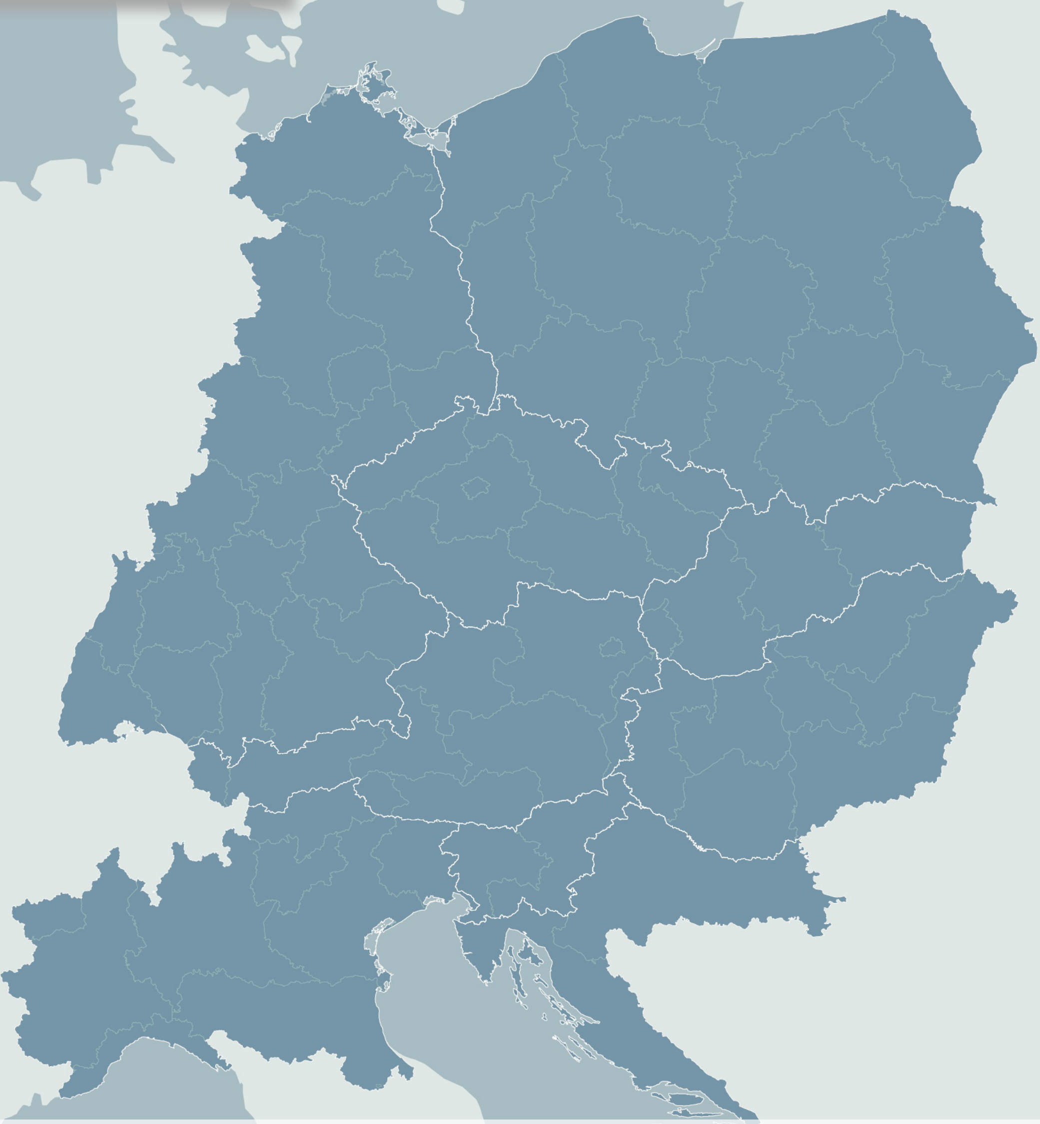
Interreg CENTRAL EUROPE

European Union European Regional Development Fund

InterGreen-Nodes



CE1444: InterGreen-Nodes

# Handbook for the adoption of Clean Fuels at Terminals

## Part 2: Energy Systems

TAKING **COOPERATION** FORWARD

# Index

# 1. Introduction

Developing innovative solutions for transshipment nodes is risky and ressource-intensive.

The InterGreen-Nodes project tested, demonstrated and evaluated a number of possible solutions. They were implemented, tested and discussed with the ports and terminals in the InterGreen-project.

In order to help other ports and transshipment facilities to impelemnt similar solutiopjns, the project set up a series of three handbooks, that cover the following topics:

- Handbook 1: Buildings and built infrastructure requiring buildings;
- Handbook 2: Use of clean, mainly electric vehicles;
- Handbook 3: Use of clean energy systems and energy storage systems.

## 1.1. Overview over the handbooks and their content

### HANDBOOK 1: Buildings and built infrastructure requiring buildings

| | |
|---|---|
|  | ***Where:***<br>Berlin (Westhafen port)<br><br>***What:***<br>Developing and operating an innercity-cargobike hub on the port premise.<br><br>***Potential Impact:***<br>Shifting freight from truck to cargobike on the last mile, with the potential to use rail for the main run (using the ports rail-road transshipment facilities). |
| | |
|  | ***Where:***<br>Port of Budapest<br><br>***What:***<br>Using BREEAM and LEED ratings to make the effects of environmental friendly building measurable.<br><br>***Potential Impact:***<br>Environmental friendly building in the areas in energy, land use, materials, pollution, transport, waste and water. |

## HANDBOOK 2: Use of clean energy systems and energy storage systems

| | |
|---|---|
| LNG Infrastructure<br> | ***Where:***<br>Freight Village Bologna<br>***What:***<br>Developing and operating an LNG gas station for trucks, to be used by customers of the freight village.<br>***Potential Impact:***<br>$CO_2$ reduction (exact numbers still pending). |
| | |
| Solar Energy<br> | ***Where:***<br>Berlin (Westhafen port) and Port of Koper<br>***What:***<br>Using solar energy to complement the energy mix used by a port.<br>***Potential Impact:***<br>$CO_2$ reduction (exact numbers still pending). |
| | |
| H2 Energy Storage systems<br> | ***Where:***<br>various<br>***What:***<br>Using hydrogen fuel cells to store electric energy during high availability times and use them when high energy demand arises.<br>***Potential Impact:***<br>Flattening usage peaks and storing energy from clean energy production, making clean energy use economically more viable). |

| | |
|---|---|
| Electric Ship  | ***Where:*** Berlin (Westhafen port) |
| | ***What:*** Using an electric ship (with battery electric and hydrogen energy storages) instead of diesel driven ships for transport on inland waterways. |
| | ***Potential Impact:*** Significant $CO_2$ reduction (exact numbers still pending). |
| | |
| Full-Electric Terminal  | ***Where:*** Berlin (Westhafen port) |
| | ***What:*** Changing port operation processes from conventional (diesel) fuel driven processes to electric drives (e.g. trucks, internal terminal freight transport, general purpose cars, utility vans, rail shunting vehicles). |
| | ***Potential Impact:*** $CO_2$ reduction (exact numbers still pending). |

## 1.2. How to transform your operation

Based on the experiences from the IhtnerGreen-Nodes project, we recommend the following steps, in order to achieve a lasting and sustainable results:

### *Step 1: From a Task Force:*

The implementation of clean solutions into you operations can be challenging and complex. Usually, numerous different areas of your operation will be impacted, ranging from transhipment and transport over energy use to funding and accounting of measures. Sometimes it can be beneficial to include customers or regional officials.

Identify relevant persons and functions at our organization and form a task force, in order to include all perspectives and viewpoints. Regular meetings can be helpful, but at a minimum, all task force members should be updated on any progress regularly and actively asked for their opinion, if their field of expertise is touched upon.

Open discussions, especially at the beginning can help identify possible problems as well as opposing goals.

## *Step 2: Identify fields of action*

The areas, in which clean solutions can be implemented vary widely. To gain an idea what possibilities you have, you can utilize the handbooks in this series and the examples described.

If you are implementing measures of this sort, the first time, it could be advisable to pick a small scale implementation project, such as substituting existing diesel-driven vehicles with “of-the-rack” electric vehicles.

A field of action could also be the use of solutions on a project, you are anyway planning to realize, such as the use of green-building-ratings on a construction project.

To ensure a seamless implementation, include the task force from step 1, into your decision.

The result of Step 2, could be a list of possible actions.

## *Step 3: Calculate probable outcomes*

A first quick calculation on costs and $CO_2$-savings can help you make a first decisions and circle in, on a number of solutions, you would like to focus on.

The InterGreen-project developed a methodology that can help you, do this calculations. You can find it on the InterGreen-Website:

- https://www.interreg-central.eu/Content.Node/InterGreen-Nodes.html

The three files you need are:

- Fact Sheet of Key Performance Indicators (KPI) System: https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/CE1444-O.T3.1-fact-sheet-Tools.pdf
- Standard Operating Procedure (SOP): https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/CE1444-O.T3.1-SOP.pdf
- KPI System Excel file: https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/O.T3.1-Basic-Model-KPI-System.xlsx

## *Step 4: Form a strategy*

Plan your next steps. This handbook series can hep you to identify these steps, absed on the experiences of others.

Discuss the strategy with your task force from Step 1.

## *Step 5: Implement*

## *Step 6: Use results for marketing an PR*

Include your marketing department and draw up a strategy, to inform others about your success.

# 2. Solar Energy Demonstrator in Koper

## 2.1. The Basics

The micro solar power plant will be set up to generate electricity from renewable sources, promote the green port and provide energy for future self-sufficiency in electricity. The purpose of setting up a micro solar power plant is to partially provide the electricity necessary for lighting the port main road connection.

The photovoltaic power plant will be implemented with photovoltaic modules placed on the roof of the existing TP TROPLES transformer station in the port of Koper (on the figure below is marked in red).

Figure: Location of micro solar power plant in the port of Koper

Figure: Existing transformer station

It is expected that 24 photovoltaic modules with a power of 330 Wp will be installed, which form a maximum, peak power of 7.92 kWp and an estimated 9000 kWh annual amount of electricity energy produced.

The solar power plant will be connected to the internal electricity network behind the existing metering point of the facility.

## 2.2. Step by Step description of the implementation

*Step 1:* Needs identified within Luka Koper company (Health protection and Ecology Department, Strategic Development Department, Investment Department); several internal meetings

*Step 2:* Including the investment of micro solar power plant in the Luka Koper annual plan for 2020 (adopted by Management Board of Luka Koper)

*Step 3:* Public procurement procedure for project documentation (PZI – detailed design and PID – project for execution works); contractor selected: E PRIHODNOST d.o.o.

- PZI documentation prepared before the construction
- PID documentation prepared after the construction

*Step 4:* Public procurement procedure for construction of micro solar power plant; contractor selected: Plan-net solar d.o.o

*Step 5:* Execution of works (foreseen until end of December 2020)

*Step 6:* Testing of the solution (foreseen until March 2020)

## 2.3. Cost and emission effects

Use the SOP and the EXCEL model from DT3.1.2, in order to calculate cost and emission effects, compared to a conventional building of the same size and function.

- Fact Sheet: https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/CE1444-O.T3.1-fact-sheet-Tools.pdf
- SOP: https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/CE1444-O.T3.1-SOP.pdf
- Excel: https://www.interreg-central.eu/Content.Node/InterGreen-Nodes/O.T3.1-Basic-Model-KPI-System.xlsx

# 3. Solar Energy Demonstrator in Berlin

## 3.1. The Basics and emission effects

EnTerra Solar Holding GmbH has installed two photovoltaic systems with a total output of 268 kWp on the roofs of BEHALA. The entire system produces 253 MWh of clean electricity per year. This saves around 224 tons of carbon dioxide. The electricity generated by the systems can supply up to 60 four-person households. Both companies thus make a valuable contribution to environmental and climate protection.

One of the two systems is operated by the Berliner Energieagentur GmbH (BEA). A photovoltaic system with a module area of 888 square meters was installed on the flat roof of a 4,200 square meter warehouse at the Westhafen location.

The total of 604 polycrystalline modules with an output of 127 kWp generate around 114 MWh of electricity per year and in this way save 74 t of carbon dioxide. The electricity generated is fed into the power grid and remunerated accordingly. BEA financed and planned the system and had it built by specialized service providers and will operate it for a period of 20 years. BEHALA will receive a corresponding share of the solar electricity remuneration.

The PV system was put into operation in 2010.

## 3.2. Lessons Learned and Experiences

The photovoltaic system contributes to the base load coverage in Berlin's Westhafen. Due to its large area, it can make a significant contribution to improving the port's emissions balance within the average useful life of 20 to 30 years.

# 4. LNG use in freight transport in Emilia Romagna

## 4.1. The Basics

The main goal of this demonstration was the realization of a new LNG station for trucks positioned within the major fright village of the Emilia Romagna region. The output of the demonstrator will be used as reference in the region to be applied in other similar location, in order to create a network of LNG plants serving the road freight transport.

The main target for this investment project are:

- freight transport companies with LNG trucks and medium/small vehicles for city logistics;

- transport companies dealing with people mobility (bus/pullman);
- cars of the people working in Interporto Bologna.

Natural gas has assumed increasing importance in the world energy scene, especially for freight transportation, with prospects for further growth in the coming decades. Compared to other fossil fuels it has a lower environmental impact (both in terms of $CO_2$ emissions and other pollutants), considerable flexibility of use, and extreme versatility of use.

Interporto Bologna SpA, the managing company of the Bologna Freight Village, in 2020 concluded a new cooperation agreement with the ENI group, the biggest Italian oil and gas company, for the enlargement of the existing fuel station with the implementation of a brand new LGN plant, the new frontier of ecological fuel. This investment founds its roots within the plans that Interporto Bologna designed to undertake a “Green Transformation” of the logistics platform. The strategy designed for this transformation include the following initiatives and investments:

- build new rail and intermodal facilities and modernize the existing ones to boost the intermodal transport and the rail transport of goods and promote the modal shift;
- enhance the digitalization of the intermodal terminal operations to bring more efficiency in the railway transport;
- implement the offer of more sustainable energy sources both for freight transport and logistics buildings such as: LNG station, electric charges points, photovoltaic systems…
- improve the environmental performances of the logistics warehouses through the LEED and BREEAM certification for all the new buildings;
- implement new business collaborations within the hub for the energy management.

The first achievement of this strategy is represented by the new LNG station opened at the beginning of 2022 which widened the offer for the truck companies operating both within the node and in the surrounding area, favouring and encouraging the road transport companies to shift from diesel trucks to LNG trucks.

Furthermore, the Company started in 2021 a project which foresees the upgrading of the intermodal terminal infrastructure, in compliance with the European standards for the TEN-T core network: 750 m rail tracks, high-capacity automatic cranes, new terminal yard and safe parking areas for semitrailers and truck drivers

## 4.2. Step by Step description of the implementation

The implementation of a LNG station within the freight village required several steps:

- preliminary market analysis to evaluate the potential demand and the best positioning for the plant;
- preliminary request to the Local Authorities for the environmental authorizations;
- definition of the strategic partnerships necessary for the project delivery, including the definition of the contractual agreements between the stakeholders involved;
- technical design and engineering of the LNG station project;
- request for authorization and building permits;
- civil works execution and installation of LNG station;

- preparation and testing phase of the plant;
- start of the LNG station operations.

The first version of the project foresaw to locate the LNG plant outside the freight village, in the main road that cross the north-east part of the Metropolitan area of Bologna and absorb a significant amount of heavy traffic, being also the main access to the freight village and the link between Interporto and the highway.

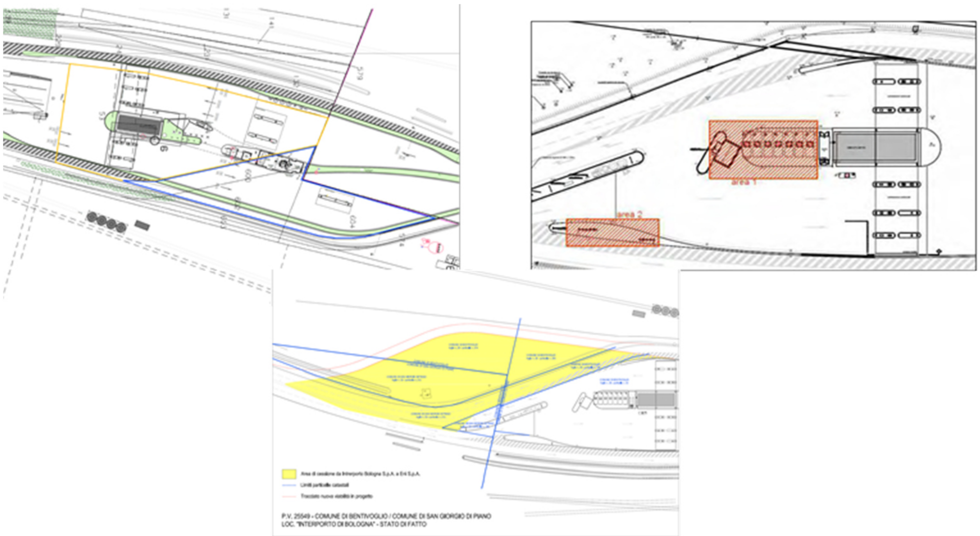
After preliminary discussions with the local authorities and a deeper analysis of the market, the project location changed in favour of Interporto Bologna, thus bringing the LNG plant inside the freight village.

The new project brought some improvements compared to the original one:

- integration of the offer to the clients (traditional fuels/LNG) in one single spot;
- integrated management of the two plants (traditional fuels/LNG);
- lower environmental impact (land consumption);
- better positioning and accessibility of the plant in relation to the main market (truck companies located within Interporto).

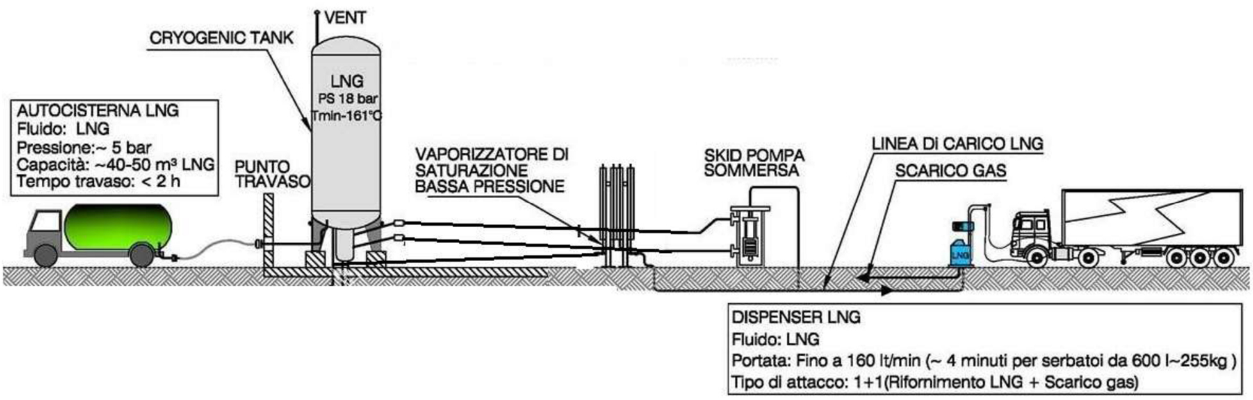
Here below the geographical representation of the project positioning and location:


In 2020, Interporto Bologna and ENI signed an agreement focused on the development of a new LNG station within the freight village and close to the traditional fuels station. Following this agreement, in January 2021, Interporto Bologna started the civil works to adapt and modify the internal road network of the freight village to accommodate the LNG station. The main challenge of the project design was the harmonization of the existing road system and the existing fuel distribution plant layout with the new LNG plant to be constructed without interfering with the daily traffic of the trucks.



After the completion of the road network modification, in March 2021, the land adaptation works to host the new plant started and lasted until July 2021. In September 2021, it started the installation of the plant infrastructure formed by external cryogenic tank, pipelines, compressor, cooler and pumps as drafted in the following schema:

Plant diagram for liquid natural gas refuelling




Source: Bernardini (BRN), 2018.

The construction and installation works lasted until the end of November 2021 and the new LNG station finally opened in January 2022, widening the offer to the truck companies operating within the node and in the surrounding area, favoring and encouraging the road transport companies to shift from diesel trucks to LNG trucks.

## 4.3. Cost and emission effect

*THE INVESTMENT*

The LNG project in Interporto Bologna required an investment of nearly 2 million Euro and 1,5 years for completion: ENI was in charge for the LNG plant, while Interporto Bologna has the ownership of the land and took care of the road network system modification.

The LNG plant of Interporto Bologna is the biggest installed by ENI in Italy, it is a new generation plant, integrated into an already existing service station. During its construction, the existing traditional station was revamped, and both are now integrated and both can be controlled and managed remotely.

The investment was driven by the necessity for the freight village but more for the road transport sector to become more green: the use of natural gas in the transport sector is considered, both at the industrial and institutional level, as an inevitable response to the increasing needs for de-carbonization of the economy. Despite the progresses of the technological innovation in the progressive development of renewables, $CO_2$ emissions are in fact expected to increase, albeit at a lower rate than in the past, thus there is the need for more investments in assets and technologies which can favour the decreasing of emissions.

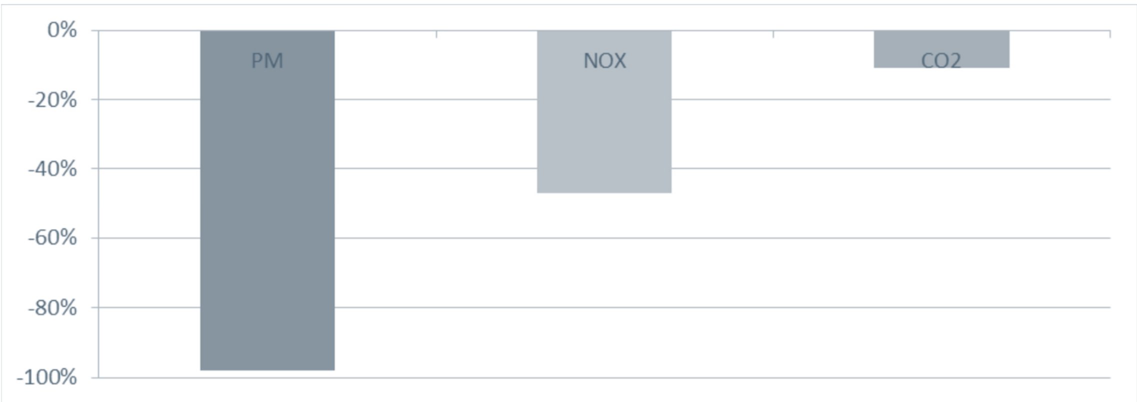
*EMISSIONS EFFECTS:*

Regarding the heavy road transport sector, the large number of studies carried out on the specific subject, show how the use of LNG, as a replacement for traditional fuels, enables:

- the reduction of SOx emissions to zero,
- the drastic reduction of NOx emissions of nearly 50%
- the significant reduction of $CO_2$ emissions and extremely low particulate emissions, with a reduction close to 90%.

Several surveys related to LNG gas emissions comparing the emissions of industrial vehicles set up with the latest generation of diesel engines, show less pollution from vehicles using liquid gas. The percentage reductions of the various pollution components vary from survey to survey. A reduction of up to 50% in NOx, almost total (up to 95%) elimination of PM10 and a reduction of up to 15% in $CO_2$ can be achieved. (Source: Freight Leader Council "Quaderno 28 – Il GNL in Italia per un Trasporto sostenibile")

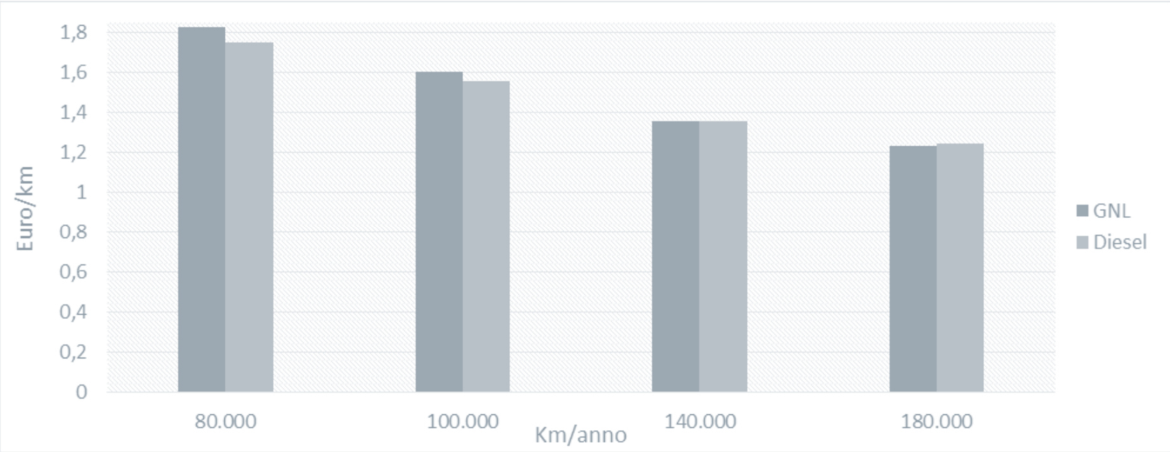
*Difference in emissions, all things being equal, between a 40 t industrial vehicle powered by LNG and a diesel one*




Source: Tuttotrasporti, 2018.

Having explained the environmental advantages of LNG in transportation, the main challenge is the assurance also of the economic benefits. From the fuel cost point of view, a dry comparison between LNG and diesel would have seen LNG-powered industrial vehicle win easily over a similar diesel model until the 1st semester 2021.

On the contrary, it has to be considered that the purchase price of a natural gas road tractor is still significantly higher than a similar diesel model. This resulted in LNG becoming more cost-effective once the annual mileage exceeds 140,000 km.



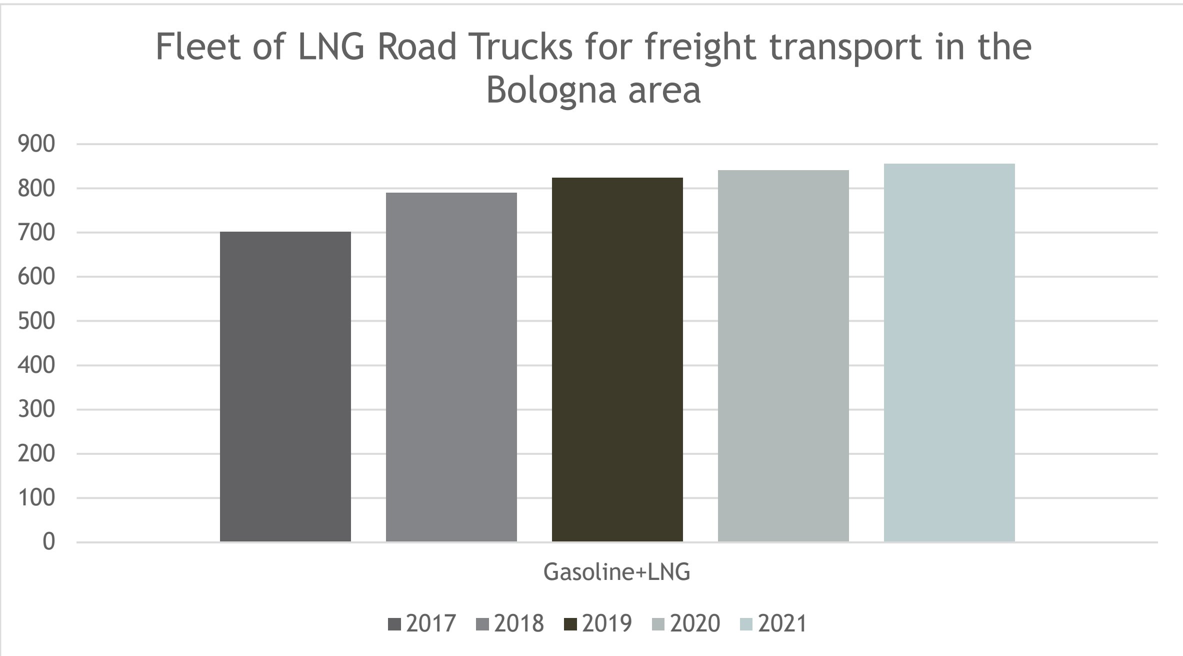

Source: Tuttotrasporti, 2018.

Nowadays, in 2022, both the costs of gas and diesel ramped up to incredibly high prices, due to the ongoing energy crisis worsen by the war in Ukraine, making the gas even more costly than the diesel.

This current situation led to an inversion of the growing trend of LNG vehicle for road transportation which has slowed down together with the transport sector greening transition.

In the table below it is reported the composition of road trucks for freight transport in the last 5 years and a graph representing the trend of LNG fleet in the metropolitan area of Bologna:

| Year | Gasoline | Gasoline+LNG | Gasoline+Methane | Electric | Diesel | Methane | Other | Total |
|---|---|---|---|---|---|---|---|---|
| **2017** | 1016 | 702 | 1449 | 38 | 14550 | 0 | 15 | 17770 |
| **2018** | 974 | 791 | 1456 | 37 | 15019 | 0 | 19 | 18296 |
| **2019** | 947 | 824 | 1437 | 34 | 14957 | 0 | 22 | 18221 |
| **2020** | 920 | 841 | 1222 | 42 | 14854 | 205 | 33 | 18117 |
| **2021** | 901 | 856 | 1173 | 53 | 15114 | 206 | 82 | 18385 |




Source: Automobile Club d'Italia

## 4.4. Lesson Learned and Experiences

*What did go well, what did not work? Were your expectations met? What could others learn from your experience?*

The plant started the operations in January 2022, but unfortunately the energy crisis that hit Europe in early 2022, further worsened by the war in Ukraine, heavily increased the price of LNG. As the LNG is now more expensive than diesel (€2.8/liter vs. €2/liter approx.), companies have decided to temporarily suspend their LNG vehicles in favor of the diesel ones.

Thus, despite the positive feedback collected by the customers and the expectations towards this plant, the market response was very low due to the energy crisis. This fact created and is creating a significant impact both on the economic projections but also on the operations of the plant.

Compared to the budget planned at the beginning of the project, that foresaw to reach 2,5 million Kg/year of LNG after the start up phase, the current situation imposed a revision of the goals set.

| | Budget (kg) | Budget revised (kg) |
|---|---|---|
| Year 1 | 800.000,00 | 250.000,00 |
| Year 2 | 1.500.000,00 | 800.000,00 |
| Year 3 | 2.500.000,00 | 1.500.000,00 |

Indeed, the LNG is filled in the external silo/tank and stored at the temperature of – 162°C. It must be sold/used within 15 days, otherwise, it must be discarded with huge economical loss. For this reason, the managing company decided to keep the plant closed in the second bimester (from march to mid May 2022) of the year, waiting for better market conditions. The plant has been re-opened again in May 2022 and Interporto Bologna is planning, together with ENI, to organize a promotional event (probably by the end of July 2022) to celebrate the plant opening and disseminate some key information on the activities performed thanks to InterGreen-Nodes project.

# 5. 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] 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.

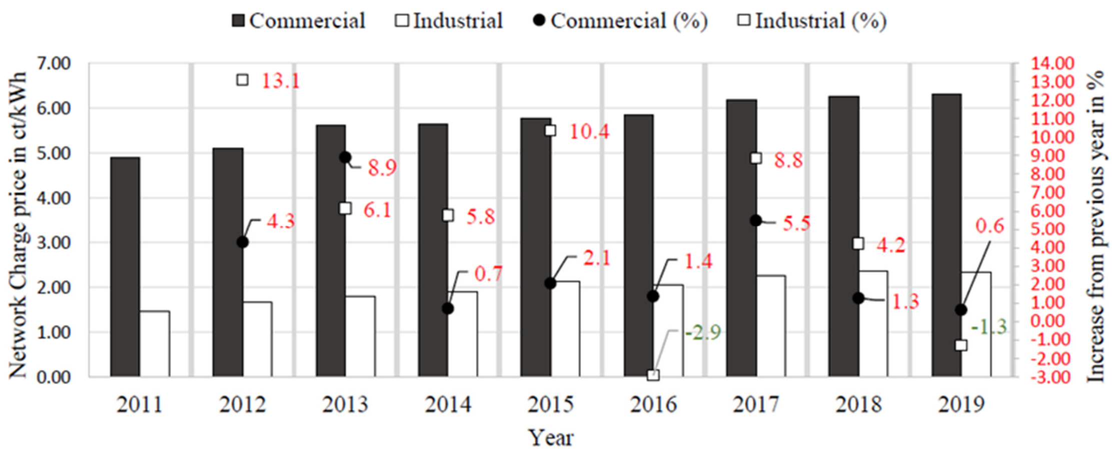



Figure 1 Network Charges price development for Commercial and Industrial Customers in Germany[3]

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

[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]

[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]

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.

### *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

[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]

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.

- *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.

## 5.1. 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.

[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]

| 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.

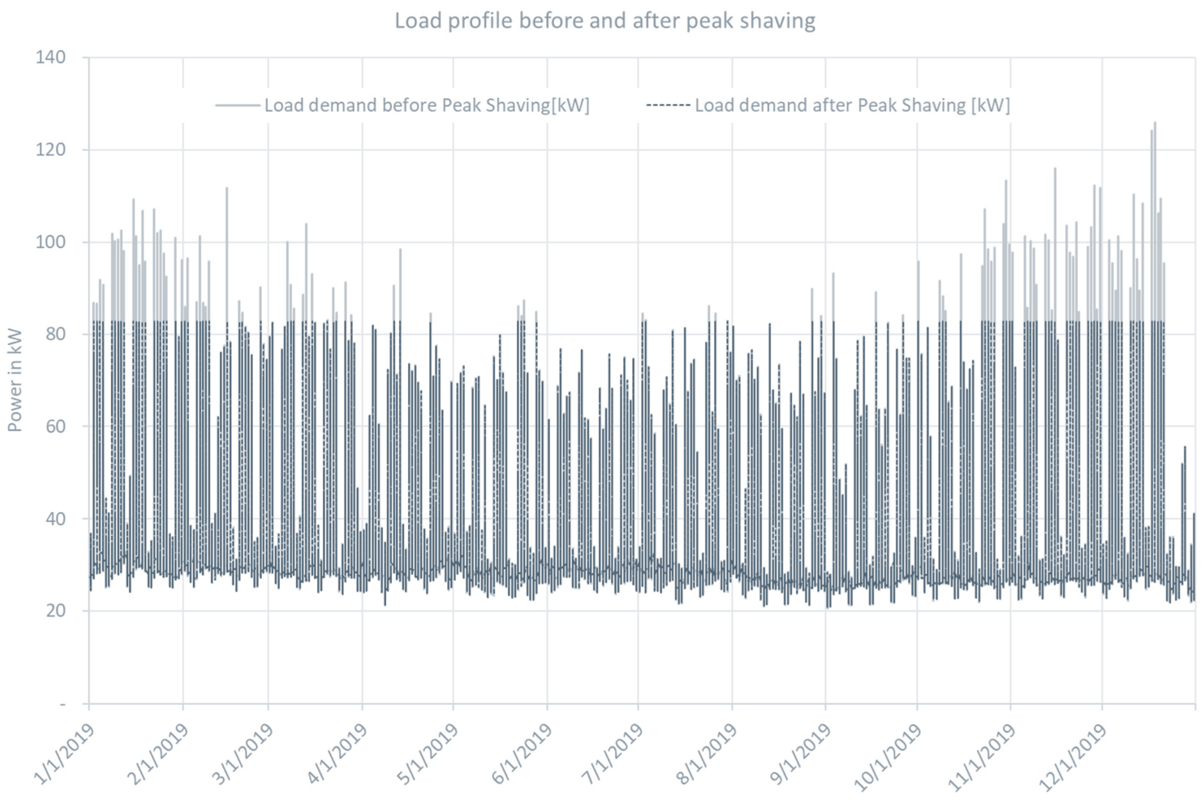



Figure 2 Example load profile of an exemplary office building demonstrating the analysis and the outcome for peak shaving.

*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.

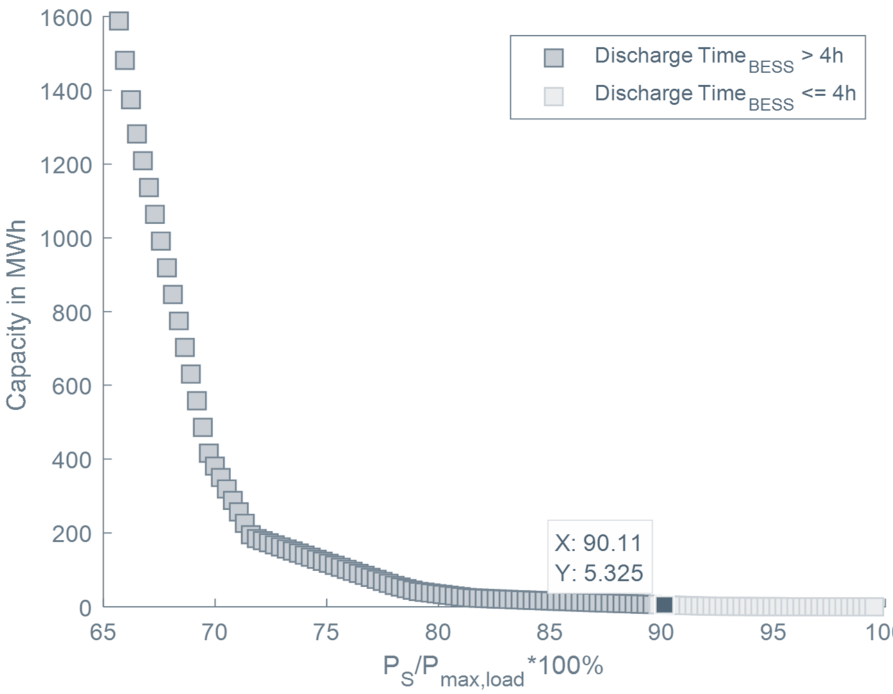



Figure 3 Relationship of Battery Energy Storage System sizes and peak shaving threshold

***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.

## 5.2. 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.

## 5.3. 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.

[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]

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 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.

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