DELIVERABLE D.T3.3.2
ENERGY STORAGE SYSTEMS IN PORTS
(INCLUDES D.T3.2.7 AND.T3.3.1)

Final assessment of greening transport measures for energy storage systems in ports

Version 2
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Index

1. Introduction

The Report about energy storage systems in ports is one of 7 pilot actions of the InterGreen-Nodes project. To demonstrate the infrastructure and technological possibilities for the application of clean fuels at the local level, meaning the last mile, and at the terminal, measures to make transport greener have been assessed and validated through stakeholder inputs.

This concluding report is the final assessment report for the pilot activity (D.T3.2.7 + D.T3.3.2) and includes the evaluation of technical performance and environmental impact measurements, as well as lessons already learned from the mid-term evaluation D.T3.3.1).

The report was prepared by associate partner ABO-Wind and provides insights into the potential benefits of battery storage energy storage applications, as well as basic information on hydrogen opportunities in ports.

2. The Basics of Energy storage systems in ports

There are several reasons why an energy storage system could be of an economical or technical benefit to European ports. In the following they are separated into the present (today’s reasons) and future applications (tomorrow’s reasons).

Today’s reasons:
Reduction of peak demand at the grid connection point is a valuable application as of today. There are several options to reduce the peak demand. The first and most times most cost-efficient way is on-site load/demand management, the second is utilization of locally already available “storage” systems (e.g. production flexibility through product tanks) or heat/cooling storage units. A battery storage system can be seen as an additional add-on to reduce further costs. These costs can be either cost for the grid connection point itself (grid-extension costs) or network charges during operation.

In some European countries, consumers with a high energy demand (in Germany the threshold is 10 GWh per year[1]) can reduce their electricity cost by equalizing their demand through power peak shaving. These incentives reduce the overall price paid in the electricity bill by decreasing Network Charges.

Network Charges are based on the costs incurred by grid operators for the general operation, maintenance and expansion of the electricity grid from the transmission over the different distribution level to the connection point of the customer. In Germany, the network charges are calculated based on specific annual costs: An electricity price and an energy price above and below 2,500 hours of use. The basic idea of the German Electricity Network Charges Ordinance (StromNEV) is to make a plausible assumption about the share of a network user to the total network costs in advance. This means companies with large load peaks that are likely to contribute to the maximum overall annual network load peak must pay higher power prices.[2]

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[1] The thresholds, rules and conditions are different in each country and will be examined case by case.

[2] Gloria, Luan Leão, „Evaluation-tool development for peak-shaving employing Li-Ion battery storage systems at different C&I customers”, MA thesis, 04.2020 on the basis of: Bundesnetzagentur (BNetzA): Monitoringbericht, 2018. URL: https: //www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/Monitoring/Monitoringberichte/Monitoring_Berichte_node.html [last checked 2019-11-14]

The historic trend in Germany predicts increasing network charges (see Figure 1). Electricity consumers who purchase large energy quantities should take early action to save network charges.

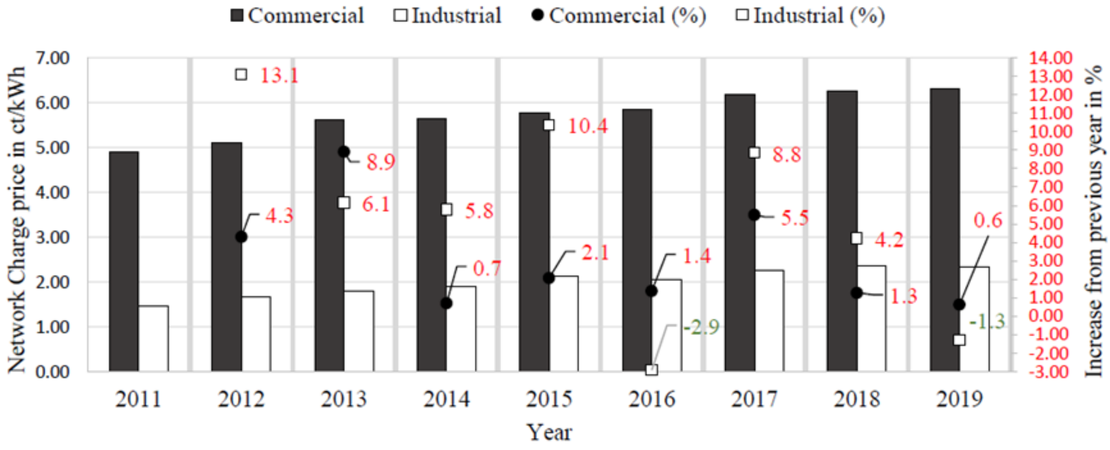

Figure 1 Network Charges price development for Commercial and Industrial Customers in Germany[3]

In Germany those incentives can be quite relevant. Paragraph 19 of the StromNEV[4] provides the possibility to reduce network charges. It rewards companies that consume at least 10 gigawatt hours per year (energy intensive consumers) and reach minimum 7,000 hours of use. These hours of use are calculated based on the total consumed energy and the maximum power in the year. The application of peak shaving reduces the maximum power extracted and thus increases the hours of use. In addition, companies with irregular peak loads don't use their maximum grid connection capacity efficiently and therefore have unnecessarily high costs. At a port such peaks could be caused by for example operating cranes, starting of machines, delivery peaks and charging of electric vehicles. With little effort behind the meter battery storage systems can be integrated into the existing power supply system and can react to cap peaks within less than a second when large and punctual power amounts are requested from the grid. With battery storages that are precisely tailored to the load profile, consumers can save up to 90 percent of their network charges.

Also, for customers with a consumption below 10 GWh per year, the option to reduce the maximum power demand withholds economic benefits through the decrease in peak power demand (peak shaving). Any peak load tends to increase network charges drastically, even if the peak appears only once a year. In order to increase profitability to an optimal level a fine-tuned battery size should be selected.

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[3] Gloria, Luan Leão, „Evaluation-tool development for peak-shaving employing Li-Ion battery storage systems at different C&I customers", MA thesis, 04.2020; on the basis of: Bundesnetzagentur (BNetzA): Monitoringbericht, 2018. URL: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/Monitoring/Monitoringberichte/Monitoring_Berichte_node.html [last checked 2019-11-14]

[4] Gesetze im Internet; StromNEV §19; https://www.gesetze-im-internet.de/stromnev/__19.html [last checked 2020-10-20]

Tomorrow's Reasons:

In the future, transport (ships, vessels, trucks, cars, trains, cargo equipment) will be more and more electrified, which consequently effects the energy supply structure at ports. This is assumed because during logistical peak times with battery electrical equipment, the vehicles will need to be charged simultaneously at the harbour. Especially the last mile to the ports will be electrified and equipped with batteries.

But not only the charging of the batteries will lead to more power demand, also diesel-based supply of the vessels during berthing is expected to be forbidden. This means that the energy and power demands required by vessels will be supplied by the ports, the so-called shore power. This also drives ship manufacturers to look for alternative motorisation supported by batteries.[5]

This causes great interference in the energy supply of the port, such as probable increase in the power needs as well as in the overall energy consumption. All together, this increase in energy consumption might convert the harbour to the condition of an energy intensive consumer. A proper control over the harbour's power peaks by a battery energy storage system can then help to control network charges or peak demand costs.

But the electrification of transportation does not only mean adding batteries to the vehicles, besides it also consists of a completely different technology: the fuel cell. Ideally the fuel cell is running on hydrogen, and many incentives currently take this direction:

First hydrogen fuel cell propelled pilot projects for ships are currently implemented, ship manufacturers announced working on the development[6]; it is same for car manufacturers who are re-introducing the technology again; hydrogen fuel stations for cars are constantly increasing in Germany[7]; more and more hydrogen fuel cell trucks[8] and busses are being built and ordered[9]; even hydrogen fuel cell trains are being ordered and implemented[10]. Often the projects are developed in a holistic approach considering the whole supply-chain of hydrogen[11]. Many European countries released their hydrogen strategies in 2020, which show a stronger support of the technology and shall increase private investments.

Ports could benefit from this development by becoming not only an electricity provider but also a hydrogen supplier by producing hydrogen at the port. This would be done by combining renewable energies (solar and/or wind) with an electrolyser. The electrolyser produces hydrogen from electricity surplus-production from the renewables. Like this any kind of means of transport could be refuelled with locally produced hydrogen.

Those changes can enable new business models. Depending on the technologies of the means of transport arriving at the port, various options are available to address their needs.

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[5] Container News; 03.09.2020; Kongsberg to equip eco-friendly autonomous ships; https://container-news.com/kongsberg-to-equip-eco-friendly-autonomous-ships/ [last checked 2020-10-26]

[6] e4ships c/o hySOLUTIONS GmbH; News; https://www.e4ships.de/english/news/ [last checked 2020-10-07]

FuelCellsWorks; 2020-04-13; Ballard Congratulates ABB and HDF Energy on Collaboration for Fuell Cell System Production to address Marine applications; https://fuelcellsworks.com/news/ballard-congratulates-abb-and-hdf-energy-on-collaboration-for-fuel-cell-system-production-to-address-marine-applications/ [last checked 2020-10-13]

[7] H2 MOBILITY Deutschland GmbH & Co. KG; Map/Start page; https://h2.live/en [last checked 2020-10-07]

[8] FuelCellsWorks; 2020-10-12; Coop puts more hydrogen trucks on the road; https://fuelcellsworks.com/news/coop-puts-more-hydrogen-trucks-on-the-roads/ [last checked 2020-10-13]

[9] H2 view; 2020-07-14; Germany deploys 40 more hydrogen buses; https://www.h2-view.com/story/germany-deploys-40-more-hydrogen-buses/ [last checked 2020-10-13]

[10] International Railway Journal, 2019-05-21; RMV orders 27 hydrogen trains from Alstom; https://www.railjournal.com/fleet/rmv-orders-27-hydrogen-trains-from-alstom/ [last checked 2020-10-20]

[11] RH2INE; startpage; https://www.rh2ine.eu/ [last checked 2020-10-20]

- *What type of technologies are envisaged?*
    - Containerised lithium-ion Battery Energy Storage Systems.
    - Renewables combined with containerised electrolyser producing the energy carrier hydrogen with renewable energies.

3. Step by Step description of the implementation

To address today's needs with battery storages for peak shaving the following steps can be described:

Step 1: Receive load power profile (in Kilowatts) from port in 15-minute (or even higher resolved) values from at least one year.

Ideally the load profile contains the overall port demand considering all activities like crane utilisation, general activity at the docks, charging stations, buildings etc. Peak shaving analysis are very load specific, therefore receiving and analysing the data from the port is mandatory to be able to develop a customized solution. In addition, the battery storage shall be capable of addressing tomorrow's needs in terms of supporting the electricity supply of vessels as well as charging vehicles. Therefore, together with the port operator the assumptions for future extensions are discussed.

Date	kW	Date	kW
1/1/2019 0:00	27.31	**12/31/2019 22:45**	25.30
1/1/2019 0:15	27.95	**12/31/2019 23:00**	24.82
1/1/2019 0:30	28.33	**12/31/2019 23:15**	25.70
1/1/2019 0:45	28.43	**12/31/2019 23:30**	26.11
1/1/2019 1:00	29.27	**12/31/2019 23:45**	26.20

The power values data received from a commercial customer described is shown in the left side and represents the first and last five power values within one year.

Step 2: Insert data into developed analysis tool. The algorithm starts by setting the peak shaving value and it ends with a pair of battery storage's power and energy pairs. A finely tuned sizing algorithm takes into account not only the battery power characteristics and aging profiles, but also the errors resulting from the aggregation of the company's available 15-minute power profiles. In this way a highly economical and secure sizing can be achieved.

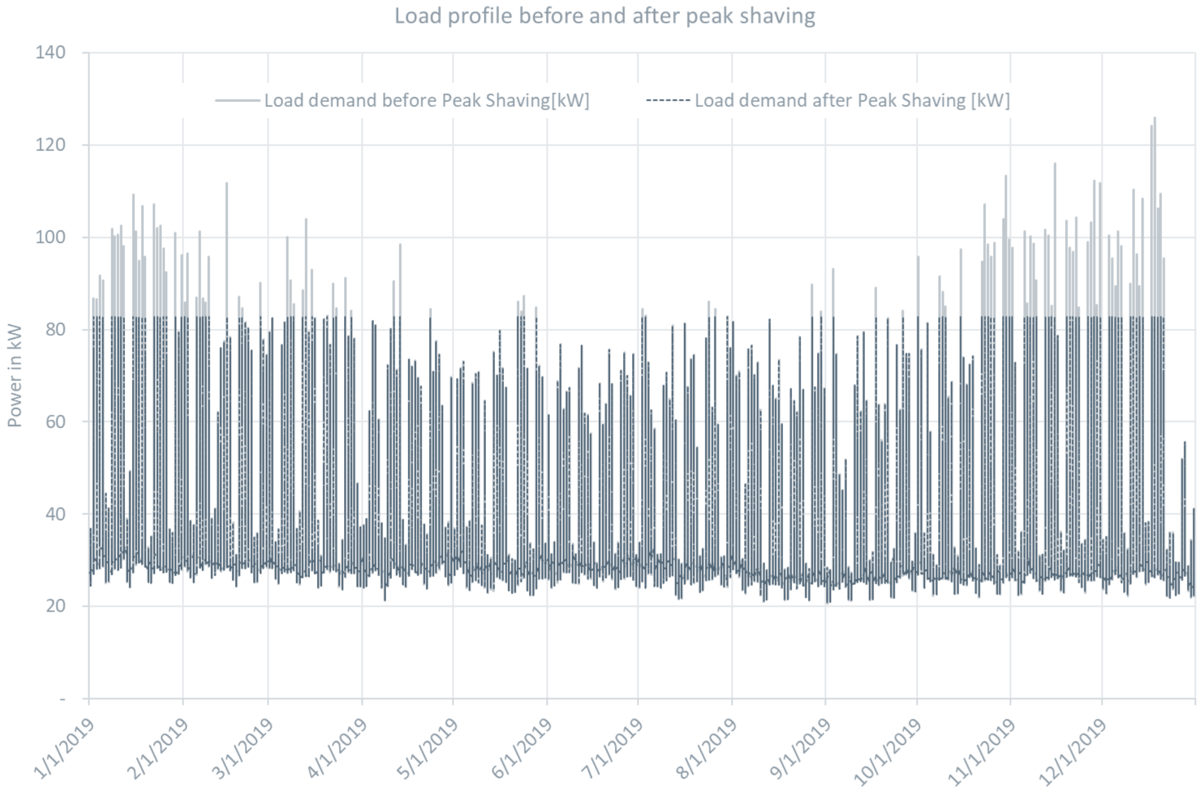

Figure 2 Example load profile of an exemplary office building demonstrating the analysis and the outcome for peak shaving.

Step 3: Discussion of results from the analysis with an economic evaluation for the customer. The peaks of the load profile will be inspected, and the battery size is calculated to cut all peaks. The average duration of peaks and its power are decisive for the battery sizing and therefore for an economic decision. ABO Wind's algorithm can calculate load profiles with a high time resolution in the range of a few seconds. Depending on the provided interval (minute or second) the details of the results increase. The selection of the most suitable battery storage system needs to be done case by case.

An analysis of Figure 3 can provide a deeper understanding on the selection of a suitable battery size. As a matter of confidentiality, the load profile of the analysed port cannot be depicted in this paper. The ports' maximum power is 18.6 MW and the yearly energy consumption of 100 GWh. Figure 3 shows battery sizes calculated for various peak shaving thresholds for the load of this port.

In the y-axis the battery size for each peak shaving threshold in percentage of the maximum power extracted from the grid is depicted. The marked point in the graph shows that for a 90.11 % percentual reduction of peak shaving power, an approximate battery size of 5.3 MWh would be necessary to cap the peaks. Additionally, the graph presents that the power decrease is not linearly followed by increase in battery sizes. Furthermore, peak shaving power thresholds below 65 % is not physically possible and the lower the peak shaving threshold the battery size becomes rather uneconomic. Taking all this into consideration, one can affirm that the peak shaving operation should be carefully examined for each individual customer in order to reach the technically and economically optimal system size.

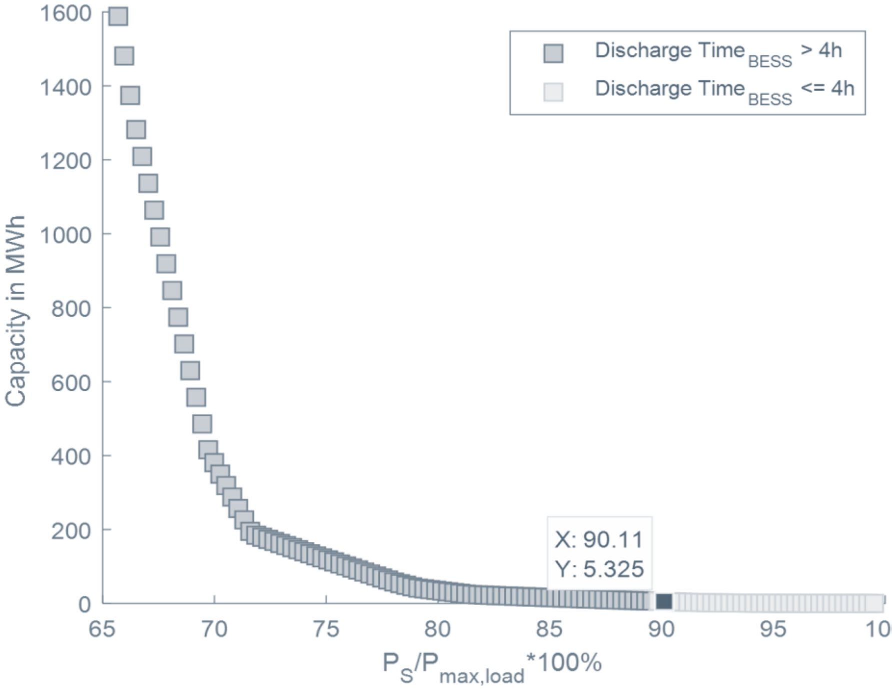

Figure 3 Relationship of Battery Energy Storage System sizes and peak shaving threshold

Step 4: Based on the results of the load profile analysis and the goals, a battery storage system can be supplied and installed. For this, a first investigation on-site with local experts of the harbour operator will be established.

To address tomorrow's needs with hydrogen the development is rather complex as more factors need to be considered. Depending on the system boundaries and the self-set goals, an overall analysis of the current and the expected situation in terms of electricity as well as hydrogen fuel demand is required. This could include the overall electricity consumption at the port and all electrified vehicles as well as the required amount of hydrogen to refuel the respective means of transport running on it. A basic engineering to size a wind or solar farm (depending on the preferences and local options) in combination with an electrolyser needs to be performed to address all energy needs or to meet self-set goals like emission reductions. Together with the harbour a suitable economic solution will be developed.

4. Cost and emission effects

Battery Storages:

A great share of industrial electricity consumers in Germany pay about 20 percent of their annual energy costs for network charges, consequently these costs are of crucial economic importance. Like described in the previous chapters the integration of battery is one opportunity after active load management and utilization of diverse on-site storage options to ensure a future-oriented economic operation. The costs depend on individual factors of the battery and need to be examined case by case suitable to the application. In general, energy intensive consumers with a 24/7 operation can have electricity cost saving in the six-digit order.

Hydrogen:

The costs of a hybrid system with an electrolyser depend even more on individual cases. Generally, the prices of hydrogen currently are[12]:

Hydrogen source	Price dependency	Price [€/kg]
Grey hydrogen industrially produced from natural gas, generating high emissions	depending on gas price fluctuation and carbon taxes	1 - 2.5
Blue hydrogen (industrially produced from natural gas, capturing emissions)	depending on gas price fluctuation and costs for emission reduction	>2.5
Green hydrogen electrolysis with renewable energy	cost of electrolyser and electricity price	3.5 - 5

For both storage technologies emission effects depend on the share of renewable energy in the power supply.

5. Lessons Learned and Experiences

Each industrial and commercial customer has its own complex surrounding. A harbour itself has diverse commercial customers integrated in the local grid. This increases the complexity for the analysis of the data and the general contractual structure. In order to be able to find the most suitable solutions it requires more detailed explanations on the harbours' structure.

The first conversations with the harbour infrastructure owners went well. It underlined that expectations and goals need to be clearly communicated between the parties, as harbours are very complex electricity consumers with multi-layers and many different consumers within one grid connection point.

In the framework of this recommendation paper our expectations on the provided power load profiles were not completely met yet. More data analytics from various harbours are needed in order to be able to make a consistent statement on the possible benefit for ports. We strongly recommend monitoring future plans for electrification of transportation considering the whole chain from space, local infrastructure, electricity demand, vehicle technology and thereto connected stationary technology.

The question when and if a battery storage system or a hydrogen generation with renewables on-site is suitable for a harbour strongly depends on the individual load profile of today and future

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[12] International Energy Agency (IEA); 2019-04-23; the clean hydrogen future has already begun; https://www.iea.org/commentaries/the-clean-hydrogen-future-has-already-begun [last checked 2020-10-19]

plans. Harbours with a decisive emission reduction plan, that consider the movement of vehicle and ship producers to go more electric will have a benefit to investigate early their current load and start the planning for an integrative behind-the-meter micro-grid with battery energy storage system, Renewables and Electrolysers. ABO Wind can support in understanding the effects of those changes and can engineer a suitable system to ensure an economic operation in the future.