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Towards Green and Smart Seaports: Renewable Energy and Automation Technologies for Bulk Cargo Loading Operations

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***Abstract* – In 2018, 4.1 billion tonnes of freight and 437 million passengers passed through the 1200 European ports. This dimension of geographically concentrated activities is the rationale that ports are characterised by a high-energy demand and a high share of emissions. Driven by a growing awareness for a cleaner environment, a stronger focus on sustainability and intensified environmental regulations, ports are forced to take responsibility when it comes to environmental issues. As a response, in recent studies, the concept of 'green ports' emerged. Simultaneously, in the context of digitalisation, the term 'smart ports' has received growing attention in the latest scientific discussions, too. Since an important driver towards greener maritime operations is linked to digitalisation, we argue that digital efforts in ports should next to the automation of inherent logistics processes also contribute to reducing the emissions and energy demands. Previous studies have primarily concentrated on the automation of container handling operations. Hence, there exists a research gap concerning the automation of bulk cargo handling operations in ports. Thus, this study addresses the question of how to automate the dry bulk cargo loading operations in the frame of a green and smart port development. The developed case study refers to the seaport of Wismar, whereby the results show that the digitalisation and greener port operations can be successfully aligned. Overall, this study extends the discussion on green and smart port development, while it contributes to the scientific literature by proving that both conceptual ideas can be achieved in the operating business.**

***Keywords* – Clean port operations; digitalisation; digital transformation; emission reductions; IIoT (Industrial-Internet-of-Things); sustainable energy management; 5G networks**

1. INTRODUCTION

Ports, as multi-activity transport and logistic nodes, play a crucial role in the development of the economy in general and the Blue Economy in particular, as ports provide the basic infrastructure and services for diverse sectors, including marine living resources, marine non-living resources, marine renewable energy, maritime transport, coastal tourism, maritime defence, etc. Hence, ports are the heart of the maritime industry, as they are the departure,

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entry and transfer points for all goods, services and persons transported by vessels [1]–[3]. Concerning Europe, in 2018, 70 % of all goods were transported to or from ports outside the EU-27, making maritime transport the most important mode for long distances [4]. In total, 4.1 billion tonnes of freight and 437 million passengers passed through the 1200 European ports in 2018 [5], [6].

This dimension of geographically concentrated activities is the rationale that ports are characterised by a high-energy demand [7] and a high share of emissions. As a consequence of growing public awareness for a cleaner environment, a stronger focus on sustainability and intensified environmental regulations [8], nowadays ports are forced to take responsibility when it comes to environmental protection and underlying pollution problems [9]–[15]. This requires a holistic green and sustainable management, where the focus is on reducing environmental pollution stemming from operations at ports. As a response to this, in recent scientific studies, the conceptual idea of 'green ports' emerged, in which environmental proactive behaviour and economic interests are balanced. According to Maritz *et al.* [16], the central idea behind the concept is to transform ports, so that they become characterised by reasonable utilisation of resources, low energy consumption and low levels of pollution. In this context, Notteboom *et al*. [17] identified in their study five core groups of actions to pursue green supply chain management (GSCM) objectives in ports, namely:

1. Green shipping;
2. Green port development and operations;
3. Green inland logistics;
4. Seaports and the circular economy; as well as
5. Actions in the field of knowledge development and information sharing.

Hence, ports as central players in the maritime sector have a crucial strategic position concerning more sustainable and greener development. As stated by Sakty [18], energy efficiency in connection with novel technology adoptions can be a pivotal tool to engage in green initiatives for a cleaner sector. Thus, the most critical in this regard is the necessity for the ports to become more energy efficient.

An important driving factor towards greener maritime operations is linked to digitalisation [2], [9]–[12]. As stressed by Iris and Lam [19], climate change mitigation is a key target for the port industry, whereby the use of innovative technologies appears as a critical conduit in achieving a transition from a carbon-intensive port industry to a low-carbon port model by harnessing renewable energy, alternative fuels, smarter power distribution systems, energy consumption measurement systems. According to their literature review article, although the number of studies in the field of energy efficiency and eco-friendliness for green ports is slowly developing, but still there are not many ports that have installed smart solutions for better energy management, which opens many research opportunities. Thereby, it needs to be noted that in the context of ports and digitalisation, the term 'smart ports' has received growing attention in recent scientific discussions [2], [10], [20]–[22]. One of the first attempts to define the idea of smart ports can be found at Yang *et al*. [23], who described visionary a smart port as a fully automated port in which all devices are connected via the IoT, and a network of smart sensors, actuators, wireless devices and data centres form the key infrastructure. As stated by Douaioui *et al*. [24], the development towards a smart port is an innovative venture that targets to enhance port competitiveness and foster entrepreneurial collaboration with port stakeholders in order to achieve vertical and horizontal integration of supply chains. Therefore, as derived by Gardeitchik *et al.* [25], the digital transformation in ports is targeted to reach the highest digitalisation level, which is characterised by the smart port vision, whereby ports are optimally connected with their environment and all ports globally with each other through the application of diverse digital technologies.

Based on these insights, it is argued in the present study that digital efforts in ports should next to the automation of inherent logistics processes also contribute to reducing the emissions and energy demands. At the same time, this implies that the concepts of green ports on the one hand and smart ports on the other hand have to be aligned on each other or synthesised, respectively. A review of the scientific literature revealed that the research on the harmonisation of the green and smart port ideas have not been sufficiently investigated until now. Indeed, Chen *et al*. [26] endorse a simultaneous pursuit of both concepts, but next to their proposed significant theoretical governance framework, it lacks practical examples and affirmation whether the inherent goals of both conceptual ideas can be actually reconciled in the operative port business. According to Creswell and Creswell [27], if a concept or phenomenon needs to be understood because less research has been done on a specific topic, particularly the qualitative research approach is useful. Therefore, the case study approach was selected for the present study.

The previous digitisation efforts in ports have primarily concentrated on the automation of container handling operations, since TEUs as a standardized unit are much easier to handle than liquid or dry bulk goods, and therefore offer optimisation potential that can be quickly achieved [2]. Clearly, significant research gaps are yet to be filled on success stories concerning the digitalisation and automation of bulk cargo handling operations in ports. Bearing this in mind, the study addresses the research question of how the dry bulk cargo loading operations can be automated in the frame of a green and smart port development. The case study that builds upon expert interviews, field research, observations and a literature review, refers to the seaport of Wismar. The research results in form a conceptualised 'green and energy self-sufficient fully automated dry bulk cargo plant' show that the digitalisation and greener port operations can be successfully aligned and thus, a substantial contribution to the development towards a green and smart seaport is made. Overall, this study extends the discussion on green and smart port development, while it contributes sustainably to the scientific literature by proving that the inherent goals of both concepts can be achieved simultaneously in the operating port business.

The paper is structured in the following way: The next section describes the theoretical background, which primarily refers to business model innovation, since process automation efforts regularly lead to the development of new business models or the adaption of established business models. In a subsequent step, the used methodology is set out. Building upon this, the research findings are presented, whereat the article rounds up with a discussion and conclusion.

2. THEORETICAL BACKGROUND

Green and environmentally friendly operations in the maritime sector enjoy high attention on the global political agenda [8]. By considering the activities of the International Maritime Organization (IMO), an emphasis lays on limiting all kinds of emissions, to reduce energy consumption and to safeguard a clean maritime environment. Hence, new approaches for ships and ports are required to improve energy efficiency, reduce emissions and realise greener maritime operations [28]. An important instrument for hoisting sustainability gains in the maritime sector lies in digitalisation [9]–[12], whereby the improvement potentials heavily depend on the regional (digital) technological readiness and innovation potential [29], [30].

Within the scientific literature concerning digitalisation in ports, one of the main focuses is on automating processes in large container ports, since among other things, automation in the case of standardised units like TEUs (Twenty-foot Equivalent Unit) is much easier to implement than – for instance – in case of dry bulk goods [3]. Such process automation efforts regularly lead to the development of new business models or the adaption of established business models [31], [32]. Business model adaptions or developments are usually associated with the output of business model innovation. According to Geissdoerfer and Vladimirova [33] as well as Mitchell and Coles [34], business model innovation is the conceptualisation and implementation of innovative business models, which incorporates the creation of completely new business models, the diversification for an increased variety of business models, the acquisition of novel business models, as well as the transformation of business models, where changes refer to the entire business model or some specific parts – like value proposition, creation, delivery, capture, relationship and network. Thus, business model innovation does not exclusively build upon the development of new business ideas, but the deployment and utilisation of existing resources and capabilities to develop new value propositions or novel forms of value creation [35]. Thereby, within the process of development, the focus goes regularly beyond the inner company perspective and involves different stakeholders, which culminates into a wider value-network perception in order to transform or create an innovative business model [36]. Moreover, the capability to regularly develop business model innovations can increase a firm's robustness against rapidly changing market conditions and environmental pressures and thus, may constitute a competitive advantage [34], [37], [38]. However, in conjunction with the digital transformation, Ibarra *et al*. [39] stress that firms have to focus on service orientation, networked ecosystems and customer orientation, and thus, in order to achieve business model innovations, have to concentrate on the optimisation of internal and external processes, the improvement of customer relationships and the creation of new value networks as well as smart products and services.

In accordance with this, the case study that refers to the seaport of Wismar in the further discourse of the present research focuses on the optimisation of the internal port processes in relation to the dry bulk loading operations. Therefore, the established business model by the port is adapted by process automation measures while the green image of the port is improved as well. For this purpose innovative and state of art technologies as well as capabilities are bundled in order to develop an enhanced form of value creation. Accordingly, the underlying processes are improved based on a stronger customer and service focus, which finally culminates in green and smart dry bulk cargo loading service at the seaport of Wismar.

3. METHODS AND METHODOLOGY

The research on automation technologies in the nexus of dry bulk cargo loading operations as well as the harmonisation of the green and smart port idea have not sufficiently investigated in the scientific literature until now. Accordingly, to the best of our knowledge, currently there exist no published work that discussed how dry bulk cargo loading operations could be automated and whether digital and green goals in seaports actually can be reconciled in practice. Following Creswell and Creswell [27], if a concept or phenomenon needs to be understood because less research has been done on a specific topic, particularly the qualitative research approach is useful. Correspondingly, in the course of the current study, the decision was made to favour a qualitative research approach. However, the research was performed based on quantitative and qualitative data, which was synthesized in order to most effectively tackle the identified research problem. Thus, the authors collected quantitative and qualitative data and combined the received information in the frame of the interpretation process that drove the showcased research findings. Therefore, qualitative research in this study represents narrative research. In the frame of narrative research, the collected information is condensed and retold [27].

The study was initiated by an internal feasibility study from Wismar seaport conducted in 2019. Building upon this, the research was complemented by field research and observations, as well as an extensive literature review of related theories and approaches, topic-related policy regulations and guidelines. In addition, the authors of the present study performed expert interviews with six project companies that are specialised in process automation, renewable energy solutions, software development, energy supply, operation of measuring points, and shipping of dry bulk goods. The structured and semi-structured expert interviews that delivered the quantitative and qualitative data lasted about one hour each and took place in January 2021. These expert interviews were prepared, performed and analysed by following the guidelines of Kvale [40] as well as Miles and Huberman [41]. In a supplementary step, a case study was elaborated according to Yin [42], which draws a holistic picture of the triangulated qualitative and quantitative data gathered in the frame of the study [43]–[45]. Accordingly, the researchers identified common functionalities of green and smart technology integrations in the dry bulk cargo loading process and thus, were able to outline additionally the advantages – in form of performance improvements – of the necessary technology adaptions and related guidelines for efficient implementations. In accordance with this, it can be noted that the qualitative research approach safeguarded the examination of the identified research problem in a comprising manner.

Lastly, the underlying research activities were performed in the frame of the still ongoing INTERREG projects CSHIPP and Connect2SmallPorts. The CSHIPP project focalizes on sustainable transport, with the goal to enhance clean shipping based on the increased capacity of maritime actors of the whole Baltic Sea Region (BSR). The project is part-financed by the ERDF, as it is implemented in the framework of the INTERREG V B Baltic Sea Region Programme. The Connect2SmallPorts project focusses on improving cross-border connectivity for a functional blue and green transport area, with the objective to enhance the quality and environmental sustainability of transport services in South Baltic Sea Region (SBSR), with a specific emphasis on digitalisation issues in small and medium-sized ports – particularly Blockchain and IoT. The project is part-financed by the ERDF as well since it is implemented in the framework of the INTERREG V A South Baltic Programme.

4. RESULTS

4.1. Case Study Description

The case study seaport of Wismar is a comprehensive port according to the analogy of the Trans-European Transport Network (TEN-T). This means that the port of Wismar can be classified as a medium-sized or regional seaport [9], [12], [20]. According to the study of Philipp [22], the port achieved a result concerning the ‘digital readiness index for ports’ (i.e. DRIP score [21]) of 3.512, which suggests that Wismar seaport can be classified as an ‘Adopter port’ (i.e. third maturity stage towards smart port development). In 2019, the overall cargo throughput amounted to 6 091 976 tonnes, whereby about 91 % are attributable to dry bulk goods. Furthermore, 4445 passengers transited the BSR seaport in 2019 [22].

Therefore, it can be noted that the seaport is specialized in the handling of dry bulk goods. In accordance with this, the case study of the seaport of Wismar targets the full automation of the dry bulk cargo plant, which will be operated by self-generated renewable energy through a combination of solar and wind power. Hereby, the aspired full automation ensures the reduction of energy consumption and downtime of the system. The envisaged ‘green and energy self-sufficient fully automated dry bulk cargo plant' builds upon the implementation of the following four subsystems:

1. 5G campus network;
2. Wind power station;
3. Photovoltaic plants, and
4. Fully automated ship loader.

4.1.1. 5G-campus network

The establishment of the 5G-campus station is an innovative endeavour since 5G network implementation is still in its early stage and so far not realised on a commercial scale in the private sector – i.e. in companies and their service processes. Hence, the aspired private 5G network implementation in the seaport of Wismar represents an absolute novelty. The so-called 5G campus network forms the basic digital infrastructure for the transmission of corresponding data in the frame of the envisaged fully automated ship loading operations. Thus, the huge amount of data that needs to be processed and managed during fully automated ship loader operations makes a 5G network support necessary. According to a conducted feasibility study, the predecessor, 4G frequency, do not fulfil the corresponding requirements. The bulk cargo plant at the terminal that will be equipped with the 5G network is showcased in Fig. 1 below.

Fig. 1. Bulk cargo plant in the seaport of Wismar [Compiled by the authors].

Within a 5G network the radio network (RAN – radio access network) connects the end devices via the base stations (gNB – next-generation Node B) with the User Plane Function (UPF) and with the 5G Core Control Plane. The gNB consist of transmission equipment, the associated antennas and a spatially separated unit for signal processing. The UPF is the gateway to control and forwarding of user data. The 5G core control plane (5GC-CP) is the core network, which consists of some individual elements that are required for separation, prioritisation and access control. The administration of user data takes place in Unified Data Management (UDM), which contains the user data including special profiles and rules. An important innovation of 5G networks is the possibility of providing local or network-related computation capacities using Mobile Edge Cloud, a local cloud infrastructure in the network applications programme, for processing without causing long parcel delivery times [46].

With such a separate 5G campus network, the campus operator becomes a local private 5G network operator. Construction and operation of the 5G campus is the responsibility of the campus operator. It should be noted that there will be no integration with the public cellular network. The following requirements need to be fulfilled:

- Building an individual, privately usable mobile network with its own network ID and strict separation from the public mobile network through separate hardware and software as well as through different radio bands;
- Local radio frequencies license for 5G must be requested at the Federal Network Agency (Germany).

4.1.2. Wind power station

The implementation of the needed wind power station represents as well an innovative endeavour since currently there is no suitable system of the required size (i.e. the maximum height of 50 m with 150 kW nominal power and an annual output of 500 000 kWh) on the market. The only system that would have fit for the envisaged requirements, the 'b.ventus machine', was withdrawn from the market due to technical problems and excessive noise emissions. Furthermore, the rotor was simply too big for a system with a total height of 50 m. Hence, the manufacturers neither of small nor of large systems currently offer a suitable system for the German market of the required size. There are some smaller systems between 50 and 100 kW available, however, some of the system concepts are relatively outdated and their annual output is not even 50 % of the predicted requirements. Moreover, field trials of such systems showed that the previously indicated output forecasts are generally doubtful. Lastly, due to the latter two points, some of these systems cannot be set up or connected to the local energy grid. Nevertheless, expert interviews with a project company revealed that such a wind power station with a maximum height of 50 m, 150 kW nominal power and an annual output of 500 000 kWh is possible to develop as well as is necessary according to the site conditions and requirements. Accordingly, such a wind power station will be piloted, while it will also receive the required certificates for the German market. The determined suitable space in the port area for the wind power station is marked green in Fig. 2.

Fig. 2. Space for wind power station [Compiled by the authors].

4.1.3. Photovoltaic plants

The overall energy demand of the bulk cargo plant will be additionally met by photovoltaic plants on some of the roofs of the warehouses in the port. There exists already a wide variety of suitable solutions on the market. Thus, this sub-system does not need to be completely newly developed – in comparison to all other three sub-systems. Electricity is currently supplied through the municipal utilities. Based on the performed feasibility study, the overall energy demand of the bulk cargo plant, which equals 1.3 million kWh per year, will be covered by a generation system that uses wind and sun in a ratio of 1:1 in the nominal power (empirical values and optimisation calculations for the corresponding latitudes, including annual mean wind in Wismar of 6 m/s). The corresponding photovoltaics, each with a 300 kW peak and an annual output of 250 000 to 300 000 kWh will be installed on suitable sun-facing roofs that are marked green in Fig. 3.

Fig. 3. Suitable facilities for photovoltaic plants [Compiled by the authors].

To sum up, through the implementation of the wind power station and the photovoltaic plants, it will be possible to operate the bulk cargo plant with self-generated renewable energy. The surplus generated energy that exceeds the own consumption will be fed into the urban grid. The annual output of the wind power station will be around 60 % in the winter half-year and 40 % in the summer half-year. Against this, in the case of the photovoltaic plants, the annual output will be around 20 % in the winter half-year and 80 % in the summer half-year. Based on these insights regarding volatility, both, the wind power station and the photovoltaic plants have been planned in a way that they culminate in equilibrium over the year regarding the overall energy demand of the bulk cargo plant. Hence, surplus generated energy in the energy productive season will be fed into the urban grid, whereby in the hardscrabble energy season, the previously surplus generated energy will be retrieved back from the urban grid.

In order to operate the system with completely self-generated electricity, the following requirements must be met:

- Wind energy station with a maximum height of 50 m and a rotor diameter of 35.7 m (so the plant is considered a so-called privileged plant and does not require a wind suitable area;
- At least 150 kW nominal power to achieve the expected annual output of 500 000 kWh with at least 6 m/s annual mean wind;
- In addition, there will be photovoltaics with at least 300 kW peak, on an area of approx. 6000 m².

4.1.4. Fully automated ship loader

The implementation of the fully automated ship loader represents as well an innovative endeavour as such a system currently do not exists on the market and thus, will be piloted. The loader consists of a chassis, rotary/swing mechanism, and boom with adjustment drive, conveyor belts and telescopic downpipe, as well as the conveyor belt for product delivery (cf. Fig. 4). This still manually controlled ship loader has a capacity of up to 600 tonnes/h for loading fertilizers, soda, potash and salts of all kinds into ships. The ship loader constructed in 1980 has already been revised several times and thus, currently corresponds to the state of the art: semi-automation and electrical engineering were implemented and revised in 2010.

Fig. 4. Bulk ship loader [Compiled by the authors].

Currently, one person manually controls the loader on site. This is done with the assistance of a radio control table, which the employee carries with him on the go. The setup or orientation before and after the start of the conveyor process is carried out manually on sight, i.e. all positioning tasks of the ship loader are currently carried out and monitored by a human being. The loader can operate with respect to a wide variety of ship types. Nevertheless, the general cargo carrier and bulk carrier without loader are the most common ship types served by the ship loader in the seaport of Wismar. Bulk carriers with loaders are very rare to load.

A standard semi-automation system has no information about the actual shape of the ship or the position of the hatches. Therefore, the operator must manually load the ship from the operator's cabin or via the remote control. Hence, in this current manual operation, the following tasks must be performed:

1. Positioning the ship loader for the new ship;
2. Distribution of the material according to the loading plan;
3. Change of hatch according to the loading plan;
4. Starting/stopping the conveyor belts.

The aim is to operate the ship loader unmanned and fully automatic in conveyor and set-up operation. This means that the ship loader should only be monitored via screens from the central control centre of the port.

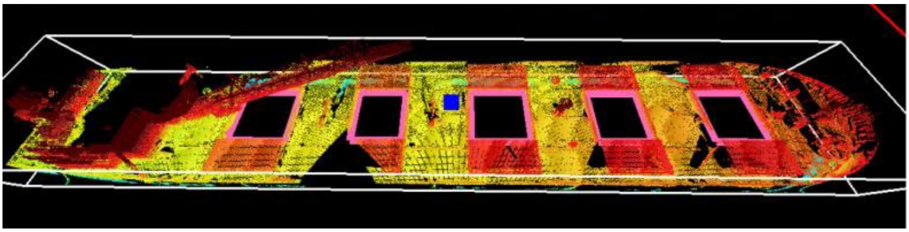

Fig. 5. 3D Scan of a bulk carrier [47].

Adding a real-time 3D ship model to the base automation system eliminates the need for manual tasks. This allows the machine control to carry out the entire loading process without manual intervention. It also provides a real-time view of the ship including all hatches, which allows much better control of the equipment during loading. Practical experience tests have shown that the necessary accuracy to automatically position a ship loader is in the range of

10 to 25 cm, depending on the material characteristics and the machine size. This requires the use of 3D scanning and GPS technology to accurately measure the ship, hatch and material position as well as the position of the machine. The 3D scan of a bulk carrier is shown exemplarily in Fig. 5.

In order to assemble a complete 3D scan during the loading process and to connect multiple scans, the exact position and orientation of the machine (i.e. loader) must be known. Conventional position sensors are usually not accurate enough and do not provide the required timestamp provided by GPS. Hence, the 3D scanners must be equipped with a special interface to mark the scan data with the high-precision time information of the GPS. These timestamps will be then available to the system to securely assign the 3D cluster of points to the position data, even while the machine is moving or delays occur during data transmission.

To ensure seamless integration and anti-collision formations, not only for the device itself but also for deck setups or equipment attachments (device structures), the following key functions must be available, which have to be configured precisely within the system:

- Automatic online generation of the ship model during loading;
- Hatch and hatch lid detection;
- Correction of stored scan data during ship movements;
- Customisation of a 3D ship model loaded from the database when the same ship (IMO number) is re-established and the first hatch is scanned;
- Movement of virtual cameras (position can be fixed to the boom, i.e. the cameras move with the boom);
- Brake and stop zones provide distance to the nearest object and activate intelligent braking functions, based on the direction of movement and distance, to stop safely from a collision with situational warnings for the operator, for hard-to-view areas and follow the independently moving structures of the machine, such as a telescopic downpipe or the operator's cabin;
- Fading areas to avoid self-identification of the machine.

The transfer of the order data, as well as the command start/stop and parking position concerning the fully automated loader will be carried out from the control room via the Port Management and Operations System. This superimposed system will communicate with the ship loader's *SCADA* system (Supervisory Control and Data Acquisition System). Thus, the communication type and the data structure have to correspond to that of an *MES* (Manufacturing Execution System) to a *SCADA*. In addition to a normal operating stop, emergency stop functions will be implemented according to the machine policy. Generally, the staff of the control station must be able to ensure proper and safe operation without looking directly and permanently into the system.

In order to implement these technical possibilities, and to prevent disconnections during data transmission, the 5G network is needed. For this purpose, however, a so-called radio network planning must be carried out in advance in order to prevent frequency ranges from overlapping that occurs between other networks and the new network.

4.2. Performance Improvements

4.2.1. Operational performance

The operational performance of the bulk cargo plant will be improved due to full automation. Among other things, this allows for operations during rain. Currently, the loading of a typical ship with a capacity of 3000 tonnes lasts on average about 11.25 hours due to varying weather conditions. The maximum loading duration of such a ship amounts to15 hours, which equals two work shifts, whereby each work shift contains 0.5 hours break for the employee, the loader. Due to automation of the entire loading process, labour is set free for other tasks within the port and no breaks occur. As a result, the loading of such a ship with a capacity of 3000 tonnes will last only 7.5 hours, which equals an occupancy rate of 100 %. This reduction in loading time or reduces the energy consumption.

As stressed by Johnson and Styhre [48], vessels spend more than 40 % of their time in ports and half of the time is not productive; whereby the two major reasons are that ports face limited working hours and ships often arrive too early or too late, which causes that the stevedores are not available to load or unload the cargo. Consequently, they estimated that one to four hours of reduced time per port call lead to a reduction in energy use of 2–8 %.

According to the proposed full automation of the bulk cargo loading plant, this energy efficiency improvement is achievable, since loading operations are streamlined and human capital in form a loader or stevedore on site at the quay is no longer needed. Furthermore, due to decreasing loading costs in Wismar seaport, the offered price to customers will be reduced as well, which in turn will result in a competitive advantage for the port.

4.2.2. Environmental performance

The bulk cargo plant has an energy demand of about 1 300 000 kWh per year, which equals about 50 % of the entire energy demand of the seaport of Wismar. According to this, the plant produces currently about 521.3 tonnes of CO_2 annually (i.e. based on average CO_2 consumption of 401 gram per kWh [49]), which can be saved to a large extent through the provision of self-generated green energy by a combination of solar and wind power, and full automation that ensures, on the one hand, the reduction of energy consumption and on the other hand the downtime of the system. This is because the wind power station will account only for about 15 tonnes of CO_2 emissions per year and the photovoltaic plants in sum only for about 35 tonnes of CO_2 emissions per year. Accordingly, at least 470 tonnes of CO_2 emissions will be saved every year (excl. energy savings due to streamlined loading operations – cf. chapter 4.2.1), which equals about 45 % CO_2 savings concerning the entire port. Hence, the switch towards a fully automated bulk cargo plant, which is powered by renewable energy, will contribute enormously to the goal of ‘green and energy self-sufficient fully automated bulk cargo loading operations’ in the seaport of Wismar.

4.2.3. Quality performance

The quality performance of the loading service concerning bulk goods will be improved as well. Of course, a series of training have to take place for the port operators with regard to the novel fully automated ship loader in order to safeguard a high-quality service level at all times. Nevertheless, especially through the fully automated process, the loading operations can be performed more accurate or precisely, respectively. This is important for the ship-owners concerning ballast water and thus, also for the environment. Ballast water is used to compensate for weight imbalance in order to maintain trim and stability. With regard to the ballast water management system, weight awareness is one of the most important indicators for load planning as it affects the balance of the whole vessel and thereafter the amount of ballast water that is needed to maintain balance. Apparently, excess ballast water leads to fuel wastage and additional issues when navigating the vessel. Moreover, using less ballast water means the reduction of negative ecological impacts due to the multitude of marine species carried in ships' ballast water tanks. A method to reduce the amount of ballast water is to plan cargo on the deck more evenly. Furthermore, it is possible to maximise the effectiveness by using the cargo itself as an effective weight for the vessel. Thus, the weight of the cargo can partly replace the weight of ballast water [10]. Hence, the case study also tackles a major issue that is characteristic for numerous ports and terminals serving vessels around the world: how can the ballast water be efficiently and sustainably reduced through the improvement of the load planning process when serving ships. The answer is obvious: Through automation of the entire loading process and thus, the gathering of real-time data through IoT sensor applications and direct processing via Artificial Intelligence (AI) systems on the basis of uploaded ship models. According to the study of Henesey *et al.* [10], an optimised load planning process can improve the usage of ballast water by 50 % to 160 %.

4.2.4. Financial performance

Finally, the analysis of the financial performance regarding the energy cost efficiency revealed a needed investment budget of about EUR 970 000 for the wind power station (EUR 770 000) and the photovoltaic plants (EUR 200 000). For the calculation of the annual annuity, the following formula was used:

$$Annuity = CAPEX + OPEX \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1}, \tag{1}$$

where

CAPEX	Capital expenditure;
OPEX	Operational expenditure;
i	Interest rate;
n	Number of years.

In accordance with the economic lifetime of the two investment components together with annual maintenance and service expenditures of 10 % and 5 % of the initial investment sums and an underlying interest rate of 6 %, the calculation yields an annual annuity of about EUR 132 098.25 for the first 10 years of the investment. By taking into account the energy savings of about 1 300 000 kWh per year and the CO_2 reductions of about 470 tonnes per year, the following prices will be achieved:

- Price per saved kWh: EUR 0.10;
- Price per saved CO_2 tonne: EUR 281.06.

These prices have to be regarded in a more differentiated manner. The German electricity prices for industrial clients range around EUR 0.15 per kWh [50], which implies energy price savings of about EUR 0.05 per kWh or energy cost savings of EUR 62 901.75 per year.

Concerning the price for a saved CO_2 tonne, a look at the German carbon tax shows a price of EUR 25.00 per tonne of CO_2 [51], i.e. the price per saved tonne of CO_2 of the investments at Wismar seaport is more than eleven times higher than the carbon tax. Accordingly, this yields a CO_2 price spread of EUR 256.06 per tonne or surplus costs for saved CO_2 of EUR 120 348.25 per year.

Hence, the energy cost savings and surplus costs for saved CO_2 result in annual surplus costs of EUR 57 446.50 for the alternative power systems in the seaport of Wismar compared to the current situation. A short analysis of the current and planned carbon pricing in the BSR reveals that the highest carbon tax rate is charged in Sweden with about EUR 110.00 per tonne CO_2, whereby all other BSR countries charge less than EUR 70.00 per tonne of CO_2. Moreover, by considering the planned carbon pricing in the EU, it can be stated that the majority of the national carbon taxes will range within the upcoming years below EUR 100.00 per tonne of CO_2 [51]. In the case of the planned investment in the alternative power systems in Wismar seaport, this is still at least 47.23 % below the break-even price (EUR 147.23).

Hence, it can be expected with a high probability that the carbon tax rates will stay significantly below the calculated price per saved tonne of CO_2 in the seaport during the full investment period of 10 years.

5. DISCUSSION AND CONCLUSION

This study investigated whether the digital and green goals in ports can be simultaneously achieved and how dry bulk cargo loading operations can be automated. The case study of Wismar seaport showcased that the digitalisation and greener port operations can be successfully aligned and thus, a substantial contribution to the development towards a green and smart seaport is made. A closer look at the performance improvements exemplifies that the planned investments in the port targeting sustainable full automation of the loading process have positive effects on several levels. Among other things, the service quality and the environmental performance are significantly improved in terms of:

1. Less ballast water use by the ship-owners and thus, less waste of ship fuel.
2. 45 % CO_2 savings concerning the entire port as well as the operational performance in terms of:
   a) reduced loading time;
   b) optimal occupancy rate of 100 % in case of the bulk loading plant and
   c) reduction of loading price for customers.

Against this, the financial analysis regarding the energy cost efficiency revealed that from an economic point of view the planned investments are not yet fully convincing. Although the needed investment budget of EUR 970 000 for the wind power station and the photovoltaic plants yields a price for the assumed energy savings of about EUR 0.10 per kWh, the price per saved CO_2 tonne is with EUR 281.06 currently eleven-times higher than the CO_2-tax of the German government. Hence, it can be concluded that only a holistic evaluation of all four subsystems together with public project support financing from 'Green Deal' sources may turn the investment into financial success. Thus, under this premise, it can be stated that the demonstrated use case of smart and green dry bulk cargo handling operations can be easily adopted by other ports.

The 5G campus network, wind power station and fully automated ship loader will be piloted. Each of the four use cases or sub-systems needs to be implemented, configured and adjusted according to the requirements and site conditions of the port in order to safeguard the achievement of the superordinate goal in form of smart and green cargo handling operations in the seaport of Wismar. Accordingly, the crux of the matter is the configuration or creation of a symbiosis between all four systems. Hence, the final challenge of the overall use case is the optimal harmonisation of all four sub-systems to one. Subsequently, the fully automated ship loader will be tested first in cooperation with a long-term customer of Wismar seaport, who moors about 30 different ship models every year at the corresponding quay in the port for receiving different sorts of bulk cargo.

According to the project management plan, the implementation of the 5G campus network is scheduled for six months. Against this, the overall implementation of the wind power station will last for 33 months. Thereby, the critical sub-tasks represent on the one hand the development of the pilot by the contracted project company, and on the other hand the consultation of the UNESCO World Heritage Advisory Board – next to the public building authority – due to the height of the facility and the fact that the Hanseatic city of Wismar belongs to the UNESCO World Heritage. The implementation of the photovoltaic plants on the roofs of the warehouses is planned with a duration of overall eleven months. The implementation of the fully automated ship loader will last for 27 months. Thereby, the critical sub-task is the sensor development by a contracted project company for the 5G compatibility. Currently, there do not exist marketable 5G sensors. Therefore, the sensors will be developed and configured according to the needs of the seaport by an external company.

Next to the limitation that arises from the made assumption (e.g. annual maintenance and service expenditures of 10 % and 5 % of the initial investment sums for the wind power station and the photovoltaic plants), the central limitation of the study is related to the lack of prior research studies on the topic (i.e. especially methodological limitations). Thus, comparable studies that focus on the full automation of a dry bulk cargo plant are currently missing. In accordance with this, future research activities should have a closer look among other things at the decreasing loading costs that arise from such automation efforts, as so far they have not sufficiently investigated in detail within the present study.

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References

[1] European Commission. The EU Blue Economy Report 2020. Luxembourg: Publications Office of the European Union, 2020.

[2] Philipp R. Smart Seaports as Innovation Drivers for Blue Growth. PhD Thesis. Tallinn: Tallinn University of Technology, School of Business and Governance, 2021.

[3] Philipp R., Prause G., Meyer C. Blue Growth Potential in South Baltic Sea Region. *Transport and Telecommunication Journal* 2020:21(1):69–83. https://doi.org/10.2478/ttj-2020-0006

[4] Eurostat. Maritime ports freight and passenger statistics 2020 [Online]. [Accessed: 21.12.2020]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Maritime_ports_freight_and_passenger_statistics

[5] Eurostat. Country level - gross weight of goods handled in all ports [Online]. [Accessed 21.12.2020]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=mar_mg_aa_cwh&lang=en

[6] Eurostat. Country level - passengers embarked and disembarked in all ports [Online]. [Accessed 21.12.2020]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=mar_mp_aa_cph&lang=en

[7] Acciaro M., Ghiara H., Cusano M. I. Energy management in seaports: A new role for port authorities. *Energy Policy* 2014:71:4–12. https://doi.org/10.1016/j.enpol.2014.04.013

[8] Philipp R., Ozarska A., Prause G. Sustainable Electronic Product Development in the Baltic Sea Region: A Regional Gap Analysis of Lab Testing Services. *Environmental and Climate Technologies* 2019:23(3):85–100. https://doi.org/10.2478/rtuect-2019-0081

[9] Philipp R. Blockchain for LBG Maritime Energy Contracting and Value Chain Management: A Green Shipping Business Model for Seaports. *Environmental and Climate Technologies* 2020:24(3):329–349. https://doi.org/10.2478/rtuect-2020-0107

[10] Henesey L., *et al*. Improved load planning of roro vessels by adopting blockchain and internet-of-things. *Proceedings of the 22nd International Conference on Harbor, Maritime and Multimodal Logistic Modeling & Simulation* 2020:58–65. https://doi.org/10.46354/i3m.2020.hms.009

[11] Henesey L., Philipp R. Evaluating LNG Bunkering Automation Technology. *World of Shipping Portugal: An International Research Conference on Maritime Affairs* 2019:16–17.

[12] Philipp R., Gerlitz L., Prause G. Regionale Häfen auf Digitalisierungskurs: Intelligentes Wachstum und nachhaltige Wertschöpfung entlang der kleinen und mittel-großen Häfen des Ostseeraumes (Regional ports on course for digitization: intelligent growth and sustainable value creation along the small and medium-sized ports of the Baltic Sea region). *Proceedings of WiWiTa 2018 Conference* 2018:77–86. (in German)

[13] Gerlitz L., Philipp R., Beifert A. Smart and Sustainable Cross-Sectoral Stakeholder Integration into Macro-Regional LNG Value Chain. *Proceedings of the International Conference on Reliability and Statistics in Transportation and Communication* 2018:36:112–126. https://doi.org/10.1007/978-3-319-74454-4_11

[14] Meyer C., Philipp R., Gerlitz L. Reinforcing Innovation and Competitiveness of SMEs by new Maritime Clustering Initiatives in South Baltic Sea Region. *Proceedings of the International Conference on Reliability and Statistics in Transportation and Communication* 2021:195:633–648. https://doi.org/10.1007/978-3-030-68476-1_59

[15] Madjidian J., *et al*. Developing a strategy for LNG powered transport corridors in the Baltic Sea Region. Presented at the *International Conference on Maritime Energy Management*, Malmo, Sweden, 2017.

[16] Maritz A., Shieh C. J., Yeh S. P. Innovation and success factors in the construction of green ports. *Journal of Environmental Protection and Ecology* 2014:15:1255–1263.

[17] Notteboom T., *et al*. The role of seaports in green supply chain management: Initiatives, attitudes, and perspectives in Rotterdam, Antwerp, North Sea Port, and Zeebrugge. *Sustainability* 2020:12(4):1688. https://doi.org/10.3390/su12041688

[18] Sakty K. G. E. Logistics Road map for Smart SeaPorts. *Renewable Energy and Sustainable Development* 2016:2(2):91–95. http://dx.doi.org/10.21622/resd.2016.02.2.091

[19] Iris Ç., Lam J. S. L. A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renewable and Sustainable Energy Reviews* 2019:112:170–182. https://doi.org/10.1016/j.rser.2019.04.069

[20] Philipp R., Prause G., Gerlitz L. Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains. *Transport and Telecommunication Journal* 2019:20(4):365–378. https://doi.org/10.2478/ttj-2019-0030

[21] Philipp R., Gerlitz L., Moldabekova A. Small and Medium-Sized Seaports on the Digital Track: Tracing Digitalisation across the South Baltic Region by Innovative Auditing Procedures. *Proceedings of the International Conference on Reliability and Statistics in Transportation and Communication* 2020:351–362. https://doi.org/10.1007/978-3-030-44610-9_35

[22] Philipp R. Digital Readiness Index Assessment towards Smart Port Development. *Sustainability Management Forum* 2020:28(1):49–60. https://doi.org/10.1007/s00550-020-00501-5

[23] Yang Y., *et al*. Internet of things for smart ports: Technologies and challenges. *IEEE Instrumentation & Measurement Magazine* 2018:21(1):34–43. https://doi.org/10.1109/MIM.2018.8278808

[24] Douaioui K., *et al*. Smart port: Design and perspectives. *2018 4th International Conference on Logistics Operations Management (GOL)* 2018:1–6. https://doi.org/10.1109/GOL.2018.8378099

[25] Gardeitchik J., Buck W., van der Deijl A. Move Forward: Step by step towards a digital port (Whitepaper, 2017). [Online]. [Accessed: 31.01.2021]. Available: https://connect.portofrotterdam.com/PortForward_Digital_Maturity?utm_source=poronline&utm_medium=website&utm_campaign=DBS2019&UTM_content=WP1

[26] Chen J., *et al*. Constructing governance framework of a green and smart port. *Journal of Marine Science and Engineering* 2019:7(4):83. https://doi.org/10.3390/jmse7040083

[27] Creswell J. W., Creswell J. D. Research design: Qualitative, quantitative, and mixed methods approaches. Thousand Oaks: Sage publications, 2017.

[28] Olaniyi E. O., Prause G. Investment Analysis of Waste Heat Recovery System Installations on Ships' Engines. *Journal of Marine Science and Engineering* 2020:8(10):811. https://doi.org/10.3390/jmse8100811

[29] Moldabekova A., *et al*. Technological Readiness and Innovation as Drivers for Logistics 4.0. *Journal of Asian Finance Economics and Business* 2021:8(1):145−156. https://doi.org/10.13106/jafeb.2021.vol8.no1.145

[30] Moldabekova A., *et al*. Digital Technologies for Improving Logistics Performance of Countries. *Transport and Telecommunication Journal* 2021:22(2):207–216. https://doi.org/10.2478/ttj-2021-0016

[31] Gerasimova V., Philipp R., Prause G. Service Design for Smart Supply Chains. *Proceedings of the International Conference on Reliability and Statistics in Transportation and Communication* 2021:195:377–388. https://doi.org/10.1007/978-3-030-68476-1_35

[32] Philipp R., Gerlitz L., Prause G. Smart Contracts for Entrepreneurial Collaboration in Logistics Networks. *Proceedings of the 11th international scientific conference 'New Challenges of Economic and Business Development – 2019: Incentives for Sustainable Economic Growth'* 2019:652–663.

[33] Geissdoerfer M., Vladimirova D., Evans S. Sustainable business model innovation: A review. *Journal of Cleaner Production* 2018:198:401–416. https://doi.org/10.1016/j.jclepro.2018.06.240

[34] Mitchell D., Coles C. The ultimate competitive advantage of continuing business model innovation. *Journal of Business Strategy* 2003:24(5):15–21. https://doi.org/10.1108/02756660310504924

[35] Schneider S., Spieth P. Business model innovation: Towards an integrated future research agenda. *International Journal of Innovation Management* 2013:17(1):1340001. https://doi.org/10.1142/S136391961340001X

[36] Sommer A. Managing Green Business Model Transformations – A Framework for Management Practice. *Managing Green Business Model Transformations. Sustainable Production, Life Cycle Engineering and Management* 2012:259–346. https://doi.org/10.1007/978-3-642-28848-7_9

[37] Chesbrough H. Business model innovation: it's not just about technology anymore. *Strategy & leadership* 2007:35(6):12–17. https://doi.org/10.1108/10878570710833714

[38] Chesbrough H. Business model innovation: opportunities and barriers. *Long range planning* 2010:43(2–3):354–363. https://doi.org/10.1016/j.lrp.2009.07.010

[39] Ibarra D., Ganzarain J., Igartua J. I. Business model innovation through Industry 4.0: A review. *Procedia Manufacturing* 2018:22:4–10. https://doi.org/10.1016/j.promfg.2018.03.002

[40] Kvale S. *Doing interviews*. London: Sage publications, 2008.

[41] Miles M. B., Huberman A. M. *Qualitative data analysis: A sourcebook of new methods*. Beverly Hills: Sage publications, 1984.

[42] Yin R. K. *Case study research and applications: Design and methods*. Newburry Park: Sage publications, 1989.

[43] Altricher H., Posch P., Somekh B. *Teachers investigate their work: An introduction to action research across the professions*. London: Routledge, 2005.
[44] Cohen L., Manion L., Morrison K. *Research methods in education*. London: Routledge, 2018.
[45] Given L. M. *The Sage encyclopedia of qualitative research methods*. Thousand Oaks: Sage publications, 2018
[46] Federal Ministry for Economic Affairs and Energy. Guidelines for 5G Campus Networks – Orientation for Small and Medium-Sized Business. Berlin: BWMi, 2020.
[47] iSAM Group. Advanced Anti-Collision System for Shiploaders [Online]. [Accessed 31.01.2021]. Available: https://www.isamamerica.com/wp-content/uploads/EN_Applik_Report_ACS_Shiploader.pdf
[48] Johnson H., Styhre L. Increased energy efficiency in short sea shipping through decreased time in port. *Transportation Research Part A: Policy and Practice* 2015:71:167–178. https://doi.org/10.1016/j.tra.2014.11.008
[49] German Environment Agency. CO2 emissions per kilowatt hour of electricity in further decline in 2019: Germany exports more electricity than it imports [Online]. [Accessed: 31.01.2021]. Available: https://www.umweltbundesamt.de/en/press/pressinformation/co2-emissions-per-kilowatt-hour-of-electricity-in
[50] Statista. Electricity prices for industries in the European Union in 2019 [Online]. [Accessed: 31.01.2021]. Available: https://www.statista.com/statistics/1046605/industry-electricity-prices-european-union-country/
[51] Word Bank. State and Trends of Carbon Pricing 2020. [Online]. [Accessed: 31.01.2021]. Available: https://openknowledge.worldbank.org/bitstream/handle/10986/33809/9781464815867.pdf?sequence=4&isAllowed=y