in obtaining expertise and knowledge of the general market and their customers' interests. Consultants do not have a share in the ownership of the projects and are not dependent on the outcome of the projects, however, there is a branding interest in terms of successful projects. They hold expert knowledge and deliver the requested work for their customers. Their interest and power are thereby low and are therefore scored as a 2.

Industry Organisations

Industry organisations represent collective interests, facilitate knowledge sharing, and lobby for favourable policies related to BESS and broader energy transition topics (Bulut, 2024). Green Power Denmark and Energy Cluster Denmark are central networks for stakeholder collaboration and policy engagement for the electricity and renewable energy sector. Green Power Denmark represents VRE developers/producers, grid operators, technology developers and advocates for policy and regulatory frameworks that support integrating renewable energy and new technologies such as PtX and BESS (Bech and Youssef, 2025). The Danish Center for Energy Storage (DaCES) is a network-based organisation for Energy Storage that works to define the needed innovation and research contribution in cooperation between universities and research-oriented companies. The organisation is thereby more research and development-oriented in terms of BESS (DaCES, 2025).

Industry organisations are interested in developing or maintaining favourable commercial market conditions for their members' businesses (Hvelplund and Arler, 2015). Many developers are interested in BESS for commercial interests such as reducing tariff costs, energy arbitrage, and improving authorisation processes, (Bech and Youssef, 2025). Green Power Denmark represents these interests of the electricity and renewable energy sectors, and if these are interested in BESS, the organisations will likewise be interested. They are, therefore, scored as 4 in interest. Industry organisations can lobby or be part of the negotiations for new market conditions and speak on behalf of their commercial members. They, therefore, scored 4 in terms of their power of framework conditions and BESS deployment.

Research and Academia

Research institutions and universities contribute to advancing and generating knowledge about BESS technologies, technical operations, grid integration strategies, and market mechanisms. They often collaborate on research projects, pilot studies, and innovation activities, especially technical operations and market structures (Hameed et al., 2023; Zhao et al., 2023). DaCES, as mentioned in the previous section, is also linked to research and academia, as its members include research institutions that cooperate with consultants and other research-oriented companies (DaCES, 2025). Danish universities and research institutes can be interested in BESS to develop Danish expertise and a thorough knowledge base for decisions. They can contribute with knowledge of technological optimisation in operation and market analyses for investors. Their work can also contribute to a system-based understanding of BESS's role, necessity, and interaction in a broader energy system planning perspective. They do not have direct power in decision-making, but rather an indirect influence, and their power is therefore scored at 2. Research institutions are not necessarily interested in deploying BESS as a technology but rather have expert knowledge of its technical prospects and influence aspects, advantages, and disadvantages. Therefore, they are scored as 2 in interest.

Citizens

Local citizens can become affected by becoming neighbours to BESS projects. Transparency, early dialogue, and information are essential to accommodate neighbours and citizens' eventual concerns (Jensen, 2025a). It is important to clarify the facts about the technology, projects, and risk management (Jensen, 2025a; Søndergaard and Ebbesen, 2025). Developers can attempt to accommodate visual impacts for neighbours and citizens by considering placement and visual appearance with plant vegetation belts (Søndergaard and Ebbesen, 2025). Through dialogue with the municipality and the developer, the citizens can have some degree of influence. Most large-scale projects in Denmark are still in an early stage of development, and it is difficult to analyse the impact on locals and citizens. The main experienced concerns by the citizens are investigated further in the following chapter 8. Locals primarily interact with the municipality and project developers (Søndergaard and Ebbesen, 2025; Jensen, 2025a). The degree of participation and involvement can significantly differ for each project. Locals are scored low on power and interest, thereby scoring 1 in both.

Battery Manufacturers

Battery manufacturers supply the technology for BESS installations, including battery cells and integrated systems. Their role is important for ensuring system reliability and efficiency. Examples of these manufacturers are ABB, CETL, Tesla, LG Energy Solutions, and Samsung, where China is dominant in manufacturing facilities, followed by the United States (Danish Energy Agency, 2024c). Given their dependence on the development of BESS for market growth, battery manufacturers are given a high score of interest of 5. Their power is scored 1 as they have no direct effect on BESS deployment in Denmark.

7.3 Overview and analysis of the stakeholders

In the final phase, Analysis, each stakeholder is placed in the Power-Interest Grid to visualise their power and interests. Figure 7.1 shows an overview of the stakeholders' scores in the power-interest grid.

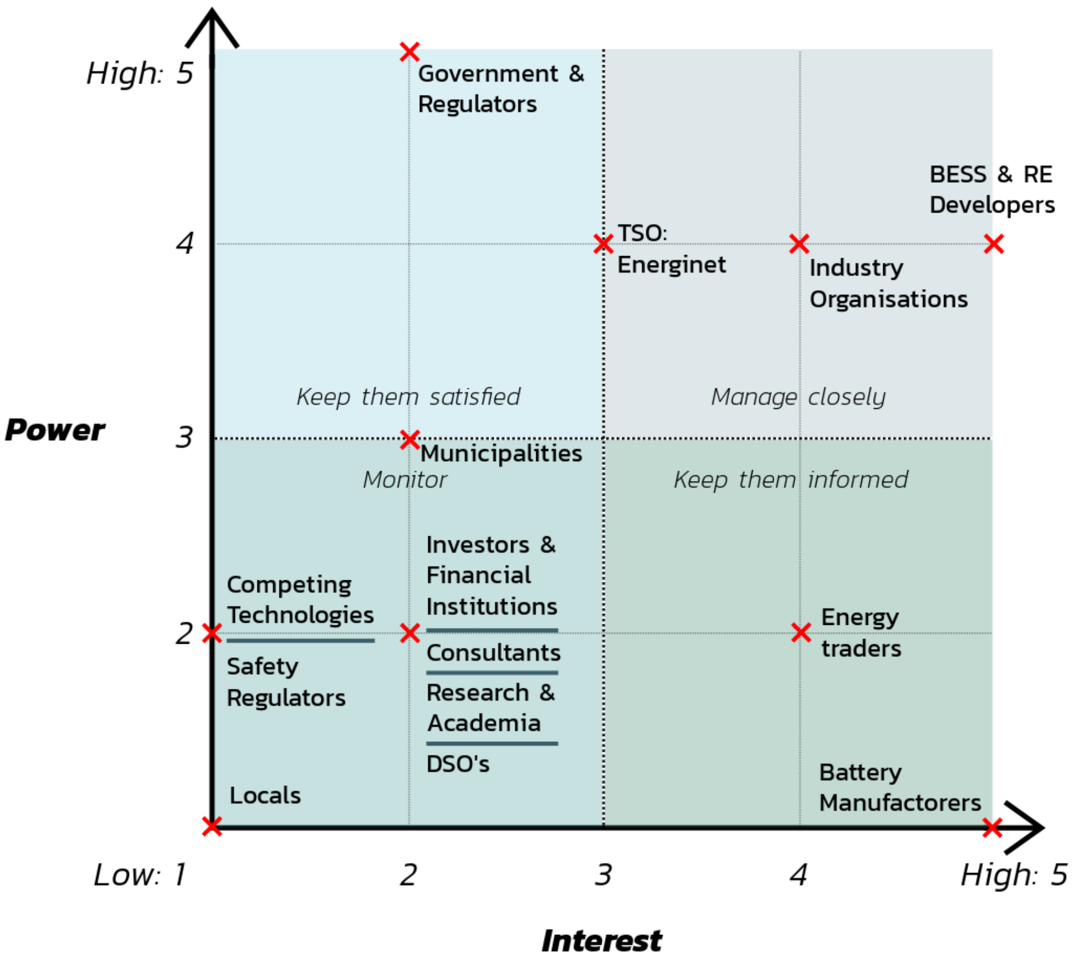


Figure 7.1. Scoring of the stakeholders.

Looking at the figure, the actors in the *"Manage Closely"* category are those with high power and high interest in the development of BESS. Economic interests or operational interests primarily drive this. These stakeholders are the primary actors driving or regulating BESS deployment in Denmark. They should be involved in decision-making about the future of BESS.

In the category *"keep them informed"*, the stakeholders with high interest but low power are placed. These stakeholders' interests are primarily monetary. Even though their influence is low, their role is important for generating revenue and driving BESS innovation. Therefore, they should be informed about changes in BESS's structural conditions and political ambitions for BESS in Denmark.

The stakeholders in the *"keep them satisfied"* category are the stakeholders with high power but low interest. These actors set frameworks, standards, and regulations and can enable or constrain BESS development in Denmark. Their interests are primarily either political or operational. The stakeholders are kept satisfied if the power grid is well-functioning and overarching political goals are achieved for the energy systems. Therefore, if BESS proves to be relevant to attaining these objectives, they could consider changing regulations to create more favourable conditions for BESS or vice versa.

The stakeholders in the *"monitor"* are those with low interest and power in BESS deployment. These actors have some financial, operational, political, or economic interests in BESS, but BESS is only a tiny part of their broader responsibilities, business activities, or interests. The stakeholders should be observed for any shifts in interest or influence that could affect BESS development.

Based on this analysis, it is found that BESS's development is primarily driven bottom-up by BESS developers, who initiate projects based on revenue optimisation and generation interests. There is no direct support or strategic prioritisation from the Danish government and regulators, which its recent maturation could explain. No support schemes or governmental targets for BESS, such as those seen for PtX and biogas, have been politically implemented, meaning its expansion relies on market-driven incentives rather than top-down policy initiatives. If BESS proves to develop and function under current market conditions and without support schemes and political targets, it could show that BESS has a strong market viability. However, this is investigated more in depth in the second analysis.

The interrelationships between stakeholders

A visualisation of the interactions between stakeholders regarding BESS planning and implementation can be seen in Figure 7.2. BESS developers are the central stakeholders in BESS planning and implementation as they are the main drivers and the ones who actively attempt to plan and build BESS facilities and, therefore, have to consider various variables such as revenue generation, regulation, technological specification, safety, etc. To navigate these variables, the developers sometimes hire consultants to assist or advise. If BESS developers want to attempt to influence the variables, they can converse with industry organisations that can try to influence regulators.

All stakeholders may have some direct or indirect relations, but in the Figure, some of the most central interactions are marked. For example, the project developer can also contact locals through private dialogue or public meetings, but it is the municipalities' responsibility to consider all common interests (Søndergaard and Ebbesen, 2025). Developers and municipalities may also have a dialogue with Energinet regarding grid capacity and expansions (Pedersen and Bundesen, 2025). Industry organisations can likewise interact with project developers and facilitate knowledge sharing, workshops, dialogue, and collaboration between several stakeholders (Bech and Youssef, 2025). Research and Academia can be seen as more or less independent stakeholders who interact and collaborate with different stakeholders, collaborate on technology development, and have an indirect influence on decision-making (DaCES, 2025).

The stakeholder analysis was conducted to investigate the organisational dimension of the technology concept. The analysis shows that, despite BESS being a relatively new technology, its organisational structure is already established and functioning. The development and deployment of BESS largely follow the same stakeholder framework as traditional VRE projects, with key actors such as developers, regulators, grid operators, municipalities, and financial institutions having similar roles. However, the development is primarily bottom-up, driven by VRE developers.

BESS introduces new dynamics within this structure. While many stakeholders involved in BESS development are the same as those of VRE, some dynamics have changed, and certain stakeholder groups are emerging with a specific focus on battery storage. The new dynamics include developers who must find and communicate with battery manufacturers to make batteries that can participate in the ancillary service markets, as well as the more influential role of Energinet in prequalifying the BESS facilities for participating in ancillary services. Energy traders must develop complex market participation strategies or algorithms for BESS to optimise its revenue generation.

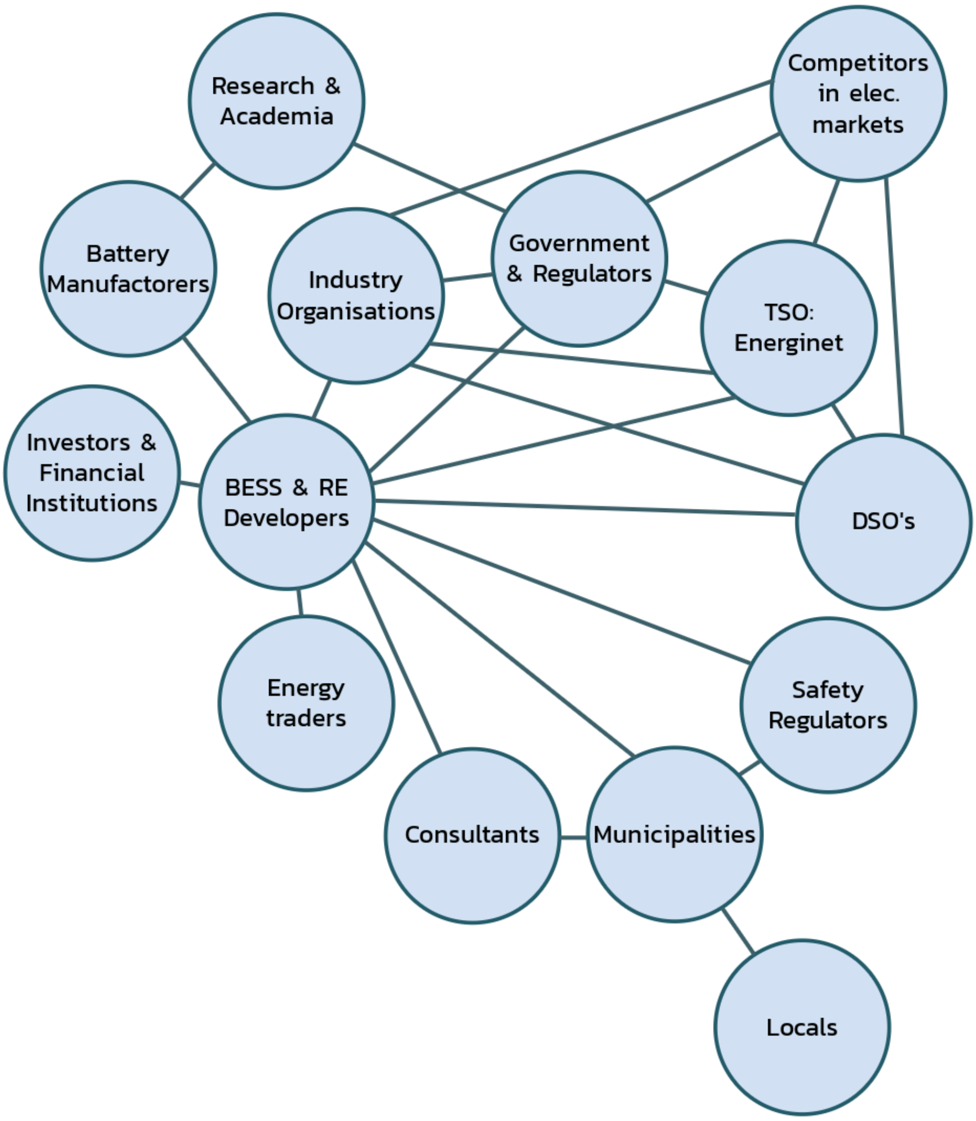


Figure 7.2. The interrelationships between the stakeholders of the development of BESS.

The role of locals, when compared to wind and PV projects, is also less important, as BESS facilities are not as visually polluting. However, this is still difficult to conclude as fewer BESS projects have been through the planning process. Denmark's current organisational setup between municipalities, regulators, and safety regulators for BESS deployment presents opportunities for improved coordination, as it is a new market entrant. The second sub-question examines the deployment and planning processes in the municipality to understand the current framework better and explore how it can support public authorisation handling and a more predictable investment environment.

Local planning and authorisation 8

This chapter addresses the second sub-question: *"How does regulatory and local planning uncertainty affect BESS planning, and which planning aspects should stakeholders consider?"* BESS represents a new type of technical infrastructure within existing spatial planning and regulatory frameworks. As outlined in Section 2.3, there is currently no comprehensive guidance for BESS's review, authorisation, and local planning in Denmark. Public administration and planning procedures are integral to BESS investment, decision-making, and deployment. This chapter explores the organisational and knowledge dimensions, their related challenges, and how the absence of established practices and regulatory clarity influences BESS deployment. The analysis draws on interviews, a response from Viborg Municipality, and the stakeholder analysis in Chapter 7. It is acknowledged that interview opinions do not necessarily represent all organisations within each stakeholder group. Additional insights are drawn from the literature study.

The following section outlines the main challenges related to the lack of knowledge and regulatory framework for planning BESS. Section 8.1 examines the Danish planning framework's current approach to BESS placement, location, and spatial planning. Section 8.2 addresses the uncertainties for emergency management. Section 8.3 covers key environmental considerations and emergency management. This can be seen as an overview and summation of the identified environmental aspects, as these perspectives cannot yet be found in the literature. Lastly, section 8.4 discusses whether there is a need for a national guideline the planning of BESS.

Lack of knowledge and planning frameworks

Stakeholders consistently highlight the lack of clear regulation and practical knowledge as key barriers to BESS planning (Bech and Youssef, 2025; Balle and Tolborg, 2025). Green Power Denmark notes that municipalities frequently contact them with questions about BESS for general knowledge. Viborg Municipality similarly emphasises that many municipalities lack the experience needed to manage large-scale BESS (Balle and Tolborg, 2025).

While Green Power Denmark represents developers' interests in simplifying planning procedures, they confirm that uncertainty is shared by both developers and municipalities. According to Viborg Municipality, the absence of national guidance creates confusion about the BESS's position within the Planning Act and addressing environmental considerations (Balle and Tolborg, 2025).

According to Balle and Tolborg (2025), Viborg Municipality lacks clear guidance from the state on how municipalities should plan for BESS facilities, regarding BESS position within the Planning Act and environmental considerations. Overall, the planning and authorisation of BESS remain new and unclear for all parties. As Green Power Denmark notes, developers and municipalities often adjust their processes as they learn the required documentation and procedures. Viborg Municipality similarly stresses the lack of practical experience in preparing local plans for BESS (Balle and Tolborg, 2025)

8.1 Spatial planning

BESS is not specifically regulated in the Danish Planning Act and thus falls under general planning rules, including rural zone regulations (The Danish Planning and Rural Development Agency, 2025). Due to growing uncertainty of the placement, the The Danish Planning and Rural Development Agency (2025) released a statement titled *Batteries in connection with RE-producing plants*, which remains the only national guidance on spatial planning for BESS.

According to the statement, municipalities can grant permission to construct BESS with a rural zone permit (Danish: Landzonetilladelse), depending on the specific local context and circumstances. This applies, for example, to small BESS projects connected to existing renewable energy installations (The Danish Planning and Rural Development Agency, 2025). Placement next to transformer substations is not explicitly addressed in the statement. Nevertheless, municipalities and developers interpret it as allowing similar treatment for BESS located near transformer substations (Bech and Youssef, 2025). As a result, the prevailing interpretation is that BESS in rural zones may only be authorised if co-located with a technical installation, such as wind turbines, PV systems, or transformer substations (Bech and Youssef, 2025; Søndergaard and Ebbesen, 2025; Albretschen, 2025; Jensen, 2025a). However, it is important that the BESS facility does not interfere with the potential expansion of the transformer substations (Jensen, 2025a). A stand-alone BESS facility would not be approved under the current interpretation if there is no other nearby technical facility (Jensen, 2025a; Bech and Youssef, 2025). However, there might be exceptions, as the statement is newer, and a few projects have been ongoing before the statement. Some municipalities exclusively plan for authorising BESS in designated commercial and industrial areas within the urban zone (Jensen, 2025a; Centrica, 2025). There is still speculation in some municipalities whether stand-alone BESS should exclusively be placed in designated industrial areas in the urban zones, as it is a technical facility. The Planning Act states that technical facilities cannot be placed within land zones, except in combination with wind, solar, or transformer stations (Bech and Youssef, 2025; Jensen, 2025a).

A BESS facility may require a local plan, depending on its scale, character, and placement in the landscape. Some BESS facilities may be exempt from a local plan if they are evaluated to be "small" (The Danish Planning and Rural Development Agency, 2025). However, it is not defined when a BESS plant can be categorised as "small" or when it becomes subject to the preparation of a local plan. Jensen (2025a) This could therefore call for a specification in regulation.

The process of a local plan is longer than a land zone permit. Simply put, a local plan begins with political approval to initiate the process. Then, a suggestion for the local plan is developed between the developer and municipality, followed by a second political treatment, and a four-week public hearing. After the hearing, eventual objections are treated, and finally, the plan has to be carried out by politicians (Danish Ministry of Urban, Rural and Church Affairs, 2024). Furthermore, the process includes screening an environmental impact assessment, and eventually an Appendix for the municipal plan. The process of a land zone permit is less comprehensive. The developer compiles an application for the municipality, including a description of the project and a site layout. The municipality handles the application and issues the land zone permit after necessary information has been provided (Danish Ministry of Urban, Rural and Church Affairs, 2024). The developer may have to procure other permits from other legislations. For example, Viborg Municipality requested and issued a Section 19 permit from the Environmental Protection Act, related to the risk of contamination of drinking water (Balle and Tolborg, 2025).

Eurowind admits that, as a developer, they prefer a short planning process and avoid the process of a local plan (Søndergaard and Ebbesen, 2025). However, they are naturally interested in a sufficient and adequate processing. For example, a land zone permit may be more susceptible to complaints with a suspensive effect up to four weeks after the issuing, which can further delay the process. In the event of a complaint, it could lead to a later reversal of approval (Søndergaard and Ebbesen, 2025). Sorø Municipality has also experienced how a developer pulled out of the project, as a local plan was assessed as necessary for the project (Jensen, 2025a).

To summarise, even though the legal framework is differentiated and uncertain, the primary approach is to issue rural zone permits for stand-alone BESS or BESS in combination with existing VRE facilities. When BESS is planned in combination with new VRE, the BESS facility is typically included in the local planning process for the entire project, including the preparation of a local plan (Søndergaard and Ebbesen, 2025; Jensen, 2025a; Balle and Tolborg, 2025).

8.2 Emergency management

One of the main considerations when planning for BESS is emergency management (Bech and Youssef, 2025; Nielsen, 2025; Søndergaard and Ebbesen, 2025; Balle and Tolborg, 2025). Lithium-ion batteries are the most commonly used in the Danish development (Danish Energy Agency, 2024a; Danish Emergency Management Agency, 2024). Li-ion batteries store energy using two electrodes and a liquid that allows lithium ions to move between them, creating charging and discharging. The liquid is flammable, so if the battery is damaged or overheats, it can catch fire or even explode (Danish Energy Agency, 2024c).

BESS has a Thermal Management System (TMS) built into the system, which monitors and regulates the temperature of each battery pack to prevent overheating, keeping the battery within an optimal temperature range for maintaining its performance and lifespan (Hesse et al., 2017). The monitoring of temperature overheating relates to the concern and risk of thermal runaway, which is central to the risk of fire. Thermal runaway is an expression for the process of a self-reinforcing heat development, happening by mistake in the battery cell (Danish Emergency Management Agency, 2024). The TMS monitors the system so mistakes can be found in time, and to eventually replace the battery cell. However, the increase in temperature can still lead to ignition spontaneously (Nielsen, 2025). The fire danger also depends on the chemical combination of the Li-ion battery. For example, the Lithium Iron Phosphate (LFP) chemistry is more fireproof than Lithium Nickel Manganese Cobalt Oxide (NMC), as it does not contain oxygen in the battery cell and has a higher ignition temperature (Nielsen, 2025).

There are currently two publications of guidelines: *Proposed fire safety requirements for BESS and storage of lithium-ion batteries* and *Guidelines for Fire Safety of Large-Scale Storage of Lithium-Ion Batteries and BESS* (English translation) by (MOE A/S, 2022; Danish Emergency Management Agency, 2024). MOE (Artelia) wrote the first report in collaboration with the Danish Emergency Agency, while the second was issued directly by the Danish Emergency Agency. The Danish Emergency Agency makes the guidelines for the municipal emergency departments for their case handling of large-scale BESS. Section 34 (2) of the Emergency Management Act allows the local departments to set conditions for buildings and structures to prevent fire risks and ensure access for extinguishing (Danish Ministry of Defence, 2017). This includes requirements for safe distances between containers or container groups and access and fire lanes (Danish Emergency Management Agency, 2023).

Emergency and fire response plans are typically required and must be prepared in collaboration with the local emergency management authorities (Danish Emergency Management Agency, 2023). The national fire safety guideline for large-scale BESS recommends a 10-meter distance from containers to road boundaries and between container groups (Danish Emergency Management Agency, 2023). However, actual distance requirements depend on the project's scale, local conditions, and individual assessments. The guideline remains general and lacks detailed layout requirements. Several stakeholders have therefore called for more specific and uniform guidance.

For example, Bech and Youssef (2025) mentions that they encounter several of their members with challenges of the distance requirements between the containers for example one municipality requires a safety distance of 20 meters between the containers, while another requires 10 meters, it means one project would require up to twice the amount of land use, depending on the municipality the facility is placed in. Some also set requirements of fire division walls between the containers (Nielsen, 2025; Albretschen, 2025). The requirements are thereby differentiated widely between the municipalities.

In addition to safety distances, handling surface water and potential fire extinguishing water remains an unresolved issue (Balle and Tolborg, 2025; Søndergaard and Ebbesen, 2025). The environmental risks relate to contamination of the local environment and drinking water, as batteries contain xenobiotics that can be released through leakage or extinguishing water (Balle and Tolborg, 2025). This is particularly relevant due to the non-negligible fire risk from thermal runaway. As a preventive measure, catch basins can be placed under the containers (Søndergaard and Ebbesen, 2025). In one case, Viborg Municipality required that all fire extinguishing water should be fully contained with no percolation allowed, due to the site's location in a designated drinking water protection area. This requirement was enforced under a permit issued pursuant to Section 19 of the Environmental Protection Act (Balle and Tolborg, 2025).

Even though the Danish Emergency Agency has formed general guidelines, there is still uncertainty and differentiation in the individual municipal departments (Bech and Youssef, 2025). A local emergency management department has not been interviewed; However, insights from other interviews suggest that local planning departments also expressed uncertainty regarding the applicable regulation, as BESS represents a relatively new type of infrastructure. (Balle and Tolborg, 2025; Søndergaard and Ebbesen, 2025). According to many of the interviewed stakeholders, the current guidelines regarding emergency management are not sufficient, and there is a need for more regulation or guidance (Balle and Tolborg, 2025; Albretschen, 2025; Søndergaard and Ebbesen, 2025; Bech and Youssef, 2025).

8.3 Local considerations

Municipalities, developers, and consultants have highlighted some local impact considerations, including visual, noise, land use, and citizen concerns. Knowledge and guidance in these areas are needed, as official entities provide no official guidance. Some of the discussions and dialogue the stakeholders have experienced are emphasised hereunder.

The visual impact

When planning for BESS, the visual impact is an aspect that affects the citizens living in areas near BESS facilities. As a result, municipalities and developers have to consider this impact. The physical form of BESS typically consists of 20-foot containers, inverters, a transformer, and a technical hub (Danish Energy Agency, 2024c).

A land zone permit issued by Viborg Municipality for a 140 MWh BESS plant covers up to 9,000 m^2, indicating that such facilities typically require less than one hectare of land (Balle and Tolborg, 2025). The needed land use area is more similar to transformer stations and significantly smaller than typically seen for PV (Søndergaard and Ebbesen, 2025). Although BESS is often considered less visually intrusive than, for example, a wind turbine or PV, there are still visual-related concerns to consider.

For instance, Søndergaard and Ebbesen (2025) points out that the visual aspect has become a point of discussion with municipalities. Particularly, the exterior colour of the containers has been discussed, as the BESS manufacturers make the containers white, as dark surfaces can increase heat absorption, thereby reducing efficiency. As a result, the developers and municipalities will explore more nature-coloured tones as a compromise between the visual and the technical. For example, Mariagerfjord Municipality suggested that EuroWind add a moss-covered roof to the

BESS facility, which could improve their appearance, illustrating how these visual considerations are a part of the dialogue. (Søndergaard and Ebbesen, 2025)

Sorø Municipality has also discussed the visual aspect of planning for BESS, where local citizens and the neighbours of a battery plant raised concerns about the appearance. As noted in Jensen (2025a), the municipality asked the developer to enter a dialogue with the neighbours to address the concern with the local environmental aspects. This discussion between the developer and citizens led to a dialogue about visual measures, including planting trees around the facility, which is considered more natural for the surroundings of a BESS facility (Jensen, 2025a).

Noise impact

Although BESS is generally not considered a major noise emitter, it still remains a point of concern when planning for a BESS facility. Sorø Municipality also mentioned that they have experienced concerns from citizens about noise emissions, indicating that it is a veritable concern (Jensen, 2025a).

According to Søndergaard and Ebbesen (2025), Eurowind notes that noise is a common concern, although their experience suggests actual noise levels from BESS are relatively low. The sound produced by a BESS facility is comparable to that of inverters in a PV installation. In many of Eurowind's projects, BESS is integrated as part of a hybrid plant with PV and wind, where noise impacts are more significant from components like wind turbines. In most cases, additional noise from BESS can be avoided if the facility is located at least 200 meters from residential areas (Søndergaard and Ebbesen, 2025).

Similarly, NIRAS observes that noise is not among the most significant environmental impacts, as the primary sound source is typically from the BESS unit's ventilation system. Nevertheless, they explored the possibility of installing noise barriers (Nielsen, 2025). Overall, while noise from a BESS facility is generally limited and manageable, it is still an important planning parameter, primarily due to its relevance to public perception and local acceptance.

Land-use impact

The restoration of land following a BESS installation is a relevant consideration. As noted by Nielsen (2025), BESS facilities are installed on concrete foundations, which may complicate future land restoration. Whether the site can be returned to natural or agricultural use depends on these factors, highlighting the importance of addressing land-use implications early in the planning process, for both developers and planning authorities (Nielsen, 2025).

Citizen concerns

Citizens play an important role in the local planning process for BESS. While BESS is relatively small in land use compared to other RE facilities, it can still spur significant concern and opposition. Both Jensen (2025a) and Balle and Tolborg (2025) report that citizens engage in the planning process by expressing their concern about the local impacts.

The planning of BESS can be compared to VRE and transformer stations, as they are technical infrastructures and are often co-located. Citizens are particularly concerned about the potential for declining property values as a consequence of a nearby BESS facility (Jensen, 2025a). There are concerns about the visual impact and landscape changes (Jensen, 2025a). Furthermore, the relatively new nature of BESS technology may contribute to heightened scepticism towards VRE (Sasson et al., 2025), and some of the critics of BESS are often located in the project of VRE and BESS as a whole (Søndergaard and Ebbesen, 2025; Balle and Tolborg, 2025).

One of the main concerns citizens also address is the risk of fire, the emission of gases in case of fire, and safety in general (Jensen, 2025a). Søndergaard and Ebbesen (2025) from Eurowind also mentions concerns raised at a citizen meeting regarding the origin, scarcity, extraction, and environmental impact of the raw materials used in BESS.

As for VRE, developers and municipalities must have the expertise and interest to engage in dialogues about public concerns so they are adequately addressed during the planning process and avoid misinformation (Weisdorf et al., 2025).

8.4 Need for national guidance

The lack of national rules has led to varying municipal approaches to BESS planning (Bech and Youssef, 2025; Albretschen, 2025; Balle and Tolborg, 2025; Nielsen, 2025). This inconsistency creates uncertainty for developers, municipalities, emergency services, and citizens. In practice, this means that similar projects may be subject to different requirements or approval criteria depending on location. For developers, this reduces predictability and increases project risk (Bech and Youssef, 2025). For municipalities, it can lead to hesitancy in decision-making and a reliance on precedents rather than formalised procedures (Balle and Tolborg, 2025). Viborg Municipality and others note that they often converse with peer municipalities for guidance, resulting in informal, uneven practices. The absence of coordinated standards slows development, resulting in resource-demanding working hours in public administration and complicating communication with citizens and other stakeholders. This raises the question of whether a national streamlined guideline or legislation for BESS is needed or beneficial.

When stakeholders were asked whether they see a potential or need for a national streamlined regulation or guidance of BESS, which is already in place for wind turbines and PV, the responses were varied.

Bech and Youssef (2025) from Green Power Denmark emphasises the importance of national guidelines in their work with BESS. The need for guidance is particularly for emergency management, which other interviewees highlighted, but also for planning and environmental considerations in general. Both developers and municipalities can use it as a step or precaution for what they need to be aware of. As presented above, the Danish Emergency Management Agency has provided the local emergency management department with guidance on how to handle a BESS facility in terms of safety. It still has some obscurities, but if a similar guidance could be made for the planning perspective, it would be beneficial (Bech and Youssef, 2025). This can especially help municipalities with less experience and knowledge of BESS facilities.

Balle and Tolborg (2025) highlights that national guidance or statements on the planning and environmental aspects could be essential to more qualified and consistent planning. As it is a new planning area, they raise the issue of municipalities standing alone to assess the environmental problems, placement, risks, and technical requirements. Viborg Municipality expresses a demand for a specific guide similar to the ones for solar and wind energy. Balle and Tolborg (2025) suggests a national guideline, handbook, or declaration, which could contribute to a more streamlined, predictable, and efficient planning process. Balle and Tolborg (2025) states that "*It will both strengthen the legal certainty and ease the dialogue with developers and citizens*".

Legal certainty plays an important role in planning processes, as it helps ensure that procedures are efficient and predictable for all stakeholders. Transparency, consistency, and clear legal rights can benefit developers, citizens, and authorities (Bulut, 2024; Sperling et al., 2010). As mentioned above in Section 8.2, the requirements of distances and firewalls between the containers differ among the local emergency management departments. This results in unequal requirements for the developers for the total land use and thereby unpredictable and unequal costs for investments. At the same time, it results in uncertainty for citizens, as safety often is a subject of concern. If the "acceptable" requirements differ between municipalities, it may lead to concerns about whether the requirements in their local area are sufficient. As emphasised before, it prolongs the process when all parties, the developers, municipalities, and the local emergency management department, are not clear and well-informed about which information and materials are needed.

Because of this lack of guidance and the unclear planning processes, case handling can become time-consuming for municipalities and developers. The municipalities' time spent examining BESS, required permissions, and communication could have been spent elsewhere. The task-group NEKST (2024) reported that processing VRE is challenged by bottlenecks and lengthy municipal processes. An indication that the municipal planners are already under capacity constraints, and time spent on investigating how to approach BESS, other municipalities' practices, communicating with stakeholders, and planning gives further workload. For developers, the prolonged process increases costs for project management and working hours. Furthermore, it delays the process of their business case, which can lead to an uncertain investment environment as markets are evolving. A precise regulation can, on the one hand, streamline and effectively process processes, thereby benefiting both municipalities and developers. On the other hand, a looser framework can sometimes ease the process, giving a large span of interpretation.

Another perspective on the lack of guidance is provided by Jensen (2025a) from Sorø Municipality, who does not explicitly express a need for a regulatory guideline or directive but notes that such guidance would be helpful and beneficial. The need for such guidance also depends on the project's scale, placement, and complexity. He particularly mentions that guidance on handling water from fire extinguishment would be advantageous (Jensen, 2025a).

The developer's perspective on standardisation is in some way different from the perspectives of the municipalities. Søndergaard and Ebbesen (2025) from Eurowind points out that the current regulatory uncertainty and the more free interpretation of the legislation can be both an advantage and a disadvantage. As a developer, they are interested in a fast and efficient process, which standardisation can either hinder or promote BESS development (Kalogianni et al., 2020). However, it is not certain what a streamlined regulatory framework for BESS would lead to regarding requirements, and the free interpretation can be an advantage (Søndergaard and Ebbesen, 2025).

Nielsen (2025) from NIRAS supports greater standardisation in planning BESS projects to streamline deployment. However, he also questions the need for standardisation, arguing that the physical constraints of BESS primarily involve container-based structures, which tend to have a relatively limited environmental impact. He mentions that the degree of standardisation ultimately depends on political decisions, whether the government opts for top-down regulation. Nielsen (2025) argues that there are advantages and disadvantages regarding top-down regulation, and says that it might be preferable to create national guidelines rather than formal legislation to allow municipalities to have self-determination.

The above shows that there are arguments for and against national legislation targeting BESS. While the Danish Planning and Land Agency provides some guidance on BESS and emergency management, a majority of the stakeholders involved in its development still express a need for more guidance or standardisation. A clearer framework can smooth the planning process and ensure better coordination and communication among authorities and stakeholders.

8.5 Establishing a national guideline for BESS

A guideline could be helpful for the various stakeholders in supporting the deployment of BESS in Denmark. Regulators, municipalities, and, to some extent, developers should collaborate to develop this standardisation or guidance. A national guideline would not only help reduce uncertainty and inconsistency in the current authorisation process but also create a more predictable investment environment for developers, while easing planning decisions for local authorities (Bulut, 2024). As a national regulator, the DEA could initiate this process of creating such a guideline, in collaboration with the Danish Emergency Management Agency, the Danish Environmental Protection Agency, industry organisations, and KL. It is essential that this process is inclusive and reflects the perspectives of stakeholders directly involved in the deployment of BESS.

The stakeholder analysis in Chapter 7, identified a group of actors with both high power and a high interest in BESS deployment, categorised as "Manage closely". This group includes BESS and RE developers, Energinet, and industry organisations. These actors are directly affected by and involved in formulating a national guideline and policy. The regulatory agencies and Energinet from the group "Keep them satisfied" should also be included to ensure that it aligns with national policies, future demand analyses, grid development, and technical pre-qualification (Bulut, 2024).

The guideline's content could be based on a series of focus areas that reflect the recurring challenges in the deployment of BESS. Bech and Youssef (2025) suggests that a guideline outlining five to six key focus areas for municipalities to consider when reviewing BESS applications could benefit local authorities. This could, for example, include criteria for BESS in rural zones, requirements for emergency management and water handling, standard expectations for documentation, and recommendations for visual and noise impacts. Clear guidance on handling surface water, fire safety, and other eventual environmental impacts would also contribute to a more uniform planning process and complement the two existing national guidelines. A framework could likewise assess and define responsibilities among stakeholders to strengthen their role and competencies (Bulut, 2024). A streamlined planning and regulatory practice for BESS could ensure consistent deployment processes across municipalities and safety jurisdictions (Balle and Tolborg, 2025).

While some developers have noted that the current flexibility occasionally could be advantageous, the broader consensus among the stakeholders is that the lack of predictability is a more significant barrier (Bech and Youssef, 2025). Both developers and municipalities are experiencing complications with the case-by-case interpretation of regulations. A guideline would provide necessary tools to the administration, balancing all interests involved simultaneously (Sperling et al., 2010). In this way, a national guideline would serve as a coordination tool rather than a restrictive intervention.

It should be noted that Denmark is part of an international order, and regulations can also be set on a higher level, e.g., at the EU level. Bulut (2024) argues that the absence of an international framework and the lack of coordinated policy actions for battery energy storage have significantly hindered the establishment of standards for technology, the management of critical mineral reserves, and cooperation.

8.6 Summary of the local planning and authorisation

This chapter has examined how regulatory and local planning uncertainty affects the deployment of BESS in Denmark. The lack of national regulation and guidance has led to varied interpretations and practices across municipalities and emergency departments, resulting in inconsistent requirements, delays, and creating an uncertain investment environment. This variation also challenges local authorities, emergency departments, and citizens, who must navigate unclear procedures and responsibilities. Key issues include uncertainty around spatial planning, local impact considerations, emergency management, and limited practical experience with BESS as a new infrastructure type.

Most stakeholders agree that national guidance is needed to improve clarity, coordination, and predictability. There is broad support for a national framework that can support local planning, ensure consistency across cases, and facilitate smoother implementation of BESS projects. A national guideline should be developed for municipalities, local emergency departments, and developers, clarifying around five to six subjects for local planning.

Markets and technology characteristics 9

This chapter provides background knowledge of electricity markets, market conditions, and BESS for the analysis in order to provide background understanding for answering the third: *"What are the business economic prospects of BESS under current market conditions, and how would changes affect its viability?"*.

Firstly, this chapter begins with an overview and context of the electricity markets in Section 9.1, followed by a more detailed description of the wholesale market, including day-ahead and intraday and the ancillary service markets, respectively, in Sections 9.2 and 9.3. Section 9.4 shows a timeline of the gate closures of all markets. Section 9.5 highlights other important market conditions relevant to the business economic analysis, such as tariffs. Finally, Section 9.6 functions as a technology overview of BESS, describing the technology and economy used for the further analysis.

Together, these sections provide a basis for the necessary market and technological context for the delimitation of the scope of the business-economic analysis that follows in Chapter 10.

9.1 General structure of markets

This and the following sections outline the characteristics of the electricity and ancillary services markets. Several parameters define these characteristics. These are, for example, the market's geographical coverage and platform, the price scheme (uniform pricing or pay-as-bid), time resolution, Gate Closure Time (GCT), minimum bid size, and direction.

The Danish power system is divided into two bidding zones, illustrated in Figure 9.1. DK1 represents the western part of Denmark, which consists of Jutland and Funen. DK1 is part of the Continental European Synchronous Area (SA). DK2 represents the eastern part of Denmark, consisting of Sealand, Lolland-Falster and Bornholm. DK2 belongs to the Nordic SA. (Energinet, 2019)

Figure 9.1. The two bidding areas in Denmark. DK1 is a part of the central European frequency area, and DK2 is part of the Nordic frequency area (Energinet, 2023).

In European countries, the electricity market is separated into the following individual markets: the forward, day-ahead, intraday market, ancillary service, and the imbalance settlement markets (ENTSO-E, 2018). The balancing between production and consumption mainly occurs on the wholesale market. Market operators like Nord Pool and EPEX Spot are responsible for facilitating and organising the trading on day-ahead and intraday. They determine the market-clearing prices, based on bids and offers, and publish the final volumes and prices

(ENTSO-E, 2018). After these markets have cleared,
Energinet is responsible for resolving eventual imbalances (Energinet, 2019). The different stages of electricity markets and financial settlement are seen in Figure 9.2. The day-ahead, intraday, and ancillary service markets are explained further in the following sections.

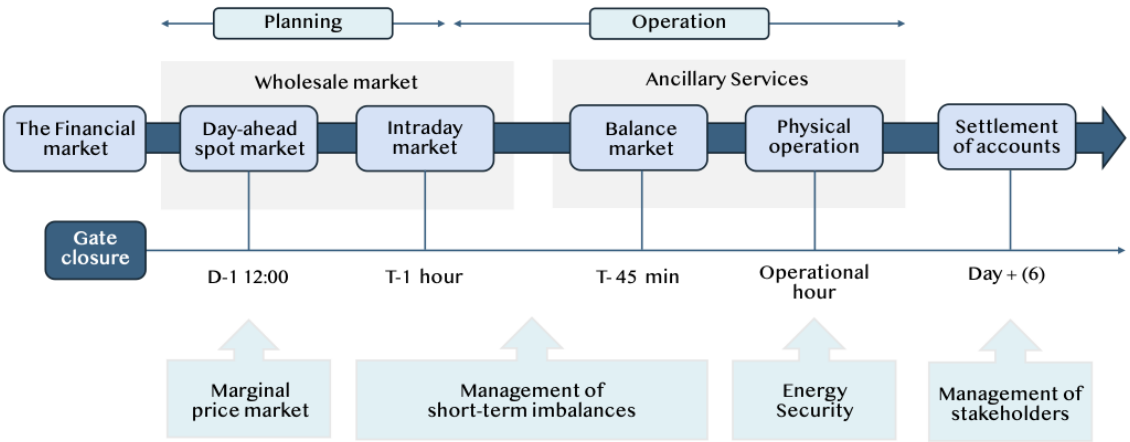


Figure 9.2. Overview of the electricity markets and stages. Inspired by Centrica (2025).

Market designs are undergoing different structural changes. The day-ahead, intraday, and ancillary service markets are transitioning from hourly to quarterly markets (Energinet, 2025b). The only market that has currently transitioned to the quarterly market time unit (MTU) is the ancillary service manual frequency restoration reserve (mFRR), which transitioned in March 2025.

Uniform pricing and pay-as-bid

This section describes the principal rules of determining the market-clearing price with uniform and pay-as-bid. Europe's day-ahead and ancillary markets use uniform-price auctions, except for the intraday market, which uses pay-as-bid. Figure 9.3 illustrates the difference between uniform-price and pay-as-bid auction mechanisms.

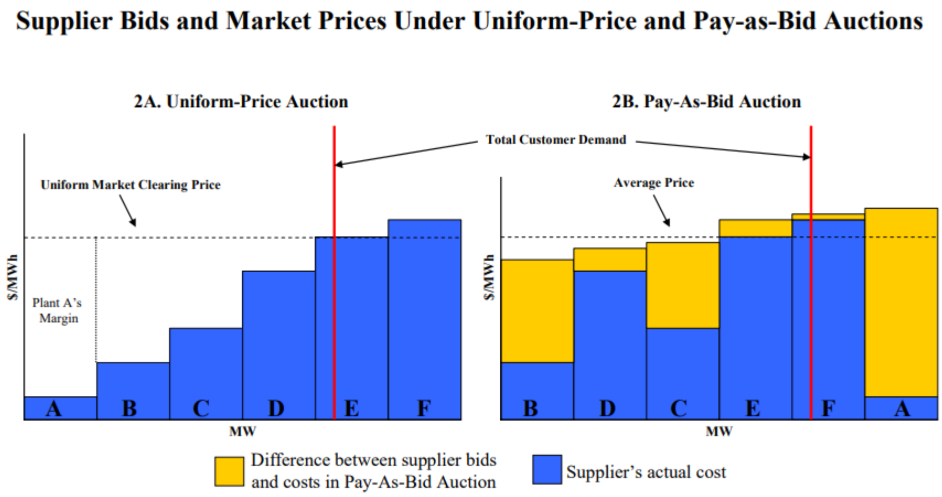


Figure 9.3. Illustration of uniform pricing auctions and pay-as-bid auctions (Tierney et al., 2008).

In a uniform-price auction, all accepted producers receive the same market-clearing price, determined by the most expensive accepted bid. This allows suppliers with lower costs to earn a margin, as shown by the difference between Plant A's cost and the clearing price (Nielsen et al., 2011). In contrast, under a pay-as-bid auction, each supplier is paid their individual bid, incentivising strategic bidding as suppliers try to predict the clearing price. This can lead to inefficiencies and higher average prices, represented by the yellow areas showing the difference between actual costs and bid prices. (Tierney et al., 2008; Klemperer, 2004)

The different pricing schemes can impact the bidding strategy for the market participants. In the uniform pricing, producing actors would offer their marginal price to ensure their opportunity to be accepted. They set a minimum bid to secure their coverage of marginal costs and required profitability (Keohane and Olmstead, 2016). For example, on Figure 9.3 2A, Supplier D in the uniform pricing, receives the market-clearing price, which is higher than their marginal costs. They might not be activated if they set their offer higher because their bid was higher than the market equilibrium point. More strategies are encountered for pay-as-bid. Here, suppliers are interested in a payment as high as possible, but still become accepted. This means suppliers could likely offer a price higher than their actual costs. This is illustrated in Figure 9.3 2B, the suppliers A-F bid higher than their actual costs (illustrated with yellow) to increase their profit as much as possible. However, they are not interested in offering it too high, considering the consequence of not becoming accepted, which happened to Supplier A.

9.2 Wholesale markets

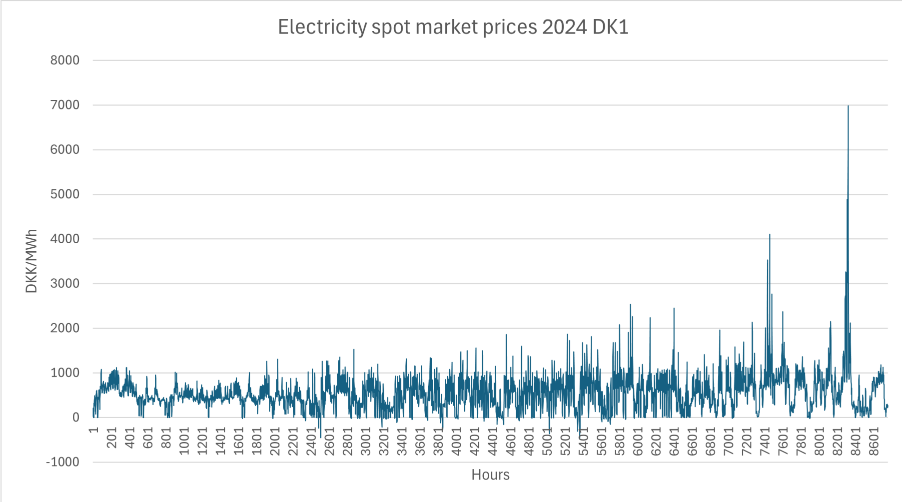
The wholesale electricity market facilitates the trading of electricity in large volumes, helping to ensure the primary balance of supply and demand. The trading happens between producers and retailers who purchase electricity for end-consumers. Electricity is traded through day-ahead and intraday markets and long-term contracts in forwards and futures markets. The following sub-sections introduce the day-ahead and intraday markets.

9.2.1 Day-ahead

Most electricity is traded in the day-ahead market, also known as the spot market. Various producers submit offers specifying the quantity of electricity they can generate at different price levels, while consumers and retailers submit bids for their electricity demands. The market is cleared 12 to 36 hours before delivery, with bids submitted by 12:00 CET on the day before delivery (D-1). The Nominal Electricity Markets Operators (NEMO), such as Nord Pool and EPEX Spot, runs the auction and determines the market-clearing prices for each hour of the next day. (Energinet, 2019)

These prices are set using the uniform pricing mechanism based on the intersection of supply and demand in each bidding zone. The market operates on a uniform pricing principle, meaning all accepted bids and offers are settled at the same market-clearing price determined by the highest-priced accepted bid (ENTSO-E, 2018). BESS can participate in the day-ahead market by submitting bids as both a consumer and a producer. It can place offers to discharge and sell electricity when prices are expected to be high and place bids to charge when prices are low (Hu et al., 2022).

The day-ahead prices used in the analysis are from 2024. This is chosen as it is the latest available dataset for an entire year. The electricity prices for the two pricing areas can be seen in Figure 9.4.



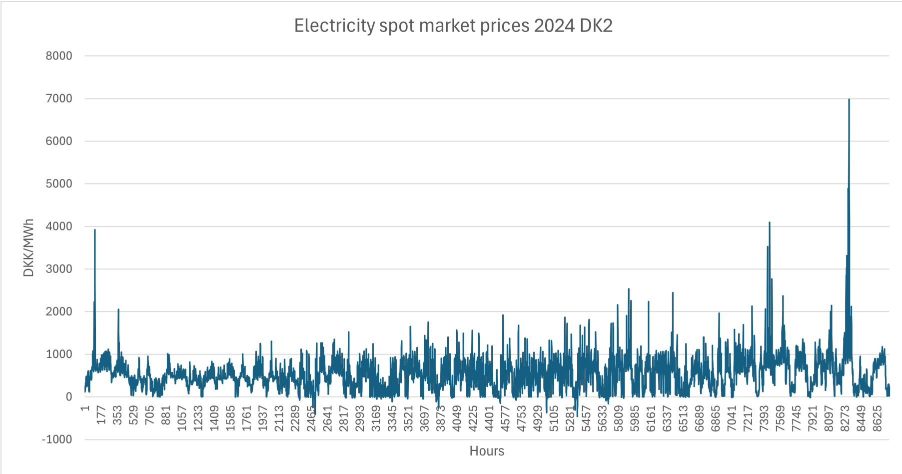


Figure 9.4. Day ahead prices for 2024 in DK1 and DK2 (Energinet, 2025b).

9.2.2 Intraday

The intraday market, also called Elbas, is a continuous trading market. It allows participants to buy or sell electricity from the day before delivery when the day-ahead market is cleared (D-1) until one hour before delivery time (h-1). It allows market participants to adjust their day-ahead market positions to compensate for shortfalls or surpluses due to asset failures, weather changes, new market opportunities, or other unexpected events. It also provides an opportunity to correct imbalances before exposure to the balancing market, where imbalance penalties may apply. (Energinet, 2019)

The intraday market operates as an order book system, where buyers and sellers submit orders to trade electricity for specific hours. Participants can sell orders when they have surplus electricity and buy orders when they face a deficit compared to their day-ahead commitments (SIDC NEMOs and Deutsche Börse AG, 2022). Unlike the day-ahead market, which uses a uniform clearing price auction, the intraday market follows a pay-as-bid principle with bilateral contracts (Energinet, 2019). Orders are matched continuously based on price and time priority. When a buyer bids at 20 EUR/MWh, any seller offering at 20 EUR/MWh or lower can be matched. The seller receives the exact price they provided, e.g., if they bid 18 EUR/MWh, they are paid 18 EUR/MWh.

If a market participant with excess or a lack of electricity to meet their day-ahead bid amount cannot find a counterparty to trade within the intraday market, they will create an imbalance. Energinet settles this deviation in the balancing market, where imbalance prices may be higher or lower than intraday prices, depending on system conditions. The producer or consumer who creates this imbalance will pay for causing the imbalance to Energinet. (Energinet, 2019) For intraday trading, both the highest and lowest prices of completed trades are available for each hour. These prices can be seen for 2024 in Figure 9.5. As mentioned, Intraday is continuous, and several orders are made or edited towards gate closure. The highest and lowest prices, do thereby only show a margin of the price levels and orders made in the market.

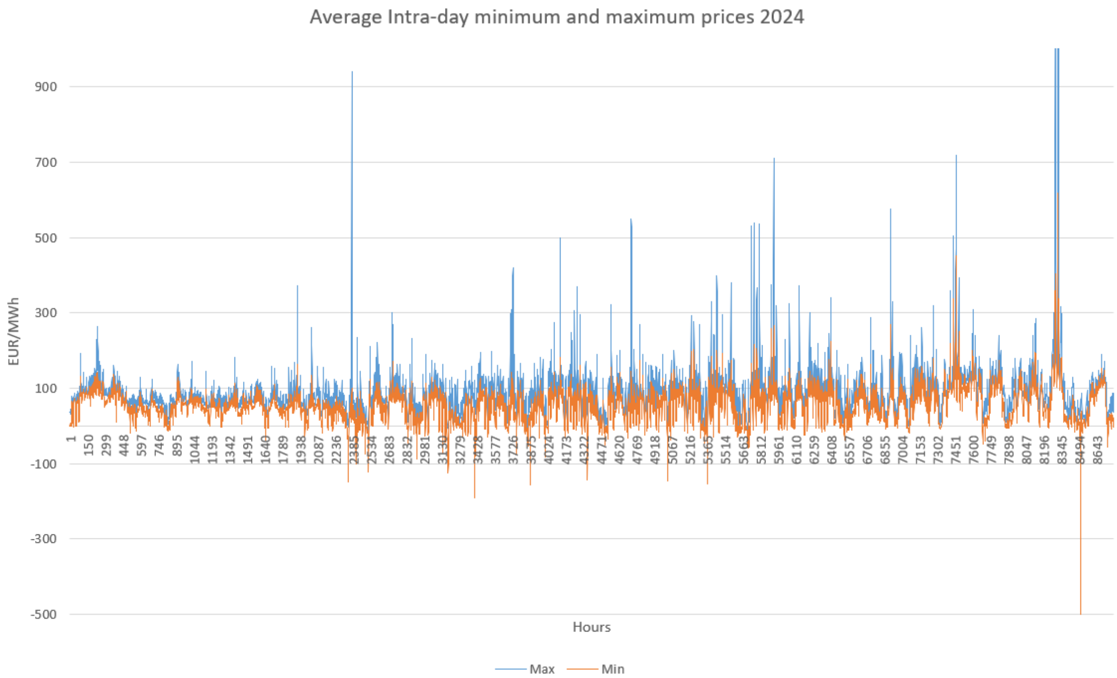


Figure 9.5. Minimum and maximum prices of intraday auctions for 2024 in DK1 (Nord Pool, 2025).

As a consumer, a BESS can charge when electricity prices are low. As a producer, a BESS can discharge and sell electricity when prices are high (Hu et al., 2022).

Studies suggest that the profit opportunities in the intraday market are higher than participation in the day-ahead market for BESS (Hornek et al., 2025; Veenstra and Mulder, 2025). This is largely due to a higher price volatility in the intraday market. While combining participation in both the day-ahead and intraday markets enables more arbitrage opportunities, studies suggest that revenue from this only increases marginally.

9.3 Ancillary service markets

Ancillary services are a support service that the Danish TSO Energinet uses to help balance electricity supply and demand and ensure grid stability around 50 Hz. This entails frequency stabilisation, restoration, and settlement of imbalances (Energinet, 2024). This section outlines the existing ancillary services in DK1 and DK2, focusing on BESS in these services.

Different suppliers of ancillary services, both producers and consumers in Denmark and neighbouring countries, provide either up- and/or downregulation in exchange for financial payment. Up-regulation happens when there is a power deficit; providers either decrease power consumption or increase production. Down-regulation is when there is a power surplus, and providers either decrease production or increase their consumption. On the production side, production units such as power plants can regulate up and down, whereas wind turbines and PV can only downregulate. (Energinet, 2024) The consumption side includes units such as electric boilers, heat pumps, industries, electric vehicles, and cooling, which can adjust consumption up and down to a certain limit. The provider can either offer their reserve product themselves or through an aggregator who groups different smaller units of flexible demand. Section 2.2 highlights that new types of suppliers have started to show interest in ancillary services. Examples of these new types of suppliers could be public swimming pools, supermarkets, or garden centres, which can reduce their consumption in some hours without having major consequences (Energinet, 2025b). Batteries are among these new suppliers for ancillary services as they can provide both up- and downregulation by charging and discharging. While their energy volume is small, they have a fast reaction time compared to other providers and are, therefore, valuable in some types of ancillary services (Energinet, 2023).

Balancing with ancillary services

Different specifications characterise the various ancillary services. The reserves are differentiated by their response time, the quantity and duration of demanded energy volumes, or how they are activated. The supply and demand for ancillary services are different in DK1 and DK2.

There are the following ancillary services for DK1:

- FCR: Frequency Containment Reserve (Primary reserve)
- aFFR: Automatic Frequency Restoration Reverse (Secondary reserve)
- mFFR: Manual Frequency Restoration Reserve (Manual reserve)

There are the following ancillary services for DK2:

- FFR: Fast Frequency Reserve (Upwards only)
- FCR-D: Frequency Containment Reserve for Disturbances (Both up- and down)
- FCR-N: Frequency Containment Reserve for Normal operations
- aFFR: Automatic Frequency Restoration Reverse (Secondary reserve)
- mFRR: Manual Frequency Restoration Reserve (Manual reserve)

(Energinet, 2025)

Figure 9.6 illustrates the principle of the ancillary services used to restore deviations in the frequency. The horizontal axis represents the response time for activation, ranging from sub-seconds to 20 minutes. The fastest services, such as FFR and FCR-D, seen at the beginning of the axis on Figure 9.6, provide rapid but limited energy reservoirs. Services like aFRR and mFRR on the right of the axis offer larger reserve capacities, contributing to power system balancing over longer durations and amounts (Energinet, 2025c). In general, faster ancillary services require less energy, while slower services require larger amounts of energy (Energinet, 2024a).

Table 9.1 and 9.2 show an overview of the specifications for each ancillary service in DK1 and DK2, respectively. Different specifications and requirements define each ancillary service. The required response time differs from 0.07 sec to 15 min, as illustrated in Figure 9.6. Other significant parameters that differentiate the services are the load factor (activated energy per sold capacity), activation frequency, and energy delivery. The daily purchased capacity is lower for the primary frequency reserves and higher for the automatic and national restoration reserves.

Markets are also defined by their symmetry, where *symmetrical* means that the bought product includes both up- and down-regulation, while *asymmetrical* means that up- or down-regulation is bid separately.

Energinet operates two markets to stabilize supply and demand: the capacity market and the energy market. The capacity market procures reserves, ensuring sufficient capacity is available in the energy market. These reserves are procured before the day-ahead market. If a provider's bid is accepted, they receive payment and must offer their capacity in the energy market. For aFRR

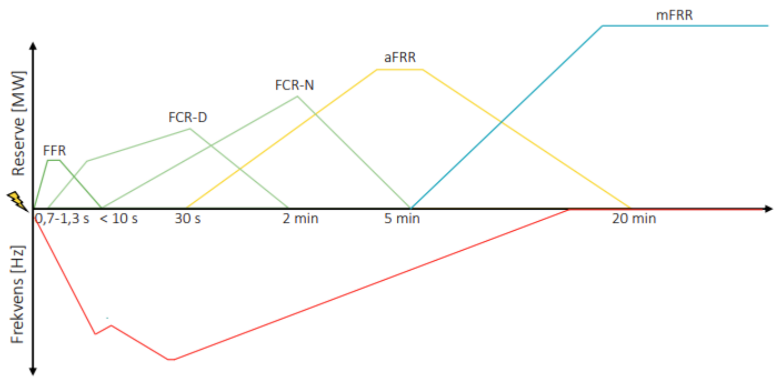


Figure 9.6. The principle of the activation of ancillary services at a dip in frequency in DK2, illustrated on a timeline of response time. DK1 only contains the three ancillary services FCR, aFRR, and mFRR (Energinet, 2024d).

and mFRR, the capacity and energy markets are separated. The capacity and energy markets are for the other ancillary services combined into a single market, serving only as a capacity market. (Energinet, 2019)

Becoming a provider of ancillary services requires prequalification by Energinet. The technical requirements are outlined in the document *Prequalification of Units and Aggregated Portfolios* (Energinet, 2025a). To participate in the balancing markets, a provider must either become a Balance Responsible Party (BRP) with access to the relevant markets or agree to provide balancing services without delivering energy (Energinet, 2025). This last option is particularly relevant for services such as FCR, FFR, and FCR-D, which do not require large energy capacities compared to aFRR and mFRR. Alternatively, providers may submit bids through an existing BRP (Energinet, 2025c).

DK1	**FCR** Frequency Containment Reserve	**aFRR** Automatic Frequency Restoration Reserve	**mFRR** Manual Frequency Restoration Reserve
Technical Specifications			
Response time	2 sec	15 min	15 min
Minimum delivery time	N/A	1 hour	1 hour
Activation	Automatic	Automatic	Manual
Load factor	0.05 %	12 %	100 %
Activation frequency	Moderate	Often	Often
Energy deliverance	Low	High	High
Market specifications			
Bid size	Min. 1 MW	1-50 MW	5-50 MW
Daily purchase	25 MW (+100)	100 MW	300 MW
Auction type	Daily	Weekly	Daily
Period on contracts	4 hours	1 hour	1 hour
Symmetry	Symmetrical	Asymmetrical (Up/Down)	Asymmetrical (Up/Down)
Capacity vs Energy market	Combined	Separate	Separate
Balance responsibility	No	Yes	Yes
Bid close time	08:00 AM	07:30 AM	07:30 AM

Table 9.1. Specifications for ancillary services in DK1. Based on Energinet (2023, 2024a, 2025).

DK2	**FFR** Fast Frequency Reserve	**FCR-D** Frequency Containment Reserve for Disturbances	**FCR-N** Frequency Containment Reserve for Normal Operations	**aFRR** Automatic Frequency Restoration Reserve	**mFRR** Manual Frequency Restoration Reserve
Technical Specifications					
Response time	0.7-1.3 sec	86% within 7.5 sec	2.5 min	5 min	15 min
Minimum delivery time	5 sec	N/A	N/A	1 hour	1 hour or month
Activation	Automatic	Automatic	Automatic	Automatic	Manual
Load factor	0%	0.05%	0.5%	12%	100%
Activation frequency	Rarely	Rarely	Often	Often	Often
Energy deliverance	Negligible	Very low	High	High	High
Market Specifications					
Bid size Min.	0.3 MW	0.1 MW	0.1 MW	1 MW	1 MW
Daily purchase	Forecast weekly need	43 MW (+200)	18 MW (+600)	50 MW	600 MW
Auction type	Daily	Daily	Daily	Hourly	Daily and monthly
Period on contracts	1 hour	1 hour	1 hour	1 hour	1 hour or month
Symmetry	Asymmetrical (Upwards only)	Asymmetrical (Up/Down)	Symmetrical	Asymmetrical (Up/Down)	Asymmetrical (Up/Down)
Capacity vs Energy market	Combined	Combined	Combined	Separate	Separate
Balance responsibility	No	No	Yes	Yes	Yes
Bid close time	3 PM	00:30 AM	00:30 AM	7:30 AM	7:30 AM

Table 9.2. Specifications for ancillary services in DK2. Based on Energinet (2023, 2024a, 2025).

9.3.1 BESS and ancillary services

This section outlines some of the considerations for participating with BESS in the ancillary services, as well as the current trends in Denmark. Furthermore, some of the planned market changes are presented, which can impact the future market for participation with BESS.

A battery is defined by its power capacity (MW) and energy capacity (MWh). For example, a 10 MW/10 MWh battery can theoretically deliver energy for one hour, and a 10 MW/20 MWh battery can deliver for two hours, if the charging, discharging and standby efficiency are not considered. BESS is characterised by its ability to deliver fast up- and down-regulation and fulfil requirements for the fastest service FFR, which requires a response time down to 0.7 sec (Hameed et al., 2023). Theoretically, BESS can deliver all types of ancillary services (Pedersen and Bundesen, 2025).

The frequency products FFR, FCR, FCR-D, and FCR-N, require the fastest response times, ranging from 0.7 sec for FFR and 2.5 min. for FCR-N. The provider measures the frequency in the grid to deliver at fluctuations automatically. These services have a low load factor ranging from an average of 0.05 % to 0.5 % of the bid size, and the required energy amount is very low. (Energinet, 2025)

For fast-response ancillary services such as FFR and FCR-D, a high power capacity (MW) can be advantageous, while keeping the energy capacity (MWh) lower to increase the bid size. This allows providers to submit larger bids without investing in expensive energy storage capacity (Hameed et al., 2023). Since FFR has no energy capacity requirement, it can be combined with other services, making it possible to place bids for FFR and FCR-D within the same hour. All services require one hour of minimum bid duration, except for FCR in DK1, where bids must be submitted in four-hour blocks, as listed below. In such cases, both the energy capacity and bid size must remain constant throughout the block (Energinet, 2025).

- Block 1: 00:00-04:00
- Block 2: 04:00-08:00
- Block 3: 08:00-12:00
- Block 4: 12:00-16:00
- Block 5: 16:00-20:00
- Block 6: 20:00-24:00

The Frequency Restoration Reserves, aFRR and mFRR, have slower response time requirements and demand larger energy volumes. Activation is initiated by a signal from Energinet, automatically for aFRR and manually for mFRR (Energinet, 2025c). aFRR is an asymmetrical service, with separate auctions for up- and down-regulation. mFRR down-regulation has only been available since October 2024, making it a relatively new option (Energinet, 2024). Participation in aFRR and mFRR in DK1 and DK2 requires the provider to be Balance Responsible or have an agreement with a BRP. (Energinet, 2025) The demand for larger energy volumes poses a challenge for batteries due to their limited energy reservoir. Participation is possible in the hourly market, but strict monitoring of the State of Charge (SoC) is required to ensure compliance Energinet (2023).

Batteries have a limited lifetime and cycle lifetime; the activation, load factor and operation can influence the battery's lifetime. The frequent and extensive charge-and-discharge cycles in aFFR and mFFR may lead to higher degradation and reduced battery lifetime (Hu et al., 2022). The frequency containment reserves with lower delivered energy are often preferred by BESS owners (Pedersen and Bundesen, 2025). Current trends are elaborated in a section below.

The timeline of the GCT for the ancillary services is illustrated in Figure 9.7. All submitted bids are sorted by their offer price per MW and will be either rejected or accepted, and paid by the uniform pricing mechanism (Hameed et al., 2023). Bids for FCR-N and FCR-D can be submitted two days (D-2) and/or one day (D-1) before operation. For FCR-D, FFR, and FCR there is only payment for the bid capacity, not the supplied energy volumes. Contrarily, for FCR-N, aFRR, and mFRR, the provider also receives payments for the MWh energy provided or absorbed (Energinet, 2023).

Changes in markets

The markets are undergoing several changes and transitions recently, currently, and in the future (IEA, 2024). Some to mention are the transition of aFRR and mFRR by entering PICASSO and MARI, respectively.

On the 1st of October 2024, Energinet entered the European energy market PICASSO to trade aFRR between TSOs. This meant that the auctions now happen daily for each hour of the following day. Entering PICASSO expands the market and increases the number of participants, leading to greater competition. This results in higher demand for ancillary services, but also more suppliers, thereby providing Energinet with increased flexibility (Energinet, 2024).

On March 4th, 2025, Energinet partially joined the European MARI platform for cross-border trading of mFRR between TSOs. The new market, called mFRR Energy Activation Market, replaces the previously manual activation of mFRR by Energinet with a digital and automated system, developed in collaboration with the Nordic TSOs of Sweden, Norway, and Finland. This transition is expected to enhance system balancing under high shares of renewable energy and reduce Energinet's costs for procuring ancillary services (Energinet, 2025b).

Due to these changes, using historical data to model future business cases involves a degree of uncertainty. This is further discussed under Sources of Error in Section 10.6 and in the discussion in Section 11.1.1.

Status and trends of BESS in ancillary services

Table 9.3 shows the pre-qualified battery capacity for different ancillary services by 2024. It should be noted that this does not include *all* grid-connected batteries, but only the ones qualified for ancillary services. The table shows that the expansion of batteries is higher in DK2. Reflecting that the revenue opportunities in FCR in DK2 have been more attractive for BESS (Ørkilde, 2025; Pedersen and Bundesen, 2025; Hameed et al., 2023).

Ancillary service	Bidding area	Capacity (MW)
FCR	DK1	1
FCR-D Up	DK2	21.9
FCR-D Down	DK2	21.4
FCR-N	DK2	6.2
FFR	DK2	17.4

Table 9.3. Prequalified battery capacity for different ancillary services. This entails both new and existing capacity by 2024 (Energinet, 2024).

While Energinet expects a general increase in demand for ancillary services, the growth varies a lot between the ancillary services. The ancillary service market of FCR-D, for which batteries have suitable technical characteristics to fulfil, has partly driven the expansion of utility-scale BESS in DK2, where around 21.5 MW has been pre-qualified for up- and down-regulation in FCR-D (Energinet, 2024). However, because of the increased participation in FCR-D, prices in this market have already decreased from 2023 to 2024 (Albretschen, 2025; Pedersen and Bundesen, 2025). Utility-scale BESS's profitability can depend on the prices of FCR, and the investment can, therefore, be sensitive to the declining prices of FCR (Münderlein et al., 2019). In *The Outlook of Ancillary Services 2024-2040*, Energinet (2024) has projected the demand of FCR-D in DK2 to stagnate towards 2030 and increase afterwards if more offshore wind is implemented. However, the demand for aFRR and FCR in DK1 will continue to grow until 2040.

Pedersen and Bundesen (2025) finds the potential of batteries participating in different ancillary markets more relevant in the future and urges battery owners to investigate more than one market opportunity, as BESS, in principle, can deliver all the different services. However, the pre-qualification process can be more straightforward for the slower ancillary services. Therefore, it is recommended to get pre-qualification by Energinet for all ancillary services to allow bidding in all markets (Pedersen and Bundesen, 2025).

Limited Energy Reservoirs

Some providers of ancillary services are classified as units with a Limited Energy Reservoir (LER), such as batteries, electric boilers with limited heat storage, or consumption units with restricted delivery durations. LER units are subject to specific requirements to ensure stable delivery despite constrained energy capacity, and these are verified during the prequalification process. Power and energy capacity requirements for LER units vary across ancillary services. For FCR, FCR-D, and FCR-N, a unit is considered LER if it can deliver full power capacity for less than two hours in each direction. For aFRR, the threshold is four hours, and for mFRR, eight hours (Energinet, 2025a).

LER units must reserve a portion of their peak power capacity and energy volume for active reservoir management to prevent the SoC from reaching its upper or lower limits. This reserve can be defined either as a percentage, e.g., 20 % of the unit's power capacity (MW), or as a duration e.g., 24 minutes of its energy reservoir (MWh). The specific active reservoir management requirements vary by ancillary service (Energinet, 2025a).

9.4 Timeline of market gate closures

Figure 9.7 illustrates a timeline of the GCT and market deadlines to give an overview of the market chronology. The balancing market for ancillary services operates with different services for DK1 and DK2, as there are different gate closure times, and the timeline is, therefore, differentiated. The chronology allows participation in different markets.

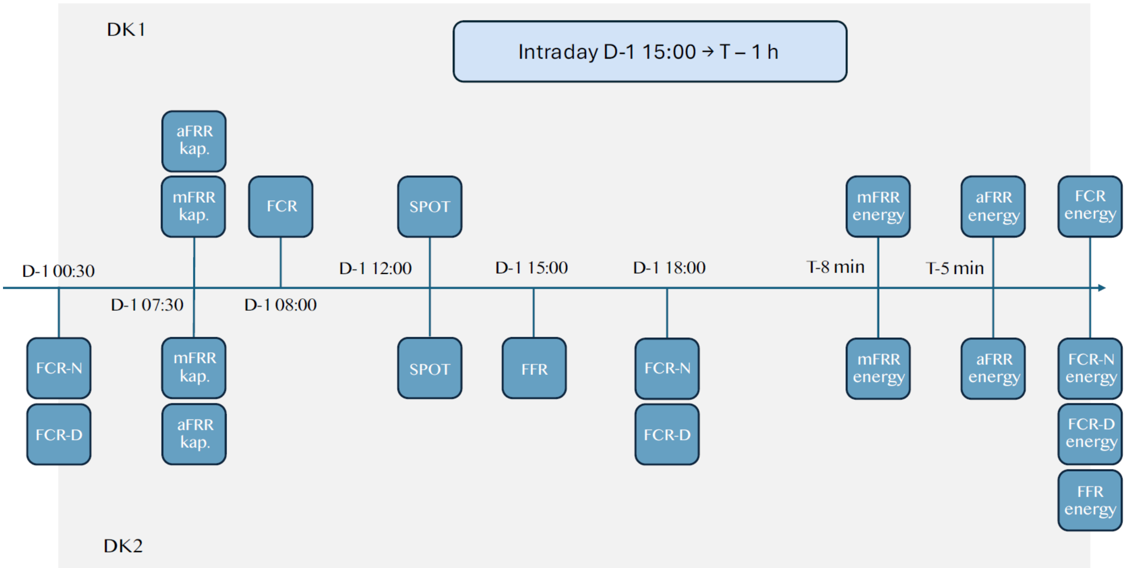


Figure 9.7. Timeline of the deadlines and activations of the different markets of both the wholesale and ancillary service markets (Energinet, 2025). Figure inspired by Centrica (2025).

The timeline determines in which order an asset manager of a BESS asset will bid into the markets. Participation in some markets might exclude involvement in others. If, for example, a battery submits a bid in the FCR market and the bid is accepted, it cannot participate in other markets, such as the day-ahead or intraday markets, during the hours it is delivering the FCR service, unless only part of its capacity was committed. This is important when modelling BESS market participation, as it highlights the order in which the battery bids into different markets.

9.5 Other market conditions

Other market and investment conditions should be considered when participating in markets and investing in an energy facility. These conditions include the installation location, grid connection charges, consumption, and feed-in tariffs. These will be introduced in the following subsections. The fees and tariffs presented in the following sections are based on data from N1, one of the largest DSOs in Denmark (N1 A/S, 2025a). N1 has been selected due to its significant market presence in Jutland and relevance to a typical grid connection in Denmark.

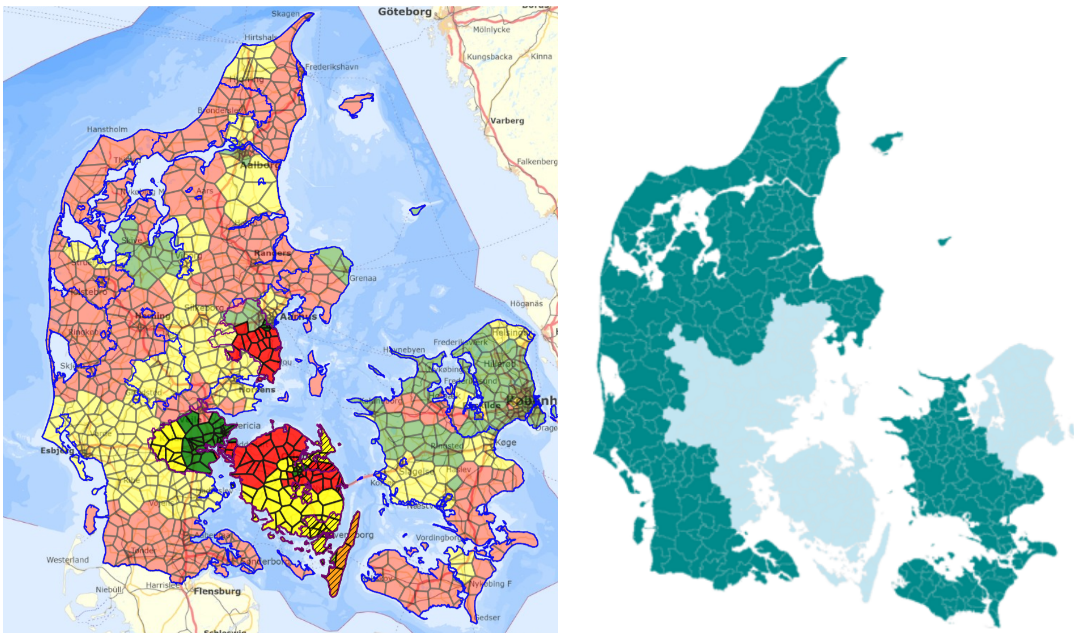
9.5.1 Connection fees

In 2023, connection fees for grid connections were introduced for producers to make developers contribute to the expenses of building and expanding stations, transformers, local grids, and more (Energinet, 2022). Connection fees are relevant for BESS as it is seen as a production and consumption unit and has to pay connection fees for both consumption and production. The connection fees are determined by the geozones, TSO-zones, and the customer category in which a facility is placed.

The geozones accounting for the distribution level can be seen in Figure 9.8a. The division into geographically differentiated cost zones reflects the aim to incentivise the placement of new production in zones that reduce the need for future reinforcements (Green Power Denmark, 2025a). It is a way to support and balance the local grids according to the load on the network. The red zones indicate areas where electricity primarily flows from the distribution network to the transmission network. The green zone represents areas where electricity mainly flows in the opposite direction, while the yellow zone signifies regions where the exchange between the two networks is nearly balanced. It is updated annually, and for some DSO, updated weekly, so tariffs remain aligned with the actual system conditions. (Green Power Denmark, 2025a)

The zones at the transmission level can be seen in Figure 9.8b, where the white areas represent consumption-dominated regions, while the green areas indicate production-surplus regions. This classification forms the basis for Energinet's geographically differentiated connection fees for transmission-connected producers. Lower fees are applied in consumption-dominated areas where new production can support local demand, while higher fees apply in areas with existing production surpluses. The purpose of this is to promote a more efficient system with a cost-reflective expansion of the electricity grid. (Energinet, 2025)

The Geozones and TSO-zones are mentioned in Tables 9.6 and 9.7 to determine the connection fee costs by geographically differentiated zones.



(a) Map of the geo-zones (Elnet, 2025). ***(b)*** Map of the TSO-zones (Energinet, 2025)

Figure 9.8. Comparison of geozone and TSO-zone maps.

The customer category for a facility is determined in collaboration with the DSO. Regulations state that the voltage level and connection point selection should be based on the option that minimises total connection costs (Danish Energy Agency, 2024d). Green Power Denmark has created the content of Table 9.4 below, which shows typical customer categories depending on the facility size. When facilities are around 100 MW, there is a possibility for them to be connected directly to the transmission grid. If a project is connected directly to the transmission grid, the facility will not have to pay connection fees to the DSO or the transformer contribution to Energinet, even if placed in a red geozone. Instead, the station contribution is paid, as seen in Table 9.7. (Energinet, 2025, 2024)

Customer Category	Voltage [kV]	Station Type	Average Facility Size [MVA]
B-high	10-20	10-20/0.4 kV station	2,000
A-low	10-20	30-60/10-20 kV station	10,000
A-high	30-60	30-60/10-20 kV station	25,000
A-high+	30-60	132-150/30-60 kV station	50,000
A-high+ (meshed)	30-60	132-150/30-60 kV station	50,000
A0 (Energinet)	132-150	132-150/30-60 kV station	-

Table 9.4. Customer category and connection point to average installation size. The customer size is in MVA, often converted directly to MW (Energinet, 2022; Elnet, 2024).

Connection fees for consumption

Connection fees for consumers can be seen in Table 9.5. Connection fees are only paid at the DSO level.

Customer Category	Cost	Unit
B-high	1,318	DKK/A
A-high	700,000	DKK/MVA
A-low	1,280,000	DKK/MVA

Table 9.5. Connection costs for consumers for A-high and A-low customers (N1 A/S, 2025c).

Connection fees for production

Connection fees to the DSO depend on the customer category and the geozone where the facility is located, as shown in Table 9.6 for selected customer categories. The customer categories are listed in Table 9.4. Connection fees, transformer contributions, and station contributions to Energinet can be seen in Table 9.7. The connection fees depend on the TSO zones seen in Figure 9.8b.

Customer Category	Red Geozone [DKK/MW]	Yellow Geozone [DKK/MW]	Green Geozone [DKK/MW]
A-high+	67,000	56,000	50,000
A-high	678,000	403,000	157,000
A-low	941,000	521,000	151,000
B-high	1,736,000	991,000	325,000

Table 9.6. Connection fees to DSO for producers in 2025, determined by the geozones on map 9.8a and customer category in Table 9.4 (Elnet, 2025).

Charge Type	Cost [DKK/MW]
Transformer contribution (Red geozones)	350,000
Connection fee	
Production surplus area	663,000
Consumption-dominated area	193,000
Station contribution	
Connected in 132/150 kV station	18.2 million DKK/bay
Connected in 220 kV station	10.7 million DKK/bay
Connected in 400 kV station	18.8 million DKK/bay

Table 9.7. Costs for transformer contribution, paid when a facility is connected to the distribution grid in a red geozone. The station contribution is only paid for facilities directly connected to the transmission grid. Connection fees to Energinet are determined by the map in Figure 9.8b (Energinet, 2025, 2024).

9.5.2 Tariffs and taxes

When a facility is connected to the distribution and/or transmission grid, grid users must pay tariffs. This means that both consumers and producers pay tariffs. Tariffs cover DSOs' and TSOs' expenses for maintaining, building, and operating the distributive and transmission-level grids (Energinet, 2025; N1 A/S, 2025b).

Feed-in and balancing tariff

The feed-in and balancing tariffs applicable from 2025 for a facility connected at the DSO level are shown in Table 9.8. Feed-in tariffs for DSOs also depend on the project's customer category, which was introduced in Table 9.4. The feed-in tariffs for DSOs also depend on which DSO area the facility is placed in. If a facility is connected at a TSO level, the facility does not pay tariffs to a DSO.

TSO/DSO	Tariff Type	Tariff Amount [øre/kWh]
Energinet	Feed-in tariff	0.3
Energinet	Balancing tariff	0.24
N1	feed-in tariff (B-high)	1.53
N1	feed-in tariff (A-low)	0.41
N1	feed-in tariff (A-high)	0.24

Table 9.8. Feed-in tariffs for the DSO, N1 and Energinet in 2024 (N1 A/S, 2024; Energinet, 2025).

Consumption tariffs and electricity tax

Consumption tariffs and electricity tax for a facility can be seen in Table 9.9. The electricity tax can largely be reimbursed for VAT-registered businesses.(Skat, 2025) Some DSOs have introduced time-differentiated tariffs depending on when the electricity is consumed, as an instrument to mitigate peak consumption hours (Jensen, 2025b). There is also an availability tariff for "self-producers," consumers who consume and produce electricity with their facility.

Tariff Type	**Tariff Amount [øre/kWh]**		
Electricity tax (reimbursed)		0.4	
Energinet tariff		12.6	
N1 - DSO tariff	**B-high [øre/kWh]**	**A-low [øre/kWh]**	**A-high [øre/kWh]**
Low-load	3.32	1.57	0.76
High-load	9.95	4.72	1.52
Peak-load	19.91	9.44	3.90

Table 9.9. Overview of tariffs and taxes for consumption of electricity in 2024 (N1 A/S, 2024; Energinet, 2025; Skat, 2025).

9.6 The technology BESS

This section begins by introducing the technology behind BESS and lithium-ion batteries. It then presents the financial considerations related to investment and Operation & Management (O&M), followed by technical aspects such as round-trip efficiency and lifetime. Table 9.10 summarises the data used for the business economic analysis and modelling of BESS market participation.

Today, Li-ion batteries are the most widely used battery technology globally, due to their high energy density and versatility across sectors. The Li-ion battery has the advantages of a high cycle life and calendar life, high energy density and efficiency, and low self-discharge. However, they also have challenges like moderate to high costs, resources, and sustainability issues. (Hoff, 2022) Li-ion battery costs have dropped significantly over the past decade to around 115 USD per kilowatt-hour by 2024, as illustrated in Figure 2.6, (Statista, 2025). This reduction is primarily driven by advances in research and development, scaling up of production processes, and improvements in energy density (IEA, 2024). Given the cost reduction, characteristics, and widespread adoption, this thesis focuses on Li-ion batteries. Figure 9.9 illustrates that the grid-tied battery system has different constituent elements.

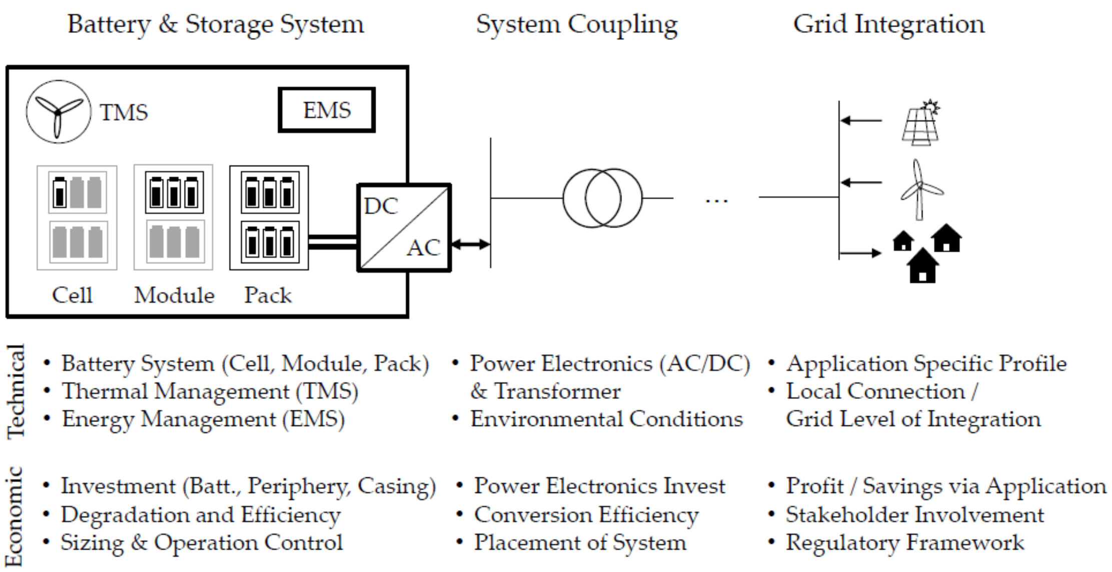


Figure 9.9. Overview of the key technical and economic components involved in BESS, system coupling, and grid integration (Hesse et al., 2017).

A BESS consists of battery cells, assembled into modules and further grouped into packs. Each pack has a Battery Management System (BMS) (not illustrated in the figure above), which continuously monitors key parameters such as temperature, voltage, and current to ensure safe operation within specified limits. A TMS regulates the battery and system temperature to maintain optimal performance and safety. An Energy Management System oversees the charging and discharging processes alongside these management systems, optimising the battery's operation based on system requirements. (Danish Energy Agency, 2024c)

A battery cell consists of an anode and cathode, separated by a liquid electrolyte covered by a porous membrane. When nearly all the lithium ions have left the negative electrode and reacted with the positive electrode, the battery is fully discharged and vice versa (Danish Energy Agency, 2024c). The endpoints of the range of discharged and charged are defined by 0 % and 100 % SoC, which defines limits within a safe range of lithium removal between the electrodes. Persistent storage at a high SoC or overcharging can accelerate the degradation of the battery cells (Veenstra and Mulder, 2025; Münderlein et al., 2019). Because of this, there are typically restrictions on the SoC operational area. The SoC can also be referred to as the SoE, which is a more operationally precise term that defines the energy capacity left in the battery (Ørkilde, 2025).

There exist different chemistries for the anode and cathode, with different associated characteristics such as price, environmental challenges, degradation of the batteries, and fire risks (Nielsen, 2025). The most widely used are Lithium Nickel Manganese Cobalt Oxide and Lithium Iron Phosphate, due to the lower prices and production volume caused by the development of the transport sector and their high energy density (Danish Energy Agency, 2024c). The battery cell chemistry, design, and overall system influence the batteries' key performance factors (Danish Energy Agency, 2024c).

Economic considerations

The applied investment costs and O&M are based on the cost projection by Cole and Karmakar (2023) illustrated in Figure 9.10. The estimated capital costs are separated into energy and power. The costs are read off from the mid-projection for 2025, and are read off as 310$ for both /kWh and /kW, corresponding to 275,060 EUR/MWh and /MW. The costs of the energy and power components are summed to get the total system costs, meaning that, for example, a 1 MWh / 1 MW system would cost 550,121 EUR/MWh. A 2-hour battery would result in a price of 825.100 EUR/MW for the total system costs (Cole and Karmakar, 2023).

The investment costs can be discussed, as different price levels are found in the literature. The technology catalogue by Danish Energy Agency (2024c), presents an investment cost of 622,000 EUR/MWh for 2030, making up around 20 % compared to the 550,121 EUR/MWh by Cole and Karmakar (2023). On the other hand, the price estimation of 550,121 EUR/MWh by Cole and Karmakar (2023) is significantly higher than the found average price of Li-ion battery packs by BloombergNEF (2023) of 127,880 EUR/MWh in 2023. However, this is only for the battery pack, and not the whole energy storage system.

The fixed O&M cost is based on Cole and Karmakar (2023), and corresponds to around 2.5 % of the capital costs for the total system capital costs in EUR/MW. All operating costs are included in the fixed O&M, and there is assumed to be no variable O&M based on Cole and Karmakar (2023).

Technical considerations

The capital and O&M costs are based on a 15-year lifetime battery operating one cycle per day, giving approx 5,500 cycles (Cole and Karmakar, 2023). The lifetime in cycles and years, efficiency, and depend on many factors such as cell chemistry, and how the battery is operated, Depth of Discharge, market participation, affecting the degradation of the battery system (Bulut, 2024). Studies use different lifetimes of cycles and years of batteries. The calendar life stretches from

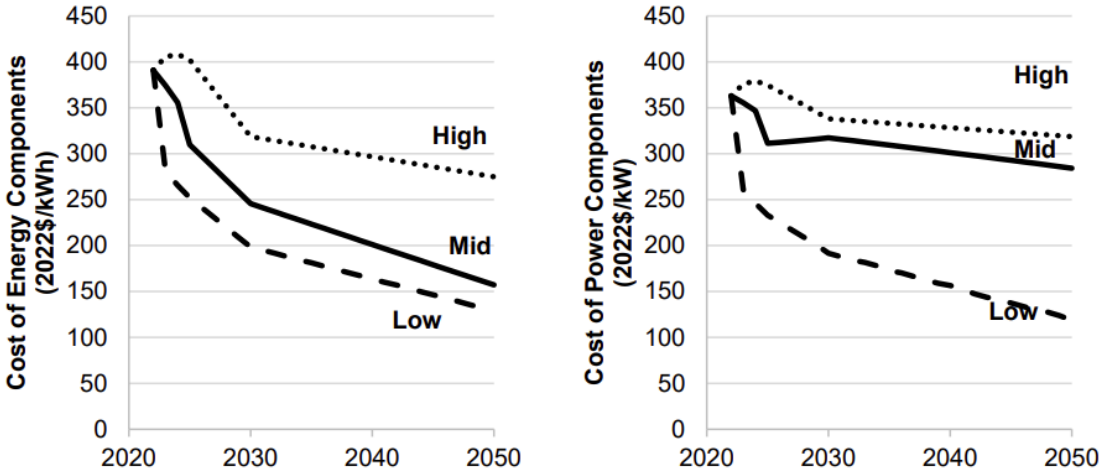


Figure 9.10. Costs projection of a lithium-ion battery systems for energy (left) and power (right) (Cole and Karmakar, 2023).

5 - 20 years in literature (Danish Energy Agency, 2024c; Deguenon et al., 2023). The lifetime Equivalent Full Cycles of the cell chemistry NMC varies between 3,000 - 10,000 cycles, and LFP has a lifetime of up to 8,000 cycles, which different sources also refers to (Danish Energy Agency, 2024c; Münderlein et al., 2019; Hu et al., 2022; Thingvad et al., 2023).

The battery has a charge and discharge efficiency, where the round-trip efficiency is used as a definition of the whole system efficiency. The round-trip efficiency, covering the AC to AC system efficiency from charge to discharge, stretches generally from 85 - 95 % in the literature (Danish Energy Agency, 2024c; Cole and Karmakar, 2023), and a round-trip efficiency of 90 % is used for this analysis (Engelhardt et al., 2022). Table 9.10 sums up the economic and technical parameters used for the analysis.

Parameter	**Value**	**Unit**
Costs of energy components	275,060.00	EUR/MWh
Costs of power components	275,060.00	EUR/MW
Fixed O&M	20,530.00	EUR/MW/year
Fixed Round trip efficiency	90	%
Lifetime cycles	5.500	cycles
Technical lifetime	15	years

Table 9.10. Data used for lithium-ion battery (Cole and Karmakar, 2023; Engelhardt et al., 2022).

The information presented in this chapter will be used in the following chapter to create market participation models, evaluate business economics, and provide background knowledge for the discussion.

The information presented in this chapter regarding market structures, participation options, and BESS technology characteristics forms the foundation for the techno-economic analysis in the following chapter. By applying this knowledge, the financial viability of a stand-alone BESS project will be assessed through market participation modelling and business-economic evaluation.

Techno-economic analysis 10

This analysis examines the third sub-question *"What are the business economic prospects of BESS under current market conditions, and how would changes affect its viability?"*. This analysis investigates the profit and product dimensions of the technology and, partly, examines how the products, storage, and ancillary services can be monetised to generate profit. The sub-question and dimension are investigated through a techno-economic analysis, where a market participation model of a BESS facility is created to investigate revenue streams.

The input from the market participation model is used to assess the business economic evaluation of BESS profitability. Finally, a sensitivity analysis is conducted to examine how price changes in different parameters affect the viability of a BESS facility. The modelling of participation and business economic calculation are attached in Appendix A and B.

10.1 Preconditions and delimitation of the modelling

This section outlines the key assumptions and decisions that define the scope of the participation strategy and techno-economic analysis of the BESS facility. These include the geographical focus, market participation, system sizing, and historical data inputs.

Choice of price zone

The analysis is limited to the Danish price zone DK1. This choice is based on the current deployment dynamics, as DK1 has not seen the same level of BESS development as in DK2. Focusing on DK1 allows for the examination of whether BESS projects are feasible and sustainable in a zone with less interest and where ancillary service markets have not been as attractive for developers (Ørkilde, 2025; Pedersen and Bundesen, 2025; Albretschen, 2025). Moreover, DK1 is particularly interesting to investigate due to its high share of variable renewable energy sources, especially wind and increasingly solar, which contributes to greater price volatility and balancing challenges (Grohnheit and Sneum, 2023). Although there has been less observed activity for projects in DK1, several projects are still under development (Danish Energy Agency, 2024a), and DK1 remains relevant for assessing investment conditions under less favourable market circumstances. As described in Section 9.3.1, DK2 has attracted interest due to its higher ancillary services revenue, particularly in FCR-D, which may already be showing signs of saturation (Pedersen and Bundesen, 2025). Within DK1, the analysis is further limited to the area covered by the DSO N1. N1 is chosen as it is the largest DSO in DK1.

Geozone and TSO-zone

The analysis is based on the yellow geozone within a TSO consumption-dominated area to ensure a mid-balanced assessment of BESS viability. As described in Section 9.5, this represents a mid-range case in terms of connection fees and tariff structures, which provides a more balanced basis for assessing BESS.

Scenarios of markets to participate in

The various scenarios in which BESS is modelled to participate are:

- Frequency Containment Reserve (FCR) + Intraday market
- Frequency Containment Reserve (FCR) + Day-ahead market
- Frequency Containment Reserve (FCR)
- Day-ahead market
- Intraday market

Although participation in aFRR and mFRR is technically possible, they are excluded from this analysis. This is primarily due to their lower suitability for short-duration batteries, as these require higher energy reservoir demands for longer durations. They require a higher energy delivery, where it is important to continuously ensure that the SoC is at the right amount for supplying the service (Energinet, 2023; Ørkilde, 2025; Albretschen, 2025). Furthermore, as emphasized in the previous chapter, the design of markets for aFRR and mFRR is undergoing significant changes, with the launch of PICASSO in October 2024, making it uncertain and less valid to investigate using historical prices, as there is not a full dataset available under the new market structure (Energinet, 2024; Pedersen and Bundesen, 2025). Another consideration is the added complexity of modelling the markets within Excel and OpenSolver. This includes time-coupling constraints such as LER requirements, where the BESS must be at a specific state of charge at certain times to participate in aFRR and mFRR, adding interdependencies between time steps and increasing model complexity. The fast response time, negligible energy delivery and symmetry of FCR are advantages for batteries and for modelling (Energinet, 2023). Therefore FCR is investigated in this thesis

Size of the BESS facility

The BESS is modelled as a two-hour battery of 10 MW / 20 MWh. This size has been chosen based on a screening of current Danish market trends and developer practices of BESS projects, such as Battman Energy's stand-alone BESS projects, which are all two-hour batteries (BattMan Energy, 2025). The sizing also ensures that the battery is not classified as a LER unit, which would limit its participation in the FCR market due to regulatory thresholds.

The two-hour battery has also been chosen to provide more flexibility for battery operation. The two-hour battery would make it more suitable for arbitrage, as wholesale markets today operate hourly. A one-hour battery would be less flexible and require frequent operation in the critical high and low SoC. The transition to a quarterly market could, in a future perspective, ease this, but with the current market, a one-hour battery would be less attractive for arbitrage trading (Ørkilde, 2025).

The capacity of the 10 MW battery categorises it in customer category A-low (see Table 9.4). As a result, the battery would most likely be grid-connected at the distribution level and subject to the corresponding tariffs and connection fees associated with this category.

BESS lifetime limitations

To prolong the lifetime of the BESS, the following operational constraints are applied in the market participation model to help reduce degradation from frequent charging and discharging. The battery is limited to two full cycles per day. Additionally, the battery's SoC is restricted to remain between 10 % and 90 % of its total capacity. As a result, the usable storage capacity is limited to 16 MWh. This approach reflects standard industry practice, as operating batteries within this range helps reduce wear and extend their operational lifespan. (Asian Development Bank, 2018; Hesse et al., 2017; Rancilio et al., 2019; Hu et al., 2018)

Historical data from 2024

The model uses historical data from 2024, the most recent full-year dataset currently available. Historical price developments from 2021 - 2024 are illustrated in Appendix C, showing that 2024 reflects market conditions within the typical range of variation observed in these recent years. It is important to note that market structures are evolving. For example, the ancillary service market mFRR transitioned to 15-minute bidding blocks in 2025, and similar changes are planned for the day-ahead and intraday markets (Energinet, 2025b). The fact that only data for 2024 is used is further discussed in Section 10.6.

10.2 Modelling approach

As outlined in the previous section, the BESS participates in five scenarios in DK1 in the three different electricity markets: FCR, intraday, and day-ahead. The constraints are incorporated into the modelling approach, which is also described in Section 6.5.

The BESS participates in the markets sequentially, in chronological order of the bidding deadlines. Figure 9.7 presents the bidding timeline. Different scenarios are modelled individually, including participation in FCR + intraday, FCR + day-ahead, FCR, intraday, and day-ahead. The subsections below describe how participation in each market is modelled.

10.2.1 FCR market participation

As written in Section 9.3.1, the FCR market operates with six predefined four-hour blocks, each requiring separate bids. The specific bidding strategy for a BESS is developed to account for expected opportunity costs across the different blocks. This condition is implemented as a constraint in the model.

In the strategy for FCR market participation, the BESS is assumed to bid in all six four-hour blocks. However, bid prices are adjusted accordingly to reflect the opportunity cost of foregoing potential earnings in the intraday markets during high-value hours. Higher bid prices are used in blocks that overlap with hours typically favourable for energy arbitrage, such as those with low or high electricity prices. The decision to participate in the FCR market in each block is based on a comparison between submitted bids and historical FCR clearing prices. If a bid is accepted, the BESS is constrained from participating in other markets during the accepted block.

The bid prices used in the FCR market modelling for each block are calculated using historical intraday price data from 2024 as a proxy for expected opportunity cost, alongside the average FCR price in 2024, which was 16.26 EUR/MW (Energinet, 2025c). A baseline bid price of 14 EUR/MW is selected to ensure that bids are generally accepted during periods with lower arbitrage potential. The bid price of 14 EUR/MW is categorised as "neutral" in Table 10.1.

Each four-hour FCR block is categorised into "neutral" and "premium" based on its overlap with the lowest historical price in intraday and day-ahead (11:00-14:00) and the highest historical price hours from (17:00-20:00), as illustrated in Figure 10.1. The opportunity cost of participating in the FCR market rather than selling in these high/low price hours is set to approximately 50 % above the average FCR price. As a result, the premium bid price is set to 25 EUR/MW, as shown in Table 10.1.

FCR Block	Category	Bid Price (EUR/MW)
00:00-04:00	Neutral	14
04:00-08:00	Neutral	14
08:00-12:00	Neutral	14
12:00-16:00	Premium	25
16:00-20:00	Premium	25
20:00-00:00	Neutral	14

Table 10.1. FCR bid prices by block with premium adjustments based on historical arbitrage potential during mid-day and evening.

To illustrate why these two FCR blocks have a premium bidding price, the averages of the minimum and maximum prices for the intraday split into FCR blocks can be seen in Figure 10.1. The figure showcases that the best-selling prices, on average, are in the 5th block (16:00-20:00) while the best prices for buying, on average, are in the 4th block (12:00-16:00) in the intraday market.

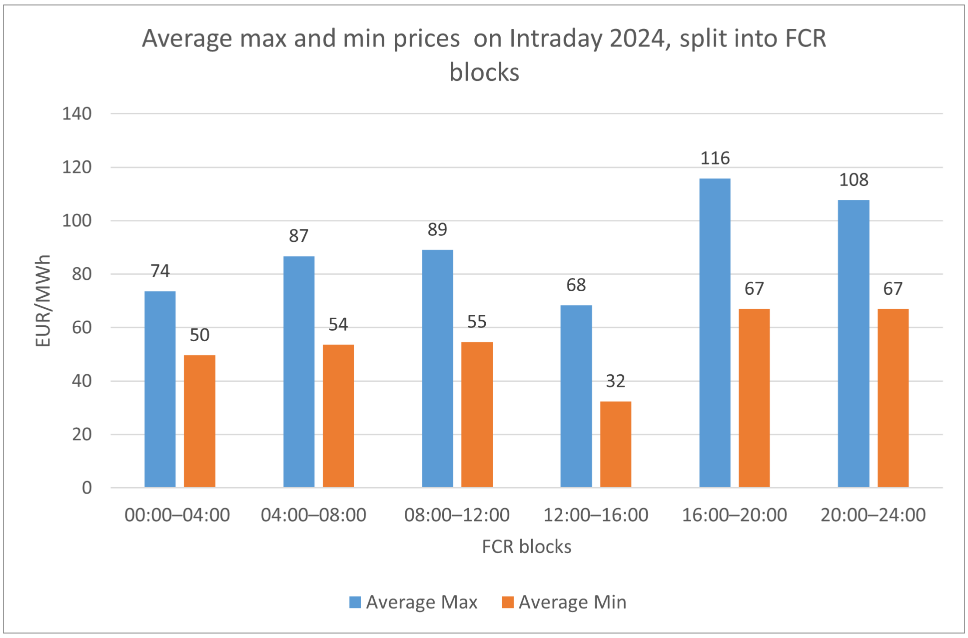


Figure 10.1. Yearly average minimum and maximum prices of intraday split into the FCR six time blocks (Nord Pool, 2025).

Modelling FCR participation, the BESS facility is assumed to act as a price taker, meaning its bids do not influence the market price. In practice, however, a 10 MW battery could contribute to market saturation, particularly given that current FCR procurement volumes are relatively low of 25 MW/h (Energinet, 2025c). The mathematical explanation for the FCR market participation is found in Section 6.5.

10.2.2 Intraday market participation

The intraday market operates on a continuous pay-as-bid basis, allowing the BESS to buy and sell electricity on an hourly basis. This market is accessed after the FCR market, and the battery can only participate in hours when it is not committed to providing FCR services. The aim of using the OpenSolver add-in in Excel is to find the optimal hours and amounts to charge and discharge to maximise annual revenue within the battery's limitations. This means that participation in the intraday market is modelled assuming perfect foresight, meaning the model has prior knowledge of the prices. The intraday market is a continuous and pay-as-bid market that requires making several assumptions about bidding in the modelling, which is a notable limitation in the calculation.

The data used for modelling intraday participation includes the minimum and maximum accepted bid prices in each hour. An assumption is that since the market is pay-as-bid, the BESS cannot consistently expect to buy at the absolute lowest price or sell at the highest price within a given hour. When charging, the BESS is assumed to, on average, pay (or get paid when there are negative prices) 75 % of the minimum price in the hour. When discharging, it is assumed to receive 75 % of the maximum price in the hour as written in Section 6.5. This factor is added to simulate a more realistic revenue stream from intraday participation.

Availability, capacity, energy limits, and the cycle limit restriction constrain intraday participation. Tariffs and the electricity tax, presented in Tables 9.9 and 9.8, are another factor impacting intraday participation. The mathematical explanation for the intraday market participation is found in Section 6.5.

10.2.3 Day-ahead market participation

The approach for modelling the BESS facility's participation in the day-ahead market follows the same overall modelling approach as in the intraday market, but with adjustments. As described in Section 6.5, the day-ahead market is based on a uniform pricing mechanism, meaning that all accepted bids are settled at the same market-clearing price for each hour. Participation in this market, therefore, assumes that the BESS facility can buy and sell electricity at these prices and operates as a price taker.

Unlike the intraday market, the day-ahead market does not have a range of accepted bids, and day-ahead only includes one set of prices. This removes the distinction between minimum and maximum trading prices, limiting the flexibility of the BESS facility to optimise arbitrage across price spreads of minimum and maximum. As in the intraday case, the battery's SoC and the maximum number of full cycles per day are included as constraints in the model. In the scenario where the FCR market and the day-ahead market are combined, the BESS facility only participates during hours when it is not committed to delivering FCR.

10.3 Results of modelling

This section presents the modelling results and illustrates the annual operational results of a 10 MW/20 MWh BESS participating in both single and multi-market scenarios in intraday, day-ahead, and FCR. Thereafter, it illustrates the annual operation for a single scenario to showcase the facility's revenue generation and utilisation.

Figure 10.2 illustrates the scenarios of the annual revenue from participating in different markets. The scenario generating the lowest revenue is the one in which the BESS facility only participates in the day-ahead market. This result is consistent with the characteristics of the day-ahead market, which typically shows lower price volatility and offers fewer arbitrage opportunities compared to the intraday market (Veenstra and Mulder, 2025).

Participating solely in the FCR market achieves the highest revenue. However, this scenario also assumes that the BESS facility wins all six FCR blocks every hour and that the price is not affected by the facility's participation, which is unlikely. Therefore, while the scenario provides an upper benchmark, it is not considered a reliable basis for further modelling. Given this, the most realistic and highest revenue generation is observed in the scenario that combines participation in both FCR and intraday, which reflects a more plausible operating strategy. Therefore, this scenario is selected for further analysis in the remainder of this chapter, acknowledging that it is still a price-taking scenario that does not affect FCR prices.

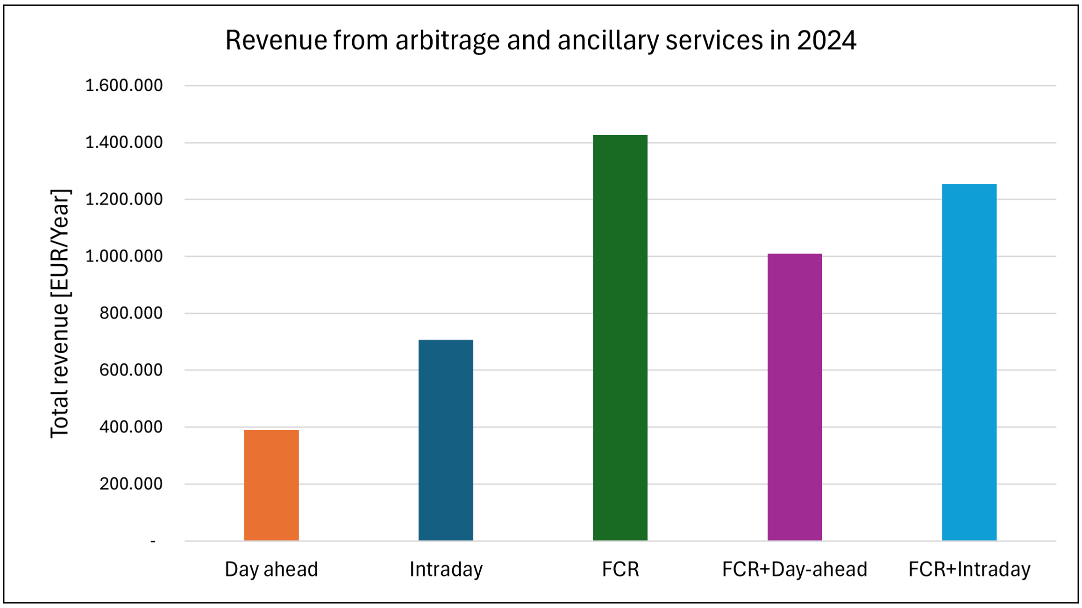


Figure 10.2. Annual revenue generation of each scenario. See Appendix A

10.4 Business economic evaluation of FCR + intraday

Following the delimitation above, this section provides an elaborated economic evaluation of the modelled BESS participation in FCR + intraday. It examines the facility's annual revenue, investment, and operational costs and then conducts a sensitivity analysis to assess its financial viability.

Revenue throughout the year

The monthly revenue from the scenario with the combined FCR and intraday market is shown in Figure 10.3 and Table 10.2, illustrating the BESS facility's revenue generation throughout the year. Tariff costs are also illustrated.

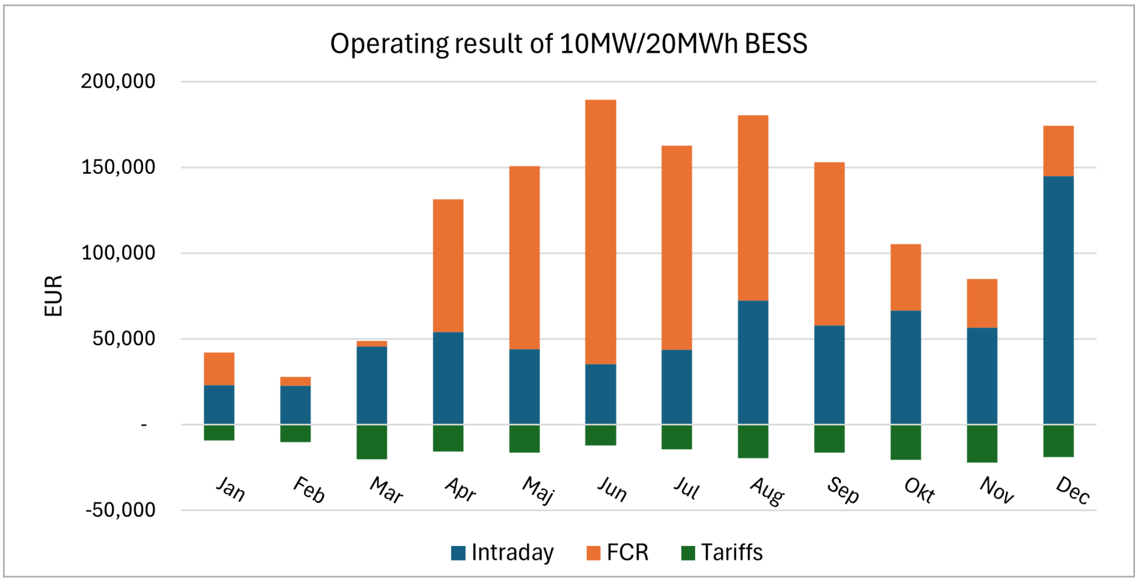


Figure 10.3. Monthly revenue of the 10 MW/20 MWh BESS participating in DK1 FCR and Intraday in 2024. See Appendix A

Month	Intraday	FCR	Tariffs
Jan	23.103	18.900	-9.277
Feb	22.498	5.309	-10.141
Mar	45.660	3.154	-20.398
Apr	53.858	77.572	-15.821
Maj	43.912	106.674	-16.463
Jun	35.147	154.226	-12.165
Jul	43.304	119.206	-14.408
Aug	72.353	108.155	-19.688
Sep	57.694	95.215	-16.479
Okt	66.517	38.698	-20.702
Nov	56.781	29.045	-22.091
Dec	144.818	29.045	-18.967
TOTAL	**665.645**	**784.411**	**-196.600**

Table 10.2. Operating revenue for Intraday, FCR, and Tariffs [EUR]. See Appendix A

The total annual revenue generated from participation in FCR and intraday after tariffs and electricity tax in 2024 is 1,25 mEUR. The total revenue from the markets is 1,45 mEUR, but there is a payment of tariffs of 0,195 mEUR that is subtracted. 54 % of the revenue generated was through the FCR market, while 46 % was generated through intraday trading. This is used in the economic evaluation in the following section to determine the payback time and the IRR, and to determine whether the BESS facility is a worthwhile investment, assuming the same revenue every year throughout the facility's lifetime.

Figure 10.4 shows how many hours of the year the BESS facility was used or not used in each market.

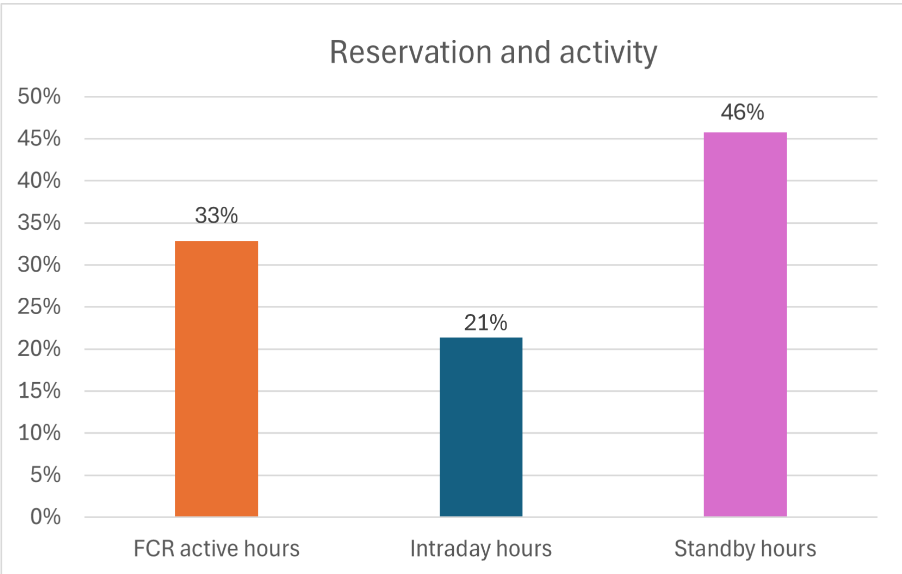


Figure 10.4. Share of hours active in either intraday or FCR market trading as well as standby hours. See Appendix A

The BESS facility's modelling found that the annual number of full cycles performed during operation was around 200 full cycles yearly. The report by Cole and Karmakar (2023) estimates the lifetime for BESS to 15 years, which is based on the assumption that one full cycle per day is completed. Meaning that the 200 full cycles per year is relatively low and could have a longer calendar lifetime than 15 years. It should be noted that the energy amount MWh from charges and discharges when the BESS is active in FCR, is not included. The energy delivery is very low and estimated to be an average of 0.1 % of the bidsize (Energinet, 2023). The actual full cycles would therefore be higher, but evaluated as negligible. With 200 cycles per year, the technical lifetime in years would likely be higher. Simplified, with a technical lifetime of 5.500 full cycles, divided by a yearly 200 cycles, the calendar lifetime would be around 27 years.

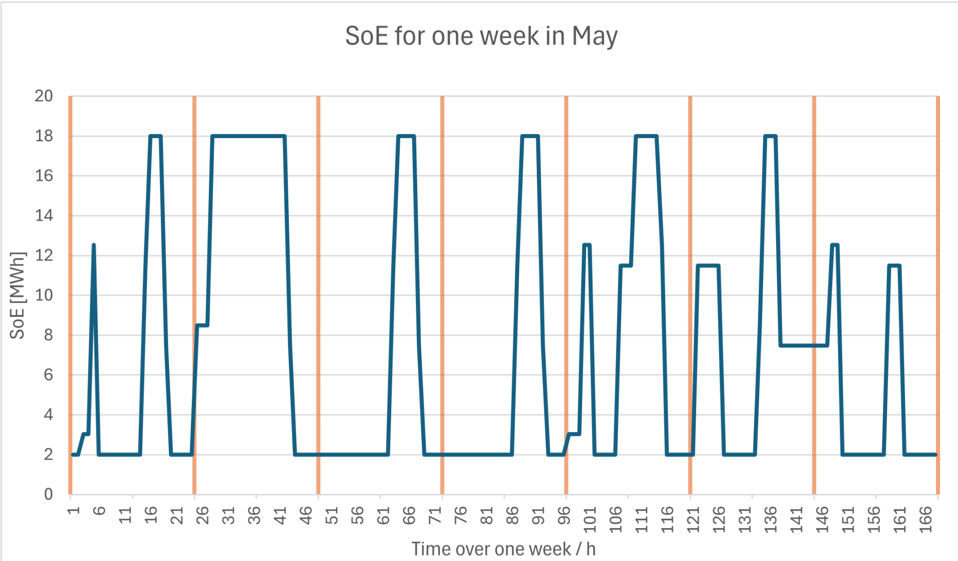


Figure 10.5. SoE of the BESS over a week in May. Orange vertical lines mark the transition between days, and the x-axis shows time in hours from 0 to 168. See Appendix A

Figure 10.5 illustrates the SoE of the BESS facility over a week in May. The BESS facility is active and stays within the limit set between 10 % and 90 % in the respective week. It reflects a pattern of regular charging and discharging with variation in depth and frequency. The operational pattern is a result of the optimisation performed in OpenSolver, which schedules charging and discharging based on price signals within the intraday market.

CAPEX and OPEX

Figure 10.6 shows the results of the BESS facility's CAPEX and OPEX.

As seen in Figure 10.6, BESS's investment costs are the primary cost when establishing a BESS facility. This includes energy, capacity and construction. The total CAPEX is 10,93 mEUR, with investment costs as the primary expenditure, followed by connection fees, which compose 24 % of the investment. The annual OPEX is 0,44 mEUR. The primary OPEX cost is the tariffs, making up 49 %, followed by fixed O&M. Consumption tariffs and electricity tax account for approximately 95 % of the total tariffs and taxes paid by the facility, while feed-in tariffs make up the remaining 5 %. This shows that expenses for consumption tariffs are significantly higher than feed-in.

Payback time and Internal rate of return

The payback time and IRR for the BESS facility are calculated using the methods described in Section 6.6. The calculations are in Appendix B.

The following calculations cover participation in FCR and the intraday market in DK1 in 2024. The 10 MW/20 MWh BESS facility has a payback time of 12.75 years. This means that the

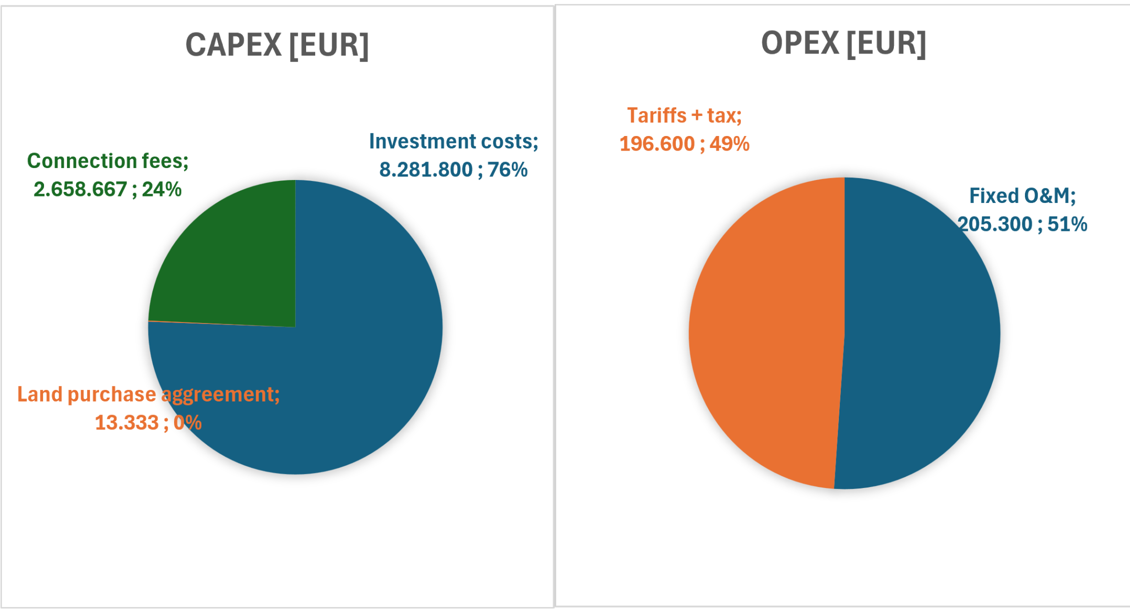


Figure 10.6. Results for CAPEX and OPEX. For 10 MW / 20 MWh BESS facility. See Appendix B

investment is recouped after around 12.8 years of the BESS facility's operation. When comparing the payback time of around 12.8 years with the project lifetime of 15 years, the robustness of the investment could be questioned. The margin between project lifetime and payback time leaves limited room for unexpected costs, market changes, or performance degradation. Therefore, while the investment may technically be viable, its financial robustness is sensitive to both operational and market uncertainties.

The IRR is evaluated to be around 6.5 % for the 10 MW/20 MWh BESS facility. This means that the investment is expected to generate a return of approximately 6.5 % annually over the project lifetime. Comparing the 6.5 % IRR to the typically acceptable range of 6 - 15 % described in Section 6.6 an IRR of 6.5 % is low but acceptable (Klimek et al., 2024). However, as the modelled BESS has around 200 cycles per year, a technical lifetime of 5,500 cycles results in a calendar lifetime of around 27 years. It would result in a better business case with an IRR of around 10 %. However, a lifetime of 27 years extends well beyond other given technical calendar lifetimes of 15 - 20 years in existing literature (Danish Energy Agency, 2024c; Deguenon et al., 2023).

A payback time of 12.75 years and an IRR of 6.5 % is low but considered acceptable within the lifetime. However, as mentioned, the margin between the payback period and the project's lifetime, combined with significant uncertainties, raises concerns about the investment's robustness. Historical data shows that prices in the FCR and intraday markets vary considerably from year to year, as illustrated in Appendix C. Due to these uncertainties, a sensitivity analysis is conducted to assess how changes in parameters impact the project's financial performance. The results of the sensitivity analysis and other uncertainties are discussed more in Chapter 11.

10.5 Sensitivity analysis

A sensitivity analysis is conducted to assess the economic robustness of BESS with the chosen bidding strategy. In this analysis, different parameters are adjusted up and down to determine how significant the effect of changes in these parameters is on the facility's financial situation. This allows for an assessment of how the financial performance responds to uncertainties or future developments. A sensitivity analysis is particularly relevant as the market is still evolving, as written in Section 9.3.1. Before presenting the results, each parameter is explained in terms of how its future development is expected to be.

- **Investment costs:** Following the current trend, investment costs are expected to decrease to 70,000 EUR/MWh in 2030 according to BloombergNEF (2023). This is expected due to continued technological advancements and economies of scale in battery manufacturing, possibly driven by EV development (BloombergNEF, 2023). However, prices may also increase in the short term. Supply chain disruptions or increasing demand for materials like lithium could increase costs.
- **Connection costs:** Connection costs are expected to continue increasing in the coming years. This trend has already been observed and is linked to increased demand for grid access, rising infrastructure costs, and the need for a major restructuring of the electricity grids (Elnet, 2025). As more electricity consumers and producers seek to connect to the grid, the cost of connection is likely to increase, particularly in areas with limited capacity.
- **Tariffs:** Tariffs for electricity consumption and feed-in are also expected to continue increasing (N1 A/S, 2025b, 2024). For BESS, the tariffs account for approximately 50 % of the OPEX costs, and changes in this parameter will significantly impact arbitrage opportunities. There are ongoing discussions about whether battery storage should be granted a special tariff status due to its potential role in balancing the grid and enabling the integration of renewable energy (Bech and Youssef, 2025; Jensen, 2025b; Albretschen, 2025). Such regulatory changes could lead to future tariff reductions or exemptions.
- **Intraday:** As the penetration of VRE in the electricity system increases, intraday prices are expected to become more volatile (Pape, 2018). This increased price spread could enhance the potential for arbitrage trading.
- **FCR:** As FCR is a relatively small market, it is sensible for saturations, particularly as more BESS systems and other technologies enter the market. As previously mentioned, a single 20 MW battery could already cover a significant share of the current FCR demand. The saturation could lead to reduced prices or operating hours, which could limit the revenue potential in the FCR market. Although the overall need for FCR is expected to increase around 25 MW/h before 2030 (Energinet, 2024), this is uncertain due to the expansion of VRE and distribution among European TSOs. Furthermore, as the model assumes that the BESS facility is a price taker, it is important to test the sensitivity of the revenue generated from this market.
- **Interest rate:** The interest rate represents the cost of capital and influences the financial viability of battery investments. When taking loans, macroeconomic conditions, risk assessments, and administrative costs affect interest rates. BESS is a relatively new technology, and market conditions change significantly from year to year, so it could be considered a risky investment, resulting in higher loan costs. (Whitman and Terry, 2012)
- **Fixed O&M:** Fixed O&M costs could increase over time due to several factors. Some of these are inflation, labour costs, or increased system complexity, which could increase expenses. Other factors, such as technological improvements, experience, and standardisation, could lead to cost reductions. While these costs are typically lower compared to investment prices or revenue-related parameters, they are still part of the overall financial performance of the system. The sensitivity analysis examines how variations in fixed O&M affect the financial robustness of BESS.

Results

Each parameter is adjusted by +-20 % to test its effect on the 10 MW / 20 MWh MW BESS's payback time and IRR. The results are summarised in Figure 10.7, which shows how the estimated payback period and IRR change in response to these changes in the parameters. The technical lifetime of 15 years is also illustrated, as some parameters exceed the payback period and thus extend beyond the expected operational lifetime.

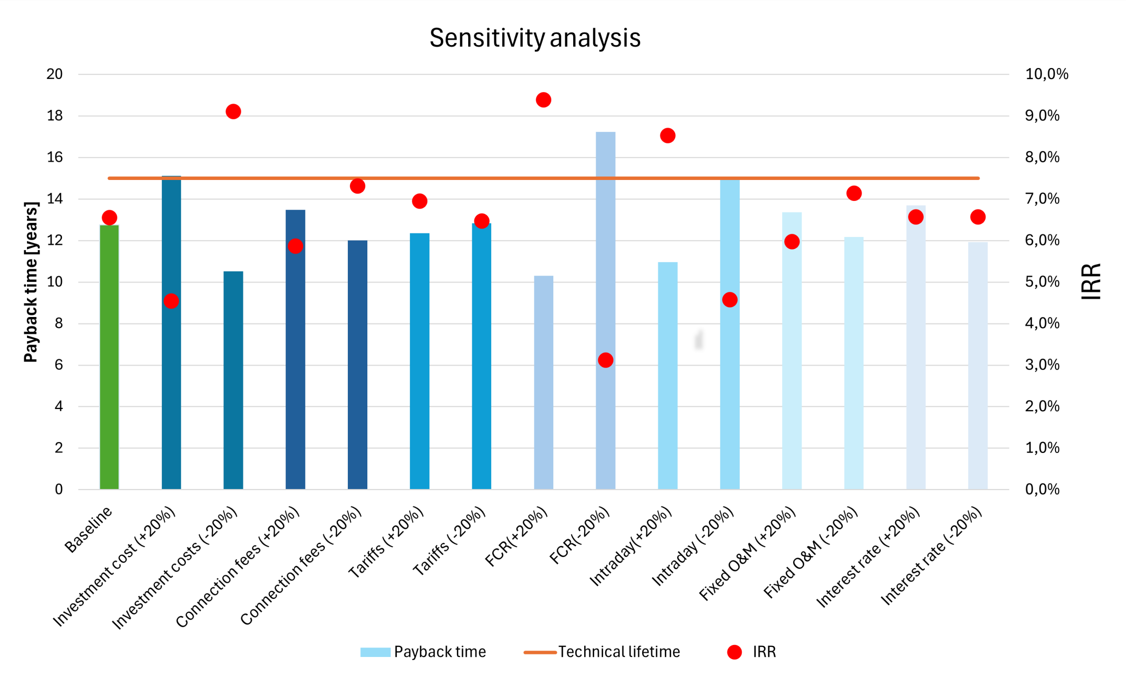


Figure 10.7. Sensitivity analysis of parameters for the model of a 10 MW/20 MWh BESS participating in FCR and intraday. Parameters were changed 20 %. See Appendix B

As shown in Figure 10.7, the sensitivity analysis shows that the payback time and IRR of the BESS are most sensitive to changes in investment costs, intraday market prices, and FCR prices. A 20 % increase in investment costs leads to a 2.4-year longer payback period and a decrease in IRR of 2 percentage points. A 20 % decrease in FCR prices increases the payback period by around 4.5 years and reduces IRR by 3.4 percentage points. BESS's sensitivity to changes in FCR and intraday prices poses a risk from a financing perspective, as year-to-year price volatility can make it difficult for banks and other lending institutions to assess whether the investment is secure enough to provide capital for stand-alone BESS facilities.

However, changes in the interest rate have a limited impact. A 20 % increase or decrease results in minor changes to payback time, indicating that the financing structure is relatively resilient within the tested range. Changing the interest rate does not affect the IRR, as the interest rate is not a part of the IRR calculation formula, so in this case there is no change. The project is also moderately affected by changes in connection fees, tariffs, and fixed O&M costs. These parameters change the payback period and IRR, but not as significantly as the intraday and FCR payments.

The sensitivity analysis highlights that the most critical parameters for BESS's financial robustness are FCR prices, intraday prices, and investment costs. Therefore, the sustainability of current investments in stand-alone BESS facilities could depend on whether the prices of these two markets increase or structural changes are implemented to favour batteries.

10.6 Sources of error

Modelling of FCR

It is relevant to consider the size of the FCR market in the modelling, which has not been included in the bidding strategy. A total of 25 MW was purchased daily in 2024 from both domestic and international market participants. (Energinet, 2025c). The modelled participation capacity was 10 MW, using a minimum acceptable price. Given the relatively small size of the FCR market in DK1, the battery would in practice account for almost 50 % of the total bought FCR capacity.

In such a situation, the BESS would likely affect prices and become a price setter. The market impact as a price setter is not captured in the model, as the BESS is a price taker, and market prices are assumed to be independent of the battery's participation. A more advanced modelling approach using market equilibrium models would be required to reflect these effects accurately.

Modelling of Intraday

The modelling of participation in the intraday market has been simplified in different ways. Firstly, the intraday market is continuous until T-1h, and operates on a pay-as-bid pricing mechanism, making it complex to model realistically. Secondly, the model assumes perfect foresight regarding prices and trading opportunities, which is not achievable in practice. Thirdly, it is assumed that 75% of the given minimum and maximum of the bids and offers. This comes with significant uncertainty, as actual trading outcomes are highly unpredictable and depend on market liquidity and competition. Offers and bids can be modified until gate closure time, and are continuously matched from an order book (SIDC NEMOs and Deutsche Börse AG, 2022).

A market participant typically has a maximum bid price, also known as a willingness-to-pay limit, which reflects the highest price they are willing to pay for electricity. Similarly, they often set a minimum offer price, or reservation price, representing the lowest price at which they are willing to sell, to avoid selling too cheaply (Keohane and Olmstead, 2016). These limits help ensure that transactions are only made when they are profitable or cost-effective, taking into account investment costs, operation and maintenance (O&M), and battery degradation. This approach has not yet been applied to intraday bidding but could be incorporated in future modelling.

Charging and discharging

In the model setup, the battery is allowed to charge and discharge within the same hour when participating in the intraday market. The model optimises revenue from both charging and discharging, which can result in the BESS performing both actions within a single hour. In practice, this is unrealistic, as market participants can only submit a bid or an offer per hour. While the battery can switch between providing upward and downward regulation, it cannot do so simultaneously with the same capacity. Addressing this would require introducing over 16,000 individual constraints. This simplification increases the modelled revenue potential by allowing the battery to exploit both sides of the market within the same hour.

The use of only one year of data

A final important source of error is using historical market data from only one year (2024) to estimate the battery's revenues. This way, it is assumed that the market conditions and earnings remain constant throughout the BESS's entire lifetime. However, both electricity prices and ancillary service revenues vary from year to year, as illustrated by the historical prices shown in the Appendix C.

From a historical perspective, understanding the yearly, monthly, and hourly fluctuations and trends in the historic price dataset in energy and ancillary service markets is important for long-term business plans for BESS owners (Hameed et al., 2023). From a future perspective, it should be remembered that markets are constructed and the framework of these markets is expected to evolve, which can further affect future revenues (Energinet, 2024). The sensitivity analysis with an increase or decrease in prices includes this aspect more or less, but a full market analysis should have entailed price forecasts in the wholesale market. This depends as much on the development of the demand curve, and the development of the price volatility is discussed further in chapter 11.

10.7 Summary of the techno-economic analysis

This chapter examined the third sub-question by conducting a techno-economic analysis. It examined the profit dimension of BESS by modelling a 10 MW / 20 MWh BESS facility participating in the FCR, intraday, and day-ahead markets in DK1 based on 2024 data. The results show that the most viable strategy under current conditions, when excluding aFRR and mFRR, is a combined participation in FCR and intraday markets, generating an annual revenue of approximately 1.25 mEUR after tariffs and taxes.

Based on this revenue, the facility has a payback time of 12,75 years and an IRR of 6.5 %, the business economic prospects of BESS in DK1 are therefore evaluated to be acceptable but weak. The payback time and IRR suggest that BESS can be economically viable, but with limited profitability and little margin for unforeseen costs or market fluctuations. The sensitivity analysis highlights investment costs, intraday prices, and FCR prices as the most critical factors influencing financial performance. Changes in these parameters significantly affect financial viability, while others, such as tariffs, interest rates, and fixed OPEX, have a more moderate impact. Future profitability of stand-alone BESS depends on market developments, continued cost reductions, and regulatory adjustments that acknowledge the potential of BESS's products, such as storage and ancillary services in the electricity system.

Discussion 11

This discussion examines the fourth sub-question *"What are BESS's main challenges and opportunities now and in the future, and how could relevant stakeholders address them?"* The chapter discusses the key challenges and opportunities facing BESS, both currently and in the future. The discussion takes its outset in the preceding analyses, literature, and interviews, and explores how relevant stakeholders can address these developments. The discussion explores the dimensions in the Technology concept from Section 5.3 with a primary focus on the business and economic prospects of BESS, particularly aspects related to the dimensions profit and product, while also addressing organisational and knowledge related aspects. The discussion concludes with reflections on BESS in the context of Choice Awareness and Smart Energy Systems, which examines how BESS fits into the discussion on technological alternatives and energy system planning.

As presented, this thesis holds constructivism as the scientific perspective, meaning markets are perceived as constructed. The viability and economy of BESS depend on the market's framework conditions and actors, as illustrated in Figure 5.3. This discussion goes through how changes in electricity and ancillary services markets, as well as changes in the broader energy system and legal framework, can impact the financial sustainability of BESS in Denmark.

11.1 Business economy of BESS

This section discusses BESS's economic prospects in terms of both the current market situation and the future. It is based on the modelling, sensitivity analysis, literature, and interviews, and is primarily related to the dimensions of profit and, to some extent, product in the technology concept. It discusses the viability of investment in BESS now and in the coming years, and the challenges and opportunities of the economic prospects in the future.

Although the discussion is structured around individual factors and parameters, it is essential to note that these are closely interrelated. BESS's business economic prospects depend not only on market prices and investment costs but also on policy design, grid tariffs, and technological development. Changes in one factor may potentially lead to positive or negative cascading effects on other factors, highlighting the complexity of assessing the future business economy of BESS. Some of these cascading effects are included in the sensitivity analysis in Section 10.5 and are discussed in the following sections.

11.1.1 Ancillary services

Based on the techno-economic analysis in Chapter 10, it was shown that the model generated over 50 % of the revenue through participation in the ancillary service market for FCR. However, a challenge for BESS is that the market prices vary a lot from year to year, creating uncertainty in how future revenue generation in this market is expected to be. For instance, in 2022 average FCR prices reached an average price of around 494 EUR/MW in August (Danish Utility Regulator, 2023). This is also shown in Figure C3 in Appendix C3. These high prices were primarily driven by a regulatory requirement that Energinet procured at least 6 - 7 MW of FCR capacity locally in DK1. This rule was removed in late 2022 and FCR in DK1 was integrated into the European joint FCR procurement platform, and market prices declined. By 2024, the average price of FCR in DK1 was around 16 euros per MW/h (Energinet, 2025c). This is an example of how the market is constructed and how market structure and size changes affect the price levels.

This kind of volatility is thereby important to consider when assessing the economic case for BESS. The sensitivity analysis also illustrated that the business economy of the BESS facility was particularly sensitive to changes in FCR prices. Given the significant year-to-year volatility in FCR prices and similar variability observed in other ancillary service markets (See Appendix Figure C3), developers and investors should enter a dialogue asset managers, such as Centrica and rely on outlook analyses by Energinet. Such dialogue can provide insights into expected market developments and help ensure that investment decisions in BESS projects are based on a well-informed foundation. The ancillary service market has been attractive for developers during the last couple of years, but with changes in market structures, demand, and supply, developers must be aware of these effects (Bech and Youssef, 2025). Various factors can influence the dynamics and prices of ancillary services. These include the market's structural aspects, the characteristics of competing technologies, and saturation. The following sections explore these challenges in more detail.

Market saturation of ancillary services

One of the central challenges facing BESS facilities in Denmark is the limited size and saturation risk of the FCR ancillary service market, which BESS is well suited to supply. It is important to note that the ancillary services market operates across national borders and encompasses total demand in coordination with neighbouring countries. (Pedersen and Bundesen, 2025). Energinet (2024) projects the demand for FCR in DK1 to increase gradually to around 50 MW/h by 2030, compared to around 25 MW/h in DK1 as of 2024. This is a small market size relative to the growing interest from battery developers. Energinet has in 2024 pre-qualified 45 MW of battery capacity (Pedersen and Bundesen, 2025). Energinet cooperates with other TSOs in the Continental Europe SA, where FCR is imported and exported across countries (ENTSO-E, 2024). In 2023, Denmark and other countries had to "import" FCR to fulfil their demand, while Germany and France "exported" FCR. Therefore, the Danish supply of FCR depends on the overall balance between countries, with a total estimated demand of 3,000 MW across the area. Shifts in this balance can also affect the Danish share of the demand, which is currently estimated at 25 MW (ENTSO-E, 2024).

The 10 MW output capacity BESS facility modelled in this thesis would already represent a significant share of the current DK1 market. As Pedersen and Bundesen (2025) noted in the interview, a single 100 MW battery could dominate the Danish share, and become a large market actor of FCR and significantly affect price levels through sheer market volume. This implies that even a handful of grid-scale batteries could saturate the market, reducing returns for all participants. According to Ørkilde (2025), this has already been observed in other countries, where high initial returns in ancillary services led to a significant increase of battery investments, which has led to increasing saturation and decreasing prices. The same is observed in DK2, where most of Denmark's pre-qualified batteries for ancillary services are located, as listed in Table 9.3, where prices in the FCR services -N and -D have attracted much interest from BESS developers. The investment in batteries for ancillary services in both DK2 and Sweden has already decreased prices, especially in FCR-D (Albretschen, 2025; Pedersen and Bundesen, 2025; Bech and Youssef, 2025). Pedersen and Bundesen (2025) observes that investments in BESS from 2022 - 2023 have covered their expenses, whereas investment in 2024 takes considerably longer to pay back. Even though the need for balancing will increase, the demand for FCR services will not increase significantly, meaning the market can quickly become saturated (Pedersen and Bundesen, 2025).

Furthermore, competing technologies, such as electric boilers and flexible industrial loads, can also bid into the FCR and other ancilliary services. There is an increasing awareness of the revenue potential in ancillary services across the entire energy system. Energinet (2025b) reports that seven times more facilities were pre-qualified for ancillary services in 2024 compared to 2023, including units from the heating and transport sectors and large electricity consumers. In 2023, electric boilers accounted for the largest share of newly pre-qualified FCR capacity (Energinet, 2024). According to the Danish Energy Agency (2024a), the installed capacity of large-scale heat pumps is expected to increase from 270 MW in 2024 to approximately 960 MW in 2030, while electric boiler capacity is projected to grow from 1,800 MW to 3,500 MW over the same period. Increased participation from these technologies may lead to even higher saturation, which should be considered in future assessments.

Based on the perspectives on market saturation and future developments, developers and investors should apply conservative price forecasts when assessing the revenue potential of ancillary services. As FCR participation accounted for over 50 % of the revenue in this thesis's models, it may also be advisable to consult with market analysts. While the FCR ancillary services can be a strong entry point for BESS projects, the size and high saturation risk makes them a volatile foundation for long-term business cases (Pedersen and Bundesen, 2025). Developers should furthermore check national BESS pipelines to avoid unprofitable deployments. Developers' business cases should also consider the potential of participating in other markets, aFRR and mFRR, and investigate the future revenue expectation from arbitrage trading.

Opportunities in aFRR and mFRR

This thesis has only modelled BESS participation in the FCR market for the ancillary service markets because of data limitations and the increased complexity of modelling aFRR and mFRR. However, due to the risk of market saturation and declining prices, it becomes increasingly important to consider the potential for BESS to participate in aFRR and mFRR.

Centrica and Energinet both emphasise that the aFRR market will likely become more important in the coming years (Centrica, 2025; Pedersen and Bundesen, 2025). aFRR prices for upregulation in DK1 during the last 8 months are illustrated in Appendix Figure C1. aFRR market has had more attractive payments than FCR, with an average of 53 EUR/MW in the period compared to 16 EUR/MW in FCR in 2024. Furthermore, Energinet projects the demand for aFRR in DK1 to increase from 100 MW in 2024 to 500 MW in 2033 (IEA, 2024). The increase stems mostly from the plans for the commissioning of offshore wind turbines in the North Sea (Pedersen and Bundesen, 2025) and expansion of wind turbines. The expansion of renewables is another uncertainty regarding BESS's future market conditions. EWII is currently only active in the FCR market with their BESS facilities, but is working towards entering the aFRR market, as they recognise the market trends and note that being among the first movers can offer a competitive advantage (Albretschen, 2025).

Two structural changes to the markets might improve opportunities for BESS in the aFRR and mFRR markets, as written in Section 9.3.1. The first change is Denmark's integration into the PICASSO and MARI platforms, which aim to trade balancing resources across borders. This integration is expected to expand participation opportunities for BESS facilities by opening access to a larger market. However, it may also lead to increased competition from a broader range of assets across Europe, potentially lowering clearing prices and putting downward pressure on revenue.

The second structural change is shifting to 15-minute MTU in the mFRR market, (Energinet, 2024), which is expected to benefit fast responding technologies such as BESS. Shorter bidding and settlement periods improve alignment between the services and the technical capabilities of BESS, which are well-suited for rapid response over short timeframes. The shift to 15-minute MTU also means that BESS's energy delivery becomes lower, making it easier for BESS to participate

(Ørkilde, 2025; Pedersen and Bundesen, 2025).

Nevertheless, the higher demand for energy capacity is a challenge for participating in mFRR and aFRR with BESS (Albretschen, 2025; Pedersen and Bundesen, 2025). These markets have higher load factors and involve more frequent charging, increasing the need for more energy capacity. The technical LER requirements for participating in aFRR are especially challenging. There are large requirements for reserving energy and power capacity for LER-units participating in aFRR requirements, as they require larger energy demands than FCR (Nielsen, 2025; Pedersen and Bundesen, 2025). For example, while FCR-D requires 0.33 MWh in reservation per MW bid, aFRR requires 4 MWh per MW, which is significant compared to the 1 - 2 hours batteries (Pedersen and Bundesen, 2025). The owner can then bid with less capacity, but it also requires maintaining the right level of SoC. Energinet sees potential for BESS participating in aFRR, but the requirements set significant limitations for BESS to ensure a sufficient delivery. Furthermore, the frequent charge and discharge have more wear on the batteries, leading to higher degradation, lowering the battery's lifetime (Engelhardt et al., 2022; Thingvad et al., 2023; Pedersen and Bundesen, 2025; EWII, 2025a).

Given the market developments and increasing volume demands in aFRR and mFRR, BESS projects should not be designed solely around the FCR market. Instead, developers should design the BESS facilities to be technically compatible with participating in aFRR and mFRR services, requiring larger capacities. BESS facilities participating in aFRR and mFRR will likely be more resilient under future market conditions. Therefore, developers of BESS facilities should consult with Energinet about the prequalification process for these markets, as well as asset managers who have knowledge about the most optimal dimensions for multi-market participation.

11.1.2 Arbitrage

Interviewees mentioned arbitrage as an important revenue factor, the feasibility of BESS (Albretschen, 2025; Ørkilde, 2025). Arbitrage trading is an important yet uncertain revenue stream for BESS, making up 46 % in the model of intraday + FCR. The spot price data from the past four years (see Appendix Figure C2) shows significant annual fluctuations in electricity prices, which can create or limit arbitrage opportunities depending on the level of volatility from year to year. For example, in 2022, which was marked by extreme fluctuations due to the energy crisis, BESS would probably have had highly favourable conditions for arbitrage. However, higher average prices do not necessarily increase BESS profitability. Instead, it is the magnitude and frequency of price fluctuations that matter. Energinet expects electricity prices to increase slightly over time and anticipates more variation in prices from hour to hour as VRE capacity expands (Energinet, 2022).

Several studies examine how increased VRE penetration affects price volatility. Seel et al. (2018) reports that while average prices decrease with higher VRE, price volatility increases, particularly with more hours of very low prices. Similarly, Liebensteiner et al. (2025) predict that expanding VREs will significantly increase electricity price volatility in Germany, driven by the interplay between VRE generation and external factors like gas and CO_2 prices. Contrarily, Wang et al. (2024) identifies a threshold effect, where volatility first increases with rising VRE but then decreases once a certain penetration level is reached. These studies show contradictory results about the effect of VRE penetration on electricity price variability. However, the variability also depends on expectations for the demand curve, meaning that demand-side flexibility may influence the extent of electricity price fluctuations (IRENA, 2019). Nevertheless, a study show that when more batteries are deployed, arbitrage opportunities diminish (Veenstra and Mulder, 2025).

The transition to 15-minute MTU in the Day-Ahead and Intraday markets is also expected to benefit BESS by increasing the flexibility and time granularity of arbitrage opportunities. A study by Metz and Saraiva (2018) shows that shorter MTUs can increase revenue potential, but also finds that arbitrage trading alone is insufficient to make BESS economically viable at current levels of price volatility. In the case study from Germany, price volatility would need to increase by a factor of seven for BESS to break even without participating in other markets (Metz and Saraiva, 2018).

This thesis's BESS model showed that nearly 94 percent of grid tariffs are consumption tariffs, ranging from 19.6 to 30.1 EUR/MWh. The consumption tariffs significantly reduce arbitrage profitability and eliminate many arbitrage opportunities. Nielsen (2025) mentions that there are discussions about whether BESS should be granted a special status in terms of tariffs; however, according to Cerius-Radius it seems no official discussions are ongoing (Nielsen, 2025; Jensen, 2025b). A special tariff status would increase possibilities for revenue generation by allowing more arbitrage opportunities for the technology. This will be discussed in depth in a later section.

11.1.3 Multi-market bidding

Multi-market participation, combining arbitrage with stacked ancillary services, is several times mentioned as important to ensure profitability (Thingvad et al., 2023; Hameed et al., 2023). As highlighted in interviews (Albretschen, 2025; Ørkilde, 2025), developers are betting on arbitrage becoming more profitable in the future, and an important factor for the feasibility of BESS. Energinet also advises developers to think holistically about market participation to ensure BESS's revenue streams from multiple market participation. Ancillary service markets can quickly become saturated, and they tell developers that it should not be the main source of income or purpose of the battery (Pedersen and Bundesen, 2025). Ancillary services should be regarded as a value-adding feature to reduce costs, rather than a sole revenue stream, as relying exclusively on them entails significant risks. The model of this thesis and the literature also indicate that relying solely on arbitrage remains a risky strategy. For a battery to generate diversified income streams and improve overall profitability, a large capacity is required to participate in the aFRR, mFRR, and wholesale markets (Bech and Youssef, 2025).

Successful participation requires a smart bidding strategy (Ørkilde, 2025). Such a strategy depends on several factors, such as accurate price forecasts. The market participation model in this thesis assumes perfect foresight in the FCR market, which is impossible in real-time market conditions. The participation strategy can also differ throughout the year. For example, when examining the spot market, the lowest prices typically occur at night during the winter, whereas in the summer, they tend to appear around midday (Albretschen, 2025). For the analysis in this thesis, the revenue stream from FCR is significantly higher during the April-September period, as illustrated in Figure 10.3. In DK2, Thingvad et al. (2023) found that payment of FCR-N was generally higher during off-peak hours and from May to August, and that payment for FFR was generally high from midnight to the early morning. As a result, the optimisation process and the setting of maximum and minimum bid and offer prices must be adjusted throughout the year. The participation strategy should consider both price opportunities and battery degradation, and it is important to balance participation across markets.

The sustainability of current investments in stand-alone BESS facilities is uncertain, given the potential saturation of the FCR ancillary service market and conflicting projections regarding future price volatility as VRE penetration increases. Nevertheless, as discussed, arbitrage trading and aFRR and mFRR may become more attractive for BESS due to the shift to 15-minute MTU, possible changes to tariff structures, and the potential for increased volatility. However, the latter two factors remain uncertain, representing significant risks.

11.1.4 Limited grid connection

A parameter, which was not a part of the model of this thesis, was the effect of choosing a limited grid access. Developers can limit grid access with interruptibility for either consumption, feed-in, or both (Jensen, 2025b). Choosing a limited grid connection can substantially reduce or remove the required connection fee (Green Power Denmark, 2025c). In the business economic evaluation, connection fees accounted for approximately 25 % of the CAPEX, corresponding to around 2.65 million EUR.

If a developer of a BESS facility chooses limited grid access in both directions at full capacity, the developer can avoid paying the connection fee (Green Power Denmark, 2025c). Additionally, customers who accept interruptibility in relation to the transmission grid can pay a reduced "nettariff" to Energinet of only 33 % of the tariff components that do not relate to network losses (Energinet, 2024b). If the tariffs are reduced then it allows for more arbitrage trading opportunities.

A limited grid connection comes with operational constraints. Choosing a limited grid access means the BESS facility is interruptible and may be curtailed during hours when the grid is congested. This could reduce revenue if the BESS cannot charge or discharge during high-value hours. Cerius-Radius acknowledges this concern but emphasises that these products are highly attractive for batteries (Jensen, 2025b). Furthermore, under typical conditions, BESS operations are often in "counter-phase" with the grid, meaning that it charges during oversupply and discharges during undersupply. This behaviour is driven by market price signals and may help reduce the risk of curtailment.

The ability to participate in ancillary service markets is another consideration. Suppose a facility has an interruptible grid access. In that case, Energinet limits participation in geographically constrained mFRR activations for consumption-side upregulation, because Energinet can control this through interruptibility, and the facility will thereby be paid with the imbalance price. However, BESS facilities with limited grid access can still participate in most ancillary service markets and the general mFRR market (Energinet, 2024b).

In summary, developers need to weigh multiple considerations when determining which type of grid connection they want for their BESS projects. Limited and interruptible access can significantly reduce both CAPEX and OPEX. However, these advantages must be weighed against curtailment risks. Uncertainty remains regarding the economic impact of interruptions, and studies are needed to assess how often such limitations and opportunities may affect the operation of a BESS facility.

11.1.5 Tariffs

As seen in the analysis of the business economy model in Section 10.3, tariffs and taxes on electricity make up around 50 % or 200,000 EUR/year. Of these, around 95 % were consumption tariffs. As mentioned, tariffs limit opportunities for arbitrage trading, and their special status was highlighted in the discussion on this topic.

BESS in Denmark is currently under the ordinary tariff structure, meaning that it pays consumption tariffs when consuming and feed-in tariffs when injecting electricity into the grid, as BESS is considered both a consumer and a producer. As a result, the same kWh may be subject to tariffs twice, once upon entry into the battery and once when it is released back into the grid. Nielsen (2025) notes the debate around the "double taxation" of batteries. Compared to other European countries, Denmark offers less favourable conditions for BESS. He addresses the complexity of this topic, involving the need for fair market conditions, technology neutrality, and the desire for BESS developers to establish viable business models. (Nielsen, 2025)

EWII argues that the current structure does not fairly reflect the role batteries can possess in supporting the electricity system and providing ancillary services, primarily since they mainly serve to shift electricity in time rather than consume or produce it in the traditional sense (Albretschen, 2025). Nielsen (2025) points to other European countries where battery storage is subject to more favourable tariff conditions, for example, Germany, which has exempted BESS from consumption tariffs on facilities connected before 2029, and Spain, Italy, and Portugal also have some form of dispensation for electricity storage units (Green Power Denmark, 2024; DACES, 2024).

Cerius and Radius, representing the DSO perspective, explain that the tariff structure is based on cost allocation principles and is subject to strict regulatory oversight. They state that both consumption and production cause costs in the grid and that the tariffs reflect this. Since total tariff income is fixed, removing tariffs from one group, or giving a special status to a technology, would require increasing them for another. According to them, there is no double-tariffing. (Jensen, 2025b)

EWII has suggested creating a dedicated tariff category for battery storage or introducing refund mechanisms when electricity is reinjected into the grid (Albretschen, 2025). Cerius and Radius indicate that while no specific changes are planned for batteries, they are open to dialogue and continuously working on making the tariff structure more cost-reflective (Jensen, 2025b). A method for avoiding all DSO tariffs and the connection fees to DSOs is to be connected directly to the transmission network. However, this is only relevant for facilities around 100 MW or larger, and it would significantly lower the tariffs and the connection fees (Albretschen, 2025).

Stakeholders such as Energinet, DSOs, the government, and other regulators should converse with universities and other countries who have experience and knowledge about BESS and its role in future energy systems. If BESS capabilities are evaluated and considered valuable, regulators could consider creating more favourable tariff conditions to boost BESS deployments.

11.1.6 Financing

The preceding discussions of the business economy of BESS highlight several challenges and opportunities, many of which create uncertainty for potential investors and lenders. Unlike well-established technologies with stable revenue models, BESS projects, particularly stand-alone installations, face financial uncertainty due to dynamic market conditions and significant differences in market prices year to year. This uncertainty directly affects the willingness of banks to provide loans (Bech and Youssef, 2025).

Factors such as macroeconomic conditions, administrative costs, and the perceived risk of a project all influence how banks determine interest rates. In the case of BESS, the lack of long-term, predictable income streams and the dynamic market conditions increase the perceived risk (Whitman and Terry, 2012). As a result, lenders may apply a risk premium, potentially raising interest rates. This thesis used an interest rate of 4.6 % in techno-economic analysis. However, given the current uncertainty connected with the future revenue generation of BESS, the rate used may be too low.

A central question is whether banks will approve loans for stand-alone BESS facilities. BESS does not generate electricity but instead stores and shifts energy or provides ancillary services. Unlike solar or wind projects, stand-alone BESS generally cannot enter into traditional PPAs, as they do not produce energy. PPAs are becoming increasingly important for securing financing for PV and wind projects, as they offer a stable and predictable revenue stream (Hundt et al., 2021). In their absence, the financial viability of stand-alone BESS relies on uncertain and potentially volatile revenue streams from energy arbitrage and ancillary services. The lack of guaranteed steady revenue streams and market uncertainties could make stand-alone BESS projects challenging to finance, particularly for smaller or newer developers who cannot provide guarantees in other ways. BESS developers, who cannot offer guarantees, could therefore consider collaborating with VRE owners to make co-location projects with wind and solar facilities to ensure a steadier revenue stream. This is discussed in the following section.

11.1.7 BESS in combination with VRE

Integrating BESS with VRE can improve both the financial and operational profile of renewable energy projects. One key benefit is the potential to secure more favorable PPA conditions (Kaur, 2022). By co-locating BESS, developers can offer an additional asset that BRP's can manage alongside the renewable facility, allowing them to optimize revenues from PV or wind turbines through strategies such as peak shaving (Ørkilde, 2025).

In PPA structures where offtakers are exposed to the timing of generation, such as shaped or firm-volume PPAs, BESS can enhance shape matching by shifting generation to better align with the offtaker's consumption profile. Improved shape matching can reduce the offtaker's reliance on the spot market to balance their load. This alignment improves price predictability and lowers exposure to market volatility, thereby increasing the PPA's value to the offtaker (Seppälä and Syri, 2025). Consequently, offtakers may be willing to pay a premium for PPAs supported by BESS-integrated VRE facilities (Kaur, 2022).

BESS can help a VRE facility to align better with trading plans submitted by the BRP to Energinet by improving power quality and smoothing injections into the grid from VRE, particularly PV (Hoff, 2022; Pedersen and Bundesen, 2025). This is an advantage for BRPs, as they must pay for any deviation caused quarterly (Energinet, 2025c). For example, a BESS can reduce imbalances caused by sudden drops in PV production, such as when clouds pass a solar farm (Pedersen and Bundesen, 2025). This lowers the BRP's risk and costs, which could lead to more favourable contract terms between the BRP and the facility owner.

Another consideration is that adding a BESS to a VRE facility makes it more attractive for VRE facilities to bid into the mFRR downregulation market. When downregulation is activated, the VRE facility continues producing, but the power is diverted to the battery instead of the grid. This allows the producer to earn activation payments while preserving generation (Statnett, 2023).

A final consideration is the more efficient use of existing grid connections. When co-locating a BESS facility, the battery can often use the same grid connection as the PV or wind installation, especially during hours when the generation facility is not operating at full capacity. Nielsen (2025) notes that, for example, a 50 MW solar PV plant might not require a full 50 MW grid connection if paired with a 10 MW battery. In such cases, the battery can absorb part of the production, potentially reducing the necessary grid connection capacity to, for example, 40 MW. While this may result in some curtailment during full load hours, batteries can help optimise the use of grid capacity. Nielsen (2025) also highlights that batteries may help relieve local grid bottlenecks. Similarly, Eurowind also argues that BESS can allow developers to install more PV capacity at existing wind or solar sites than the current grid connection typically permits. This is especially relevant in situations where building permits are time-limited, and new grid connections are delayed for several years. In such cases, BESS offers a creative and temporary workaround to move projects forward without losing permits (Søndergaard and Ebbesen, 2025).

In summary, BESS and variable renewable energy technologies offer complementary strengths that can enhance the overall business case when deployed together. Considering these synergies and reflecting on the techno-economic analysis's results, BESS may currently be best suited for co-placement with VRE facilities in DK1, as this can help reduce tariff and tax spending, lower investment costs, and decrease lender uncertainty.

11.1.8 Summary of the discussion of the business economy of BESS

While several barriers exist, such as market saturation, tariff structures, and financing difficulties, opportunities exist, including multi-market participation, regulatory changes, optimised grid connections, and synergies with variable renewable energy. To improve the conditions for BESS deployment, relevant stakeholders such as developers, grid operators, and regulators should investigate if BESS is an important technology for the future Danish energy system because of its capabilities to provide ancillary service, improve revenue generation of VRE by peak shaving and potentially assist in increasing VRE penetration needed to reach climate targets. Furthermore, developers of BESS facilities could consider co-locating with VRE to decrease uncertainties and utilise the synergies that exist when BESS is placed with VRE, especially PV. Lastly, BESS owners and asset managers should consider bidding in multiple markets to secure revenues and mitigate price fluctuations.

11.2 Organisation and knowledge

The dimensions of Organisation and Knowledge in the Technology concept from Section 5.3 are essential for understanding the current framework of BESS as a technology. While BESS is getting increased attention from developers and investors, the regulatory framework isn't in place. Sperling et al. (2010) evaluates the planning framework for wind power development, which can partly be transferred to BESS. Besides the financial structures, then *public administration and planning procedures* is considered a central factor for the deployment and implementation of the infrastructure (Sperling et al., 2010). The administration and procedures should be formed to support a smooth administrative handling, providing necessary tools to the administration, while balancing all interests involved simultaneously (Sperling et al., 2010).

As written in the Chapters 7 and 8, many of the same stakeholders involved in VRE are also involved with BESS. However, there is no established national guideline for planning for BESS. Projects are often placed where approval for the planning process is easier, rather than where they offer the greatest value to the energy system and a local planning perspective (Pedersen and Bundesen, 2025; Bech and Youssef, 2025). Location decisions are typically based on planning opportunities and not grid needs or the potential for integration in the energy system (Bech and Youssef, 2025).

The lack of a regulatory framework and guidance leads to differentiated authorisation and is time-consuming for public administrations and developers. From a developer perspective and business economy, the uncertainty in developing specific projects leads to an uncertain investment environment. As emphasised in section 11.1.1, many uncertainties are linked to the ancillary service market, and market saturation is a relevant risk to consider when underpinning an investment on revenues from these products. Albretschen (2025) from EWII and Ørkilde (2025) from Centrica Energy further note that there are advantages of becoming the first in a market. The delayed and uncertain planning processes are an important factor for developers' business economy, whose investment case can depend on the time perspective. As an example, Sorø Municipality experienced that a developer withdrew an application after it was assessed by the municipality that the project would require a local plan (Jensen, 2025a). The prolonged processes mean costs for engineering and project management working hours, which should be included in the project development. These working hours are not included in the business economic calculation of this thesis, but should also be considered.

As concluded in Chapter 8, no national guidelines are currently specific to BESS, leading to substantial variation in local planning practices. This creates uncertainty for local administrations, emergency management, and citizens, resulting in inconsistent assessments and varying requirements across projects. The lack of standardisation makes case handling time-consuming for municipalities. Instead of each municipality investigating and developing approaches independently, centralized information and knowledge sharing could contribute to broader knowledge building and more efficient processes.

Central market stakeholders could consider collaborating further with national authorities or organisations, such as Green Power Denmark and the national organisation KL, to push for clearer planning procedures. As written in Section 7.3, developers rely on others such as municipalities, Energinet, emergency services, and industry organisations to navigate the regulatory and safety requirements. Strengthening collaboration among these groups could help address the lack of regulation and knowledge. A central stakeholder for the knowledge building and sharing as well as the development of a national guidance or regulation, is the regulator: the Danish Energy Agency. They could lead the cooperation of a guidance document for public administrations between KL, the municipalities, developers, and other national agency departments.

Within this thesis, BESS can be understood as a radical technological change, as it represents development across several dimensions of the Technology concept, as written in Chapter 5. Declining investment costs, increased focus on creating improved market conditions, and a regulatory framework can improve the economic prospects for BESS. These developments highlight that BESS could become a technology with the potential to influence how flexibility is provided in the future energy system. However, as BESS is not the only solution for this, its further integration will depend on more changes in dimensions, including market design and institutional frameworks.

Guidance or regulation may also support a more consistent planning practice, particularly where the responsibilities for planning should be allocated. This is also relevant when looking at the Figure 5.3, which illustrates each stakeholder's ability to impact the market design. A general statement of the government and regulator's standpoint regarding BESS could further benefit all stakeholders. The Planning Act stipulates that the Danish planning framework should consider both the possibility of commercial development and the societal interests. The government and regulators should not implement support schemes and improve the framework conditions solely because it could improve the profitability of investors and developers. It is important to consider the landscape developments and the socio-economic and resource perspective of the whole energy system. Increasing VRE penetration can also be done by other methods, such as the heating sector, industry, and PtX (Lund, 2024). These perspectives of the energy system are further discussed in the following section.

11.3 Choice Awareness and Smart Energy Systems

This thesis contributes to creating choice awareness by examining BESS as one of several technological alternatives for addressing challenges in the electricity system, particularly storage and ancillary services. As Choice Awareness theory outlines, it is important to highlight that different technological options exist and that their deployment reflects a conscious choice, not an inevitability. In the context of increasing VRE penetration, BESS competes with other flexibility and storage solutions such as PtX and electric boilers.

This thesis focuses on the second thesis of Choice Awareness theory, which argues that raising awareness about alternative technologies is essential for informed decision-making. Through a techno-economic analysis of BESS, this thesis aims to provide developers, regulators, and policymakers with a better basis for assessment. This includes identifying which areas could be improved if BESS is to become an important part of the future energy system and if increased deployment is needed to meet national targets. The findings of the thesis, for example, show that if BESS is to be promoted, adjusting conditions, such as revising tariff structures or offering national planning guidance for municipalities, could support wider deployment of BESS. Changes in energy politics would also result in a shift between the stakeholders, shown in Figure 5.3 in Chapter 5. Changing parameters in the institutional market design (Box B) changes the dynamics in the existing market design, including the technical, political, and stakeholder elements. If changes are implemented in one box, it would affect the economic framework conditions of BESS.

Every technology should be perceived and evaluated in the context of the concrete energy system (Lund, 2024). Whether BESS should be an integrated part of the energy system varies in each country and over time. While other European countries have implemented subsidies and special tariff schemes for BESS (DACES, 2024), the Danish state has kept neutral. According to Bech and Youssef (2025) from Green Power Denmark, this could be due to the high security of supply in Denmark, and there has therefore not been a direct pressure for large-scale BESS implementation.

Other newer technologies can also participate in the ancillary service markets, such as large-scale electric boilers, VtG, PtX, and industries with a large electricity demand (Energinet, 2025b).

Using these services instead can be effective from a resource and integrated perspective, as they already have another purpose in the energy system (Nielsen, 2025). Electric boilers are already prominent competitors for fast-response ancillary services like the FCR. Nevertheless, Pedersen and Bundesen (2025) from Energinet, highlights that batteries in some cases still have some beneficial qualifications compared to electric boilers in terms of response time. Electric boilers are well-suited for the aFRR market due to their activation time and ability to handle larger energy volumes, while batteries are better suited for certain FCR markets that require faster response times (Pedersen and Bundesen, 2025). In addition, electric boilers require heat storage to operate flexibly. The annual variation in fluctuations from VRE leads to changing balancing needs from year to year, thus varying flexibility requirements. PV production is more variable during spring due to increased cloud cover, as illustrated in Figure 2.4, which creates a greater need for fast-response resources. Although PV fluctuations are less pronounced in summer, electric boilers are also used less during this period, limiting their contribution to system flexibility. This creates a gap that must be filled by other technologies (Pedersen and Bundesen, 2025). Therefore, Pedersen and Bundesen (2025) emphasised the importance of maintaining a broad portfolio of assets and technologies, such as batteries and electric boilers, to ensure system balance throughout the year, highlighting the need to investigate the available technologies.

In the context of SES , BESS can have several roles. First, BESS can help mitigate grid congestion by peak shaving, supporting grid stability in transmission and distribution networks. Peak shaving can also increase the amount of VRE that can be integrated in the energy system by storing excess production and supplying electricity during periods with low wind and solar output (Chen et al., 2020). For example, Energinet estimates that during periods of low wind and solar, the electricity shortage could be up to 2 GW in the day-ahead market in some hours (Energinet, 2024c). When comparing the 2 GW to the pipeline and expectations in Denmark, the DEA has projections of 0,7 GW installed battery capacity by 2050 (Danish Energy Agency, 2024a); however, grid operators like Cerius and Radius have already reported receiving applications for over 1.5 GW in their areas (Jensen, 2025b). Similarly, developers such as BattMan Energy claim to have 3 GW of BESS projects in their pipeline (BattMan Energy, 2025). While not all of this capacity will necessarily be realised, these figures indicate significant interest and highlight the potential scale of BESS deployment, from just two DSO's and one developer, and if these capacities get implemented, a significant amount of renewable electricity generation could be stored and used in scenarios where electricity shortages happen. In addition, trends across neighbouring countries and synchronous areas influence the development of ancillary services and electricity prices. It thus depends on the broader evolution of the European energy system (Energinet, 2024).

BESS has been discussed regarding its role for ancillary services, peak shaving, integration, and VRE. The interviews illustrated that BESS is being considered for several other appliances in the energy system. Green Power Denmark, mentions how both harbours, industries, and CHP are interested (Bech and Youssef, 2025). Different Danish ports have shown interest in BESS because of weak grid connections, limiting their ambitions for electrification. Even CHP plants have shown interest in a faster reaction time, where BESS should act as a buffer at the beginning of the feed-in until the CHP plant has reached its desired capacity. Lastly, several industries and companies, ranging from farmers to the medical and food industries, are interested in BESS for behind-the-meter. Both for covered electricity demand in peak hours, and especially for the security of supply for industries. Some industries depend on a stable supply of electricity, where small "shocks" of voltage fluctuations can cause significant impacts on production (Bech and Youssef, 2025; Pedersen and Bundesen, 2025). So, as some industries can deliver ancillary services with a flexible demand, some can likewise be highly dependent on a stable supply.

This shows how BESS can and is becoming an integrated part of the Danish energy system in several positions, for different purposes, owned by many energy actors. Its impact should be investigated from a broad perspective. Furthermore, massive deployment could cause system sub-optimisations, calling for a holistic system analysis of the effects. In a SES perspective, analyses should be conducted to compare the large-scale implementation of BESS with other technological solutions for balancing and storage, in a 100 % renewable energy system, from a resource and socio-economic perspective. Furthermore, the importance of BESS and its role should be discussed holistically; other parameters should also be taken into account, such as the critical and strategic mineral management, when compared to the alternative uses of these resources and the alternative technologies (Montana et al., 2025; Bulut, 2024). Related to this, the EU and the Danish government regulators might consider the question of dependency on other nations (Bech and Youssef, 2025). The production of Li-ion batteries globally primarily originates from China, (Danish Energy Agency, 2024c; IEA, 2024), which can raise a geopolitical question of becoming dependent on providers outside the EU (Bech and Youssef, 2025). Policymakers and regulators should evaluate whether the current conditions accurately reflect the appropriate role of BESS in Denmark from a system perspective, together with universities, neighbouring countries, DSOs, and TSOs, to determine if a clearer strategic direction and supportive framework are needed.

12 Conclusion

In response to Denmark's transition towards a fully renewable energy system, characterised by increasing shares of VRE and the associated need for enhanced system flexibility, balancing, and storage capacity, this thesis has investigated the prospects of BESS. The study focuses on BESS's financial viability, deployment challenges, and organisational context in Denmark, emphasising a large-scale and stand-alone facility. However, the business economic analysis centres on stand-alone systems; the potential benefits of combining BESS with VRE sources are also discussed. Given the increasing demand for balancing services and the phasing out of conventional dispatchable generation, the thesis evaluates BESS's current regulatory and business economic conditions to expand the knowledge base.

Four sub-questions were analysed and discussed to assess BESS from stakeholder, planning, and market perspectives. The first analysis mapped the key stakeholder groups involved in BESS deployment and examined their influence, roles, and interests. It highlighted that although the organisational framework of BESS resembles other VRE technologies, BESS introduces new dynamics, especially related to regulatory conditions, emergency management and market prequalification. The analysis showed that the development of BESS is primarily driven by private BESS and VRE developers, while public institutions such as Energinet, municipalities, and local emergency departments shape the framework within which these actors operate, and that official targets and strategies on a national level do not exist.

The second analysis examined how regulatory and local planning uncertainty affects BESS deployment. It found that the lack of national guidance results in varying municipal approaches to authorisation and planning. The uncertainties may also prolong project development timelines and increase the overall development costs of BESS facilities. Municipalities are tasked with managing a new type of infrastructure without consistent procedures, creating uncertainty for authorities and developers. This uncertainty affects investment decisions and underlines the need for a national planning framework to support coherent deployment across municipalities. The significant concerns involve emergency and fire risks, water handling, spatial planning, visual and noise impacts, which should be addressed in such a national guideline. National regulators, involving central stakeholders, could initiate the process for formulating such a guideline.

The third analysis investigated the business economic prospects of stand-alone BESS in relation to current market conditions in DK1 for 2024. A techno-economic model of a 10 MW / 20 MWh lithium battery participating in the FCR and intraday markets was developed with an additional analysis of participation in the day-ahead market. The modelling showed that stand-alone BESS in DK1 can be financially viable but has limited profitability, with a payback period of approximately 12,75 years and an IRR of 6.5 %. A sensitivity analysis showed that investment costs and market revenues from FCR and intraday trading are critical to project viability.

The fourth analysis explored current and future challenges and opportunities for BESS. It highlighted key issues such as market saturation, regulatory uncertainty, dynamic market structures, and competition from other flexibility technologies like electric boilers and PtX. The FCR market carries a risk of saturation due to market size and increasing participation. aFRR is projected to increase, and market actors highlight its future potential. With the recent development of mFRR to 15-minute MTU, the market is becoming more relevant for BESS participation. Furthermore, greater volatility in wholesale electricity prices may enhance the profitability of arbitrage trading. These developments create favourable conditions for BESS but require more strategic engagement. In this context of co-placement, BESS and VRE offer complementary strengths that can enhance the overall business case when deployed together. Based on the results of the techno-economic analysis, BESS may currently be best suited for co-placement with VRE facilities in DK1 to decrease uncertainties.

The discussion concludes that regulators, developers, universities, DSOs, and TSOs should holistically evaluate BESS's future role and importance. If BESS is assessed to be an essential technology for the future Danish electricity system, a more supportive regulatory framework could be implemented, including revised tariff structures and national planning guidelines. Developers should not rely solely on one market, such as FCR, but rather pursue multi-market participation. Ancillary services should be considered an add-on rather than the primary business case. Such a diversified strategy can mitigate market saturation effects on economic viability and may also support the integration of variable renewable energy.

This thesis finds that stand-alone BESS in DK1 faces business, economic, and planning challenges. The financial viability of BESS projects is currently acceptable but weak, facing significant uncertainty. Addressing planning and regulatory uncertainty, and potentially adjusting tariffs, could improve the investment environment for BESS. Whether BESS becomes a continuously central part of the Danish energy system will depend on conscious political and institutional decisions, not only on technical or economic trends. In this regard, coordinated communication and collaboration among stakeholders such as the Danish Energy Agency, TSO, municipalities and DSOs is essential to develop a coordinated planning, strategy and understanding of BESS in a 100 % renewable energy system. BESS can contribute to the growing need for system services and storage; however, many other technologies can also provide such services, and the business case for stand-alone BESS remains sensitive due to the limited market size. The findings contribute to increased choice awareness by highlighting BESS's opportunities and challenges in a business, economic and Danish context to illustrate areas of improvement if BESS is deemed an important technology for achieving society's goals.

References

Albretschen, 2025. Thomas Bjerring Albretschen. *Interview with Thomas Bjerring Albretschen, Asset Manager at EWII Energi A/S, an energy concern. Held 21.02.2025*, 2025. Resume in Appendix G.

Asian Development Bank, 2018. Asian Development Bank. *Handbook on Battery Energy Storage System.* Asian Development Bank, 2018. ISBN 9789292614706. URL `https://www.adb.org/sites/default/files/publication/479891/handbook-battery-energy-storage-system.pdf`.

Balle and Tolborg, 2025. Birgit Balle and Mads Tolborg. *Written response of questions via e-mail from Birgit Balle, surveyer and Mads Tolborg, project leader of RE planning at Viborg Municipality. Recived 28.04.2025*, 2025. Direct responce in Appendix L.

BattMan Energy, 2025. BattMan Energy. *Projects*, 2025. URL `https://battman.energy/projects/`. Accessed: 17.04.2025.

Bech and Youssef, 2025. August Bech and Anders Bitsch Youssef. *Interview with August Bech and Anders Bitsch Youssef, consultants at Green Power Denmark, a Industry organisation of the Danish power sector. Held 19.02.2025*, 2025. Resume in Appendix E.

BloombergNEF, November 2023. BloombergNEF. *Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh*, 2023. URL `https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/`. Accessed: 24.04.25.

Bogdanov et al., 2021. Dmitrii Bogdanov, Manish Ram, Arman Aghahosseini, Ashish Gulagi, Ayobami Solomon Oyewo, Michael Child, Upeksha Caldera, Kristina Sadovskaia, Javier Farfan, Larissa De Souza Noel Simas Barbosa, Mahdi Fasihi, Siavash Khalili, Thure Traber and Christian Breyer. *Low-cost renewable electricity as the key driver of the global energy transition towards sustainability.* Energy, 227, 120467, 2021. ISSN 0360-5442. doi: https://doi.org/10.1016/j.energy.2021.120467. Accessed: 24.05.2025.

Booth et al., 2012. Andrew Booth, Diana Papaioannou and Anthea Sutton. *Systematic Approaches to a Successful Literature Review.* SAGE Publications, 2012. ISBN 978-1-4462-0102-0.

Brinkmann and Tanggaard, 2015. Svend Brinkmann and Lene Tanggaard. *Kvalitative metoder*, volume 2. Hans Reitzels Forlag, 2 edition, 2015. ISBN 9788741259048. Chapter 1. Interviewet: Samtalen som forskningsmetode, by Lene Tanggard and Svend Brinkmann. Chapter 7. Documentanalyse, by Kennet Lynggard, Chapter 10. Mixed-methods-forsknings, by Morten Frederiksen.

Bulut, 2024. Evrencan ¨Ozcan Merve Bulut. *How to build a state-of-the-art battery energy storage market? Challenges, opportunities, and future directions.* Journal of Energy Storage, 86, 111174, 2024. doi: https://doi.org/10.1016/j.est.2024.111174.

Centrica, 2025. Centrica. *Slides by Centrica: "Erfaringer fra BESS optimering i andre markeder og betydning for fremtiden i Danmark" - Temadag Green Power Denmark 31. Oktober 2024. The slides were provided from the interview with Niels Nielsen from Niras.*, 2025. Accessed: 19.03.2025.

Centrica Energy Trading, **2025**. Centrica Energy Trading. *Annual Report 2024*, 2025. URL https://annualreport.centricaenergy.com/2024/. Accessed: 26.03.2025.

Chen et al., **2019**. Junxin Chen, Massimiliano Rossi, David Mason and Albert Schliesser. *Entanglement of propagating optical modes via a mechanical interface*. Nature Communications, 11(1), 943, 2019. doi: 10.1038/s41467-020-14768-1.

Chen et al., **2020**. Tianmei Chen, Yi Jin, Hanyu Lv, Antao Yang, Meiyi Lin, Bing Chen, Ying Xie and Qiang Chen. *Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems*. Trans Tianjin Univ, 26, 208–217, 2020. doi: 10.1007/s12209-020-00236-w.

Cole and Karmakar, **2023**. Wesley Cole and Akash Karmakar. *Cost Projections for Utility-Scale Battery Storage: 2023 Update*, National Renewable Energy Laboratory (NREL), 2023. URL https://www.nrel.gov/docs/fy23osti/85332.pdfe. Accessed: 15.04.2025.

Cremoncini et al., **2024**. Diana Cremoncini, Guido Francesco Frate, Aldo Bischi, Tim Tørnes Pedersen, Gorm Bruun Andresen, Anders Bentien and Lorenzo Ferrari. *Optimal participation of a wind and hybrid battery storage system in the day-ahead and automatic frequency restoration reserve markets*. Jounal of Energy Storage, 94(112309), 2024. doi: https://doi.org/10.1016/j.est.2024.112309.

DaCES, **2025**. DaCES. *Om Dansk Center for Energilagring*, 2025. URL https://daces.dk/. Accessed: 19.03.2025.

DACES, **2024**. DACES. *Strategisk Indsats: Anbefalinger til en styrket dansk energiplanlægning*, 2024. URL https://daces.dk/wp-content/uploads/2024/09/FINAL_Strategisk_Indsats_Sept2024_OnlineVersion.pdf. Accessed: 13.05.2025.

Danish Emergency Management Agency, **2024**. Danish Emergency Management Agency. *Temahæfte - Indsats ved brand i BESS*, 2024. URL https://www.brs.dk/globalassets/brs---beredskabsstyrelsen/dokumenter/forskning-statistik-og-analyse/2024/-121224_-publikation_bess-pub-.pdf. Accessed: 07.05.2025.

Danish Emergency Management Agency, **2023**. Danish Emergency Management Agency. *Vejledning om brandsikring af større oplag af litiumionbatterier samt BESS*, 2023. URL https://www.brs.dk/da/nyheder-og-publikationer/publikationer2/alle-publikationer/2023/vejledning-om-brandsikring-af-storre-oplag-af-litiumionbatterier-samt-bess/. Accessed: 07.04.2025.

Danish Energy Agency, **2022a**. Danish Energy Agency. *Samfundsøkonomiske beregningsforudsætninger for energipriser og emissioner 2022*, 2022a. URL https://ens.dk/analyser-og-statistik/samfundsoekonomiske-analysemetoder. Accessed: 22.04.2025.

Danish Energy Agency, **October 2024a**. Danish Energy Agency. *Analyseforudsætninger til Energinet 2024*, 2024a. URL https://ens.dk/analyser-og-statistik/analyseforudsaetninger-til-energinet. "Sammenfatningsnotat", "Baggrundsnotat - El-lagring" and "Baggrundsnotat - Termisk el- og varmeproduktion" Accessed: 22.05.2025.

Danish Energy Agency, **2024b**. Danish Energy Agency. *Technology Brief - Update of Hydrogen Production via Electrolysis in the Technology Catalogue (Jan 24)*, 2024b. URL https://ens.dk/analyser-og-statistik/teknologikatalog-fornybare-braendstoffer. Accessed: 18.02.2025.

Danish Energy Agency, **2025a**. Danish Energy Agency. *Stor interesse for milliardpulje til CO2-fangst og -lagring: 16 selskaber ønsker at søge*, 2025a. URL https://ens.dk/presse/stor-interesse-milliardpulje-til-co2-fangst-og-lagring-16-selskaber-oensker-soege. Accessed: 07.04.2025.

Danish Energy Agency, **2025b**. Danish Energy Agency. *PtX-strategi og politiske aftaler*, 2025b. URL `https://ens.dk/forsyning-og-forbrug/ptx-strategi-og-politiske-aftaler`. Accessed: 07.04.2025.

Danish Energy Agency, **2023**. Danish Energy Agency. *Energy Statistics 2023*, 2023. URL `https://ens.dk/sites/ens.dk/files/Statistik/energistatistik_2023.pdf`. Accessed: 18.02.2025.

Danish Energy Agency, **2022b**. Danish Energy Agency. *Security of Electricity Supply Towards and After 2030*, 2022b. URL `https://ens.dk/media/2124/download`. Accessed: 11.02.2025.

Danish Energy Agency, **April 2024c**. Danish Energy Agency. *Technology Data - Energy storage*, 2024c. URL `https://ens.dk/analyser-og-statistik/teknologikatalog-energilagring`. Chapter 180: Lithium-ion batteries for grid-scale storage - Last accessed: 07.02.2025.

Danish Energy Agency, **2024d**. Danish Energy Agency. *Vejledning til regler om nettilslutning af VE-anlæg*, 2024d. URL `https://ens.dk/sites/default/files/media/documents/2024-10/vejledning_til_regler_om_nettilslutning_af_ve-anlaeg_0.pdf`. Accessed: 21.02.2025.

Danish Ministry of Climate, Energy and Utilities, **2023**. Danish Ministry of Climate, Energy and Utilities. *Klimaprogram 2023*, 2023. URL `https://www.kefm.dk/Media/638315764817167867/Klimaprogram%202023.pdf`. Accessed: 07.05.2025.

Danish Ministry of Climate, Energy and Utilities, **2025a**. Danish Ministry of Climate, Energy and Utilities. *Strategi og styring*, 2025a. URL `https://www.kefm.dk/ministeriet/strategi-og-styring`. Accessed: 07.04.2025.

Danish Ministry of Climate, Energy and Utilities, **2021**. Danish Ministry of Climate, Energy and Utilities. *Bekendtgørelse af lov om klima - LBK nr 2580 af 13/12/2021*, 2021. URL `https://www.retsinformation.dk/eli/lta/2021/2580`. Accessed: 11.02.2025.

Danish Ministry of Climate, Energy and Utilities, **2025b**. Danish Ministry of Climate, Energy and Utilities. *Ny politisk aftale om grøn strøm fra havvindmøller bidrager til et grønnere og mere sikkert Danmark*, 2025b. URL `https://www.kefm.dk/aktuelt/nyheder/2025/maj/ny-politisk-aftale-om-groen-stroem-fra-havvindmoeller-bidrager-til-et-groennere-og-mere-sikkert-danmark`. Accessed: 24.05.2025.

Danish Ministry of Climate, Energy and Utilities, **2025c**. Danish Ministry of Climate, Energy and Utilities. *Regeringen investerer i mere havvind og grøn brint*, 2025c. URL `https://www.kefm.dk/aktuelt/nyheder/2025/jan/regeringen-investerer-i-mere-havvind-og-groen-brint-`. Accessed: 17.03.2025.

Danish Ministry of Defence, **2017**. Danish Ministry of Defence. *Bekendtgørelse af beredskabsloven - LBK nr 314 af 03/04/2017*, 2017. URL `https://www.retsinformation.dk/eli/lta/2017/314`. Accessed: 07.04.2025.

Danish Ministry of Urban, Rural and Church Affairs, **2024**. Danish Ministry of Urban, Rural and Church Affairs. *Bekendtgørelse af lov om planlægning - LBK nr 572 af 29/05/2024*, 2024. URL `https://www.retsinformation.dk/eli/lta/2024/572`. Accessed: 07.05.2025.

Danish Utility Regulator, **2023**. Danish Utility Regulator. *The Danish Electricity and Natural Gas Markets 2022*, Forsyningstilsynet, 2023. URL `https://forsyningstilsynet.dk/Media/638282924096043761/The%20Danish%20Electricity%20and%20Natural%20Gas%20Markets%202022.pdf`. Accessed: 27.05.2025.

Danmarks Nationalbank, 2023. Danmarks Nationalbank. *Interest Rates - Sources and Methods*, 2023. URL https://www.nationalbanken.dk/media/wevbmvw3/interestrates-sources-and-methods.pdf. Accessed: 01.05.2025.

Degen et al., 2024. Florian Degen, Miriam Mitterfellner and Achim Kampker. *Comparative life cycle assessment of lithium-ion, sodium-ion, and solid-state battery cells for electric vehicles.* Journal of Industrial Ecology, 1, 1–16, 2024. doi: 10.1111/jiec.13594.

Deguenon et al., 2023. Lere Deguenon, Daniel Yamegueu, Sani Moussa Kadri and Aboubakar Gomna. *Overcoming the challenges of integrating variable renewable energy to the grid: A comprehensive review of electrochemical battery storage systems.* Journal of Power Sources, 580, 233343, 2023. URL https://doi.org/10.1016/j.jpowsour.2023.233343.

Egholm, 2014. Liv Egholm. *Philosophy of Science: Perspectives on Organisations and Society.* Hans Reitzels forlag, København, 2014. ISBN 9788741256573.

Elnet, 2025. Elnet. *Tilslutningsbidrag for produktion*, 2025. URL https://elnet.dk/nettariffer-priser-gebyrer/tilslutningsbidrag-produktion. Accessed: 21.02.2025.

Elnet, 2024. Elnet. *Bilag 1: Uddybende metodebeskrivelse - Standardtilslutningsbidrag*, 2024. URL https://elnet.dk/files/media/document/Bilag-1-Uddybende-metodebeskrivelse-Standardtilslutningsbidrag.pdf. Accessed: 21.02.2025.

Energinet, 2023. Energinet. *CASE - BATTERIER: Systemydelser med batterier*, 2023. URL https://energinet.dk/media/jjri0ngd/case-batterier-1.pdf. Accessed: 12.02.2025.

Energinet, 2025a. Energinet. *Prequalification of Units and Aggregated Portfolios - Version 2.1.3 Valid from February 18, 2025*, 2025a. URL https://energinet.dk/el/balancering-og-systemydelser/adgang-til-systemydelsesmarkederne/praekvalifikation-og-test/. Doc. 13/80940-106 Accessed: 11.04.2025.

Energinet, 2025b. Energinet. *7 gange så mange anlæg vil levere systemydelser*, 2025b. URL https://energinet.dk/om-nyheder/nyheder/2025/01/30/7-gange-sa-mange-anlaeg-vil-levere-systemydelser/. Accessed: 05.03.2025.

Energinet, 2025a. Energinet. *Energinets opgaver*, 2025a. URL https://energinet.dk/om-os/opgaver/. Accessed: 26.03.2025.

Energinet, 2024. Energinet. *Outlook for Ancillary Services 2024-2040*, 2024. URL https://energinet.dk/media/aobhuqqk/151124_en_outlook-for-ancillary-services-2024-2040.pdf. Accessed: 14.02.2025.

Energinet, 2019. Energinet. *Introduktion til elmarkedet - Kort introductio til engros- og detailmarkedet*, 2019. Dok. 18/08514-1.

Energinet, 2024a. Energinet. *Notat: Introduktion til systemydelser*, 2024a. Dok. 14/02811-173.

Energinet, 2025b. Energinet. *Energinet balancerer nu elnettet hvert kvarter*, 2025b. URL https://energinet.dk/om-nyheder/nyheder/2025/energinet-balancerer-nu-elnettet-hvert-kvarter/. Accessed: 11.03.2025.

Energinet, 2024b. Energinet. *Vilkår - Nettilslutning med midlertidigt begrænset netadgang for produktionsanlæg mv. i transmissionssystemet*, 2024b. URL https://energinet.dk/media/dlyesb10/vilkaar-midlertidigt-begraenset-netadgang-produktion-transmission.pdf. Accessed: 12.02.2025.

Energinet, 2025c. Energinet. *FCR, Frequency Containment Reserves, DK1*, 2025c. URL https://www.energidataservice.dk/tso-electricity/FcrDK1. Frequency Containment Reserve data for DK1, Accessed: 16.04.2025.

Energinet, 2022. Energinet. *Elpriser - Baseret på de seneste opdaterede forudsætninger*, 2022. URL https://energinet.dk/media/y2xdqydf/elpriser-af21-notat-februar-2022.pdf. Acessed: 25.05.2025.

Energinet, 2025. Energinet. *Aktuelle Tariffer*, 2025. URL https://energinet.dk/el/elmarkedet/tariffer/aktuelle-tariffer/. Accessed: 21.02.2025.

Energinet, 2024c. Energinet. *Redegørelse for elforsyningssikkerhed 2024*, Energinet, 2024c. URL https://energinet.dk/media/ibep3n0t/horingsversion-redegorelse-for-elforsyningssikkerhed-2024.pdf. Accessed: 17.05.2025.

Energinet, 2025a. Energinet. *aFRR, Automatic Frequency Restoration Reserves, Capacity Market.* https://www.energidataservice.dk/tso-electricity/AfrrReservesNordic, 2025a. Accessed: 15.05.2025.

Energinet, 2024d. Energinet. *Balancemarkedet - introduktion til systemydelser.* https://energinet.dk/media/c23n2rvf/praesentation-af-balancemarkedet.pdf, 2024d. URL https://energinet.dk/media/c23n2rvf/praesentation-af-balancemarkedet.pdf. Opdateret juni 2024.

Energinet, 2025b. Energinet. *Elspot Prices, Dataset*, 2025b. URL https://www.energidataservice.dk/tso-electricity/Elspotprices. Accessed: 24.04.2025.

Energinet, December 2024. Energinet. *Faktaark: Producentbetaling for transmissionstilsluttede produktionsanlæg 2025*, 2024. URL https://energinet.dk/media/o4gkdo0p/21_03559-190-faktaark-producentbetaling-for-transmissionstilsluttede-produktionsanlaeg-2025-10708965_4_1.pdf. Accessed: 09.04.2025.

Energinet, 2025c. Energinet. *Forskrift C2: Balancemarked og balanceafregning - Dok. 20/02087-30.* https://energinet.dk/media/pv0lz5jc/forskrift-c2-opdateret-18-marts-2025.pdf, 2025c. Accessed: 15.05.2025.

Energinet, 2020. Energinet. *Security of Electricity Supply Report 2020*, 2020. URL https://en.energinet.dk/media/vqbeouf2/security-of-electricity-supply-report-2020.pdf. Accessed: 11.02.2025.

Energinet, 2022. Energinet. *Energinets Godkendte Producentbetalingsmetode*, 2022. URL https://energinet.dk/media/bhmcix44/energinets-godkendte-producentbetalingsmetode.pdf. Dok. 21/03559-127, Accessed: 27.05.2025.

Energinet, 2025. Energinet. *Systemydelser til levering i Danmark: Udbudsbetingelser, Gældende fra 04. marts 2025*, 2025. URL https://energinet.dk/media/rkvdymux/21_10162-24-udbudsbetingelser-for-systemydelser-til-levering-i-danmark-mfrr-eam-10877149_2_1.pdf. Dok. 21/10162-24, Accessed: 27.05.2025.

Engelhardt et al., 2022. Jan Engelhardt, Andreas Thingvad, Jan Martin Zepter, Tatiana Gabderakhmanova and Mattia Marinelli. *Energy recovery strategies for batteries providing frequency containment reserve in the Nordic power system.* Sustainable Energy, Grids and Networks, 32, 100947, 2022. doi: 10.1016/j.segan.2022.100947.

ENTSO-E, 2018. ENTSO-E. *Balancing in Europe: An Overview of Electricity Balancing and Balancing Markets in Europe*, ENTSO-E, 2018. URL https://eepublicdownloads.entsoe.eu/clean-documents/Network%20codes%20documents/NC%20EB/entso-e_balancing_in%20_europe_report_Nov2018_web.pdf. Accessed: 10.04.2025.

ENTSO-E, 2024. ENTSO-E. *ENTSO-E Balancing Report 2024*, 2024. URL https://eepublicdownloads.entsoe.eu/clean-documents/news/2024/240628_ENTSO-E_Balancing_Report_2024.pdf. Accessed: 19.05.2025.

EU, 2023. EU. *Europa-Parlamentets og Rådets forordning (EU) 2023/1542 af 12. juli 2023 om batterier og udtjente batterier, om ændring af direktiv 2008/98/EF og forordning (EU) 2019/1020 og om ophævelse af direktiv 2006/66/EF*. Official Journal of the European Union, L (1542), 2023. URL http://data.europa.eu/eli/reg/2023/1542/2024-07-18.

EU, 2024. EU. *Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union's electricity market design*. Official Journal of the European Union, L(1747), 2024. URL http://data.europa.eu/eli/reg/2024/1747/oj.

EWII, 2025a. EWII. *Om EWII*, 2025a. URL https://www.ewii.dk/om-ewii/. Accessed: 26.03.2025.

EWII, 2025b. EWII. *Batterier skubber til grøn omstilling*, 2025b. URL https://www.ewii.dk/erhverv/el/batterier/. Accessed: 26.03.2025.

Neil Fligstein and Ryan Calder. Architecture of Markets. In Robert A. Scott and Stephen M. Kosslyn, editor, *Emerging Trends in the Social and Behavioral Sciences*, pages 1–15. John Wiley & Sons, 2015. doi: 10.1002/9781118900772.etrds0023.

Good Tape, 2025. Good Tape. *Good Tape - About Us*, 2025. URL https://blog.goodtape.io/about/. Accessed: 27.05.2025.

Green Power Denmark, 2025a. Green Power Denmark. *Geozonekort for standardtilslutningsbidrag for produktion*, 2025a. URL https://geozonekortet.greenpowerdenmark.dk/home. Accessed: 14.03.2025.

Green Power Denmark, 2025b. Green Power Denmark. *Om os*, 2025b. URL https://greenpowerdenmark.dk/om-os. Accessed: 26.03.2025.

Green Power Denmark, 2024. Green Power Denmark. *Store batterier er det grønne energisystems schweizerkniv*, 2024. URL https://greenpowerdenmark.dk/nyheder/store-batterier-er-groenne-energisystems-schweizerkniv. Accessed: 10.05.2025.

Green Power Denmark, 2025c. Green Power Denmark. *Tarifering af batterier i dag og i fremtiden*, 2025c. URL https://elnet.dk/files/media/document/Tarifering%20af%20batterier%20i%20dag%20og%20i%20fremtiden_0.pdf. PowerPoint-præsentation, offentliggjort af Green Power Denmark, Accessed: 27.05.2025.

Grohnheit and Sneum, 2023. Poul Erik Grohnheit and Daniel Møller Sneum. *Calm before the storm: Market prices in a power market with an increasing share of wind power*. Energy Policy, 179, 2023. doi: https://doi.org/10.1016/j.enpol.2023.113631.

Hameed et al., 2023. Zeenat Hameed, Chresten Træholt and Seyedmostafa Hashemi. *Investigating the participation of battery energy storage systems in the Nordic ancillary services markets from a business perspective*. Journal of Energy Storage, 58, 106464, 2023. doi: 10.1016/j.est.2022.106464.

Hesse et al., 2017. Holger C. Hesse, Michael Schimpe, Daniel Kucevic and Andreas Jossen. *Lithium-ion battery storage for the grid - A review of stationary battery storage system design tailored for applications in modern power grids*. Energies (Basel), 10(12), 2017. URL https://doi.org/10.3390/en10122107.

Hoff, 2022. C. Michael Hoff. *Energy Storage Technologies and Applications*. Artech House, 2022. ISBN: 978-1-63081-908-8.

Hollebeek et al., December 2020. Linda D. Hollebeek, V. Kumar and Rajendra K. Srivastava. *From Customer-, to Actor-, to Stakeholder Engagement: Taking Stock, Conceptualization, and Future Directions*. Journal of Service Research, 2020. doi: 10.1177/1094670520977680. Accessed: 10.03.2025.

Hornek et al., 2025. Timothée Hornek, Youngsub Lee, Sergio Potenciano Menci and Ivan Pavić. *The Value of Battery Energy Storage in the Continuous Intraday Market: Forecast vs. Perfect Foresight Strategies*, 2025. URL `https://arxiv.org/abs/2501.07121`. Accessed: 27.05.2025.

Hu et al., 2018. Jiahua Hu, Mushfiqur R. Sarker, Jianhui Wang, Fushuan Wen and Weijia Liu. *Provision of flexible ramping product by battery energy storage in day-ahead energy and reserve markets*. IET Generation, Transmission & Distribution, 12(10), 2256–2264, 2018. doi: 10.1049/iet-gtd.2017.1522.

Hu et al., 2022. Yu Hu, Miguel Armada and María Jesús Sánchez. *Potential utilization of battery energy storage systems (BESS) in the major European electricity markets*. Applied Energy, 322, 119512, 2022. URL `https://doi.org/10.1016/j.apenergy.2022.119512`.

Huang and Li, 2022. Wen Huang and Heng Li. *Game theory applications in the electricity market and renewable energy trading - A critical survey*. Frontiers in Energy Research, 10, 1009217, 2022. doi: 10.3389/fenrg.2022.1009217.

Hundt et al., 2021. Steffen Hundt, Johanna Jahnel and Andreas Horsch. *Power Purchase Agreements and Financing Renewables: An Interdependency*. Journal of Structured Finance, 27 (1), 35–50, 2021. doi: 10.3905/jsf.2020.1.119.

Hvelplund, 2011. Frede Hvelplund. *Innovative Democracy and Renewable Energy Strategies: A Full-Scale Experiment in Denmark 1976-2010*. Energy, Policy, and the Environment, 2011. doi: 10.1007/978-1-4614-0350-0_6. Accessed: 10.03.2025.

Hvelplund, 2001. Frede Hvelplund. *Electricity Reforms, Democracy and Technological Change: Electricity Systems, "Market Liberalization" Reforms, Governance Systems, Internationalization, and the Need for New Democratic Governance Systems - The Danish Case*, Institut for Planlægning, Aalborg Universitet, 2001.

Frede Hvelplund and Finn Arler. Kapitel 4: Demokrati og bæredygtighed. Energiområdet som case. In Finn Arler, Mette Alberg Mosgaard and Henrik Riisgaard, editors, *Bæredygtighed : værdier, regler og metoder*, pages 99–125. Aarhus universitetsforlag, 2015.

IEA, 2023. IEA. *Annual grid-scale battery storage additions, 2017-2022*, 2023. URL `https://www.iea.org/data-and-statistics/charts/annual-grid-scale-battery-storage-additions-2017-2022`. Accessed: 02.04.2025.

IEA, 2024. IEA. *Batteries and Secure Energy Transitions - World Energy Outlook Special Report*, 2024. URL `https://www.iea.org/reports/batteries-and-secure-energy-transitions`. Part of World Energy Outlook 2023. Licence: CC BY 4.0, Accessed: 02.04.2025.

IRENA, 2019. IRENA. *Demand-side flexibility for power sector transformation*, International Renewable Energy Agency, Abu Dhabi, 2019. URL `https://www.irena.org/publications/2019/Dec/Demand-side-flexibility-for-power-sector-transformation`. Accessed: 15.05.2025.

Jensen, 2025a. Hans Henning Jensen. *Interview with Hans Henning Jensen, Planner and Landscape Manager at Sorø Municipality. Held 23.04.2025*, 2025a. Resume in Appendix K.

Jensen, 2025b. Mads Paabøl Jensen. *Interview with Mads Paabøl Jensen, Senior Lead Regulatory Advisor at Cerius Radius, A Danish DSO. Held 18.02.2025*, 2025b. Resume in Appendix D.

Kalogianni et al., 2020. Eftychia Kalogianni, Christiaan Lemmen, Peter van Oosterom, Abdullah Kara, Efi Dimopoulou and Robert Thompson. *Developing a spatial planning information package in ISO 19152 land administration standard.* Land Use Policy, 88, 104111, 2020. doi: 10.1016/j.landusepol.2019.104111.

Kaur, 2022. Amandeep Kaur. *Batteries + Storage: The Implications of Integrating a Battery Energy Storage System into Renewable Energy Power Purchase Agreements.* Oil and Gas, Natural Resources, and Energy Journal, 7(4), 911–947, 2022. URL https://digitalcommons.law.ou.edu/onej/vol7/iss4/5. Accessed: 15.05.2025.

KEFM, Oktober 2024. KEFM. *Lovforslag 33 - Forslag til lov om ændring af lov om klima. (Nye klimamål for 2045 og 2050).*, 2024. URL https://www.ft.dk/samling/20241/lovforslag/l33/20241_l33_som_fremsat.htm. Accessed: 14.02.2025.

Keohane and Olmstead, 2016. Nathaniel O. Keohane and Sheila M. Olmstead. *Markets and the Environment.* Foundations of Contemporary Environmental Studies. Island Press, second edition, 2016. ISBN 978-1610916073.

Killer et al., 2020. Marvin Killer, Mana Farrokhsereshta and Nikolaos G. Paterakis. *Implementation of large-scale Li-ion battery energy storage systems within the EMEA region.* Applied Energy, 260(114166), 2020. URL https://doi.org/10.1016/j.apenergy.2019.114166.

Klemperer, 2004. Paul Klemperer. *Auctions: Theory and Practice.* The Toulouse Lectures in Economics. Princeton University Press, 2004. ISBN 978-0691119250.

Klimek et al., 2024. Julia Anna Klimek, Jordan Klimek, Emilia Barej-Kaczmarek, Bogdan Gębski, Sebastian Kołodziejczak and Albert Terelak. *Infrastructure Fund as an Alternative Driver in the Implementation of Green Energy Policy in European Countries.* Energy Reports, 11, 1766–1773, 2024. ISSN 2352-4847. URL https://doi.org/10.1016/j.egyr.2024.01.041.

Kommunernes Landsforening, 2025. Kommunernes Landsforening. *KL - Local Government Denmark*, 2025. URL https://www.kl.dk/om-kl/english/kl-local-government-denmark. Accessed: 15.05.2025.

Kujala et al., 2022. Johanna Kujala, Sybille Sachs, Heta Leinonen, Anna Heikkinen and Daniel Laude. *Stakeholder Engagement: Past, Present, and Future*, 2022. URL https://doi.org/10.1177/00076503211066595. Accessed: 26.03.2025.

Kvale and Brinkmann, 2015. Steinar Kvale and Svend Brinkmann. *Interview: Det kvalitative forskningsinterview som håndværk.* Hans Reitzels Forlag, Danmark, 3 edition, 2015. ISBN 9788741263779.

Liebensteiner et al., 2025. Mario Liebensteiner, Fabian Ocker and Anas Abuzayed. *High electricity price despite expansion in renewables: How market trends shape Germany's power market in the coming years.* Energy Policy, 198, 114448, 2025. doi: 10.1016/j.enpol.2024.114448.

Lin and Magnago, 2017. Jeremy Lin and Fernando H. Magnago. *Electricity Markets - Theories and Applications.* John Wiley & Sons, Incorporated, Newark, 2017. ISBN 9781119179375. Chater 3: Microeconomic Theories pp 57-96.

Lincoln and Guba, 1985. Yvonna S. Lincoln and Egon G. Guba. *Naturalistic Inquiry.* SAGE Publications, Beverly Hills, CA, 1985. ISBN 978-0803924314.

Lund et al., 2025. H. Lund, P.A. Østergaard, M. Yuan, P. Sorknæs and J.Z. Thellufsen. *Energy balancing and storage in climate-neutral smart energy systems.* Renewable and Sustainable Energy Reviews, 209, 115141, 2025. doi: 10.1016/j.rser.2024.115141.

Henrik Lund. Chapter 2 - Choice Awareness theses and Chapter 6 - Smart Energy Systems and Infrastructures. In Henrik Lund, editor, *Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modelling of Fully Decarbonized Societies*, pages 15–34, 123–174. Academic Press, third edition edition, 2024. ISBN 978-0-443-14137-9.

Lund et al., 2021. Henrik Lund, Brian Vad Mathiesen, Jakob Zinck Thellufsen, Peter Sorknæs, Miguel Chang, Mikkel Strunge Kany and Iva Ridjan Skov. *IDAs Klimasvar 2045: Sådan bliver vi klimaneutrale*, Ingeniørforeningen IDA, 2021.

Lund et al., 2022. Henrik Lund, Jakob Zinck Thellufsen, Peter Sorknæs, Brian Vad Mathiesen, Miguel Chang, Poul Thøis Madsen, Mikkel Strunge Kany and Iva Ridjan Skov. *Smart energy Denmark: A consistent and detailed strategy for a fully decarbonized society*. Renewable and Sustainable Energy Reviews, 168, 113777, 2022. URL `https://doi.org/10.1016/j.rser.2022.112777`.

Andrew J. Mason, 2012. Andrew J. Mason. OpenSolver - An Open Source Add-in to Solve Linear and Integer Progammes in Excel. In Daniel Klatte, Hans-Jakob Lüthi and Klaus Schmedders, editors, *Operations Research Proceedings 2011*, Operations Research Proceedings, pages 401–406. Springer, 2012. doi: 10.1007/978-3-642-29210-1_64. Accessed: 10.03.2025.

Meesenburg et al., 2020. Wiebke Meesenburg, Andreas Thingvad, Brian Elmegaard and Mattia Marinelli. *Combined provision of primary frequency regulation from Vehicle-to-Grid (V2G) capable electric vehicles and community-scale heat pump*. Sustainable Energy, Grids and Networks, 23, 100382, 2020. doi: 10.1016/j.segan.2020.100382.

Metz and Saraiva, 2018. Dennis Metz and João Tomé Saraiva. *Use of battery storage systems for price arbitrage operations in the 15- and 60-min German intraday markets*. Electric Power Systems Research, 160, 27–36, 2018. doi: 10.1016/j.epsr.2018.01.020.

MOE A/S, 2022. MOE A/S. *Forslag til brandtekniske krav til BESS og oplag af litium-ion batterier*, 2022. URL `https://www.brs.dk/globalassets/brs---beredskabsstyrelsen/dokumenter/forebyggelse/2023/-forslag-til-brandtekniske-krav-til-bess-og-oplag-af-litium-ion-batterier-.pdf`. Accessed: 15.05.2025.

Montana et al., 2025. Francesco Montana, Maurizio Cellura, Maria Luisa Di Silvestre, Sonia Longo, Le Quyen Luu, Eleonora Riva Sanseverino and Giuseppe Sciumè. *Assessing Critical Raw Materials and Their Supply Risk in Energy Technologies-A Literature Review*. Energies, 18(1), 2025. ISSN 1996-1073. URL `https://www.mdpi.com/1996-1073/18/1/86`.

Münderlein et al., 2019. Jeanette Münderlein, Marc Steinhoff, Sebastian Zurmühlen and Dirk Uwe Sauer. *Analysis and evaluation of operations strategies based on a large scale 5 MW and 5 MWh battery storage system*. Jounal of Energy Storage, 24(100778), 2019. URL `https://doi.org/10.1016/j.est.2019.100778`.

N1 A/S, 2025a. N1 A/S. *Hvem er vi?*, 2025a. URL `https://n1.dk/om-n1`. Accessed: 30.04.2025.

N1 A/S, 2025b. N1 A/S. *Gældende Priser*. `https://n1.dk/gaeldende-priser`, 2025b. Accessed: 09.04.2025.

N1 A/S, 2024. N1 A/S. *Tidligere priser 2024*, 2024. URL `https://n1.dk/priser2024`. Priser gældende fra 01.12.2024 - 31.12.2024.

N1 A/S, 2025c. N1 A/S. *Tilslutningsbidrag for forbrugsanlæg*. `https://n1.dk/tilslutningsbidrag-forbrugsanlaeg`, 2025c. Accessed: 09.04.2025.

NEKST, 2024. NEKST. *Afrapportering fra NEKST-arbejdsgruppen - Mere sol og vind på land*, 2024. URL `https://www.kefm.dk/Media/638444494605230189/Nekst_Mere%20sol%20og%20vind%20pa%C2%B0%20land.pdf`. Accessed: 16.05.2025.

Nielsen, 2025. Niels Nielsen. *Interview with Niels Nielsen, Consultant engineer at Niras. Held 11.03.2025*, 2025. Resume in Appendix I.

Nielsen et al., 2011. Steffen Nielsen, Peter Sorknæs and Poul Alberg Østergaard. *Electricity market auction settings in a future Danish electricity system with a high penetration of renewable energy sources - A comparison of marginal pricing and pay-as-bid.* Energy, 36(7), 4434–4444, 2011. URL https://doi.org/10.1016/j.energy.2011.03.079.

NIRAS A/S, 2025. NIRAS A/S. *Om NIRAS*, 2025. URL https://www.niras.dk/om-niras/. Accessed: 26.03.2025.

Nord Pool, 2025. Nord Pool. *Intraday Hourly Statistics - DK1*, 2025. URL https://data.nordpoolgroup.com/intraday/intraday-hourly-statistics?deliveryDate=latest&deliveryArea=DK1. Accessed: 11.04.2025.

Pape, 2018. Christian Pape. *The impact of intraday markets on the market value of flexibility - Decomposing effects on profile and the imbalance costs.* Energy Economics, 76, 186–201, 2018. URL https://doi.org/10.1016/j.eneco.2018.10.004.

Pedersen and Bundesen, 2025. Andreas Simoni Huse Pedersen and Maibrit Vester Bundesen. *Interview with Andreas Simoni Huse Pedersen and Maibrit Vester Bundesen, Engineers at Energinet, the Danish TSO. Held 19.02.2025*, 2025. Resume in Appendix F.

Phillips and Burbules, 2000. D. C. Phillips and N. C. Burbules. *Postpositivism and Educational Research.* Rowman & Littlefield, 2000.

Radius Elnet, 2025. Radius Elnet. *Om elnettet*, 2025. URL https://radiuselnet.dk/om-elnettet/. Accessed: 20.03.2025.

Rancilio et al., 2019. Giuliano Rancilio, Alexandre Lucas, Evangelos Kotsakis, Gianluca Fulli, Marco Merlo, Maurizio Delfanti and Marcelo Masera. *Modeling a Large-Scale Battery Energy Storage System for Power Grid Application Analysis.* Energies, 12(17), 2019. URL https://doi.org/10.3390/en12173312.

Remmen et al., 1986. Arne Remmen, Jens Müller and Per Christensen. *Samfundets Teknologi: Teknologiens Samfund.* Systime, 1986.

Remmen et al., 2011. Arne Remmen, Lone Kørnøv and Michael Søgaard Jørgensen. *Making Ends Meet: Economic Rationalities and Moralities in the Circular Economy*, Aalborg University, 2011. URL https://vbn.aau.dk/ws/portalfiles/portal/56684837/Making_end_meets_22_08_11.pdf. Accessed: 10.03.2025.

Sarungu, June 2024. Cornelius Mellino Sarungu. *Stakeholder Analysis Using The Enhanced Salience, Power-Interest, and Stakeholder Cube Diagrams.* Ultima Infosys: Jurnal Ilmu Sistem Informasi, 15(1), 35–41, 2024. ISSN 2085-4579. URL https://ejournals.umn.ac.id/index.php/SI/article/download/3483/1522/. Accessed: 05.03.2025.

Sasson et al., 2025. Efrat Sasson, Júlia Kádár, Tal Zohar, Naama Yacobi and Tal Keren-Zur. *Social Acceptance of Energy Storage Technologies: Empirical Evidence from the Southern Arava Region, Israel.* Sustainable Energy Research, 12(8), 2025. URL https://doi.org/10.1186/s40807-025-00150-6. Accessed: 10.05.2025.

Seel et al., 2018. Joachim Seel, Andrew Mills, Ryan Wiser, Sidart Deb, Aarthi Asokkumar, Mohammad Hassanzadeh and Amirsaman Aarabali. *Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making*, Lawrence Berkeley National Laboratory, 2018. URL https://emp.lbl.gov/publications/impacts-high-variable-renewable.

Seppälä and Syri, 2025. Simeon Seppälä and Sanna Syri. *Wind, PV, and Hybrid Power Plant Operation in Competitive Nordic Electricity Market With High Profit Cannibalization.* International Journal of Energy Research, 2025, 2025. URL https://doi.org/10.1155/er/8850556. Accessed: 10.05.2025.

SIDC NEMOs and Deutsche Börse AG, 2022. SIDC NEMOs and Deutsche Börse AG. *Continuous Trading Matching Algorithm - Public Description*, 2022. URL https://www.nordpoolgroup.com/48fa80/globalassets/download-center/cacm-regulation/public-description-of-the-continuous-trading-matching-algorithm.pdf. Accessed: 29.04.2025.

Skat, 2025. Skat. *Generelt om godtgørelse af energiafgifter og CO_2-afgift.* https://skat.dk/erhverv/afgifter-paa-varer-og-ydelser-punktafgifter/godtgoerelse-af-energiafgifter/generelt-om-godtgoerelse-af-energiafgifter-og-co2-afgift, 2025. Accessed: 09.04.2025.

Snyder, 2019. Hannah Snyder. *Literature review as a research methodology: An overview and guidelines.* Journal of Business Research, 104, 333–339, 2019. doi: 10.1016/j.jbusres.2019.07.039.

Sorknæs et al., 2019. Peter Sorknæs, Søren Roth Djørup, Henrik Lund and Jakob Zinck Thellufsen. *Quantifying the influence of wind power and photovoltaic on future electricity market prices.* Energy Conversion and Management, 180, 2019. URL https://doi.org/10.1016/j.enconman.2018.11.007.

Sperling et al., 2010. Karl Sperling, Frede Hvelplund and Brian Vad Mathiesen. *Evaluation of wind power planning in Denmark - Towards an integrated perspective.* Energy, 35(12), 5443–5454, 2010. doi: 10.1016/j.energy.2010.06.039.

Statista, 2025. Statista. *Lithium-ion battery price worldwide from 2013 to 2024 - (in 2024 U.S. dollars per kilowatt-hour)*, 2025. URL https://www.statista.com/statistics/883118/global-lithium-ion-battery-pack-costs/. Accessed: 13.02.2025.

Statistics Denmark, 2025. Statistics Denmark. *StatBank Denmark - Outstanding domestic loans from banks by domestic sector, instrument, data type, currency, maturity (original maturity), purpose and time*, 2025. URL www.statbank.dk/DNRUUPI. Accessed: 22.04.2025.

Statnett, 2023. Statnett. *Wind and Solar in the Nordic Reserve Markets: Challenges and Possibilities of Weather Dependent Production*, Statnett, 2023. URL https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/marked/reservemarkeder/nordic-wind-and-solar-publication-.pdf. Accessed: 17.05.2025.

Szabo et al., 2024. Laszlo Szabo, Magda Moner-Girona, Arnulf Jæger-Waldau, Ioannis Kougias, Andras Mezosi, Fernando Fahl and Sandor Szabo. *Impacts of large-scale deployment of vertical bifacial photovoltaics on European electricity market dynamics.* Nature Communications, 15 (6681), 2024. URL https://www.nature.com/articles/s41467-024-50762-7.

Søndergaard and Ebbesen, 2025. Jacob Hollerup Søndergaard and Gustav Damsgaard Ebbesen. *Interview with Jacob Hollerup Søndergaard, Project Manager - Environment and Gustav Damsgaard Ebbesen, Project Manager- Local Engagement at Eurowind Energy. Held 13.03.2025*, 2025. Resume in Appendix J.

The Danish Council on Climate Change, 2024. The Danish Council on Climate Change. *Statusrapport 2024*, 2024. URL https://klimaraadet.dk/sites/default/files/node/field_file/Klimar%C3%A5det_Statusrapport%202024.pdf. Accessed: 11.02.2025.

The Danish Planning and Rural Development Agency, 2025. The Danish Planning and Rural Development Agency. *Batterier i tilknytning til VE-producerende anlæg*, 2025. URL `https://www.plst.dk/plantemaer/tekniske-anlaeg/batterier-i-tilknytning-til-ve-producerende-anlaeg`. Accessed: 14.04.2025.

Thingvad et al., 2023. Andreas Thingvad, Guillaume Le Ray Charalampos Ziras, Jan Engelhardt, Rasmus Rode Mosbæk and Mattia Marinelli. *Economic Value of Multi-Market Bidding in Nordic Frequency Markets*. Proceedings of International Conference on Renewable Energies and Smart Technologies, 2023. doi: 10.1109/REST54687.2022.10023471.

Tierney et al., 2008. Susan F. Tierney, Todd Schatzki and Rana Mukerji. *Uniform-Pricing versus Pay-as-Bid in Wholesale Electricity Markets - Does it Make a Difference?*, 2008. URL `https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=c3562df03267aa6490e9552715f98169b0488bb7`. Accessed: 10.03.2025.

Veenstra and Mulder, January 2025. Arjen Veenstra and Machiel Mulder. *Profitability of Batteries in Day-Ahead and Intraday Electricity Markets: Assessment of Operation Strategies with Endogenous Prices*, University of Groningen, January 2025. URL `https://ssrn.com/abstract=5081715`.

Wang et al., 2024. Guanghao Wang, Erwann Sbai, Le Wen and Mingyue Selena Sheng. *The impact of renewable energy on extreme volatility in wholesale electricity prices: Evidence from organisation for economic co-operation and development countries*. Journal of Cleaner Production, 484, 144343, 2024. doi: 10.1016/j.jclepro.2024.144343.

Weisdorf et al., 2025. Matti Weisdorf, Kasper Tang Vangkilde and Simon Lex. *Diverging energy horizons: Rethinking public resistance in the Danish renewable energy transition*. Energy Research and Social Science, 121, 103945, 2025. doi: 10.1016/j.erss.2025.103945.

Whitman and Terry, 2012. David L. Whitman and Ronald E. Terry. *Fundamentals of Engineering Economics and Decision Analysis*, volume 18. Morgan & Claypool Publishers, San Rafael, CA, 2012. doi: 10.2200/S00410ED1V01Y201203ENG018.

Claes Wohlin, 2014. Claes Wohlin. Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering. In *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering (EASE '14)*, pages 1–10. ACM, 2014. doi: 10.1145/2601248.2601268.

Yuan et al., 2022. Meng Yuan, Peter Sorknæs, Henrik Lund and Yongtu Liang. *The bidding strategies of large-scale battery storage in 100% renewable smart energy systems*. Applied Energy, 326(119960), 2022. doi: https://doi.org/10.1016/j.apenergy.2022.119960.

Zhao et al., 2023. Chunyang Zhao, Peter Bach Andersen, Chresten Træholt and Seyedmostafa Hashemi. *Grid-connected battery energy storage system: a review on application and integration*. Renewable and Sustainable Energy Reviews, 182(113400), 2023. URL `https://doi.org/10.1016/j.rser.2023.113400`.

Zhu et al., 2024. Qing Zhu, Jiade Xi, Xin Hu, Heap-Yih Chong, Yijun Zhou and Sainan Lyu. *Stakeholder Mapping and Analysis of Off-Site Construction Projects: Utilizing a Power-Interest Matrix and the Fuzzy Logic Theory*. Buildings, 14(9), 2865, 2024. doi: 10.3390/buildings14092865.

Çalışkan and Callon, 2010. Koray Çalışkan and Michel Callon. *Economization, Part 2: A Research Programme for the Study of Markets*. Economy and Society, 39(1), 1–32, 2010. doi: 10.1080/03085140903424519.

Ørkilde, 2025. Michael Mejdahl Ørkilde. *Interview with Michael Mejdahl Ørkilde, Portfolio Manager at Centrica Energy Trading A/S. Held 03.03.2025*, 2025. Resume in Appendix H.

Market participation modelling

A

See the attached Excel spreadsheets for modelling for market participation in:

- **Appendix A0**: FCR + Intraday market model
- **Appendix A1**: FCR + Dayahead model
- **Appendix A2**: Dayahead single market model
- **Appendix A3**: Intraday single market model

Business-economics calculations

B

Historical Spot, FCR, mFRR and aFRR prices in DK1

C

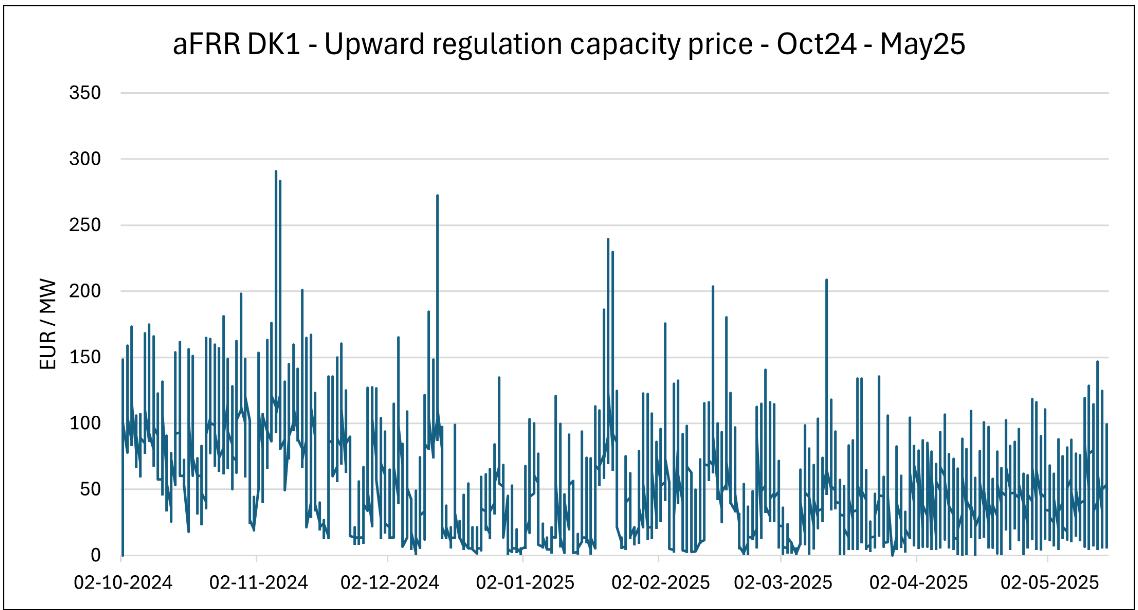


Figure C1. Historical prices for aFRR upward regulation, capacity market in DK1. Only data for October 2024 to May 2025 have been available (Energinet, 2025a).

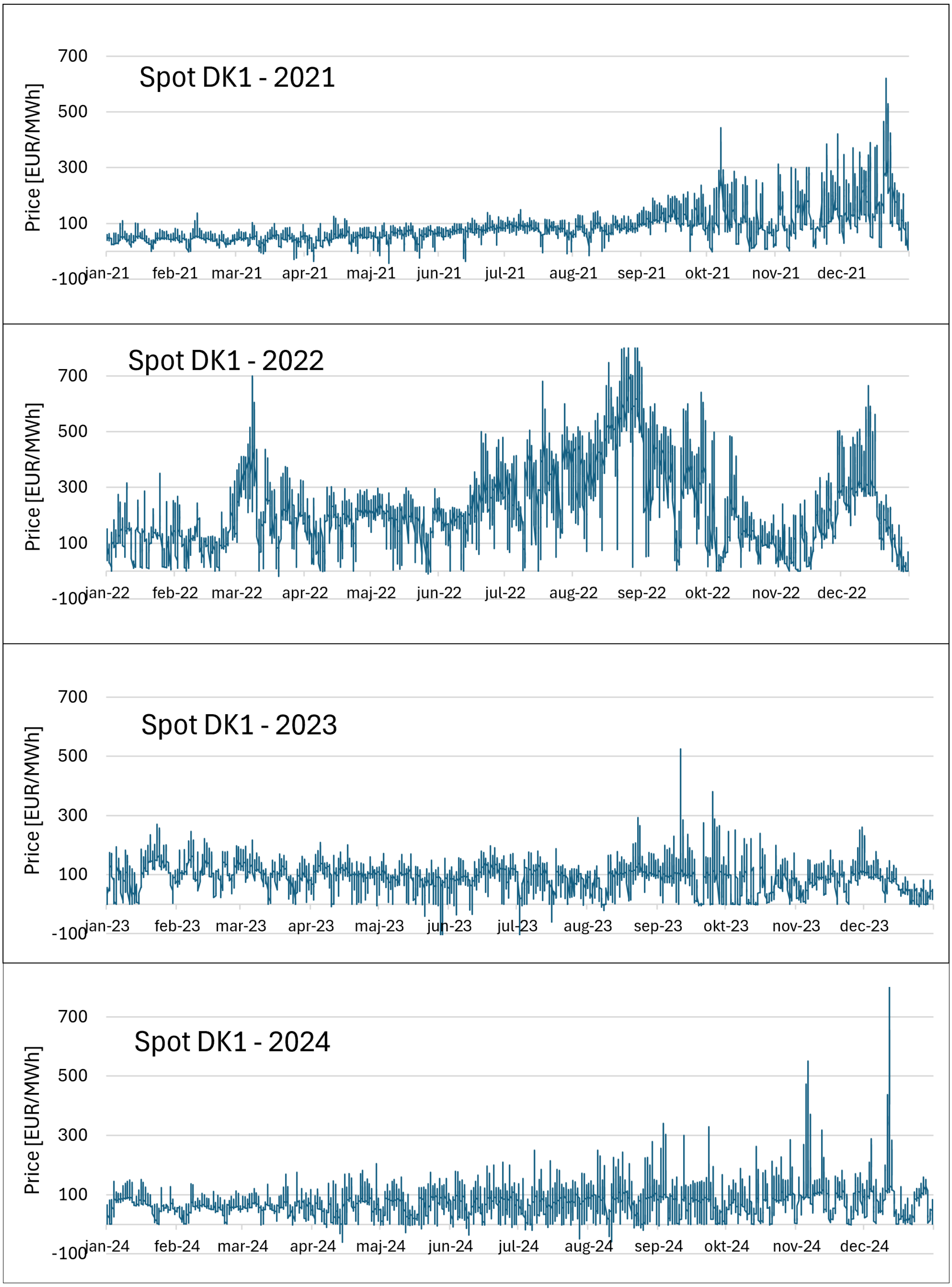


Figure C2. Historical spot prices DK1 2021-2024 (Energinet, 2025b).

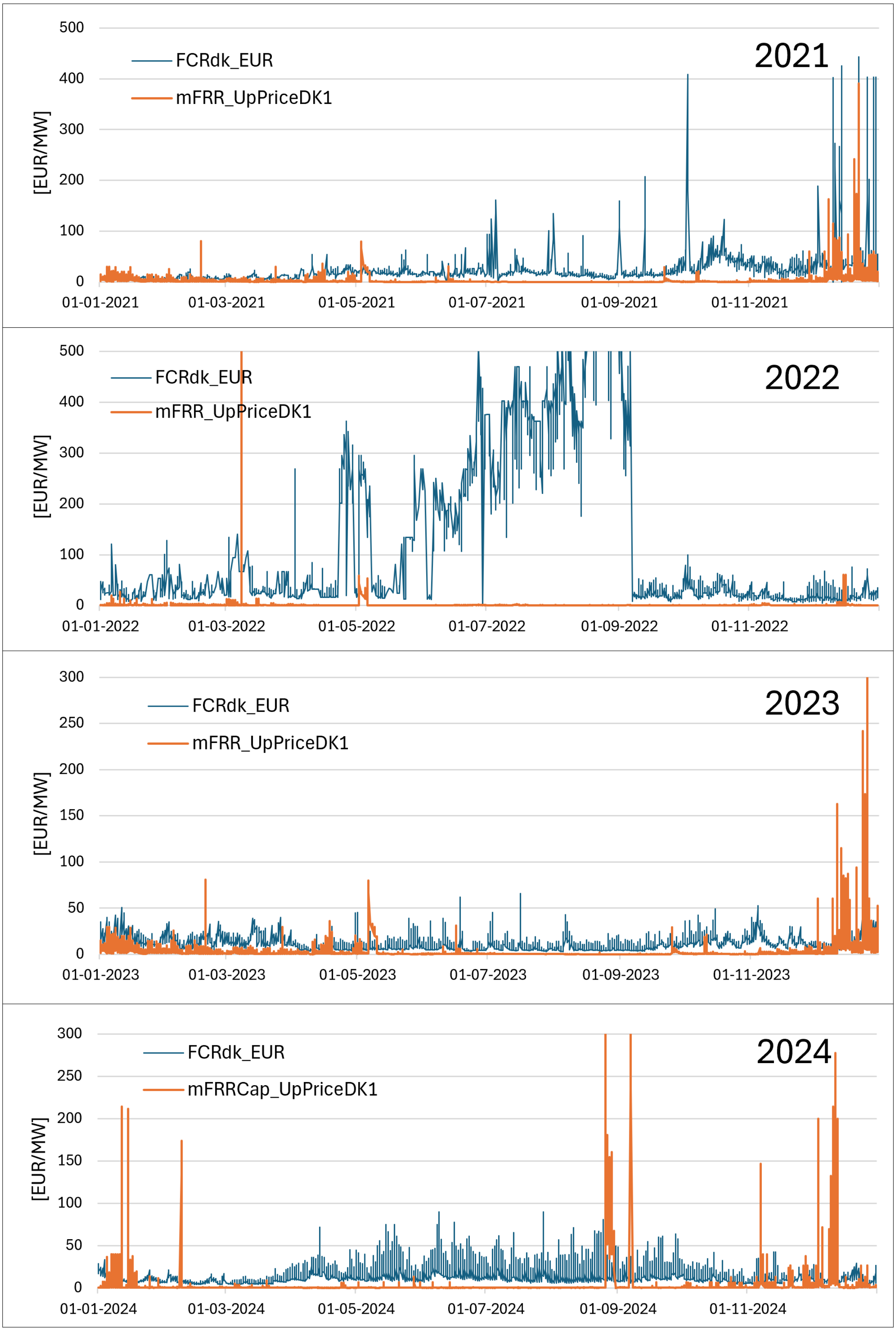


Figure C3. Historical prices for FCR and mFRR upregulation in DK1 (Energinet, 2025c).

Interview - Cerius-Radius D

Interview with Mads Paabøl Jensen, Senior Lead Regulatory Advisor at Radius:

Date: 18-02-2025
Location: Microsoft Teams
Attending: Mads Paabøl Jensen, Helena Thougaard Jensen & Rikke Hoffmann

Mads Paabøl Jensen from Radius and Cerius participated to discuss batteries and the electricity grid. He mentioned that there is a high demand for connecting batteries and that this is a task that needs to be addressed.

Mads Paabøl Jensen introduced himself and his background as a mathematical economist and consultant in the energy sector. He works with regulation of the electricity distribution grid and has experience with both electricity and gas distribution, as well as gas storage.

There is a high demand for connecting batteries, and Mads Paabøl Jensen noted that they have received inquiries totalling 1,500 MW, of which 75 MW have been connected. He emphasised the that the large demand is dependent on many factors, and not an expression of what will be developed .

Mads Paabøl Jensen discussed grid planning and tariffs in relation to batteries. He mentioned that they have a tariff model approved by the authorities and that they do not discriminate between technologies. He also stressed that they maintain reserve capacity in various places to respond to unforeseen events and that the grid can be expanded if necessary.

Mads Paabøl Jensen spoke about collaboration and legislation regarding batteries and the electricity grid. He mentioned that they have a good dialogue with stakeholders and authorities and are working on developing a new tariff model. He also emphasised that they follow the laws and regulations for electricity distribution. Mads Paabøl Jensen discussed the placement of batteries in relation to the electricity grid. He explained that they have a screening process to help identify the best locations for batteries and that there is a self-regulating mechanism to ensure that batteries are placed where they can be most effective.

The meeting concluded with Mads Paabøl Jensen thanking the participants for the conversation and encouraging them to reach out with further questions. He emphasised that they are open to dialogue and collaboration with stakeholders and authorities in the development of the electricity grid and the battery sector.

Interview - Green Power Denmark

E

Interview with August Bech og Anders Bitsch Youssef, Consultants at Green Power Denmark:

Date: 19-02-2025
Location: Microsoft Teams
Attending: August Bech, Anders Bitsch Youssef, Helena Thougaard Jensen & Rikke Hoffmann

Green Power Denmark works with batteries and the electricity market, including through a department titled "Market, Heating, and Intelligent Energy" that focuses on electricity markets and CHP plants. They have also established a network for BESS developers in Denmark.

Batteries are viewed as a potential part of the solution to the challenges of the electricity market. However, challenges remain, especially concerning tariffs, legislation, and communication between stakeholders. A shared understanding and proper regulation of the market are needed. While batteries can help stabilise the grid, planning and developing battery installations remains a significant hurdle.

The interview highlighted the need for continued efforts and collaboration between stakeholders to advance the electricity market and battery technologies. It was noted that both balance-responsible parties and developers must be involved to ensure batteries can support grid stability. Green Power Denmark expressed willingness to facilitate contact with other actors in the sector.

Looking ahead, batteries may play a growing role in addressing electricity market challenges, yet there are still issues related to the development and implementation of new technologies. A collective understanding of the regulatory framework and stronger cooperation between stakeholders will be essential. Green Power Denmark remains committed to work with others to develop battery technologies and improve the electricity market.

Interview - Energinet

F

Interview with Andreas Simoni Huse Pedersen and Maibritt Vester Bundesen, Engineers at Energinet:

Date: 21-02-2025
Location: Microsoft Teams
Attending: Andreas Simoni Huse Pedersen, Maibritt Vester Bundesen, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

The interview focused on the role of battery energy storage systems (BESS) in the Danish power grid and their integration challenges. Energinet, as the transmission system operator (TSO), is responsible for grid regulation and system balancing. Batteries are considered a promising solution, particularly for delivering ancillary services, though their limited energy capacity was noted as a constraint.

There is an increasing need for capacity and flexibility in the grid, especially to deliver services like Frequency Containment Reserve (FCR) and Automatic Frequency Restoration Reserve (aFRR). Batteries can contribute, but they must be sufficiently charged to be effective. Moreover, there is concern about potential market saturation if battery deployment grows too rapidly.

The ancillary services market is evolving rapidly with growing demand for flexible technologies like batteries. However, price volatility and market unpredictability pose challenges for long-term planning and investment. Batteries' value is tied closely to their ability to react quickly, but this same responsiveness can lead to oversupply in certain markets.

Energinet collaborates with Distribution System Operators (DSOs) regarding the role of batteries at the local grid level. Batteries can support local stability, but only if correctly dimensioned and integrated. Coordination between DSOs and the TSO is essential to avoid conflicting signals or overinvestment.

Batteries hold significant potential in the future Danish electricity system, especially for stabilisation and flexibility services. However, the risk of market saturation and the challenge of ensuring adequate charging remain key concerns. Ongoing regulatory work and cross-sector collaboration will be necessary to ensure that batteries are effectively integrated into both the transmission and distribution grids.

Interview - EWII

G

Interview with Thomas Bjerring Albrechtsen, Asset Manageer at EWII:

Date: 27-02-2025
Location: Microsoft Teams
Attending: Thomas Bjerring Albrechtsen, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

Thomas Bjerring Albrechtsen introduced both himself and the company EWII. EWII is a multi-utility provider operating within electricity, heating, and water, and also owns an electricity trading business and a portfolio of battery assets.

With an engineering background from the University of Southern Denmark, the speaker has experience working with energy systems. EWII has developed a model for evaluating the business cases for battery storage projects.

EWII is currently involved in several battery initiatives, including projects on Bornholm and Lindeø, and is planning further capacity expansion. A primary challenge remains establishing a profitable business case, particularly as system profits have declined.

The company participates in system services such as Frequency Containment Reserve (FCR) and is working to enter the market for Automatic Frequency Restoration Reserve (aFRR). They also identify opportunities in combining battery systems with solar and wind energy. Further discussion focused on market entry strategies, pricing mechanisms, and optimisation techniques. The speaker reiterated the need for deep understanding of the market to ensure economic viability.

EWII intends to develop larger-scale battery projects and sees value in hybrid solutions involving other energy sources. Efforts are also being made to improve modelling and operational optimisation of battery assets.

The speaker advised starting with simple modelling approaches and building complexity based on experience. A strong understanding of the electricity market and price dynamics was emphasised as key to developing viable business cases.

The meeting provided valuable insights into EWII's experiences with battery storage. It highlighted both the opportunities and challenges in the sector and stressed the importance of market knowledge in achieving profitable outcomes.

Interview - Centrica

H

Interview with Michael Mejdahl Ørkilde, Portfolio Manager at Centrica Energy Trading A/S:

Date: 03-03-2025
Location: Centrica Energy Trading A/S: Skelagervej 1. 9000 Aalborg
Attending: Michael Mejdahl Ørkilde, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

Michael from Centrica Energy introduces himself and describes his role as Portfolio Manager. He gives an overview of Centrica's work, focusing on their activities as a balancing service provider and their participation in system service markets.

The discussion moves to the potential for modelling a standalone, grid-scale battery installation. The conversion goes on, how the project group can model the market participation and Ørkilde, gives input to the approach. The group discusses methods for optimising battery operation, including how to manage imbalances in the electricity market. They explore the use of algorithms and artificial intelligence as tools to improve operational efficiency and decision-making in real time.

Dialogue covers regulation, market structure, and future expectations. The importance of cooperation between different actors is stressed, alongside a continued focus on optimising battery operations and managing market volatility.

The conversation includes reflections on how the battery market may evolve in the coming years. Participants also consider practical modelling tools, such as Excel, for simulating and testing different operating strategies under future market conditions.

The meeting ends with a discussion on how to use the gathered insights to progress the project. Collaboration and ongoing development are seen as essential to moving forward effectively.

Interview - NIRAS

I

Interview with Niels Nielsen, Consultant at NIRAS:

Date: 11-03-2025
Location: Microsoft Teams
Attending: Niels Nielsen, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

The speaker introduces himself and outlines the main objectives and challenges of the project. He has an academic background in physics engineering with a specialisation in surface physics and catalysis.

He has previously worked with the Danish Energy Agency and the Danish Centre for Energy Storage. Since February, he has been employed at NIRAS, where his work primarily focuses on the electrification of district heating. He also discusses local planning practices and municipal regulations related to battery installations.

The discussion includes several technical considerations regarding battery systems, particularly safety and fire risk. He also mentions the potential for co-locating battery installations with wind turbines or solar PV systems.

The speaker envisions a future in which batteries play a key role in grid stabilisation and efficient energy use. However, he also notes ongoing challenges, such as potential market saturation and various technical limitations.

He recommends consulting official guidelines and working towards standardised frameworks for battery deployment. He also highlights opportunities for integrating batteries with technologies like electric boilers and solar PV.

There is significant potential for batteries in Denmark, but regulatory and planning frameworks at the municipal level remain a key obstacle. Technical challenges such as grid connection and system scaling are also discussed.

The speaker advises tailoring battery solutions to specific cases and site conditions. He describes how simplified models in Excel, based on key assumptions, can be used effectively to support the early planning phase of battery projects.

The conversation ends with the speaker thanking the interviewer and expressing hope that the discussion has been helpful.

Interview - Eurowind Energy

J

Interview with Jacob Hollerup Søndergard and Gustav Damsgaard Ebbesen, Project Managers for environment and local engagement at Eurowind:

Date: 13-03-2025
Location: Microsoft Teams
Attending: Jacob Hollerup Søndergard, Gustav Damsgaard Ebbesen, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

The meeting focused on the integration of battery storage systems into existing wind and solar parks. Jacob and Gustav from EuroWind introduced themselves and outlined their professional backgrounds, highlighting their roles in the planning and environmental assessment of battery projects.

They explained that their work is driven by the ambition to optimise the use of renewable electricity by integrating batteries into renewable energy parks. The goal is to make better use of generated power, reducing curtailment and enhancing energy system efficiency.

Several challenges were discussed, including issues related to local planning, environmental assessments, and emergency preparedness. They also noted public concerns such as visual impacts, noise, and fire risks. Furthermore, they expressed concern about battery recycling and the handling of end-of-life waste.

Jacob and Gustav emphasised the importance of strong collaboration with municipalities, emergency services, and local communities. They stressed that effective communication and transparency are crucial for securing support and ensuring safe and compliant deployment of battery systems. A solid understanding of battery technology, including its limitations and potential, is considered essential.

Looking ahead, EuroWind intends to scale up its battery initiatives and deepen integration with renewable assets. However, they recognise that grid connection, tariff structures, and evolving market conditions remain key challenges.

The meeting provided valuable insights into the opportunities and obstacles associated with battery energy storage in Denmark. Jacob and Gustav expressed their openness to continued dialogue and a shared commitment to addressing these challenges through collaboration and knowledge exchange.

Interview - Sorø Municipality

K

Interview with Hans Henning Jensen, planner at Sorø Municipality:

Date: 23-04-2025
Location: Microsoft Teams
Attending: Hans Henning Jensen, Helena Thougaard Jensen, Thomas Christian Kold Kjær & Rikke Hoffmann

The interviewer introduces themselves and the project, and discusses the planning and approval of battery facilities in the municipality with an employee from Sovehøj Municipality. The employee's work includes reviewing technical installations and creating local plans.

The employee's experience with battery facilities is limited, but there have been six enquiries, three of which have resulted in approval. There have been challenges related to the battery developers, as this is their first time applying for permits.

There has been uncertainty about whether battery facilities can be located in rural or urban zones, but the employee's municipality has granted permission for installations in rural zones. The employee's experience is that local emergency services are not always aware of the requirements for battery facilities. Citizens have expressed concerns about battery facilities, particularly in relation to fire safety and visual impact.

The employee's municipality has had little contact with the national authority regarding battery facilities, but has been in dialogue with other municipalities. There is a need for more guidance and clearer planning frameworks for battery facilities. The employee's municipality expects more enquiries about such facilities in the future.

There is uncertainty regarding how future battery facilities should be planned and approved. There is a need for more streamlined planning processes, and the employee's municipality is looking forward to further guidance and regulation from the national authority.

The interviewer thanks the employee for their time and insights. The employee's experience and concerns regarding battery facilities provide valuable insight into the challenges municipalities face in the planning and approval of such installations.

Mail response - Viborg Municipality

L

Mail response from Birgit Balle, surveyer and Mads Tolborg, Project leader for RE planning at Viborg Municipality:

Date: Received 28-04-2025
Location: Outlook e-mail

Interesse *Hvordan har I oplevet interessen for stor-skala batterier i jeres kommune?* I forhold til VE-projekter har interessen fra udvikler/bygherres side indtil været meget begrænset, og vi har pt. kun ét projekt, ud af de 8 VE-projekter vi pt. arbejder med, hvori der indgår et batterianlæg. Selv i det projekt er batterianlægget først blevet en del af projektet efter vi afholdt idéfase og borgermøde samt modtog et hav af høringssvar, og det var ikke en del af den oprindelige projektansøgning. Derud over er der søgt én landzonetilladelse til et batterianlæg i tilknytning til en eksisterende transformerstation.

Har der været lidt/meget? Har det været overraskende? Interessen har været meget lav indtil videre, og umiddelbart har det ikke været så overraskende, da dette generelle fokus primært har været - og stadig er - på at få udskiftet eksisterende fossile brændsler med grøn energi, og knap så meget på hvordan vi skal lagre den overskydende strøm. Vi møder dog ofte argumentet om at strøm skal bruges i det øjeblik det produceres, så hvorfor skal Viborg Kommune så producere 4 gange så meget strøm, som kommunen forbruger, og derfor formoder vi at interessen for batterilagring vil blive større i fremtiden.

Hvilken type projekter har det været? Både stand-alone og i sammenhæng med vind og sol? I forhold til VE-projekter har vi som sagt kun ét projekt, hvor et batterianlæg indgår og det er et projekt som pt. omfatter ca. 120 ha solceller og 3 vindmøller af op til 170 meters højde. Desuden en landzonetilladelse som vedlagt.

Lokalplanlægning *Hvilke udfordringer har I overordnet stødt på i planlægningsprocessen, hvis der har været nogle?* I det konkrete VE-projekt, hvor vi stadig er tidligt i planlægningsfasen, har implementeringen af et batterianlæg - indtil videre - ikke medført nogle ændringer, da projektet allerede skulle miljøvurderes alligevel og det forventes at lokalplanen vil indeholde bonusvirkning, så der ikke skal udstedes en landzonetilladelse. Når vi når frem til udarbejdelsen af lokalplan mv. samt miljørapport, vil batterianlægget forventeligt få betydning for projektet grundet skærpede krav fra risikomyndighederne ift. brandhensyn, sikkerhedsafstande, opsamling af brandslukningsvand mv. Derudover skal der udtages et område på mellem 0,5-1 ha til placering af batterianlægget, der skal tages stilling til opsættelse af hegn, etablering af adgangsveje, mv.

Har der været usikkerhed om hvorvidt, der skulle laves lokalplan for anlægget, eller har det været intuitivt at give tilladelse via landzonetilladelse? I forhold til VE-projektet indeholdende batterianlægget, så har der ikke været tvivl om at der skulle udarbejdes en lokalplan mv. I landzonesagen var planlæggerne ikke i tvivl om, at der ikke var lokalplanpligt for det forholdsvis lille projekt i nær geografisk tilknytning til en transformerstation.

Har der væres tilstrækkelig udmelding fra staten omkring, hvordan man bør planlægge for BESS? Herunder placering jf planloven samt de miljømæssige forhold. Nej, der har ikke været tilstrækkelig udmelding fra staten om, hvordan kommunerne bør planlægge for batterianlæg - hverken i forhold til placering efter planloven eller de miljømæssige forhold. På nuværende tidspunkt oplever vi, at både udviklere og kommuner i høj grad orienterer sig mod, hvad andre gør, fordi der mangler en målrettet lovgivning eller vejledning. Det skaber usikkerhed og forskellig praksis. En statslig udmelding eller vejledning ville derfor være et væsentligt skridt i retning af en mere ensartet og kvalificeret planlægning.

Synes I der burde laves en specifik lovgivning eller vejledning for batterianlæg lignende bekendtgørelse og vejledning for vind og sol, eller ser I ikke et behov for det? Ja, vi ser et klart behov for en specifik vejledning eller bekendtgørelse for batterianlæg, svarende til det, der findes for vind- og solenergi. I dag er der stor variation i, hvordan kommunerne griber planlægningen an, og det skaber usikkerhed for både kommuner, udviklere og borgere. En fælles ramme - fx i form af en håndbog eller bekendtgørelse - vil kunne bidrage til en mere ensartet og effektiv planlægningsproces

Har I følt jer "klædt på" til at lave en landzonetilladelse for BESS? Det har været en ny type teknisk anlæg at sagsbehandle, og det har været lidt svært at få ansøger til at beskrive projektet, da ansøger også er ny på markedet. Projektet har også ændret sig undervejs, efterhånden som ansøger har fundet ud af, hvordan arealet skal disponeres med forskellige delelementer af det samlede anlæg. De sværeste emner at få belyst i sagsbehandlingen har netop været miljøhensyn og hensyn til beredskab.

Miljø *Har der været tilstrækkelig viden omkring, hvilke krav der skulle sættes til beredskab og miljøforanstaltninger?* Vores miljøafdeling kom frem til, at der i den konkrete sag krævedes en § 19 tilladelse - som vedlagt.

Hvad ser I som de væsentligste miljøpåvirkninger fra BESS, hvis der er nogle? Det kommer helt an på placeringen - er det i værdifuldt landskab, er det tæt på naboer, er det i et område med drikkevandsinteresser osv. Umiddelbart vurderer vi de væsentligste potentielle miljøpåvirkninger fra batterianlæg til at være støj, visuel påvirkning og potentielle risici i forhold til brand og kemikaliehåndtering.

Beredskab *Har I selv haft kontakt med det lokale beredskab? Har I oplevet at, de har følt sig forberedt og informeret omkring sikkerhedsforanstaltniger og beredskab?* I forhold til VE-projektet indeholdende batterianlægget, har vi ikke haft dialog med beredskabet om dette endnu, da vi stadig er tidligt i planlægningsfasen. I forbindelse med landzonesagen havde byggesagsafdelingen kontakt med beredskabet, og det var så vidt vides svært for beredskabet at forholde sig konkret til en hel ny anlægstype. Så vidt jeg er orienteret, var udgangspunktet for ansøger, at anlægget slet ikke kunne brænde - hvilket beredskabet fik ansøger overbevist om, at det kunne det godt.

Har det lokale beredskabet haft klare retningslinjer/krav til opstiller? I forhold til VE-projektet indeholdende batterianlægget, har vi ikke haft dialog med beredskabet om dette endnu, da vi stadig er tidligt i planlægningsfasen. Så vidt vides har beredskabet arbejdet sig frem til, hvordan man skulle forholde sig til det. Detaljerne kender vi ikke, da det er en sagsbehandling i Midtjysk Brand & Redning - foruden i et vist omfang i vores byggesagsafdeling.

Borgere *Hvad har en overordnede reaktion været fra naboer/borgere?* Har de haft interesse i projektet og hvad har været de primære bekymringer, hvis der har været nogle? I forhold til VE-projektet indeholdende batterianlægget, har den overordnede reaktion fra naboer og borgere primært været præget af modstand mod projektet som helhed. Batterianlægget blev dog inddraget som en del af projektet netop for at imødekomme nogle af de bekymringer, der blev rejst i høringssvarene - særligt argumentet om, at den producerede strøm skal udnyttes med det samme. Her har udvikler/bygherre foreslået lagring via batterier som en løsning. I landzonesagen var der ingen reaktioner fra naboer eller andre. Hverken nabobemærkninger eller klager.

Viden og samarbejde *Eftersom storskala batterier er helt nyt i dansk planlægning, mener I der har været mangel på viden for lokalplanlægning?* Ja, vi oplever helt klart, at der mangler både viden og praktisk erfaring i forhold til lokalplanlægning for storskala batterianlæg. Det er et nyt område i dansk planlægning, og i dag står den enkelte kommune i høj grad alene med at vurdere placering, miljøforhold, risici og tekniske krav - ofte uden klare retningslinjer. Der er behov for en national vejledning, håndbog eller bekendtgørelse, som kan skabe en mere ensartet og forudsigelig planlægningspraksis. Det vil både styrke retssikkerheden og lette dialogen med opstillere og borgere.

Har I oplevet noget samarbejde/sparring/kommunikation om BESS mellem kommuner? Har andre kommuner ringet til jer og jeres erfaring, eller har I rakt ud til andre kommuner, for at høre om deres erfaringer? Viborg Kommune har ikke haft direkte kontakt med andre kommuner omkring erfaringer med planlægning af BESS. Til gengæld oplever vi, at flere opstillere kontakter os for at høre, hvordan vi forholder os til placering og planlægning af batterianlæg. Der spørges bl.a. ind til, om vi foretrækker, at BESS placeres som en integreret del af VE-projekter, i tilknytning til disse, eller i eksisterende industriområder. I forbindelse med landzonesagsbehandlingen kontaktede flere kommuner os, men da problematikkerne var forskellige, var der ikke så meget konkret erfaringsudveksling.

Er der noget i processen for planlægning af BESS generelt, som I ser burde være anderledes? Fx samarbejde med aktører, statslig udmelding, miljøundersøgelser, lovgivning, information mv. Der mangler i dag en tydelig og ensartet tilgang til, hvordan kommuner skal planlægge for batterianlæg (BESS) - uanset om de indgår som en del af et større VE-projekt, optræder som selvstændige anlæg eller ønskes placeret i industriområder. Det skaber usikkerhed og forskellig praksis på tværs af kommunerne. En klarere statslig ramme, der tager højde for de forskellige typer anvendelser og placeringer, ville understøtte både en smidigere planproces og bedre koordinering med aktører og myndigheder.

Compiled transcriptions from the interviews

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