REDII Ports | Interreg North Sea | Co-funded by the European Union | MOSS HAVN

Stationary batteries in the Port of Moss

Decision report

SWECO

Audit history

Version no.	Date	Description of the change	Prepared by	Approved by
00	April 12, 2024	Draft for comments	Linna V. Nguyen Håkon Blågestad	Eirik Hordnes
01	June 17, 2024	Final Version	Håkon Blågestad	Håkon Blågestad

Sweco Norway AS	Organisasjonsnr. 967032271
Project	Utredning stasjonært batteri Moss Havn
Project number	10236918
Customer	Moss Havn KF
Author	Linna V. Nguyen, Håkon Blågestad
Controlled by	Eirik Hordnes
Approved by	Eirik Hordnes
Date	2024-06-17
Version no.	01
Document reference	Stationary Battery in the Port of Moss - Final version

Summary

The Port of Moss is in the process of electrifying the port operations. High ambitions of reaching zero emissions by 2030 will have a significant impact on the electrical energy and power need. The port is a part of the REDII ports project and has through this received funds to investigate the possibility of installing a battery electric energy storage system (BESS) to compensate for some of the effects from this transition.

This report aims to analyze the port's current and anticipated energy usage, including solar power production potential, and explores various business models for BESS deployment, including frequency regulation and peak shaving. The report also considers different placements for the BESS within the port, such as centralized or decentralized locations.

The report also outlines the future energy needs based on the growth of zero-emission vehicles and shore power requirements. It acknowledges the current limitations of the shore power system and the grid, proposing that a BESS could be an integral part of a solution.

Finally, the report emphasizes the necessity of an Energy Management System (EMS) for optimal battery operation and provides cost and saving estimates for implementing a BESS system at the Port of Moss.

The report concludes with a recommendation of investing in a 1 MWh to 2 MWh battery, in combination with a solar panel system with 302 KWp and a associated microgrid to both peak shave the loads in the port, relive some of the strain on the local power grid and contribute to the flexibility and frequency reserve markets. The necessary investments in the battery system and solar panels are estimated at 6 400 000 NOK for 1 MWh to 10 000 000 NOK for 2 MWh. This does not include the costs associated with establishing the microgrid.

Table of Contents

Definitions and Abbreviations

This section of the report includes key definitions and abbreviations used throughout this document.

BESS	Battery Energy Storage System
BIPV	Building-integrated photovoltaics
DOD	Depth of discharge
SOC	State of charge
SOH	State of health
IRR	Internal Rate of Return
NPV	Net Present Value
NSR	North Sea Region
PV	Photovoltaics
REDII	Renewable Energy Development and Intelligent Implementation
TCO	Total Cost of Ownership
FFR	Fast Frequency Reserves
FCR	Frequency Containment Reserve
aFRR	automatic Frequency Restoration Reserves
mFRR	manual Frequency Restoration Reserves
STS crane	Ship-to-shore crane
RTG crane	Rubber tyred gantry crane
TSO	Transmission system operator
DSO	Distribution System Operator
NOK	Norwegian kroner
EMS	Energy management system
kWp	Kilowatt peak

1 Introduction

As part of REDII Ports (funded by INTERREG NSR and co-founded by the European Union), the Port of Moss aims to reinforce the electrification agenda of North Sea Region (NSR) ports and strengthen its position as a green port. The installation of battery capacity is seen as a step towards improving the position of ports in terms of becoming national energy hubs. The installation of a battery system will ensure a more levelized power consumption for the entire port's operations, including cranes, shore power, lighting, heating, electric cars, and future infrastructure for charging facilities for electric trucks and heavy equipment such as reachstackers.

Port operations require a significant amount of power, and when multiple vessels are at the port simultaneously, it can lead to challenges for the electricity grid. Both in terms of the equipment needed to handle the cargo, but also if the ship uses shore power when at port. To overcome this, energy providers wish to incorporate batteries as buffers that can be charged when there is a surplus production of green power or good capacity in the power grid. The Port of Moss intends to explore the possibility of installing a battery system to support the harmonization of the local power grid.

1.1 Background and Purpose of the Decision Report

The Port of Moss is one of Norway's most important container ports and an important logistics node in the Oslofjord region.

The aim of this report is to assess the feasibility of implementing a battery energy storage system (BESS) at the Port of Moss. The initial stage involves a comprehensive analysis of the infrastructure and energy consumption of the port, to evaluate the current and future energy consumption patterns of the port. This entails mapping out the current energy consumption of the port, including energy consumption for operational port activities such as handling terminal equipment and loading and unloading cargo ships. Furthermore, this study evaluates the potential increase in energy consumption for shore power and operational port activities to anticipate a future scenario where the port becomes a zero-emission facility, aligning with its goal to achieve zero-emission status by 2030.

Furthermore, this report will include an evaluation of various battery technologies, as well as the potential for renewable energy production such as solar power. Sweco will then compare battery solutions, storage capacity and energy system concepts in terms of benefits and drawbacks, quantifying the costs and savings for each. An economic analysis and evaluation of potential financing options for the implementation of the BESS, will also be conducted. The final step will be to outline the recommended strategy for implementing and operating the battery storage system for the Port of Moss.

Based on the findings from the analysis and recommendations arising in this report, Sweco will collaborate with the Port of Moss to develop a detailed technical requirement specification and business plan for the potential installation and integration of the battery storage system.

2 Battery technology and implementation

2.1 Batteries

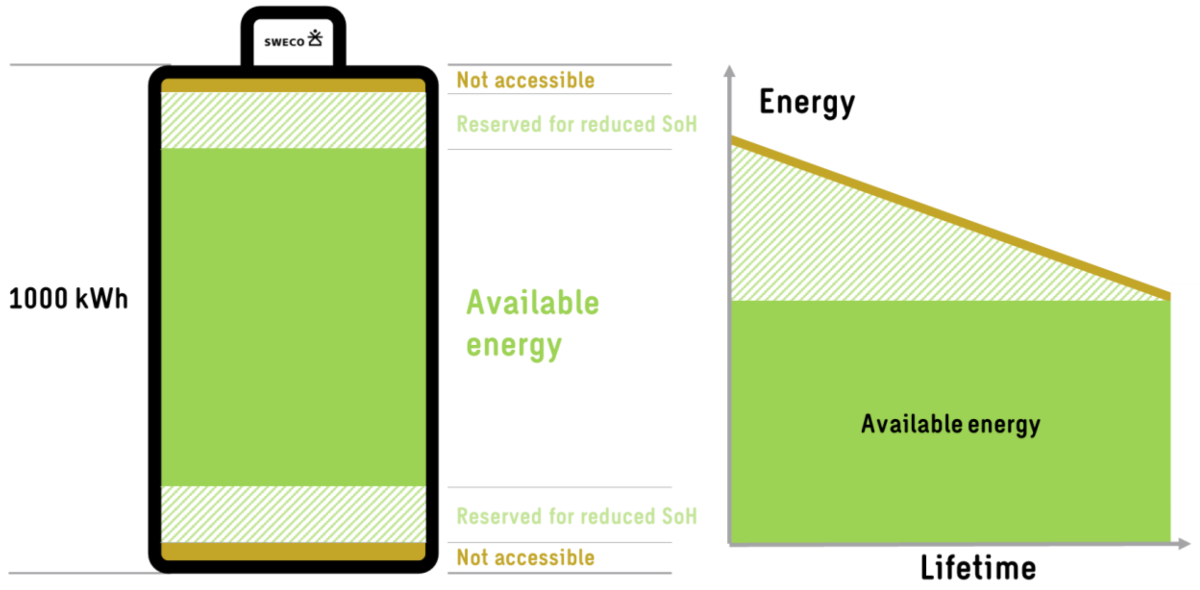
The use of batteries for stationary applications in Norway are still in an initial phase, but there are several established manufacturers of such batteries. Stationary batteries are offered in a range of sizes, from small-scale of some kWh to MWh scale.

Batteries have a selection of technical concepts that are crucial for choosing the right battery for its purpose. These include:

- Storage capacity
- C-rate
- Depth of Discharge (DoD)
- State of Charge (SoC)
- State of Health (SoH)

The storage capacity is the most important concept, as it determines how much energy that can be stored in the battery. The related concept DoD is also of importance, as some batteries have a limitation of the use range compared to the whole capacity of the battery. DoD indicate the allowed usage range of the battery, from a 100% charged state. If the DoD is limited to 40%, does it mean that only 60% of the energy capacity is available for usage. The C-rate indicates how fast the energy can be discharged from the battery, and therefore the maximum power that can be delivered from the battery at a specified timespan. Batteries that have a very high C-rate tends to have a lower gravimetric density, whilst lower C-rate have higher gravimetric density. However, for stationary applications, the gravimetric energy density is of less relevance. The C-rate varies amongst different battery suppliers but is typically around maximum 1C for stationary applications.

The concepts are illustrated in Figure 1, with an example battery of 1000 kWh storage capacity.



2

FIGURE 1 – OVERVIEW OF CONCEPTS RELATED TO A BATTERY.

State of Health (SoH) is used to indicate the degradation of the battery, expressed as a percentage of the remaining battery compared to the initial battery capacity. A SoH of 80% indicates that the battery can store maximum 80% of the initial storage capacity after a period of degradation over time. The maximum degradation can either be most affected by time (calendar life) or by the usage pattern and central aspects as SoC-range and cycles.

The lifetime of the battery is dependent on two main variables: the DoD and calendar time. With increasing DoD-regime, the expected number of cycles are decreasing. In addition, batteries have a calendar governed lifetime. The lifetime is often determined by which SoH is seen as reasonable. For maritime batteries or cars, the accepted SoH is typically around 80%. For a stationary battery, a lower SoH may be accepted. The expected calendar lifetime of stationary batteries is limited to around 10-15 years, and a conservative reinvestment plan can assume a necessary reinvestment every 10th year if the number of cycles does not limit the lifetime within this timeframe.

Even though battery technology has been implemented rapidly in several different sectors, there are a limited number of commercial suppliers of stationary batteries in Norway. Battery technology is as of 2024 mainly based on lithium-ion technology, with a varying chemical combination of either iron phosphate, nickel, mangan, cobolt and aluminium. New battery technologies, less dependent on minerals such as cobolt and lithium, are emerging but yet to be commercialized. As of today, lithium-ion based technology is the baseline for stationary batteries.

The costs of batteries have decreased dramatically in the latest years, and a 2/3 cost reduction has found place since 2013 on Lithium-ion batteries according to BloombergNEF [1]. The current price (2023) is around 150 $/kWh battery capacity (pack-level), and BloombergNEF expects the price to drop below 100$/kWh within 2026 [2]. However, prices from suppliers in Norway indicates a higher price range for commercial, stationary batteries, with an investment price of around 400$/kWh.

There are a number of suppliers of commercial batteries in the marked, and many of them are big industrial companies such as Siemens, Hitachi, ABB and GE. Batteries are also provided by smaller niche-suppliers such as ECOStor, Northvolt, and Nilar. Most suppliers offer containerized solutions. Figure 2 shows an overview of the different levels of a battery, from cell level, to module, rack and container.

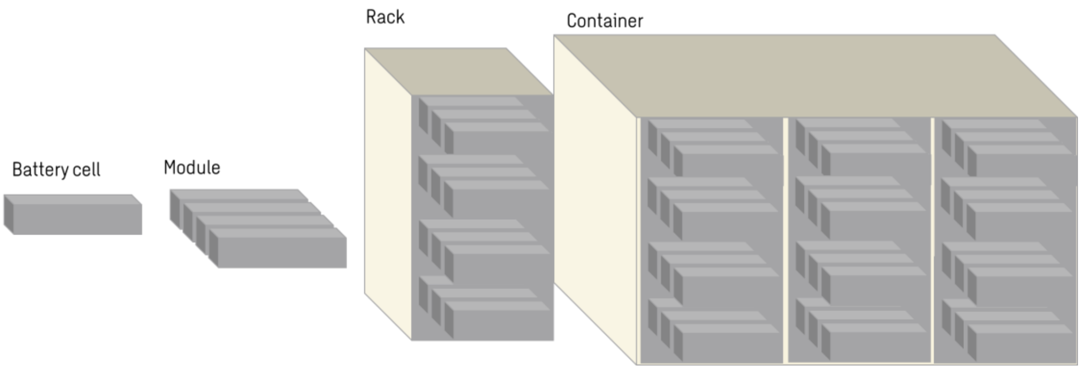


FIGURE 2 – BUILDUP OF A BATTERY FORM A BATTERY CELL, MODULE, RACK AND UP TO A CONTAINER

A list of different suppliers with their technology and technical specifications are listed in Table 1 (note that all the information is gathered 06.03.2024 and technology is rapidly evolving, meaning that the battery specifications may change in near future).

Table 1 - Overview of a selection of different battery manufacturers. Note that the list is not comprehensive.

	Siemens	Hitachi	ABB	GE	ECOStor	Northvolt	Capture Energy
Product name	Bluevault	PQPlus	eStorage Flex/Max	ESU RSU-4000		Voltrack	PowerBox
Technology	Lithium-Ion	Lithium-Ion (NMC)	Lithium-Ion (NMC)	Lithium-Ion (NMC)		Lithium-Ion	Lithium-ion (LFP)
Scalability	Rack: 60 kWh	Rack: 68.5 kWh	Container solutions: 550 kWh – 5.5 MWh	Container solution 20': 4184 kWh	Module/container 40': 40 kWh/750 KWh	Rack: 175 kWh	Container solution: 1,1MWh/2MWh
C-rate*	-	<0,5	<1	0,3	0,75/1,3	1	-
Intended use	O&G and maritime batteries	Electricity regulation	Electricity regulation	Electricity regulation	Electricity regulation	Electricity regulation	Electricity regulation
Other comment	Racks can be combined to increase total capacity	Racks can be combined to increase total capacity					Container can be combined to increase total capacity

**Based on maximum output from one rack/module.*

2.2 Examples of batteries in stationary use

As our energy system is expected to have increasing share of renewable power, batteries are a quickly emerging technology for integration in the energy system. In the EU, several pilot projects have been initiated with the implementation of stationary batteries. Several of the EU-projects has led to specific pilot projects, and it is relevant to highlight some of the projects and the results that have been obtained in the pilots:

Skagerak Energy lab (part of EU-project Eneuron)

This project had installed 800 kW photovoltaic (PV) power and a 1 MWh BESS on a football stadium.

Resolvd EU project

This project aims to find solutions to how solar power can be integrated in a low voltage energy system with limited capacity. The system includes one lithium-ion battery and one lead-acid battery, which contributes to regulate the produced power to regulate the power supply in the area. The battery also work as an energy backup solutions in times of instability in the supply of energy from the main grid to the local grid. The batteries were small with only capacity to even out fluctuations, with a 30 kWh lithium-ion battery and 14 kWh lead-acid battery.

In addition to large and highly funded EU-projects has also commercial projects for batteries in use taken place, some examples:

Smart Senja

Senja is a fishing community and dependent on stable access to power. To ensure that the power access for the industry is stable, they installed some of the largest batteries in Norway, with the installation of one 0.8 MW battery and one 2 MW battery. The plan is that the batteries, combined with smart energy systems, shall ensure stable power supply to the local industry at any time. The batteries are supplied by Rolls-Royce Solutions Berlin.

Brattøra, Trondheim

A combination of power producing buildings (Powerhouse, BI and Miljødirektoratet) in Trondheim is linked to a large battery which distribute the energy among the buildings, and also neighboring buildings around. The buildings are also connected by a local grid to distribute energy.

Skipet, Bergen

At Skipet in Bergen 2nd life batteries from cars are used as battery storage for the installed solar power. The combined capacity is 150 kWh. This battery system can both contribute to storage of the solar power, as well as electricity regulation and peak shaving.

As these examples show, both at the research and innovation level, but as well in commercialized projects, batteries are used to regulate the electricity and store solar power. Acknowledged as emerging technology, it is still considered a mature technology to deploy as a part of the energy system in Moss Port.

2.3 Placement of batteries in the local system

Several strategies for implementing batteries in the local power system has been analyzed for the port. These are a centralized placement, decentralized placements and a mobile battery or vehicle to grid (V2G). The concepts are illustrated in Figure 3. The different need for electricity is here illustrated by the smart meters, in Norwegian "Avanserte Måle- og Styringssystemer" (AMS).

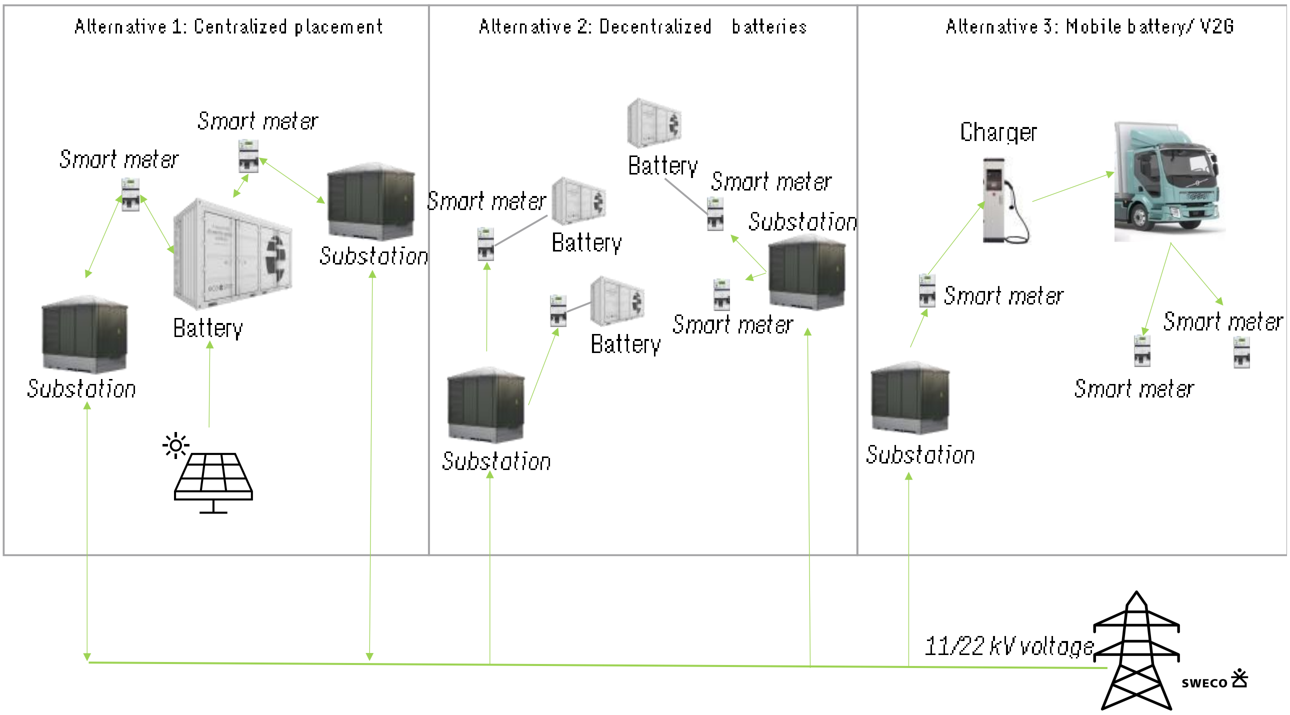


FIGURE 3 – POSSIBLE INTEGRATION ALTERNATIVES FOR BATTERIES IN THE LOCAL ENERGY SYSTEM

Alternative 1 is based on placing a larger battery in a centralized location and then connection the various needs with a local transmission grid often referred to as a microgrid. Although the system in Moss Port is not likely to only run in such an island configuration, we will still use the term microgrid to describe the local system.

Alternative 2 suggests placing several smaller batteries in what is known as a behind-the-meter (BTM) configuration. This configuration does not require establishing a microgrid in the same way as alternative 1 and may thus reduce the change of having to apply for a concession for operation the electrical system. However, the price of a battery reduces with the storage capacity of the battery. So multiple decentralized batteries may have a higher total cost than one larger battery. The batteries will also only be able to service the consumption its directly connected to.

Alternative 3 illustrates a concept which relies on a mobile battery, that can be in the form of an electric truck with vehicle to grid compatibility. This means that the truck can supply energy from the truck's internal battery. The battery can then be moved between loads in the system to supply additional energy where this is needed. The price of an electric truck is often comparable, or in some case lower, than that of a stationary battery with the same storage capacity.

2.4 Battery Energy Storage System business models

A battery can be introduced in several different business models, where the goal is to find the most economic usage of the battery. Note that some of these models does not necessarily fulfill a goal of high self-sufficiency degree if coupled with renewable energy and focus on the optimal economical usage of the battery. Which of the two that is prioritized must be considered. The different business models include:

2.4.1 Frequency regulation and flexibility markets

The increasing share of renewables in the energy mix is creating a system with more frequency and load variation, which again creates less stable grid. Frequency regulation with a battery is a method of regulating the battery power to the grid, with a rapid expansion in Sweden, Denmark and Finland, but is yet not so common in Norway. Such regulation can be awarded by the grid operators. If renewable energy production is introduced to the system, excess production will be stored in the battery as long as the battery have available storage capacity. To be able to participate in the frequency regulation market, one can contribute with several services. These are the Fast Frequency Reserves (FFR), Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserves (aFRR) and manual Frequency Restoration Reserves (mFRR). There are different technical requirements for contribution to the reserves, mostly varying in response time, minimum delivered power and the total time one can deliver said power [3]. There are also other market initiatives such as the marketplace Nodes and the market EuroFlex [4]. Participation in these flexibility markets are good additions to the other economic models.

2.4.2 Price arbitrage

Price arbitrage is simply following stock strategy; buy low, sell high. The storage in the battery is controlled by the electricity prices, and the battery will be charged when prices are low and discharged and sold when the electricity price is high

2.4.3 Peak shaving

Peak shaving strategy is meant to control the maximum power that is served from the grid, either to avoid a costly increase of the grid in the area, to reduce the grid tariff, or both. Peak shaving means that energy is provided from the battery in time periods when the load in the local system is higher than a certain level. The battery is then used to lower the monthly peak load as to reduce the tariffs to the DSO.

2.4.4 Increased self-consumption

This strategy is relevant when there is local electricity production included in the system. The strategy is based on increasing the self-consumption of this locally produced electricity instead of exporting it to the grid.

It is natural to combine this model with peak shaving, and other strategies, as the main reason for introducing the battery will be to supply the area with energy in periods when the load is high, and charge the batter when load is low. The usage pattern can however be somewhat different from a pure peak shaving strategy.

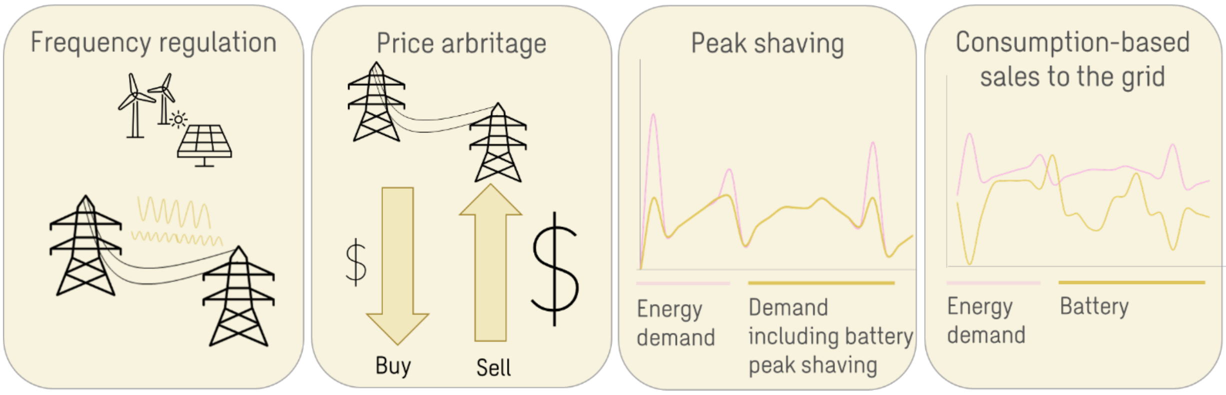


FIGURE 4 – ILLUSTRATION OF BUSINESS MODELS FOR A BATTERY ENERGY STORAGE SYSTEM

2.4.5 Energy communities

If multiple companies band together, they can form what is called an energy community. They split energy when one has high energy consumption and when the other has low. New customers can connect to the grid without waiting in queue. With batteries and local energy productions the community can function without more energy from the grid. In the case of the port of Moss, a energy community concepts involving ASKO Maritime and Bastø Fosen who operates sea drones and electric truck chargers and electrical ferries could be explored [5]. This is however dependent on agreements between the parties that regulates how the system is operated, how the energy is shared and a joint energy management system capable of controlling the energy flow in accordance with the previously mentioned agreements.

2.4.6 Strategy choice and energy management

As already described under 2.4.4. Increased self-consumption, it is natural to combine a model based on increased self-consumption with a peak-shaving model. Furthermore, peak shaving, price arbitrage and frequency regulation can all be combined, with a given priority of the preferred strategy. As frequency regulation is not common in Norway yet, frequency regulation as a strategy is not a part of our dimensioning procedure, but the benefits and challenges are discussed as a supplement to peak shaving, price arbitrage and consumption. An estimate of the economic benefits from participation in frequency regulation and flex markets is taken into account in the economic analysis.

The energy management system is in charge of performing the strategical choices and is therefore important so that the battery performs optimally at any given time. A smart system capable of choosing the right strategy will give significant economic gains and can reduce the size of any potential construction contribution to the DSO.

3 Technical Analysis

To assess the feasibility of implementing a battery storage system at the Port of Moss, it is crucial to evaluate the current and future energy consumption patterns of the port. Therefore, the first part of the technical analysis includes a comprehensive analysis of these consumption patterns. The analysis considers the energy consumption for operational port activities, such as loading and unloading cargo ships and handling terminal equipment and anticipate a future scenario for a zero-emission port with an increased energy consumption to shore power and port activities. Ultimately, the analysis provides a foundation for the development of a detailed technical and business plan that outlines the implementation and integration of the BESS at the Port of Moss.

3.1 Area and Infrastructure

The area of the port of Moss is a compact port area with limited space available. This affects the possibilities in the area for complex energy production systems. Solar power is therefore the only energy production technology deemed feasible to implement at the port. There are two large logistics buildings located in the area, which only one of them considered as suitable for installation of solar panels by the port administration.

The port areas electricity needs are served by eight electrical substations. These are marked in dark blue in Figure 5. Five of these are owned and operated by the Distribution System Operator (DSO), Elvia. Two are owned and operated by business operating form the port, Bastø Fosen who operates a ferry between Moss and Horten and ASKO Maritime that operates two sea drones between the two cities mentioned. ASKO Transport have also established fast charging for electrical trucks at the port. One substation, HE0004 is supplying the Ship to shore (STS) crane with high voltage power. This has a capacity of 800 kVA. The shore power system is supplied with 600 kVA. They are all marked in the map included as Figure 5.

The area where charging infrastructure for electrical port equipment such as reachstackers is going to be established are marked in yellow with the planned area for charging of external electrical trucks are marked in light blue. The port has asked for 2 MW of power from the DSO to supply this infrastructure.

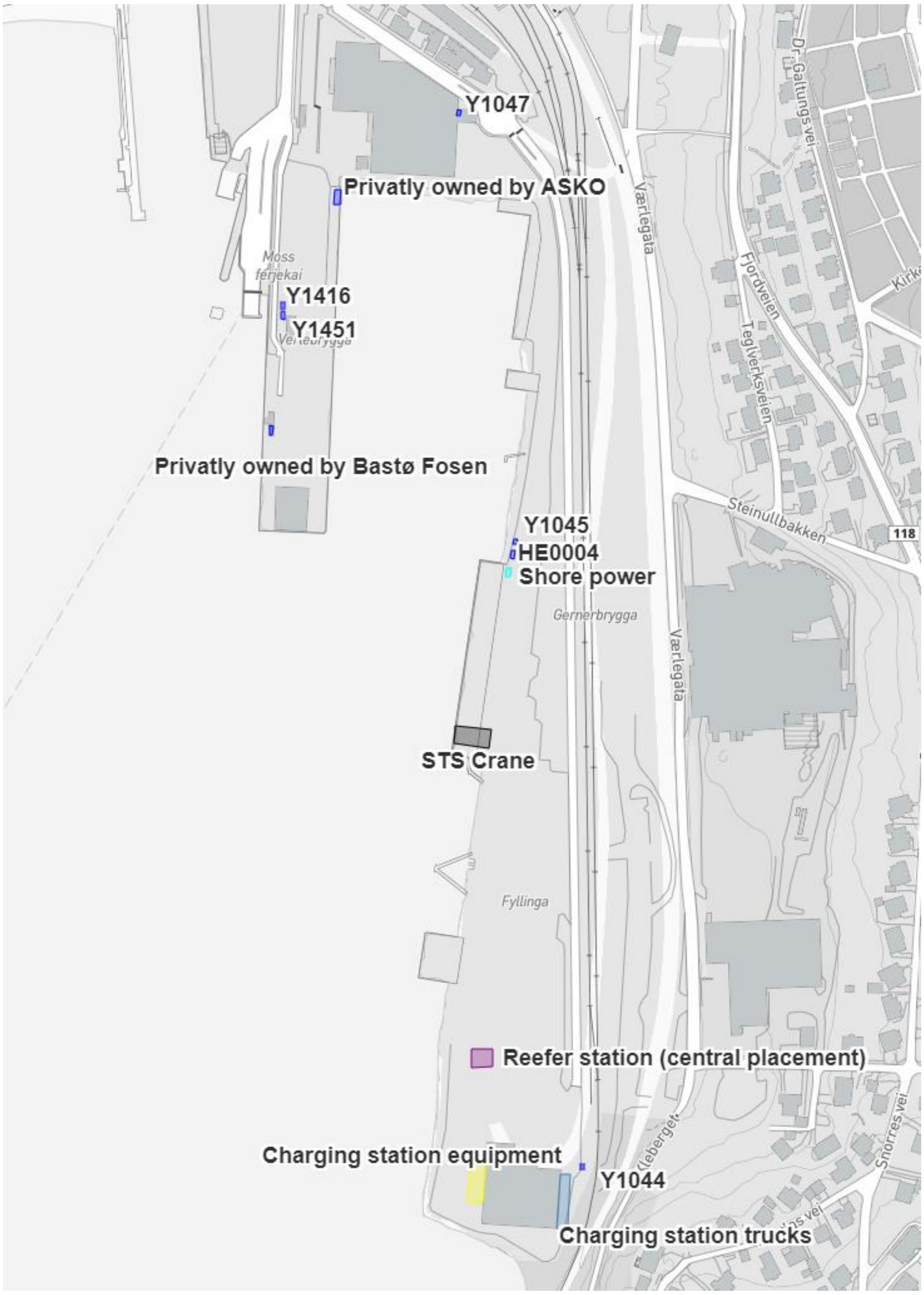


FIGURE 5 - MAP OF INFRASTRUCTURE AT THE PORT. THE MAP INCLUDES IDENTIFIED ELECTRICAL SUBSTATIONS, PLANNED CHARGING EQUIPMENT AND OTHER INFRASTRUCTURE. ELECTRICAL SUBSTATIONS ARE MARKED IN DARK BLUE.

3.2 Mapping of current energy demand

The port area has an energy demand related to the operation of the different vehicles and machines that handle the logistics, in addition to electricity need for logistic buildings located in the port. Shore power was established in the port in 2019 and is therefore available, but few ships are ready to use shore power and its historical usage is therefore very limited. In the future, use of shore power is expected to increase, which will lead to an increase in the overall energy demand in the port. The shore power system has two outlets capable of delivering 500 kVA each. The system was per 2023 constricted by the power grid supplying it and only one outlet could be used at a time. The system is supplied with 690 V and can per now use 600 kVA.

The energy demand in the port today is based on consumption from the two main buildings in the port area, barracks, the electrical equipment that are present today, and the diesel consumption for the fossil-based machines and equipment. The equipment that are present in the port today is:

- Reachstackers – 4
- Terminal tractors – 2
- Forklift – 1
- Wheel loaders – 2
- STS crane – 1
- Mobile crane

The reachstackers are diesel fueled as of today. The two terminal tractors are diesel fueled but will soon be replaced by electric variants. The forklift is also diesel fueled. One of the wheel loaders are electric and one runs on diesel. The STS crane is electric while the mobile crane is powered by diesel. The port is also employing one battery electric van, one small battery electric truck and one electric work boat. The port will acquire two rubber tyred gantry cranes (RTGs). These will run on an electrical energy supply in the form of either a busbar or by a cable relay. The port is also planning on expanding their operational hours by having one to two reachstackers in service to 22:00 each night. The RTGs will also run for 06:00 to 22:00 when they are implemented.

For the fossil-fuel based equipment, the current consumption is converted to electricity need for corresponding electrical machines and vehicles. The assumptions for the energy conversion are summarized in Table 2.

Table 2 – assumptions for the energy conversion.

	Diesel	Electrical vehicle
Energy efficiency (tank to wheel)	30%	85,5%
Gravimetric energy density (kWh/L)	10,0	-

The total energy consumption of the port when all consumption is converted to kWh is 3 356 739 kWh per year. This is illustrated in Figure 6. The electrical peak power is however modest as this is already existing buildings, some charging of electric vehicles already in use and operation of the STS crane.

All power consumption is given in kWh per hour (kWh/h) and denoted in kW. This is because the highest resolution of the data received from the DSO is hourly. The real power consumption in any given moment can therefore be higher than this value since the data is for the mean power consumption over an hour.

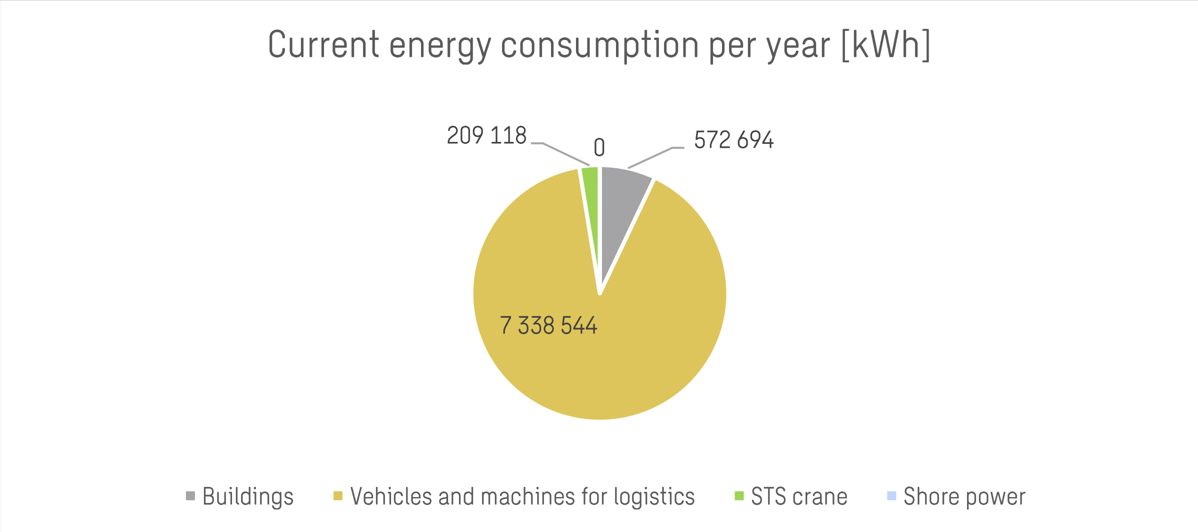


FIGURE 6 – CURRENT YEARLY ENERGY DEMAND OF THE PORT

The current peak power is estimated to 304 kW, including electricity needs for building, electricity for charging existing electrical vehicles, and existing shore power. This is shown in Figure 7.

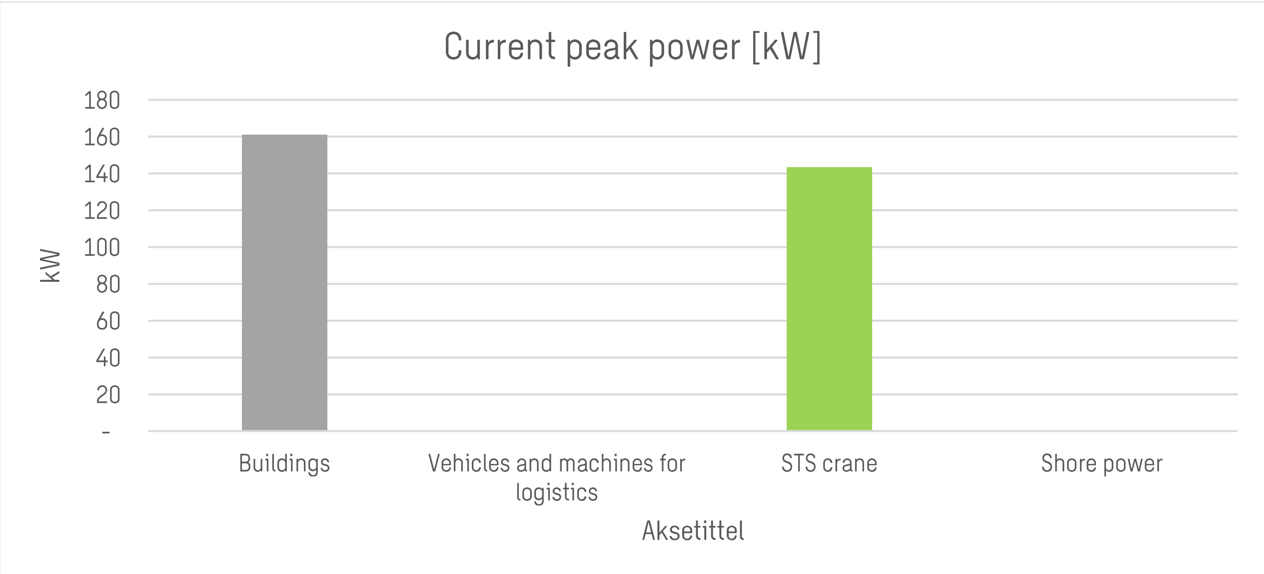


FIGURE 7 – CURRENT ELECTRICAL PEAK POWER USE

The power consumption of the ferries from Bastø Fosen has also been analyzed. The analysis of the route table shows that the charger for the electric ferries is in use in the time frames seen in Table 3. This is to investigate synergies between the port and the other companies in the area. No information about the operation of the sea drones and electrical trucks belonging to ASKO has been available in a format suitable for this analysis.

TABLE 3 – CHARGING SCHEDULE FOR BASTØ FOSENS ELECTRICAL FERRIES. THE TABLE SHOWS THE START OF CHARGING PERIODS BASED ON THE FERRIES SCHEDULES. EACH CHARGING PERIOD LASTS 14 MINUTES. THIS TIME INCLUDES RAMPING UP AND DOWN THE POWER AND CONNECTING/DISCONNECTING THE CHARGER.

Start charging period (14 min)		
Monday - Friday	**Saturday**	**Sunday**
04:30:00	06:15	06:15
05:15:00	06:45	07:00
06:15:00	07:30	07:45
06:45:00	07:45	08:30
07:15:00	08:15	09:15
07:55:00	08:45	10:00
08:15:00	09:15	10:45
08:50:00	09:45	11:15
09:25:00	10:15	11:45
09:45:00	10:45	12:25
10:20:00	11:15	12:45
10:55:00	11:45	13:20
11:15:00	12:15	13:55
11:50:00	12:45	14:15
12:25:00	13:15	14:50
12:45:00	13:45	15:25
13:20:00	14:15	15:45
13:55:00	14:45	16:20
14:15:00	15:15	16:55
14:50:00	15:45	17:15
15:25:00	16:15	17:50
15:45:00	16:45	18:25
16:20:00	17:15	18:45
16:55:00	17:45	19:20
17:50:00	18:15	19:55
18:25:00	18:45	20:15
18:45:00	19:15	20:45
19:20:00	19:45	21:15
19:55:00	20:15	21:45
20:15:00	20:45	22:15
20:45:00	21:15	22:45
21:15:00	22:00	23:30
21:45:00	22:45	
22:15:00	23:45	
22:45:00		
23:30:00		
23:45:00		

The charger has a power output of 9 MW. This means that adjusted to MWh per hour as the other power consumption data that the highest power use during any hour of a day is 3,7 MWh/h. But the power peak during that hour is closer to 8 MW. The analysis shows that the ferries usually chargers two times per hour, so the power peak is reached two times per hour.

Each charging sessions is 14 minutes which means that for approximately 30 minutes each hour, the power could be available from the electrical substation supplying the charger. This could be exploited to for instance charge the ports equipment or the BESS if this electrical substation where to be connected to the rest of the infrastructure in the port.

This is relevant in the context of forming an energy community, a concept discussed in Chapter 2.4.5, with Bastø Fosen and/or ASKO. This could enable the port to use the power available when the chargers for the ferries, sea drones and electrical trucks are not in use. This could also reduce the need for capacity increasing measures in the grid supplying the port and in the overlaying grid. The practical implementation of such a community is however complex and would require a close partnership with the aforementioned businesses. This capacity and power need is therefore not included in the analysis performed in this report. Integration of the charging infrastructure and substations operated by Bastø Fosen and ASKO Maritime into a possible microgrid in the port area should however be considered as a possibility.

3.3 Estimations of the Future Energy Consumption

The estimations of the future energy consumption are based on the current energy demand converted to electricity, in addition to anticipated growth related to zero-emission vehicles in the port, and the need of shore power to the ships.

The shore power potential is estimated based on the consumption data provided by Enova. The port log is used to identify what categories of ships are anchored at the port and for how long. The need is then calculated and estimated on an hourly basis for a year. The port log for 2022 is used as a basis. Note that the calculations do not consider that the system currently in use are only capable of providing 500 kVA to two separate ships and that per 2023, it was only operational at 500 kVA for one ship and not two at a time. This means that hourly power and electricity consumption in the calculations will be higher than the current technical limitations would allow in practice. This is however not a critical point as the number of ships capable of receiving shore power is increasing over time and the calculation is based on 100% of anchored ships being able to use shore power. The technical side can therefore be improved gradually as the demand for shore power increases. The limitation placed on the shore power installation by lack of capacity in the overlaying grid does however indicate that a scaling of the use of this system would trigger mandatory financial construction contributions to the DSO. This may however be avoided if one utilizes BESS, as the 500 kVA could be provided from the storage unit.

As of 2024, many electrical vehicles and machines to implement in a zero-emission port is found available on the commercial market. Some of the equipment is directly connected to the grid and run on continuous power. However, most applications are rechargeable, as an electrical vehicle (EV). In addition to the existing equipment in the port, the need for two Rubber-tired Gantry crane (RTG) is also identified and its power demand is added to the future energy demand. The analysis is also carried out with one reachstacker being operational to 22:00.

The electrical reachstacker used as a basis for these calculations are a Kalmar Electric Reachstacker 45T with a battery capacity of 407 kWh and a capacity for fast charging at 350 kW. The added power need from the two RTGs are approximated by adding the power demand of the existing STS crane two times. This is seen as a reasonable simplification since the RTGs will be powered by cable or busbar and the power usage and peaks will therefore be significantly lower than if the cranes where to be equipped with batteries and thus have a need to be charged. The terminal tractors are based on the Kalmar electric TX12 tractor with a battery storage unit of 112 kWh and with the possibility to recharge with a 150 kW fast charger. The power demand of the cranes is assumed to be like that of the STS crane and a design day based on a day with high usage of the STS crane is used. Charging of road transportation trucks are not taken into account since the power for these are already allocated from the DSO. They will have a power peak of 700 kW if both 350 kW chargers are in use at the same time.

A charging plan is used to predict the power usage over a 24-hour period. This plan assumes that most of the charging is done slowly overnight when there is no activity in the port. Fast charging is included in the plan where this is necessary to maintain operation throughout the opening hours of the port. Some equipment is also assumed to not be used as expansively as others and can thus be charged more throughout the day. This reduces the power peaks. The assumed charging plan are included in Table 4.

TABLE 4 – CHARGING SCHEDULE FOR EQUIPMENT

	Reachstackers operational from 0600-2200	Reachstacker operational from 0600-1800	Terminal tractors	Truck	Wheel loaders
0000-0100	32,9	20,0	14,0	12,4	44,8
0100-0200	32,9	20,0	14,0	12,4	44,8
0200-0300	32,9	20,0	14,0	12,4	44,8
0300-0400	32,9	20,0	14,0	12,4	44,8
0400-0500	32,9	20,0	14,0	12,4	44,8
0500-0600	32,9	20,0	14,0	12,4	44,8
0600-0700	0	0	0	0	0
0700-0800	0	0	0	0	0
0800-0900	0	0	0	0	0
0900-1000	0	0	0	0	0
1000-1100	246,6	0	0	12,4	44,8
1100-1200	0	264,6	0	0	0
1200-1300	0	0	0	0	0
1300-1400	0	0	150	0	22,4
1400-1500	0	0	0	12,4	0
1500-1600	0	0	0	12,4	0
1600-1700	246,6	0	0	12,4	44,8
1700-1800	0	20,0	0	12,4	44,8
1800-1900	0	20,0	0	12,4	44,8
1900-2000	0	20,0	0	12,4	44,8
2000-2100	0	20,0	0	12,4	44,8
2100-2200	0	20,0	0	12,4	44,8
2200-2300	32,9	20,0	14,0	12,4	44,8
2300-0000	32,9	20,0	14,0	12,4	44,8

The estimation of the future energy demand is based on the conversion of fossil fuel usage of the existing machinery that is in the process of being replaced by electrical equipment, a ramping up of the usage of shore power to a level where all ships anchored to the port uses it and the introduction of extended operational hours in combination with the addition of two RTGs. The future energy demand for a year is shown without the use of shore power in Figure 8, and with use of shore power included in Figure 9. As seen when comparing Figure 6 to Figure 8 and 9, the future energy usage from the equipment such as reachstackers goes down. This is because of the increased efficiency of electric machinery. The need for electric energy does however increase as all the energy needed is electrical and no longer supplied from fossil fuels.

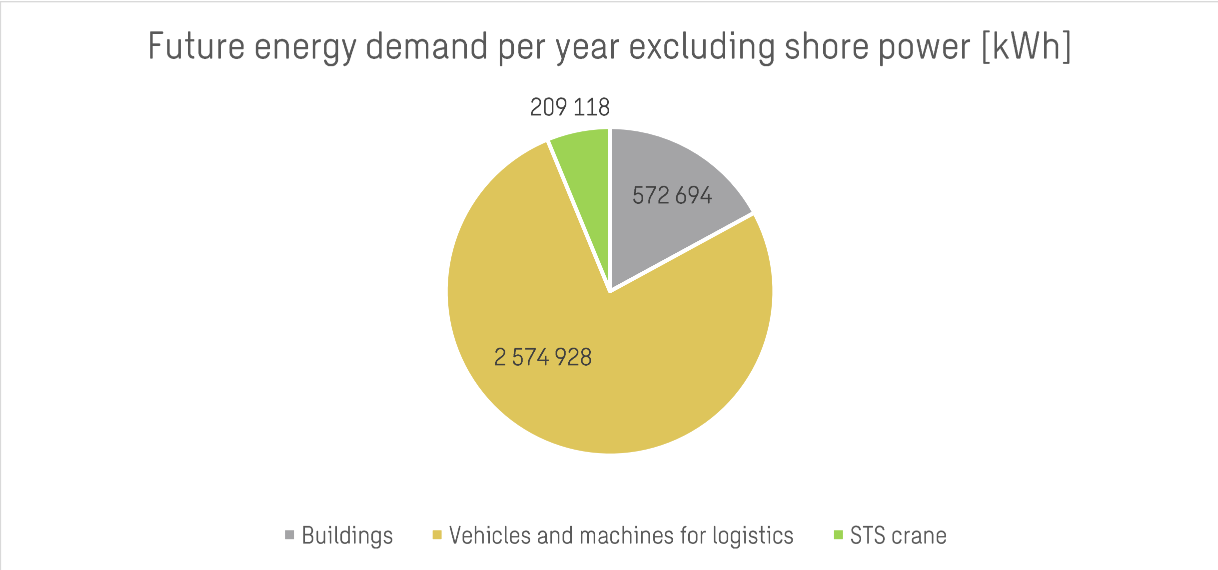


FIGURE 8 – FUTURE ESTIMATED ENERGY DEMAND OF THE PORT WITH ALL EQUIPMENT BEING ELECTRICAL WITHOUT THE USE OF THE SHORE POWER SYSTEM

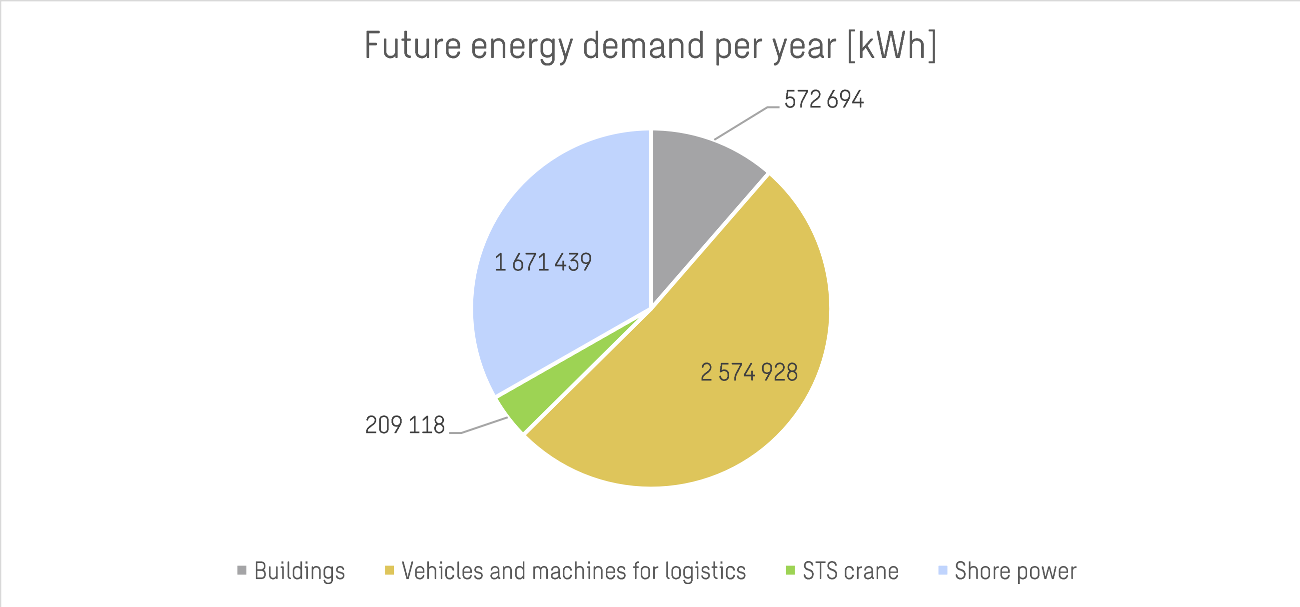


FIGURE 9 - FUTURE ESTIMATED ENERGY DEMAND OF THE PORT WITH ALL EQUIPMENT BEING ELECTRICAL WITH THE USE OF THE SHORE POWER SYSTEM

The predicted peak power increases significantly for the future scenario. This is mainly caused by the use of the shore power system along with the charging of electric machinery according to the charging plan presented in Table 4. As mentioned previously, the shore power system is assumed to be used on all ships even though it currently provides 500 kVA and not 1800 kVA as the predicted peak power suggests is necessary. This is done to reflect the ambitions of the port. The predicted peak power of charging electrical machinery and operating the two RTGs is estimated to be 826 kW. The peaks are presented in Figure 10.

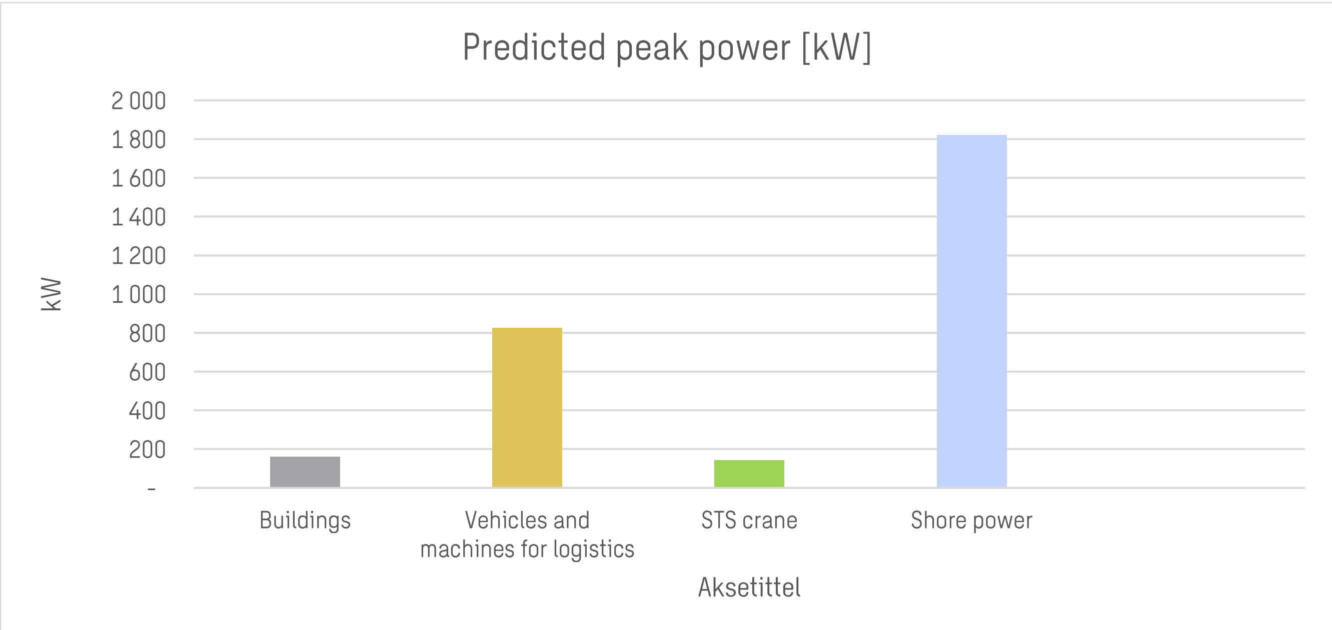
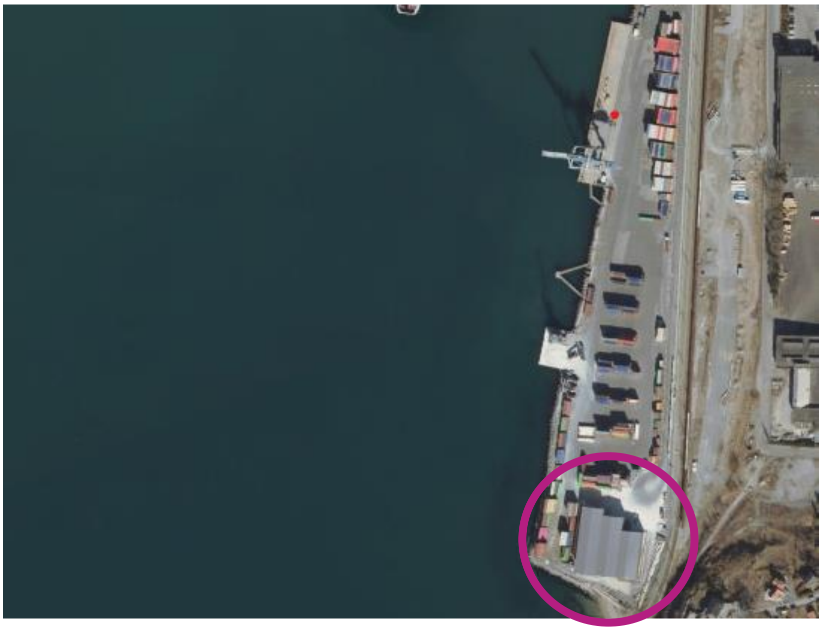


FIGURE 10 – ESTIMATED PEAK POWER NEED FOR THE PORT

3.4 Solar energy potential

The potential of renewable energy production is limited in the port area. This analysis is therefore concentrated around a building suggested by the port authorities. Other buildings could also be analyzed on a later date.

The potential for solar energy production at the location of the storage facility in the southern east of the Port (see location in Figure 11) is analyzed using Sweco's own solar PV tool. The necessary data is obtained from the European Commission's photovoltaic geographical information system *PVGIS*.



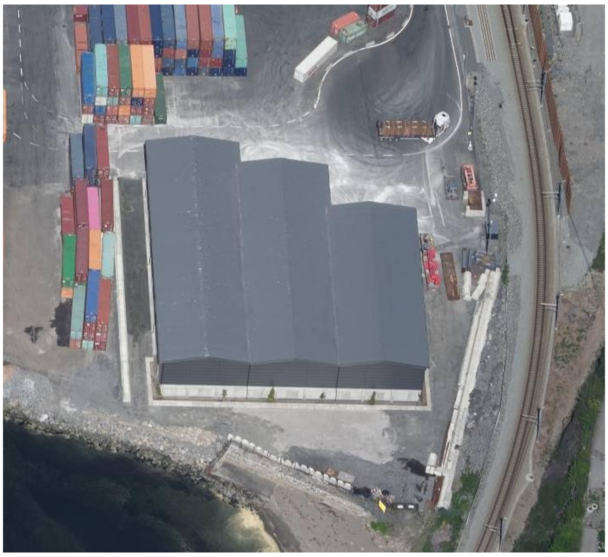


FIGURE 11 – LOCATION OF BUILDING AND SATELLITE PHOTO OF THE BUILDING THAT IS CONSIDERED FOR INSTALLATION OF PV SYSTEM. WEST, SOUTH AND EAST FAÇADE OF THE BUILDING IS CONSIDERED IN THE ESTIMATION OF THE POWER PRODUCTION POTENTIAL.

The performance of a grid-connected PV system without battery storage is investigated to estimate the monthly and yearly energy production potential. The calculations take into account factors such as the solar radiation, temperature and type of photovoltaic module of choosing [6].

Assumptions for PV estimation

- The calculation is based on the database *PVGIS-SARAH2*, reference year set to 2019.
- As only one reference year is used, the actual production will vary on a year-to-year basis. Estimation based on one reference year is still believed to make a valid indication of the production potential.
- The potential for solar energy production from building integrated PVs are simplified by using a tool that is specialized for roof-mounted PV panels.
- The specific production capacity is set to 190 kilowatt peak (kWp)/m^2. This is a moderate estimation, and suppliers tend to estimate with a higher specific production capacity.
- The specific cost of a PV panel is set to 7840 NOK/kWp. This is a moderate to conservative estimation, and the price vary amongst suppliers.
- 3D map from Kommunekart.com as shown in Figure 12 is used for the area estimation of the façade. The western, southern, and eastern façade is used for the estimation.

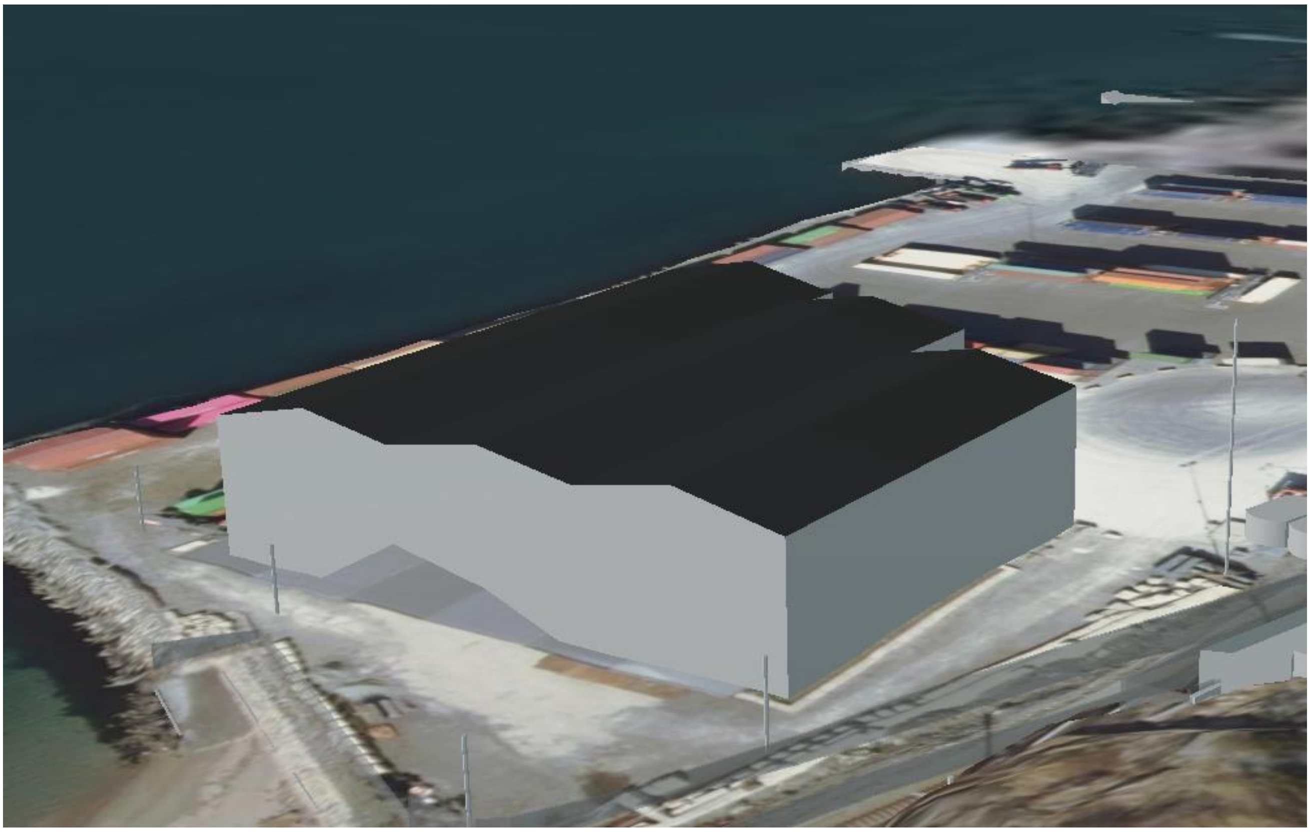


FIGURE 12 - BUILDING AS SHOWN AT KOMMUNEKART.COM, WHICH IS THE FOUNDATION FOR THE ESTIMATION OF THE POWER PRODUCTION POTENTIAL OF THE FRONTS.

The estimation, including the prerequisites on slope, azimuth, and area available, are summarized in Table 5:

Table 5 - Prerequisites on slope, azimuth, and available area

		Slope	Azimuth	Area (m2)	Production capacity (kWp)
Available area and production capacity					
	Walls, south	90	0	571	108
	Walls, west	90	94	617	117
	Walls, east	90	-86	400	76
Sum				1588	302

This initial estimation shows positive results for solar power production on the indicated building, with a high specific production (555 kWh/kWp) and an acceptable LCOE of 0,85 NOK/kWh.

4 Battery energy storage system

4.1 Grid integration method

As described in Chapter 2.3, there are different ways of integrating BESS in the local power system. Alternative 2 with smaller batteries behind every meter in the port area either connected by a virtual or physical microgrid is unnecessary since the main power peaks happens in close proximity to one another. The power need for the buildings not in this specific area is low and the distance one must dig to connect these with a microgrid would expand the cost significantly. A virtual microgrid could also be a solution, but previous experience suggests that the DSOs are not willing to implement this.

Alternative 3 is a novel, but impractical concept. It might require less investment in hardware and infrastructure, but the practicality in moving the vehicle to the right place at the right time seems difficult to resolve.

Alternative 1 is therefore our recommended solution for implementing a BESS in the energy system at the Port of Moss, is one stationary battery located in the southeast area of the port, hereafter called Warehouse South. The battery can be connected to one, or more, of the electrical substations in the area and can connect vital infrastructure with high power demand, like the shore power system, the reefer stations, and the charging infrastructure for the electrical machinery. This can be done by a microgrid, and the port has some underground cable conduits that may be used for this purpose.

The suggested solution does not connect all buildings and meters, but rather the equipment and charging stations that will have the highest power demand. This removes the cost of laying a microgrid to areas with smaller peaks in power consumption such as offices. The economic analysis of the battery system has however been conducted for both scenarios, with the results for the suggested layout being presented. The economic benefit of including all buildings in the port is assumed to be mitigated by the cost of expanding the microgrid. See Figure 13 for the suggested layout. The blue lines outline the microgrid connecting the main infrastructure in the port together.

Since the port have a high voltage (1 kV or higher) system suppling the STS crane, the port has a license from the regulatory body responsible for the grid in Norway to own and operate a grid in the port area. This means that the suggested microgrid can be high voltage without applying for this license. Such a system will ensure that the battery can supply the STS crane and the new RTG cranes and that the possible integration with the infrastructure owned and operated by Bastø Fosen and ASKO is easier.

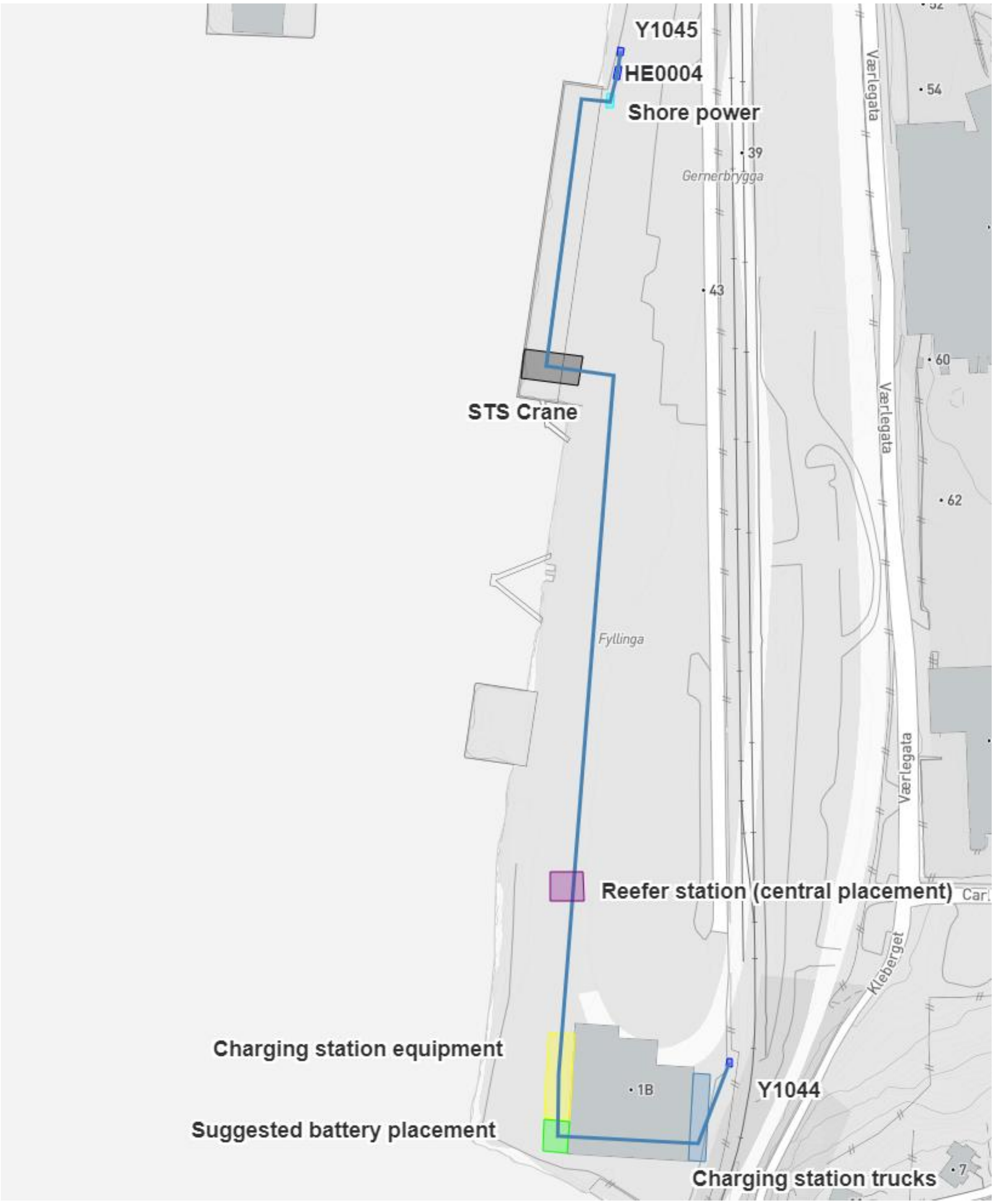


FIGURE 13 – SUGGESTED LAYOUT OF MICROGRID IN REFERENCE TO LOADS AND SUGGESTED PLACEMENT OF SOLAR PANELS

4.2 Dimensioning procedure

The dimensioning of the battery is based on a combination of the business models described in Chapter 2.4.

The consumption is the backbone of the estimation, and the priority is to all times have sufficient energy for the port area. Peak shaving is added on top of the model based on increased self-consumption, where a maximum load is defined for the port area, where the battery will supply the top load that exceed the load limit. Different load limits for each month over a year is explored to find the best alternative. If the load limit is too low, the amount of energy contained in the peak over the limit increases and the battery must be considerably bigger to compensate for this amount of energy. This means that a smaller battery would not be able to supply the amount of energy needed to perform the peak shaving.

Furthermore, price arbitrage is added as a strategy for charging and recharging the battery. The battery will be charged when electricity prices are low, and as a rule of thumb, discharged when the electricity prices are high. However, the peak shaving has priority over the price arbitrage, meaning that the battery will be discharged even though electricity prices are low if the load limit of the area is reached.

The results accounts for the suggested installed solar panels and the estimated cost of these.

The battery charge – and discharge strategy is as follows, where the priority of strategy is indicated:

1. **Peak shaving.** The system does always make sure that the battery has sufficient power to supply the system in high-load periods, where the load limit is reached, so the battery can fulfill peak-shaving.
2. **Price arbitrage**. As long as sufficient energy to the battery to supply in peak shaving periods is secured, further charging and discharging times of the batteries are governed by electricity price.
3. **Consumption.** If enough power is secured to be able to peak-shave, and the electricity prices are low with limited variation, the battery capacity can fluctuate based on the load variation. When load is increasing (within the load limit), the battery is discharging, and when the load is decreasing, the battery is charged.

The dimensioning is thereby completed by given charge- and discharge strategy as outlined above. Furthermore, the battery capacity is dimensioned by the estimated energy consumption described in Chapter 3.3, where different consumption for the different parts of the port is estimated based on current demand and future predictions. Furthermore, the estimated solar energy production is added in the dimensioning, meaning that solar power is added as energy supply and added to the battery charge- and discharge strategy. The dimensioning procedure is outlined in Figure 14.

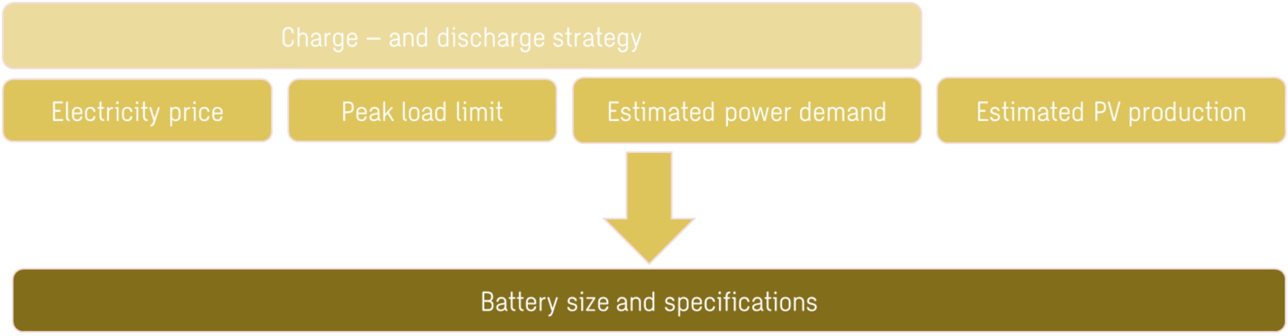


FIGURE 14 – FLOW OF DIMENSIONING PROCEDURE

A possible estimate of yearly revenue from contributing to the flexibility market is then subtracted from the price. This estimate is based on data gathered from the Danish and Swedish markets and from dialog with suppliers. Suppliers of batteries mainly used as income sources in the Swedish and Danish frequency reserve (FFR-D), intraday markets and local flexibility markets, informs of yearly incomes between 3 000 000 and 6 000 000 NOK per installed MWh in storage. We have in this report used conservative to moderate income estimates from flexibility and frequency reserve market between 250 000 and 1 000 000 NOK per installed MWh and used this as a basis for economic scenarios and income estimates presented in Chapter 4.3.

4.3 Results

Based on the dimensioning procedure as described in the previous chapter, different alternatives for stationary batteries are suggested. Three sizes are presented in this chapter, small, medium, and large. The small battery illustrates an example with a battery between 100 and 300 kWh. Medium is around 1000 MWh and large in the magnitude of 5000 MWh. This is done based on an initial dimensioning that showed significant differences between these size ranges. A small battery triggers a smaller investment cost but does not have the same saving and earning potential as a bigger battery. Similar, the bigger alternatives are more costly, but can for instance reduce the power peaks considerably and has the potential of more income from alternative markets such as the FFR-D market. Since battery size is a sliding scale, three concrete sizes were chosen to illustrate the different advantages and disadvantages. All sizes are presented with economic results based on no income from flexibility or frequency markets and 3 alternative income levels 250 000 NOK, 500 000 NOK and 1 000 000 NOK per MWh installed storage capacity in income from the markets.

The savings for the battery systems is in all instances greatest in terms of tariff savings when not taking flexibility markets and frequency reserves into account. Tariff savings accounts for 50- % to 60 % of the savings when excluding income from frequency reserve - and flexibility markets.

4.3.1 Small battery

A small battery of 100 kWh will have an investment cost between 2 800 000 and 3 000 000 NOK. This includes the cost of the solar panels. The system is economical profitable without income form flexibility markets or frequency reserves and has a payback time of 16,8 years. The maximum peak is however only cut with 137 kW as seen in Figure 15.

Yearly income from frequency and flexibility markets (NOK/MWh)	Total estimated yearly saving/income (NOK)	Estimated payback time (years)
0	273 000	17
250 000	298 000	15
500 000	324 000	13
1 000 000	374 000	11

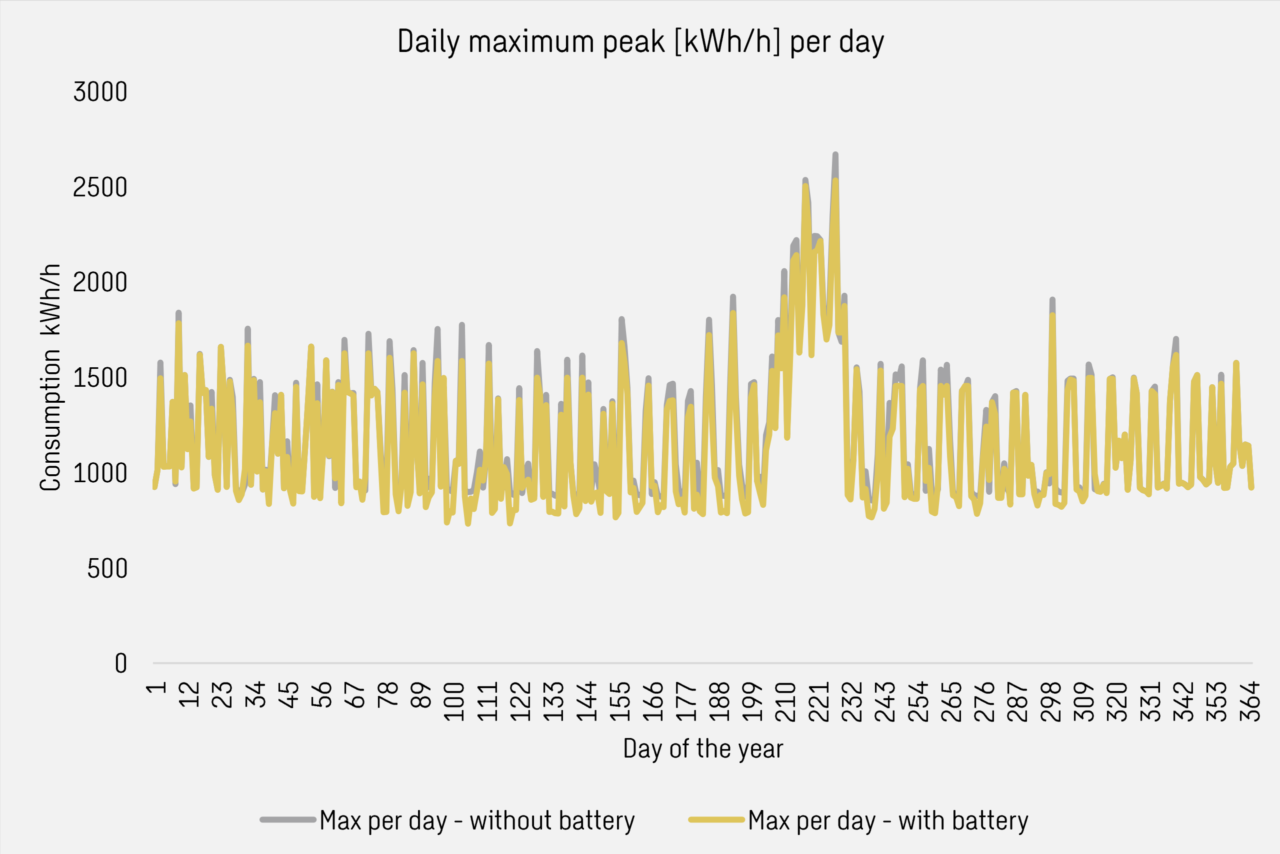


FIGURE 15 – ILLUSTRATION OF POWER NEED WITH AND WITHOUT A 100 KWH BATTERY

The smaller size of the battery does not permit it to peak shave larger energy amounts, but it does contribute to reduce the peak loads slightly. This battery does not contribute in any significant way, however. It is a small supplement to the energy system, but the battery size is so small that it is not deemed justifiable to establish a microgrid to accomplish peak shaving across all the bigger electrical demands in the port. An alternative is to have the battery connected only to the charging stations and use it for peak shaving in a more local fashion.

4.3.2 Medium battery

The calculations shows a investment cost of 6 400 000 NOK to 10 000 000 NOK for a system between 1 and 2 MWh including the cost of the solar panels. The result presented in this subsection is for a 1 MWh battery. The battery has a payback time under 30 years if the income from the flex market is 159 000 NOK per MWh per year or higher. A payback time of 15 years or under is reached if the income from the flexibility market is 333 000 NOK per MWh per year or higher.

Yearly income from frequency and flexibility markets (NOK/MWh)	Total estimated yearly saving/income (NOK)	Estimated payback time (years)
0	533 000	Over 30 years
250 000	783 000	24
500 000	1 034 000	12
1 000 000	1 535 000	5

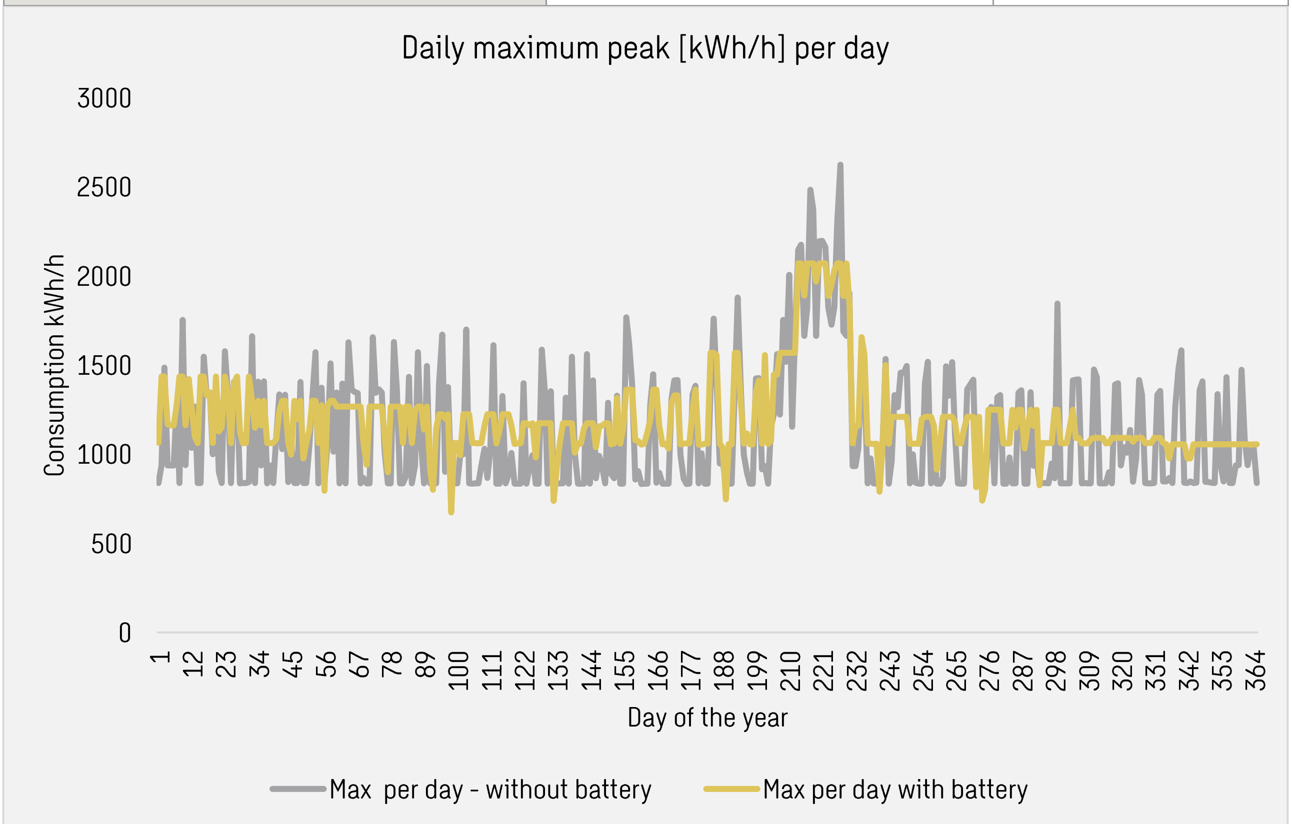


FIGURE 16 - ILLUSTRATION OF POWER NEED WITH AND WITHOUT A 1000 KWH BATTERY

The maximum power usage is with implementing a medium sized battery peak shaved from 2625 kW to 2071 kW. This could potentially save the port up to 800 000 NOK in construction contribution to the DSO. This is based on the cost of upgrading the electrical substations and transformers but does not take into account if the overlying grid has capacity or not. Lack of capacity in this grid could increase the size of the construction contribution considerably.

4.3.3 Large battery

The investment cost for a battery in the 5 MWh size range is around 22 500 000 NOK. This includes the solar panels. The battery has a payback time under 30 years if the income from the flex market is 404 000 NOK per MWh per year or higher. A payback time of 15 years or under is reached if the income from the flexibility market is 517 000 NOK per MWh per year or higher.

Yearly income from frequency and flexibility markets (NOK/MWh)	Total estimated yearly saving/income (NOK)	Estimated payback time (years)
0	815 099	Over 30 years
250 000	2 068 208	Over 30 years
500 000	3 321 317	16
1 000 000	5 827 535	4,5

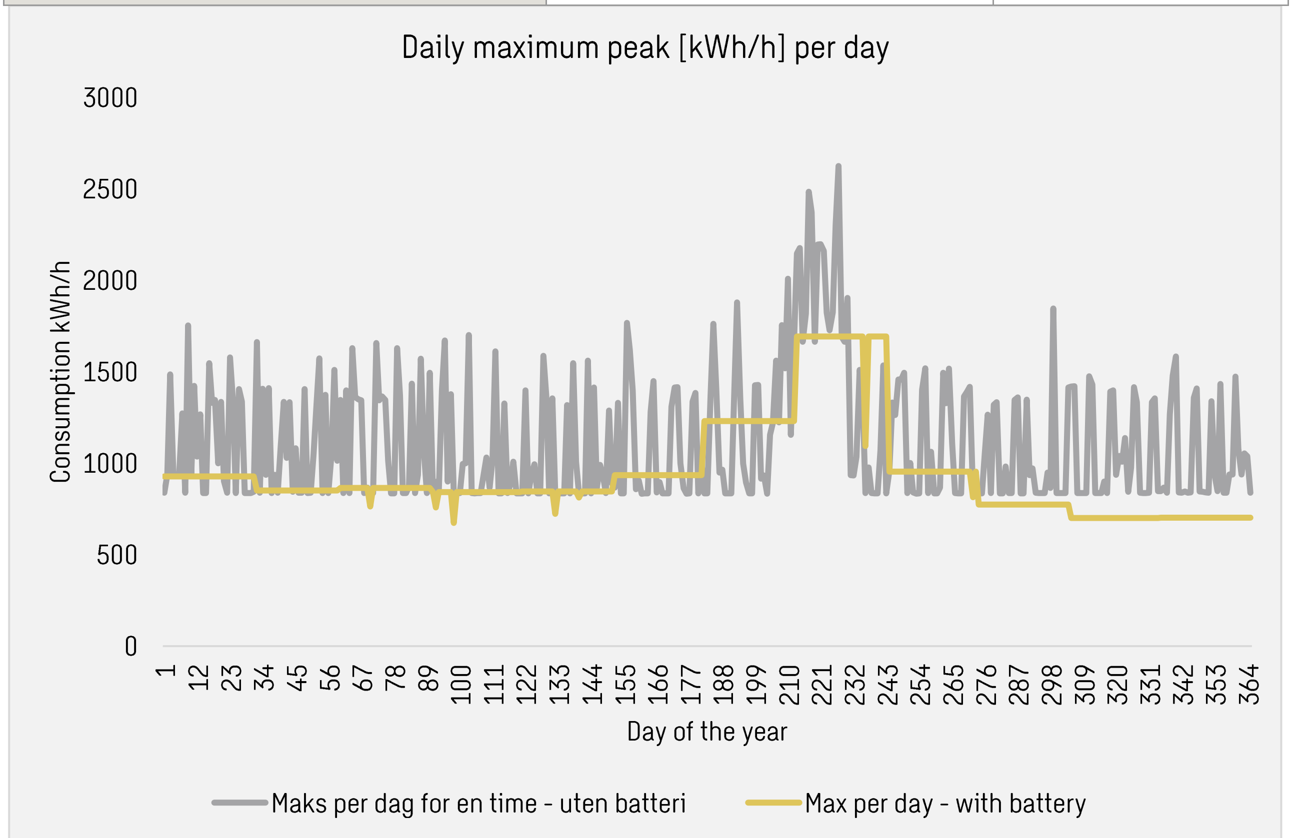


FIGURE 17 - ILLUSTRATION OF POWER NEED WITH AND WITHOUT A 5000 KWH BATTERY

By implementing the large battery, a peak shaving of almost 900 kW can be enabled, from 2625 kW to 1739 kW. This could potentially save the port up to 1 000 000 NOK in construction contribution to the DSO. This is based on the cost of upgrading the electrical substations and transformers but does not take into account if the overlying grid has capacity or not. Lack of capacity in this grid could increase the size of the construction contribution considerably.

5 Conclusion

The economic results suggest that a small battery will be profitable without contributing to the flexibility market and frequency reserve. It is also a smaller economic risk but has less potential when it comes to earnings from the market or reducing the need for a larger potential grid upgrade. This is however the only size of battery that is economically profitable without participation in the flexibility or frequency reserve markets.

A medium size battery in the range of 1 MWh to 2 MWh gives a sizable reduction in the power peak of 554 kW for a 1 MWh BESS and 742 kW for 2 MWh. With an income from the markets that is higher than 333 000 NOK and 411 000 NOK per year per MWh installed respectively, the batteries will have a payback time under 15 years. This income seems conservative based on experience from Sweden and Denmark along with the increased need for flexibility in Norway. With the introduction of the improved intraday market opportunities between the price areas NO1 in Norway, SE3 in Sweden and DK1 in Denmark, this is becoming even more realistic [7]. There are 2 MWh BESS that fits in a 40 ft container commercially available.

The large battery in the size around 5 MWh gives a peak shaving from 2625 kW to 1639 kW. This reduction can as mentioned reduce the cost of a construction contribution to the DSO considerably. This size does however have an investment cost of over 22 000 000 NOK. It will also be quite sizeable in terms of the physical installation. Several 20 ft or 40 ft containers could be required to house the technical equipment.

The suggested layout of the microgrid does not cover the whole port area as mentioned. It is concentrated on the areas with high power consumption. This is centered around Warehouse South where chargers for truck charging and reachstacker charging are under planning. This is also the warehouse where the solar panels are planned installed. This is also in close proximity to the STS crane, the future placement of the RTG cranes, reefer stations and the shore power system. The minimization of the microgrid gives a lower total cost, while still connecting the most important infrastructure. The microgrid should however be planned so that infrastructure that is owned and/or operated by Bastø Fosen and ASKO Maritime could be integrated at a later stage if this is deemed beneficial by all parties. The cost of this microgrid with planning, procurement and construction is not included in our cost estimates.

Our recommendations are therefore a battery in the size range between 1 and 2 MWh. This will give a moderate investment cost between 6 400 000 NOK to 10 000 000 NOK and a payback time that is sensible given a conservative scenario in terms of earnings from frequency reserve market and flexibility market. A BESS with 1 to 2 MWh storage is also big enough to have the potential to reduce future construction contributions to the DSO considerably and reduce the load on the grid.

There is however potential risk of having to pay construction contribution fees for such a big battery if the grid does not have the necessary capacity for the port to supply electricity from such a large battery. The necessity and potential size of the construction contribution is per now being evaluated by the DSO.

It is, as illustrated by the economic results, important to have a system that can control the functioning of the battery as to always preform the most beneficial functions at any given time. This control system is often called an energy management system (EMS) and is a crucial part of the successful operation of the system. This has to be thoroughly evaluated when considering a system to invest in, so that the system is able to maximize the benefits provided by the installation of the BESS and solar panels.

Works Cited

[1] BlombergNEF, "Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh," [Online]. Available: https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/?utm_source=social-o&utm_medium=LI_BNEF&utm_term=11935109986&utm_campaign=732078&tactic=732078&linkId=251458283.

[2] BloombergNEF, "Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh," [Online]. Available: https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/ .

[3] Statnett. [Online]. Available: https://www.statnett.no/for-aktorer-i-kraftbransjen/systemansvaret/kraftmarkedet/reservemarkeder/introduksjon-til-reserver/. [Accessed 22 01 2024].

[4] Nodes. [Online]. Available: https://nodesmarket.com/project/euroflex/. [Accessed 13 02 2024].

[5] Sintef. [Online]. Available: https://blogg.sintef.no/sintefenergy-nb/energisamfunn-kan-redusere-nettkoen/. [Accessed 15 March 2024].

[6] European Commision (EU), "Photovoltaic Geographical Information system (PVGIS)," 04. 12. 2023. [Online]. Available: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#api_5.2.

[7] S. kraftnät. [Online]. Available: https://www.svk.se/press-och-nyheter/nyheter/balansansvar/2024/forbattrade-handelsmojligheter-pa-intradagsmarknaden-mellan-se3-dk1-och-no1/. [Accessed March 13].

Transforming Society Together

with the Port of Moss

SWECO