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Matthäus Wuczkowski

in participation of Paul Schumacher

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# 1 | Introduction

Maritime activities are an important part of the European economy. More than one third (37%) of the goods traded within the European Union (EU) is exchanged by ship (European Community of Ship owner's Association, 2016). The share of shipped goods between the EU and third-countries (non-EU countries) is even higher. In 2016, 47.6% of the value of EU-28 exports and 50.8% of the value of EU-28 imports were exchanged on water (Eurostat, 2017).

A low carbon development is necessary in the maritime sector in order to meet international climate agreements. Maritime transport emissions represented around 13% of the overall EU greenhouse gas emissions from the transport sector in 2015 (European Commission, 2019a). The International Maritime Organization (IMO) estimated in its latest Greenhouse Gas Study that the maritime transport system is responsible for around 2.5% of the global greenhouse gas emissions (IMO, 2014).

Most vehicles used in the maritime transport business are powered by fossil fuels. In addition to $CO_2$, these emit substances like sulphur dioxide (SO2), nitrous oxides (NOx) or particulate matter (PM) which have a negative effect on the environment and/or human health. The precise emissions from the use of diesel fuel depend on the composition of the used fuel. Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO) represent 90% of energy consumption by international shipping (Fenhann, 2017). These fuels have a relatively low price because they are produced more or less directly from crude oil, mostly as a residual.[1]

The European Commission is anticipating a significant increase in maritime transport and trade through a higher level of global economic integration (European Commission, 2019b), making a low carbon development of the maritime sector even more relevant in the future. Ports are key actors in the maritime sector because they provide the infrastructure for most maritime activities and also for many non-maritime activities such as power generation or on-site industrial production. This makes them important actors for the energy transition. According to the World Ports Climate Initiative (2010), a decarbonised port is a port which is resource-efficient in both stationary and mobile sources (i.e. super-/infrastructure, machinery and vehicles). Thus, decarbonising ports means reducing emissions and becoming more efficient at the same time.

Moreover, regional ports face two specific issues. First, regional ports have to be specialised in order to compete against bigger ports. Second, the financial resources of re-

[1] However, these fuels possess a high content of the substances mentioned above, in particular sulphur. In the Sulphur Emission Control Areas (SECAs), fuels are not allowed to contain more than a defined share of sulphur. This has led to a reduced use of MDO in the Northern and Baltic Sea with sulphur limits of 0.1%, but SECAs are unpopular outside European waters. With the exception of California, the limit in all other waters is 1.5% (MARPOL Annex VI, IMO, 2019). Stricter regulations come into effect in the near future; a global limit of 0.5% will apply from January 2020 onwards.

gional ports are often limited. Both issues imply that regional ports have to look for innovative measures to reduce their emissions. The smaller size of regional ports allows testing potential innovative measures, some of which might be implemented in larger ports. The DUAL Ports project aims to decarbonise regional ports through innovative port investments that help minimizing the ecological footprint (cf. Box 1). Stimulating eco-innovation, carbon emission reduction and sustainable use of resources constitute a high priority for the European Commission. Regional ports are often multi-functional in the sense that logistic, manufacturing and energy-related activities are carried out in the port area. Thus, innovative port decarbonisation strategies are potentially related to a broad field of activities.

This action plan at hand will address the questions how ports can increase their efficiency, enhance their role in the industry, and become more sustainable. After presenting low carbon port activities within the DUAL ports project (Section 2), the paper will derive implications for low carbon emission policies (Section 3). The last section (Section 4) concludes.

Box 1

DUAL Ports - Developing Low carbon Utilities, Abilities and potential of regional entrepreneurial Ports

The DUAL Ports project aims to decarbonize Regional Entrepreneurial Ports (REPs)´ resources through a shared eco-innovation port program that minimizes their environmental footprint.

The objective is to specifically develop sustainable utilities and abilities of REPs. This will be achieved by collaboratively piloting and managing technologies, and implementing processes that tackle targeted measurable direct/indirect emission/pollution sources. The project will ultimately enhance ports' organizational/operational (energy) efficiency and performance, facilitating decarbonisation at reduced cost and with added value. As demonstrated by last years´ offshore wind energy developments in the EU and beyond, ports can not only be key centres for innovation, tests and integration of emerging technologies, but also a place to leverage participation and to foster multiplier effects, e.g. by triggering value-for-money clustered activities that generate employment and benefit the environment. The officials of the participating ports and local authorities are expected to implement initiatives that will reduce carbon emission.

A transnational approach will be adopted to allow the DUAL small & medium size ports to capitalize on this potential, overcoming their individual limited staff, funding and capability to identify the most effective solutions on their own. Only few measures have been selected due to the limited project duration and size of the partnership, but these measures are expected to have a considerable impact on the way ports can act as facilitators between enterprises, research centres and public authorities to enable user-driven eco-innovation in the North Sea area. The Port of Oostende is project leader of DUAL Ports.

The total budget of the project is 8.6 Mio Euro, the European Regional Development Fund's (ERDF) contribution is 50 percent, while the duration is from 2016 to 2021 (DUAL Ports 2019).

# 2 | Low-carbon activities within DUAL Ports

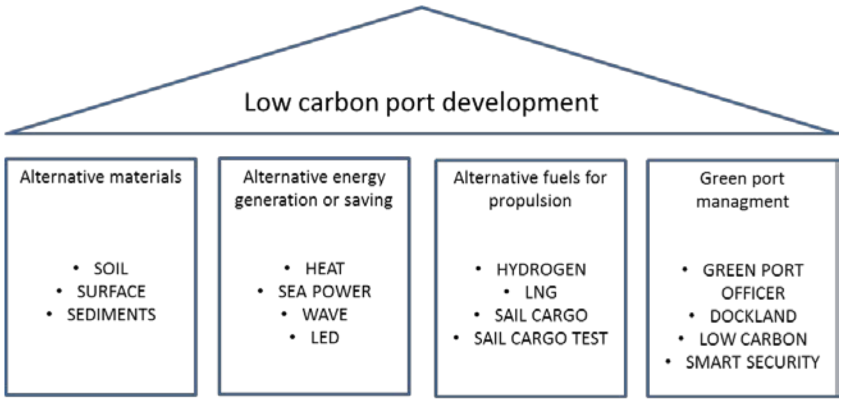
The objective of the DUAL Ports project is to reduce the environmental footprint of regional ports (cf. Box 1) through investments in infra- and supra-structure. None of the ports from the DUAL Ports project are part of the main transportation node of the so-called Trans-European Transport Network (TEN-T)[2], which implies that they have to rely on other networks in search for innovation and partners.

Several technologies regarding superstructure (buildings, bridges etc.) and infrastructure (quay, roads etc.) are tested. The pilots within the DUAL ports project can be conceptually divided into four groups:

i) alternative materials (for constructions) in port areas,
ii) alternative energy generation or savings,
iii) indirect port emission savings through alternative fuels for propulsion, and
iv) green port management.

Figure 1 shows the list of the pilots belonging to the respective groups. A short description of the pilots will be given.

Figure 1: Fields of activity and DUAL Ports pilots




Source: HWWI.

[2] The TEN-T is a European Commission policy towards the implementation of a European-wide network of different modes of transport (roads, railway, inland waterways, ports, terminals etc.). The Core Network covers the most important transportation connections and nodes within the European Union by 2030, whereas the Comprehensive Network shall cover all European regions by 2050.The overall objective of TEN-T is to remove bottlenecks and eliminate technical barriers that exist between the transportation networks of EU Member States. Furthermore, with this objective it shall strengthening et al. the economic and territorial cohesion of the EU. The policy seeks to achieve this aim through the construction of new infrastructures, the adoption of smart technologies, alternative fuels and universal standards for sustainable infrastructure investments.

## 2.1 | Alternative material use and treatment in ports

**Reuse of soil in port area development[3]:** This investment project is related to the expansion of the port through the creation of additional quays. The green investment aspect of the project of the Port of Vordingborg is that waste and recycled materials are used for construction filling which would normally go to a landfill. This is beneficial for the investor because he or she is payed for receiving the waste instead of paying for conventional materials. Secondly, there is an environmental benefit for the society since less material goes to a landfill. Furthermore, a port expansion with conventional materials would require a lot of sand, which has to be dredged from the seabed in a rather energy-intensive process. As the alternative material can also be obtained from locations closer to the port, the emissions created in relation to the transport of the construction material can also be reduced.

**Absorbing and reducing greenhouse gases by special surfaces[4]:** The shipping and port industry depends heavily on fossil fuels. Most large vessels have their diesel generators running when moored in a port. The exhaust gases from marine vessels (and other vehicles) contain large amounts of nitrous oxides (NOx) and sulphur oxides (SOx). A potential counter-measure is the investment in a NOx-absorbing asphalt in port areas. Air-purifying asphalt contains titanium dioxide, a photo-catalytic material which removes the nitrous oxides from the air and converts them into harmless nitrate with the aid of sunlight. The nitrate will be simply rinsed away by rainfall. This pilot is of interest for port infrastructure and also for general road investments because roads were still the most frequently used mode of transport to connect EU ports with inland destinations in 2015 (Pastori, 2015).

**Sediment treatment[5]:** In some parts of ports, sediments contain environmental pollutants. This prevents the use of water depth conservation measures and thus, the long-term use of certain parts of the harbour. Therefore, an innovative and sustainable concept for the removal of pollutants in the port's sediments should be developed. The objective of sediment treatments should include:

(i) examination of the actual load situation by taking and evaluating samples and creating a pollutant cadastre;

[3] Pilot project SOIL; the main partner is Port of Vordingborg, Denmark (DUAL Ports 2019).

[4] Pilot project: SURFACE; the main partner is Port of Skagen, Denmark (DUAL Ports 2019).

[5] Pilot project: SEDIMENTS; the main partner Niedersachsen Ports, Germany (DUAL Ports 2019).

(ii) development of an innovative and sustainable concept for the careful and long-term removal of pollutants (incl. presentation of sustainable sediment removal procedures; identification of suitable ways of sediment disposal; estimation of implementation costs; elaboration of necessary licensing requirements);
(iii) examination of ways of re-using treated sediments in port building activities
(iv) evaluation of the measures developed with regard to realisability, contribution to pollutant reduction and cost efficiency;
(v) implementation of an innovative concept for the long-term removal of environmental pollutants in the Emden harbour.

Within the pilot project, the operator Niedersachsen Ports wants to develop the concept in cooperation with the operator of the floating and dry dock and other ports from the DUAL Ports project according to which the required water depths can be permanently ensured in a green manner. The findings of the concept could be applied to other ports, as environmental pollutants create a general problem for many European harbours. Finding innovative ways of cleaning and re-using the sediments in the port area means also to avoid the expensive transport of dredged contaminated material to treatment plants throughout Europe and thus save massive carbon emissions.

## 2.2 | Alternative energy generation or saving

**External heating systems[6]:** One possibility for ports is to optimize the production of energy surplus from wind, solar and sea-based power systems by integrating it to the local heating system, thus reducing the carbon footprint by introducing an intelligent heat pump system combining smart heat exchangers technology. With this technology, the local port is able to provide (green) energy to the local users. An intelligent heat pump and exchanger will be introduced, modified, tested and investigated in the DUAL ports project. The introduction will be done in cooperation with the companies in the local business cluster of the Port of Hvide Sande. Moreover, the introduction of an internal transport solution in the port area will be sought, based on hydrogen generated by surplus renewable energy systems. This will help to minimize the carbon footprint and discharge of SOx and NOx in the local area.

[6] Pilot project: HEAT; the main partner is Port of Hvide Sande, Denmark (DUAL Ports 2019).

**Wave energy supply/infrastructure**[7]**:** The potential of wave and tidal energy to supply sustainable energy to ports and hydrogen production facilities is tested within the project. For this, a versatile and robust wave energy converter has been developed. Its technology shows a good performance in a very broad range of wave climates and it excels in survivability. The technology has been demonstrated at scale in the past at sea. In 2014/2015, a fully functional device was installed one km from the coast of the Port of Oostende. Over the last three years, it has been developed further and a first full scale device was built to be monitored in Orkney. In the pilot, the developer Laminaria will deploy this device at the Billia Croo site and feed the produced energy into the Orkney electrical grid. A detailed analysis of its power production and potential for other sites will be performed. This project will also demonstrate the sustainability of the device over a longer period of time and offer the possibility to improve operations and maintenance strategies. Combining wave energy and hydrogen production in ports is a win-win situation. Hydrogen installations can be supplied with a steady supply of locally produced renewable energy and wave energy developers have the potential to supply not only the electrical grid, but also vessels.

Shipping today is mainly fuelled by fossil energy carriers. The DUAL Ports project has set out the goal to show the potential of hydrogen for ports and shipping. Hydrogen is a clean and compact carrier of energy and therefore offers great potential in making ports and shipping more sustainable. Setting up hydrogen fuelling stations and converting ships to run on hydrogen is a possible option to make shipping and ports greener. Another major part of solving this issue is producing the energy in a sustainable way. Wave energy is an ideal source to supply the port hydrogen installations with energy. Ports are by definition close to the sea and many ports have wave energy resources nearby. Furthermore, wave energy is probably one of the most stable and predictable renewable energy resources which results in more efficient use of the hydrogen installations. The test and its performance results will therefore be a valuable source of information for those partners interested in such, today still immature, technology.

**Lighting in port areas**[8]**:** One sustainable and efficiency-driven project is the installation of an intelligent LED lighting system for track fields in ports. An innovative lighting concept at the rail track area in the Port of Emden has been implemented over the past months as part of the DUAL Ports project. Within the port, this track field is used to aid in the transhipment of motorized vehicles, for the shunting and switching, staging and parking, the loading and unloading of car carrier trains). The types of jobs to be performed, as well as the different areas in need of illumination, require individual lighting scenarios.

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[7] Pilot projects: SEA POWER and WAVE; the main partners are Laminaria and Port of Oostende, both Belgium (DUAL Ports 2019).

[8] Pilot Project: LED; the main partner is Port of Emden, Germany (DUAL Ports 2019).

The smart control unit is the centre piece of this new system. Motion sensors and light and track sensors capture the requirements for the individual situation. Remote-controlling the system is achieved through a web connection and provides light wherever and whenever needed, and at the exactly required light intensity. When the tracks are idle, a medium illumination of five lux (~0.5 fc) is sufficient for jobs like general and site security. Shunting requires 15 lux (~1.4 fc), while any unloading operation requires an average light intensity of 30 lux (~2.8 fc).
The lighting system is fitted with LED technology, resulting in lower operating and maintenance costs and an overall longer life of the lamps. The lower electricity consumption reduces the carbon footprint of the port.

## 2.3 | Indirect energy savings: Alternative fuels for propulsion

**Hydrogen/ Liquefied natural gas use in ports and connected areas[9]:** Hydrogen is a unique zero carbon fuel that can be created from water through electrolysis. An alternative to MDO and HFO is to develop bunkering system in co-site to ports and to use the storage system for ferries and other vessels. Hydrogen can efficiently help to reduce GHG emissions from ships. The hydrogen can also be converted to methane. This methanisation technology is not considered within the DUAL Ports project but demonstrates the relation between hydrogen and (in particular synthetic) methane with regard to cleaner ship propulsion.

LNG terminals can provide alternatives to heavy fuel driven vessels, local production factories and road transportation. This supports the EU's Alternative Fuels Infrastructure Directive (European Union, 2014) that LNG shall be available at all TEN-T Network ports.

Existing and future Air Pollution Emission Control requirements have great impact on the production and operation of all kinds of premises and machinery, such as factories, vehicles, vessels etc. Many businesses are currently being strongly encouraged or even forced by local authorities and/or EU regulations to significantly lower their emissions. Numerous companies, ship- and truck owners etc. are evaluating and planning to change their production methods and propulsion systems to operate GHG-neutral and use more sustainable fuel, such as LNG.

When switching from MDO or HFO to LNG, it may not be concealed that a reduction of carbon footprint is only achieved once the methane is not allowed to slip into the atmosphere. The global warming potential of methane is 24 times that of carbon dioxide

9 Pilot project: HYDROGEN and LNG, main partners are ITM Power, UK, and Port of Skagen, Denmark (DUAL Ports 2019).

and hence, already small quantities emitted may distort a positive carbon footprint balance. Methane may slip to the atmosphere by incomplete combustion of engines or by losses during the bunkering process. Engine manufacturers are working hard to improve combustion processes and bunkering systems are, by now, closed systems not releasing any gas to the atmosphere once operated properly. It is the obligation of a port to monitor LNG bunkering to ensure safe and environmental-friendly operations.

Most regional ports are too small to be able supply LNG through their own bunkering stations. These ports will more likely employ LNG tank trucks or LNG-barges.

**Sail cargo test/platform[10]:** The aim of another DUAL ports pilot is to test the adaptation of a sailing vessel to innovatively transport cargo by combining wind propulsion and hydrogen. The first step will be refurbishing a sailing vessel to carry cargo up to 52 tons. The next step will be to become a zero emissions sailing vessel, using hydrogen to fuel an electric motor to go in and out of ports.

In order to promote sailing cargo, it is necessary to establish a new cargo transport network since conventional vessels operate with different conditions. An internet platform could possibly help developing the accessibility of this transport mode for industries and customers. Although transporting goods by sailing vessels could reduce both carbon emissions and costs, there are currently no concrete projects which are achieving this. This is due in part to

(i) a lack of sail cargo shipping companies with a business plan;
(ii) insufficient vessel capacities (running under the consideration of economies of scales);
(iii) a lack of awareness of the potential of sail cargo on part of cargo owners and the general public;
(iv) hindering policies and regulations regarding sailing ships in ports and transnational maritime shipping on sailing ships.

The potential for a wind-propelled vessel to be converted innovatively into a cargo vessel for the sustainable transportation of commodities by combining wind and hydrogen could extend the green component of transportation.

[10] Pilot project: SAIL and SAIL CARGO TEST; main partner are Fair Wind Trust and Celtic Cruises, both UK (DUAL Ports 2019).

## 2.4 | Green port management

**Green port strategies/management**[11]**:** A crucial factor of success in becoming a more sustainable regional port is the development of a green port or sustainability strategy.

Sustainable thinking and acting should be engrained in the business activities and become an integral part of the corporate culture. Sustainability must be reflected in the daily work thought processes, actions, and within the decision processes of employees. This is how awareness for responsibility and an internalized philosophy for sustainable action can be created. The benefits of a strategical approach are obvious:

(i) A strategy shows how the goals of a sustainable port company can be achieved.
(ii) It creates awareness for new challenges and solutions, e.g. in environmental protection and gives colleagues a clear orientation.
(iii) It helps planning the right measures, implementing them in the ports and verifying their success.
(iv) It drives the initiation of measures and ensures a continuous improvement process.
(v) Ports can position themselves as responsible organizations and strengthen their market position.

It is important to provide clarity and to define the effects of own port activities on different environmental aspects (e.g. air emissions, water quality or soil). This is why the environmental and social effects resulting from a port's direct or indirect business activities should be at the core of the sustainability strategy. Concrete targets should be defined that give a clear picture of how ports will address social, environmental and economic challenges, and thus making a significant contribution to a sustainable port development. With the help of a system of indicators, the sustainability performance can be made measurable and the achievement of goals can be made transparent and comprehensible. A regular review of the goals helps assessing whether the port is on the right track; targets and indicators have to be adjusted if needed.

The strategy should be accompanied by a management system to ensure its implementation and a continuous improvement process. In order to achieve this, resources must be made available: financial resources as well as material and personnel. Especially human resources are quite important for the coordination of the sustainability strategy and management within the company, and for the initiation, implementation, and maintenance of projects.

[11] Pilot project: DOCKLAND, LOW CARBON, GREEN PORT OFFICER, and SMART SECURITY; main partners are Port of Oostende, Belgium, Port of Emden, Germany, the three Ports Zwolle, Kampen and Meppel, the Netherlands (DUAL Ports 2019).

## 2.5 | Assessing the benefit of low carbon activities

When planning to lower the carbon footprint associated with a certain economic activity, the question arises how to decide whether a particular measure is "useful". In the following, several aspects concerning the ex-ante assessment of low carbon measures (in and around ports) shall be discussed.

As part of the DUAL Ports project, the HWWI developed a corresponding cost-benefit tool (Cost benefit tool). The focus of this action plan is not on the technical details of the tool but rather on relevant general aspects regarding a meaningful ex-ante assessment of the benefit of low-carbon activities (in ports). The technical details of the tool can be found in Jahn/Wedemeier (2019).

The main objective is to combine the economic and ecological dimension in the assessment. Regarding the economic assessment of projects, decision makers have standard approaches at hand. A very general criterion is a benefit-cost ratio: The sum of (discounted) monetary inflows associated with a certain project is divided by the sum of (discounted) monetary outflows. A ratio above one indicates a "useful" project from the business point of view.

The integration of the ecological dimension is achieved by monetizing the carbon emissions from energy use. This is necessary because the carbon emissions are not accounted for by the planner in the classical cost-benefit ratio because the emissions don't have to be purchased. The EU provides estimates for the social costs of carbon which are exactly the costs that need to be added to the (private) costs for an overall ("welfare") assessment of a project. The result is an extended benefit-cost ratio which internalizes the external effect of carbon emissions.

A very important issue for the integrated assessment of investment projects is a meaningful definition of the business unit to which the investment, i.e. the costs, benefits and emissions can be attributed. The considered business units should be as small as possible in order to focus on the relevant processes and associated carbon emissions. Considering ports, different potential low-carbon investments address different business units. Whereas a new heating system might affect the cost of the storage business, other operations such as the loading and unloading of ships would not be affected at all.

In many cases, low-carbon development investments are integrated into "regular" replacement cycles. Staying with the example, the heating system in a certain (port) area may have reached the end of its lifetime and needs to be replaced. The decision maker wants to assess different possibilities. The alternative to a "green" investment such as geothermal heating is usually not "no investment" but rather a conventional investment where the heating system is replaced by one of the previous type. Such a comparison between green investment and conventional alternative is suggested for an assessment which actually helps making decisions.

Furthermore, for some projects, it can be useful to distinguish the implementation from the operation period. For larger and more general infrastructure investments, it might be impossible to identify a concrete business unit or process to which the investment is associated. More generally speaking, the costs and benefits of the operation period may be unknown. In this case, a benefit-cost-ratio as such has no interpretation but can still be used to compare a green option with a conventional one by considering only the implementation as such.

Finally, some low-carbon development investments in ports such as LNG bunkering facilities aim at the reduction of carbon emissions of customers and not of the port itself. Therefore, they should ideally be part of the customer's assessment. However, the customer's emissions can still be seen as indirect emissions of the vendor. Including indirect emissions in the assessment is useful to increase the awareness for emissions along the supply chain. Regarding the accounting of emissions (and thus, the benefits from avoided emissions), the planner has to make sure to avoid a double counting of the same ton of carbon.

## 2.6 | DUAL Ports workshop results

Within the DUAL Ports project, several ideas and projects have been discussed in workshops.[12] Their aim was to identify needs, challenges and methods for developing eco-innovative port programs and to inform about the innovation potential of decarbonizing regional ports through hands-on transnational pilot actions.

Summarizing the workshops' results, emission-reducing projects can usually be classified along two dimensions: the "level of emission reduction" and the "burden of implementation due to technical and financial boundaries". These two dimensions form a 2x2 matrix that results in the following four groups of low carbon measures.

[12] Among others, an event took place during the European Week of Regions and Cities in Brussels, Belgium, on 10th of October 2018 („Innovative green port solution in small and medium sized ports"), a workshop on LNG opportunities in Skagen, Denmark. on September 20th, 2018, and in Zwolle, the Netherlands, on April 24th, 2019, and a workshop on Green Port Officer Transfer in Oldenburg, Germany, on May 27th and 28th, 2019.

Measures with a low level of emission reduction combined with a low burden of implementation are labelled “NOW!”-methods that fill existing gaps and result in incremental benefits. They consist of process optimization (e.g. through digitization), increased measurement of environmental indicators, education and training for staff and management to raise awareness of ecological problems, and enhanced energy efficiency of buildings (e.g. through proper insulation).

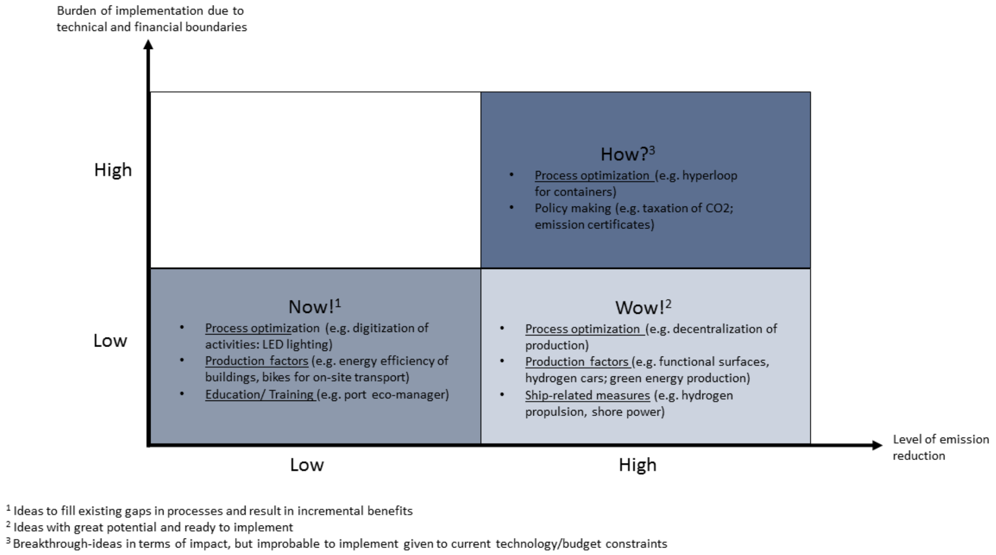
Second, measures with a high level of emission reduction combined with a low burden of implementation are labelled “WOW!”-methods. Green energy production is an example for this group of methods, a focus in the DUAL Ports project is e.g. on wave and wind energy generation close to the ports. The role of power supply at ports will gain importance, particularly on the vessel side, e.g. through an increasing use of shore power. On the other hand, on the non-vessel side, all other vehicles such as cranes or trucks shall switch from fossil fuels to electric engines. Further methods consider the use of bikes for on-site transports or the use of white surfaces for an increased albedo effect at ports.

Third, measures with a high emission reduction potential but also a high burden of implementation are entitled as “HOW?”-methods and contain breakthrough ideas that are impossible to implement with the current state of technology and budget. Similar to the previous two groups, the focus lies on process optimization. An example, but visionary, is the idea of a tube system (“hyper-loop”) which could transport containers within ports or to transportation nodes in the hinterland (e.g. freight yards).

And finally, fourth, measures with a low emission reduction potential and a high burden of implementation are of little interest since they don’t generate additional value for new concepts of ecologically and economically efficient ports. Therefore, they don’t need to be pursued any further.

The matrix helps sorting ideas of measures along the two dimensions level of emission reduction and burden of implementation due to technical and financial boundaries. Within the workshops, several initiatives of low carbon measures regarding the aspects of process optimization, production factors, education/training, ship-related measures, and policy making have been discussed (cf. Figure 2).

Figure 2: Classification of decarbonisation measures




Source: Przybyłek, A.; Zakrzewski, M. (2018); HWWI.

# 3 | Implications for low carbon policies

In the following, the perspective shall be widened from the DUAL Ports project towards a general consideration of low carbon development and policies in the maritime sector. The decarbonisation goals at the EU level will be reviewed and opportunities for regional ports to achieve these goals will be identified.

## 3.1 | Low carbon development in the EU maritime sector

By the "White Paper 2011 – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport" (European Commission, 2011), the European Commission adopted a roadmap of 40 concrete initiatives to improve mobility and to reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60 percent until 2050.

The key goals include

(i) a cut of at least 40 percent in shipping emissions;

(ii) a 50 percent shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.

In 2013, the EU adopted a strategy for progressively integrating maritime emissions into the EU's policy to reduce greenhouse gas emissions (European Commission, 2013). As a first step, the European Parliament and the European Council adopted the Regulation (EU) 2015/7575 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport (the "EU MRV Regulation") (European Commission, 2015a) in April 2015, which was completed in 2016.

According to the EU MRV Regulation, shipping companies must report their annual $CO_2$ emissions and other relevant information arising from their ships' voyages to and from ports, and within European Economic Area (EEA) ports. These obligations for shipping companies started in 2017 with the preparation and submission to accredited verifiers of monitoring plans. The monitoring of fuel consumption, $CO_2$ emissions and energy efficiency started in 2018 and the first emissions reports were due in April 2019.

The IMO followed the EC-scheme by establishing an IMO Data Collection System which entered into force in March 2018 and the collection of fuel consumption data which started on January 1st, 2019.

As a result, from 2019 onwards, ships calling into EEA ports are obliged to report under both the EU MRV Regulation and the IMO Data Collection System. However, both schemes are not fully aligned and in order to avoid excessive administrative burden, the

European Commission released a "Proposal for the Regulation of the European Parliament and of the Council" in February 2019, amending Regulation (EU) 2015/757 in order to take appropriate account of the global data collection system for ship fuel oil consumption data (European Commission, 2019c).

These regulations already in force or soon coming into force do not address ports directly but refer to those by stating "other actors of the shipping sector (such as; ship builders and marine equipment manufacturers, cargo owners, logistics companies and ports) are increasingly concerned to reduce their carbon footprint through improved technology and operations and to use the data to stimulate improvements to the energy efficiency of ships" (European Commission, 2019c).

Ports are transhipment hubs operating under national regulations which need to comply with EU-regulations covering industrial infrastructure and operations. Currently, there are no EC-regulations explicitly addressing the carbon footprint of ports beyond generally stating that mitigation is required in order to contribute to fulfilling the greenhouse gas emission target for 2050. However, as part of its research and innovation agenda, the Commission launched the "Port of the Future" call in 2016 as part of the HORIZON 2020 programme to encourage innovation in ports and links with port cities including environmental topics.

The borderline of ports as carbon dioxide emitters is identified by the gates (road and railway) and the jetty. Formally, a port is not responsible for carbon footprints off the port area. However, ports can organize and control hinterland transport and assist ships to reduce their carbon footprint by providing shore-based power and organizing LNG-bunkering. Thus, the potential port impact on local carbon footprint is considerably higher than just on port processes.

## 3.2 | Role of regional ports

Ports are nodes of the regional, national and global transport chains, which are challenged to contribute to a reduction of the EU-transport carbon footprint by 60% until 2050. Regional ports, in general small and medium ports, operate under similar conditions as large ports do, but on a smaller scale. However, ports with only regional significance do not usually have the same access to public funding as larger ports and hence, innovative measures including those aiming at the reduction of the carbon footprint are difficult to finance.

It is commonplace that transport infrastructure is a vital pre-requisite for the development of the economy, and ports play a prominent role in this context. Moreover, ports in general induce high direct and indirect employment (Lemper et al. 2019). Thus, regional ports are facilitators of regional socio-economic development and should not be left alone in the battle for lower carbon footprints. This task calls for joint efforts of industry, administration, policymakers, science and society.

Just because of lack of budgets, regional ports are usually not in the position to finance comprehensive sustainability measures to become "green". Regarding the reduction of the carbon footprint, quid pro quo solutions must be found, i.e. measures must not only reduce GHG-emissions (carbon dioxide and equivalents) but at the same time result in a payback through increase of process efficiency. As the carbon footprint of a port depends almost completely on energy consumption, there are good opportunities to at least partly finance measures by energy savings.

The core activity of a port is to provide transhipment services from shore to ship or vice versa. There might, however, be many other activities associated to a port from freight stations to refrigerated cold stores and from container repair to workshops making project cargo fit for sea transport. In most cases, these activities are commercially independent services and need to be considered independently from terminal operations. In the end, the carbon footprint of the whole port counts and individual contributions need to become accumulated. It is therefore advisable to establish an inter-company carbon footprint taskforce to tackle carbon dioxide emissions and equivalents to join endeavours and to learn from each other.

There are a few sources of carbon dioxide equivalents in a port not related to energy consumption, e.g. hydrofluorocarbons (HFC), used for refrigeration and air condition units, and sulphur hexafluoride (SF6), applied as insulation gases in e.g. power transformers. As their global warming potential is much higher than that of carbon dioxide, the GWP of SF6 is 23,900 times that of carbon dioxide, careful operation when storing, re-filling and use may have a significant mitigation effect on the carbon footprint even when only small quantities are to be considered.

### 3.3 | Opportunities for regional ports

Methodologies and best practice experiences how to mitigate carbon dioxide emissions from port operations are available. However, small and medium ports commonly do not have the resources to implement the whole scope of solutions. An action plan, roadmap or green port management (cf. Section 2.4) is required to provide guidance for successful reduction of the carbon footprint, even when resources are rather restricted. Many fields of activities could be addressed (cf. Table 1).

The calculation of the carbon footprint of a port based on the consumed (fossil) energy should not be considered as a cumbersome exercise but as an opportunity to realize efficient and transparent operations. Mitigation of carbon dioxide emissions of a port in general is achieved by reducing the energy consumption of the port and by increasing the share of regenerative energies.

To reduce energy consumptions, technical, organizational and behavioural measures are possible (cf. Table 2).

A core problem of ports is the lack of individual meters to measure consumption related to defined processes and equipment. As one can only manage what can be measured, installation of meters is crucial but costly. Thus, intelligent solutions based on the port process map, allowing step-by-step improvements to eventually achieve all required consumption figures is a reasonable approach and a core activity of Port 4.0 as a synonym for the digital port.

Moreover, it is worthwhile investigating the energy consumption profiles of different industrial port activities and consider the implementation of a joint demand-consumption scheme to balance peak loads and to optimally exploit volatile regenerative energies as e.g. from wind turbines or solar panels. Any technical solution to realize such a scheme requires a high-capacity buffer battery. Redox-flow batteries currently provide the most promising energy storage technology for ports, however, require high investment.

The control of the energy mix, improvement of power factor and load shedding calls for a smart energy management system. Potential savings are significant; however, converting existing systems and installation of a comprehensive energy management system requires big budgets. Therefore, this is primary a technical solution for a greenfield port/terminal or a comprehensive technical upgrade of a port.

Table 1: Carbon footprint assessment in ports

| Fields of activity | Description of selected examples |
|---|---|
| Identification of operational boundaries of all port actors not only for practical reasons but because carbon footprint reporting is a management task associated to business units. | – Terminal operators<br>– Storage services<br>– Haulage services<br>– Packing and stripping services<br>– Container cleaning & repair<br>– Canteens |
| Process map showing all relevant port processes providing the architectural framework to apply an energy management system. To not get lost in a high number of individual processes, port processes should become clustered. | – Berth operations<br>– Quay operations<br>– Marshalling<br>– Storage/Stacking (including reefers)<br>– Interchange<br>– Gate operations<br>– Equipment maintenance<br>– Administration<br>– Staff services<br>– Special services (non-terminal operations when integrated into port services)<br>– Inventories (handling equipment and other energy-consuming inventories)<br>– Yard areas<br>– Cold stores<br>– Buildings (office, workshops, social areas such as showers, coffee rooms, canteens etc.) |
| Implementation of an energy management system (EnMS) according to ISO 50001 to systematically record energy consumption, type (grid power, locally generated power, fuels, gas, distant heating) and source | |
| Quantification of greenhouse gas emissions based on EnMS-figures and conversion factors associated to energy type and source (ISO 14064-1) | |
| To minimize administration efforts and to base all energy consumption and greenhouse gas emissions recordings on the same consistent operational database, an integrated approach to manage energy and capture carbon footprint in one management system is recommended | An integrated QM-system combining ISO 14001, EMAS and ISO 50001 linked to other management standards as e.g. ISO 9001 will increase efficiency and support compliance |
| Energy consumption and associated carbon dioxide emissions (resp. equivalents) should serve as KPIs. | Setup of a continuous improvement scheme |

Source: HWWI.

Table 2: Classification of measures to reduce energy consumption in ports

| Measure | Description |
|---|---|
| Technical | – Replacement of equipment by fuel-/energy-saving systems<br>– Recuperation of energy (e.g. when lowering loads or braking vehicles)<br>– Avoidance of standby consumption<br>– Improvement of power factor (balance of inductive and capacitive loads)<br>– Load shedding (avoidance of peak loads) |
| Organizational | – Intelligent storage of commodities / vehicles / containers to avoid long distances and re-stowage<br>– Double cycles (container terminals) |
| Behavioural | – Training of crane and vehicle drivers to drive economically<br>– Explanation of principles of energy saving. |

Source: HWWI.

## 3.4 | Ports' priorities and actions

The European Sea Port Organisation (ESPO) represents port authorities, port associations and administrations of the sea ports of the member states of the European Union and of Norway. In the ESPO's Environmental Report, the organization interviews representatives of EU ports about their identification and monitoring of environmental risks to establish a list of the port's priorities for action and compliance.

In a first set of question, the ESPO collects yes and no answers about several ecological management indicators, e.g. "Does the port have an Environmental Policy?" (positive response rate in 2018: 96%); "Does the port have defined objectives and targets for environmental improvement?" (positive response rate in 2018: 93%); or "Does the port has a publicly available environmental report?" (positive response rate in 2018: 68%). All of these ports are members of EcoPorts Network.[13]

In a second catalogue of questions, the report captures sea ports' environmental monitoring attempts. Precise questions refer to the monitoring of waste, energy consumption, water quality, air quality, sediment quality, carbon footprint, marine ecosystems, soil quality, and terrestrial habitats.

[13] EcoPorts is the main environmental initiative of the European ports. It was initiated by a number of ports and has been fully integrated into the ESPO since 2011. The initiative principle of EcoPorts is to create a field on environment between ports. The initiative presents 25 countries, 114 EcoPorts members (among others Port of Bremen/Bremerhaven, Niedersachsen Ports Emden Branch, Hamburg Port Authority, Port of Rotterdam Authority, Port of Le Havre Authority), 33 pers certified ports, and 53 ISO certified ports (EcoPorts Network, 2019).

In a third list of questions, the report tries to establish a ranking of the top environmental priorities of the sea port sector according to the ports' managing bodies. In different intervals, the representatives of the sea ports prioritized different criteria of ecological measures (cf. Table 3). As portrayed below, "air quality" has remained the number one priority for the ports' managing bodies from 2013 to 2018 whereas the top priority of 2004, "Garbage and Port waste", is now missing in the current top seven ranking. In 2018, for the first time, the priority "climate change" appears in the ranking. Moreover, city port issues are regarded of high relevance by European ports. This is as well reflected in the development (ESPO, 2018).

Overall, the report shows that environmental topics matter in the context of regional port development. Smaller ports also should consider implementing environmental protection measures, many of them already participating in the main green port initiative of European ports. However, there is still enormous potential for positive development and participation.

Table 3: Top 10 environmental priorities[1]

| | 2004 | 2009 | 2013 | 2016 | 2018 |
|---|---|---|---|---|---|
| Air quality | 6 | 2 | 1 | 1 | 1 |
| Energy consumption | : | 7 | 3 | 1 | 2 |
| Noise | 5 | 1 | 4 | 3 | 3 |
| Relationship with community | : | 6 | 6 | 4 | 4 |
| Ship waste | : | : | 5 | 6 | 5 |
| Port Development (land) | 9 | 10 | 9 | 7 | 6 |
| Climate Change | : | : | : | : | 7 |
| Water quality | : | : | 10 | 8 | 8 |
| Dredging operations | 2 | 4 | 7 | 10 | 9 |
| Garbage/ Port waste | 1 | 3 | 2 | 5 | 10 |
| Dredging disposal | 3 | 5 | : | : | : |
| Dust | 4 | 8 | 8 | 9 | : |
| Hazardous cargo | 7 | : | : | : | : |
| Bunkering | 8 | : | : | : | : |
| Port development (water) | : | 9 | : | : | : |
| Ship discharge (bilge) | 10 | : | : | : | : |

[1] Priority areas according to the ports' managing bodies by year.

Source: ESPO 2018, HWWI.

# 4 | Conclusion

Summing up, it has become apparent that energy use in the form of fossil fuels is the main source of carbon emissions in/of ports. Therefore, substituting energy from fossil carriers with less emission-intensive alternatives offers the biggest potential to decarbonise ports. Additional emission reductions can be achieved through improved efficiency, e.g. through intelligent management of energy use and generation and, more generally, through process optimization.

The paper at hand gives some insights to low carbon activities, i) alternative material use and treatment in ports; ii) alternative energy generation or savings; iii) alternative fuels for propulsion; and iv) green port management. In principle, small ports face the same issues as larger ports in terms of decarbonisation. Regional ports may be more suited for the testing of innovative technologies on a smaller scale. In order to systematically decarbonise ports, the focus should be on individual business units (storage, un-/loading, power/heat generation etc.), which may even be separate businesses. Green port management plans are helpful to coordinate the efforts of different actors and to ensure a regular monitoring of the progress.

Moreover, in many cases ports, especially small ports are not just a transhipment site to move cargo and passengers from shore to sea and vice versa, but a conglomerate of various industrial services, frequently including production sites. An coordinated energy demand and supply cluster allows sharing costs, making technical solutions and experts' advice affordable also for smaller ports. To commence is easy and simple: sitting together to share ideas and to identify opportunities.

From a national or international public policy perspective, decarbonisation can be achieved through a carbon emissions certificates or carbon tax. On the one hand, the EU has already established a carbon trading systems (EU Emissions Trading Systems), but it concerns mainly energy intensive industries. Since there was a high supply of permits on the market, carbon prices in the EU remained low for years. The programme currently has a relatively limited effect on avoiding emissions. For diminishing emissions, it is worthwhile to consider an EU-wide system to all sectors and to reduce the number of free certificates. On the other hand, it could be efficient to implement a tax-based instrument (Pigovian tax). It is simply intended to directly charge the producer of the emission for the negative externality on society.

To conclude, regional ports in the EU are capable of achieving the desired decarbonisation targets. As they are less able than bigger ports to manage the corresponding transitions by themselves, superordinate policies are beneficial. Policies fostering low carbon development of regional ports may consider, firstly, financial assistance regarding one-time switching costs in the field of energy generation, secondly, networking assistance regarding the exchange of best practices between different actors, and thirdly, research assistance regarding the development of innovative low carbon measures which can be tested in the smaller regional ports.

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