MERI KOTKA

DIGITALIZATION OF PORTS´ ENVIRONMENTAL MANAGEMENT TOOLS

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SUMMARY

This survey introduces environmental management tools that are used in ports around the world and describes practices which can help ports improve their environmental performance. With insights from two expert interviews and an online questionnaire, the prevalence of these tools' usage in some ports of Finland and Russia is discussed.

As more and more detailed data is available about the port area through automated real-time measuring devices, environmental management software can produce helpful and easy-to-read predictions, reports and analyses about the port operations. With the help of these analyses, ports can change their operations into a more sustainable direction and at the same time achieve better cost-efficiency. The digitalization process requires expertise and a lot of collaboration between the ports' many stakeholders, which might slow down this development. However, there are already many examples of ports that use digital environmental management tools in the Baltic Sea.

Certified environmental management systems that offer guidelines for good environmental practices are already well adopted in the Baltic Sea's ports but improving the environmental performance beyond current regulations and legislation is needed. Clearly the biggest producers of emissions in a port are the ships at berth and waiting access to the harbor. Thus, the biggest positive impact on the environment that a port can do is to begin using the Just-In-Time arrival method which enables incoming ships to optimize their speed and route. This requires connecting the ships' and ports' information management systems for improved communication. This development emphasizes the importance of good communication and streamlined exchange of information, which is why digital information management systems will prove to be even more useful in mitigating and tackling the effects of the global pollution disaster.

As more digital tools are being used in ports, their interconnectivity might pose a challenge. Careful planning of the overall IT-infrastructure is preferred to be done in collaboration with other ports and ports' stakeholders. This will also help the sharing of data in the future. During this phased implementation of digitalization, it is recommended to install automated real-time data measuring devices to fully grasp the benefits of digital environmental management tools. Although social acceptance was found to still be the biggest hindrance in digitalization, it is likely to be overcome with the incentivizing economic benefits that accompany the adoption of these tools.


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1 | INTRODUCTION

1.1 Purpose and structure of the survey

This report concentrates on the sustainable development and green growth of ports with a focus on how it can be boosted with (digital) environmental management tools (EMT). The aspect of growth is important because it works as an incentive for companies to adopt a sustainable growth strategy that reaches beyond the current regulations and standards. Sustainability is generally accepted to encompass economic and social aspects in addition to the environmental, which is why economic activities and environmental protection can be furthered at the same time with the adoption of tools for green growth. To incentivize ports towards sustainable development, it is important to note that there is no real conflict between sustainability and economic growth (Ala-Harja and Helo 2015, 11–21; Zhu and Zarkis 2007, 4333–4355; Vachon and Klassen 2006, 795–821).

Environmental management has the goal of mitigating the impact human actions have on nature and the recreational value of its surroundings. A safe and environmentally sustainable port area is better for all parties included. The list of EMTs mentioned in this survey is by no means exhaustive, but it nevertheless gives a good overview of resources and available technologies to mitigate climate change and further the development towards a more sustainable shore use in the Eastern Gulf of Finland.

1.2 Methodology and the research questions

This survey uses open source academic papers as well as reports from different past and ongoing projects that focus on port sustainability and smart solutions. Two in-depth interviews were held with key informants who were seen to have the most current knowledge about digital EMTs in the Baltic Sea ports. Additionally, an online questionnaire was used to collect information from Finnish and Russian ports on the Baltic Sea. The online questionnaire did not yield results as hoped, with only six answers from Finland and one from Russia. This shortcoming has been acknowledged during the process and other sources are emphasized accordingly. This survey aims to answer the following main research questions:

1. What kind of EMTs are being used in ports and in what extent?
2. How can they be digitalized?
3. What kind of digital EMTs are available at the market?
4. What are the barriers in using digital tools in ports?

The first research question is discussed in chapters 2 and 3 with insights from interviews and the online questionnaires, while the second question is answered in chapter 4. Chapter 5 gives answers to the third research question while the last question is answered in chapter 6.

Environmental management is defined in this survey as management of a society's interaction and impact with the environment (NEC 2011, 1). Digitalization is defined in the survey as betterment of innovative usage of digital information and technology.[1] As such, the search for digital EMTs means to search for innovative ways of using digital data and technology to manage ports' interaction and impact with the environment. The survey concentrates on how different digital tools, methods and technologies can be used to improve environmental management in ports.

1.3 Motivation to change

Ports in the Eastern Gulf of Finland need to develop their processes towards a more sustainable and resilient direction to mitigate climate change and the global pollution disaster. There are multiple factors that create this need, of which rising sea-levels, storms, and the resulting shifts in markets and operational delays are the main variables to be addressed to maintain sustainable and cost-efficient port operations. If these threats are not acted upon proactively and beforehand, they will eventually cause sudden and drastic losses in profits and affect supply chains on a national level. Local and international environmental authorities have set stricter standards for ports to follow, but to really change things for the better, ports need

[1] Digitalization has no clear definition, but it can be understood as a world-wide trend and cultural change in which knowledge is utilized in a digital form with digital technologies (Saarikoski & Helminen 2019a, 11).

to act together and implement EMTs that go beyond the current standards and legislation. Fortunately, improving ports' environmental impacts also creates possibilities to increase their cost-effectiveness while at the same time fostering a greener image for public relations.

As the entire marine shipping sector is focused on reducing its emissions, ports are also developing strategies to lower their environmental impact on the local and global community. Ships and ports are intrinsically connected and to truly cut seafaring-related emission levels, shipping companies also need to apply new technologies to their fleets. Developing greener ports helps to achieve this by offering incentives for the ships that have adopted sustainable measures in their operations.

The main environmental problems caused by port activities are the insufficient recycling of waste, insufficient wastewater disposal, water pollution from ship maintenance and the inefficient use of energy. Accidents in ports can also have a high impact on the surrounding environment. (Sánchez 2011.) Petrol and electricity are the main causes of energy related emissions along with heating gas, heating oil and district heat (HPC 2018, 4). Clearly the biggest contributor of emissions in a port are the ships at berth and ships waiting for access to port (Merk 2014, 10). Therefore, tools for improving the coordination between ships and ports to optimize the arrival is crucial, although it is not the only option. The challenge for ports is how to identify the most feasible and cost-efficient environmental management measures. There are numerous EMTs that have been created for seaports which range from regulations and trainings to automated systems measuring the ports operations in high detail.


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2 | ENVIRONMENTAL MANAGEMENT TOOLS IN PORTS

2.1 Environmental policy, auditing, permits and reporting

The environmental policy shows the aims and intentions that the port has towards environmental protection. It signals commitment to environmental management, but it is also an important tool for ports' internal processes since it makes the respective port authorities reflect on the port's environmental sphere of influence and set its sustainable development targets accordingly. The environmental policy is the first step in a well-functioning environmental management system (EMS) (see 2.2). Almost all ports in Europe have an environmental policy (95 % in 2019) and 65 % have it publicly available (ESPO 2019, 5–7).

To enforce and keep track whether a port is doing what it has agreed to in national and international legislation as well as in other standards and regulations, an environmental auditing process can be undertaken. Although the auditing schemes are voluntary, the port can indicate that environmental matters are handled well by the port with allowing a third-party inspection. In Finland, environmental auditing plans are usually made after a port or a project attains its environmental permit.[2] Finland's environmental protection legislation states that permits are needed for all activities involving the risk of pollution. To gain the permit, emissions must be limited to levels that are obtainable by using best available techniques (Ympäristö.fi 2020).

In Russia, the environmental permit system is being updated since the legislation in the field of waste management is undergoing a major reform. Depending on the level of environmental impact, the port is obliged to obtain either a single environmental permit or three separate permits for air, wastewater discharges and waste disposal.[3] The Ministry of Natural Resources and the Environment is the main authority that coordinates five different agencies of which the Federal Supervisory Service for Nature Management (Rosprirodnadzor) is the most relevant for environmental management and permits. From the 1st of January 2019 onwards, the most environmentally impactful (Category 1 of 4) organizations must apply for an integrated permit before 2025. (Bartholomy et al. 2020.)

Reporting about the success or the hindrances in a port's operations towards environmental protection will not only give an honest and open image for public relations but also it should work as an internal tool to record and show progress towards the targets in the port's environmental policy. Combining a regional or global set of ports' report statistics will show long-time trends, which in turn can be used to predict effects of a force majeure and to better

[2] This integrated environmental permit is issued by the Regional State Administrative Agencies under Finland's Water Act (587/2011) and the Environmental Protection Act (527/2014). (Ministry of the Environment 2016.)

[3] The integrated permitting regime is regulated by Federal Law No. 7-FZ On Environmental Protection, amended on 1st of January 2019 and the Russian Government Decree No. 143 On the Issuance, Reissuance, Revision, Amendment and Revocation of Integrated Environmental Permits. 13th of February 2019.

react to sudden changes in the future. Digital tools for measuring energy, emissions and waste can help a port to create visual and comprehensive reports about selected topics. This eases the workload to collect the required information for the environmental authorities while at the same time improves the quality of internal and external communication.
In Finland, the reporting is done according to the environmental permits via the electronic system YLVA, which is upheld by The Centres for Economic Development, Transport and the Environment. Ports usually also publish their environmental reports on their webpages for transparency According to the reformed environmental legislation in Russia, category 1 (most polluting) organizations must install equipment that automatically report emission volumes and pollutant concentrations to a state database. Organizations that belong to categories 2, 3 or 4 must do an internal programme for ecological control and report annually on the volumes of emissions and waste among other things. (Bartholomy et al. 2020.)

2.2 Environmental Management Systems

An EMS is a framework for measures which take into consideration the organization's structure, plans and resources for developing, implementing, and maintaining a policy for environmental protection. The EMS improves a port's environmental performance and provides a systematic way of managing its environmental affairs. It is also important for developing management structures to address the immediate and long-term impacts of services and processes on the environment. (Reddy 2017, 10.)

A systematic review of a port's environmental effects and the mitigation thereof gives order and consistency to address environmental concerns. This can be done through the allocation of resources as well as evaluation and improvement of practices, procedures, and processes. There are multiple EMS standards that a port can follow, but the most common is the international environmental management system standard ISO 14001. Other certified EMS' are the Eco-management and Audit Scheme (EMAS) developed by the European Commission and the Port Environmental Review System (PERS) by the European Sea Port Organization (ESPO).

Majority of seaports worldwide have implemented a limited set of ISO14001 EMS properties, operations or programs. This approach is commonly known as a "fence line EMS" and is done since a full compliance of the ISO standard can be time consuming and costly. Because of this, many ports have started a self-monitored environmental management system to benefit from the improved operational efficiencies, cost savings and public relations. Although this is a good direction to develop overall, it should be noted that adopting an audited EMS can have significant benefits for a port in terms of identification and management of environmental risks as well as gaining the regulatory authority's confidence. (PIANC 2014, 59.)

ISO 14001 is the main tool in the field of international environmental management, and its requirements can be summarized as:

a) Produce an environmental policy that shows commitment to relevant legislation and to continually enhance its performance regarding environmental sustainability. A person should be appointed to be responsible for the system's coordination.

b) Set targets for improving environmental performance based on a review of the port's environmental activities. The port's interactions and impacts must be identified along with the environmental compliance requirements.

c) Implement the measures mentioned in its environmental policy.

d) Audit the performance of its EMS periodically and take corrective action if targets have not been met.

e) Carry out a management review of the EMS at the end of the target period and make required changes to the EMS according to the audit results. New targets will have to be set to contribute towards the policy of continual improvement. (NEC 2011, 12.)

The Eco-management and Audit Scheme (EMAS) is used generally by organizations in the European Union and abroad by organizations which have important trade relations inside the EU. It aims to provide recognition for those organizations that have taken action to protect the environment and improve their environmental performance. Hence, it is a very similar tool to the ISO14001 although EMAS is more aimed towards the European Union member country organizations.

Another established EMS scheme is the Port Environmental Review System (PERS). It is specifically created by the European Sea Port Organization (ESPO) within their EcoPorts project to help port authorities with the changes needed to achieve its sustainable development goals. PERS has gained the reputation of being the only port-sector specific EMS standard. This system defines a standard for good practices in port environmental management and is a good first step to take in implementing an EMS. PERS already incorporates the main requirements of ISO 14001 and can be achieved for specific sectors of a port, enabling a smooth transition to environmental sustainability.

In Europe, the existence of a certified EMS' (ISO, EMAS, PERS) in ports has risen from 54 % in 2013 to 71 % in 2019. In Europe 53,7 % of the EMS certificates are ISO and 26,9 % are EcoPorts' PERS. 10, 4 % have both ISO and PERS certificates, while 4,5 % have certificates of ISO, PERS and EMAS. (ISO & EMAS 3%; 1,5 % EMAS only.) In Finland most ports follow the

ISO system, although the Port of Pori is certified with Ecoports' PERS as well. (ESPO 2019, 5–7; Interview source 2020a). Baltic ports overall have better environmental performance compared to the rest of Europe (Klopott 2016, 21).

2.3 Environmental Impact Assessment

The environmental impact assessment (EIA) procedure ensures that the environmental implications of decisions made by port authorities are taken into account when extending the port area or making modifications to it. The impact assessment analysis is summarized in a report which is discussed in a public consultation before making a final decision and informing the public of it. The EIA is an important instrument in the European Union's environmental policy and is based on three directives (Directive 85/337/EEC, Directive 2001/42/EC and Directive 2003/35/EC) making it a part of ports' legal compliance inside the European Union. These same directives can work as exemplary standards that organizations worldwide can follow.

An important part of the EIA procedure is the Environmental Impact Statement (EIS) which summarizes the studies carried out to assess the environmental impact. This includes major controversies in the project plan and what issues are to be resolved. Different alternatives for the project should be described to consider changes in location, technology, or investments. This is all done to assess the requirement and utilization of resources and the generated waste. The EIS also lists the aspects of environment that are most likely to be affected by the port expansion or other project. These can include models of water or air quality and currents to show the dispersion of a potential pollutant or oil spill models which are based on advection-dispersion models and also take into account processes such as volatilization, settling of tars and wind dispersion. (Verbeeck & Hens 2004, 106–107.)

The main environmental attributes that should be assessed in an EIA are listed below in TABLE 1. These attributes show how vast the theme of environmental management is. To fully screen the real-time or future environmental effect a port has, professionals with a very wide level of expertise should be consulted. A comprehensive EIA requires knowledge in environmental sciences, health, process design, coastal engineering, chemical/mechanical engineering, oceanography, water resources, marine biology, social/environmental/natural resource economics and sociology. (Verbeeck & Hens 2004, 104)

TABLE 1.
Examples of environmental attributes for port and harbor projects to consider in an Environmental Impact Assessment. (Verbeeck & Hens 2004, 107.)

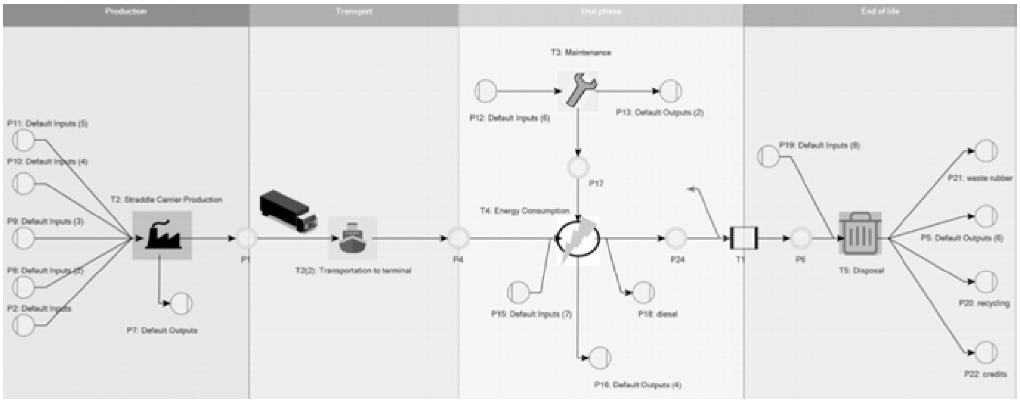
Meteorological parameter	Noise	Land
Wind direction	Noise levels	Land use
Wind speed	Noise attenuating factors	Soil, slope and draining characteristics
Temperature gradients	Noise sensitive receptors	Topography
Atmospheric stability	Wind direction	Terrestrial ecology
Daily rainfall		

Air quality parameter	Ecological parameters	Sediment quality parameters
Gaseous and particulate matter	Endangered species	Sediment transport or littoral drift
SO2	Fishing	Sediment biology
NOx	Breeding areas and animal habitats	Sediment toxicology
CO		
HC		
Heavy metals		
HC=NMVOC		

Water
Hydrodynamics (tides, waves, currents, shoreline profile)
Physical (pH, salinity, temparature, oil, grease, total suspended solids, total dissolved solids, turbidity)
Chemical (dissolved oxygen, biological oxygen demand, nutrients, heavy metals, and toxic components)
Biological (faecal coliforms, phytoplankton, zooplankton)
Water demand or consumption
Water resources
Socio-economic parameters
Population (target receptors)
Standard of living (water supply, roads, recreational value of surrounding areas)
Commercially valuable materials, species and recreational areas

2.4 Life cycle assessment

A life cycle assessment (LCA) means to identify an asset's various environmental impacts from the day it is first acquired until the day it is disposed of. This kind of an asset-specific analysis is done to find ways for cost-efficient environmental impact mitigation. LCA can be applied to specific machinery, services or individual processes within a port. The four major phases of an LCA are: goal and scope definition, life cycle inventory analysis, life cycle impact analysis and the interpretation. A proper LCA takes into account the mining of raw materials, their production processes, transportation, usage phase and finally the disposal of the produce. (Scharpenberg et al. 2018, 8.) Because finding out all this information would be very time consuming for a port, it is recommended to use LCA software with ready-made databases for this purpose. These software include SimaPro, Air.e, openLCA, Umberto, GaBi, REGIS, eBalance, EIME, Quantis, TEAM 5.2, iPoint, LifeCycleTracker and Aveny LCA 2. Conducting LCA's on the different options for investment will assist in the decision-making process by uncovering the amount of influence they have on the environment.



PICTURE 1.
Example of the life cycle of a straddle carrier (Scharpenberg et al. 2018, 13).

GreenPort Industry Database is an online tool for browsing environmentally better alternatives for the solutions a port needs. The directory can be consulted by purchasers who strive to improve environmental practices and corporate responsibility in the port industry. It covers a huge area of different categories (consultants, classification societies, emission control, events, finance & legal, floating plant & equipment, fuel sources, health & safety, lighting & electrical, logistics, port authorities, port equipment, port maintenance, power generation, products & services, shipping companies, terminal operators, trade associations & representative bodies as well as training & recruiting). (GreenPort 2020a.) International Maritime organisation's (IMO) **Global Integrated Shipping Information System** can also prove helpful. These online tools are practical for anyone working in marine ports and terminals because they give centralized access to numerous companies providing environmentally sustainable solutions.

TABLE 2.
Good practices and criteria that are recommended for the Port of Helsinki to include in its procurement process for minimizing its carbon footprint. (Valosalmi 2020, 90.)

Recommendations for ports' procurement processes	
Good practices	Dialogue with market participants allows suitable benchmarks to be identified and suppliers to start the necessary studies before the actual tender
	Ensuring service life performance with warranty conditions and a spare parts service, as well as an agreement on the recycling of equipment at the end of the contract
	Default settings and instructions or training from the supplier for the energy-efficient use of devices
	Avoiding disposable products and parts
Example criteria	Best energy-efficiency (or water usage) levels as the minimum criterion
	Minimum requirements that ensure a long and comprehensive warranty and the availability of spare parts
	The device supports power management features
	Additional points for more comprehensive or longer warranty / eco-label compliance (eg TCO Certified)

2.5 Risk analysis

Environmental risk analysis helps in identifying existing problems and provides a framework for port management to make decisions. A proper risk analysis helps to anticipate risks of planned actions and overall helps to ensure the safety of a port. An accident in a port is dangerous not only to the workforce affected but also to the environment and the regional economy.

Ecoports has created a **Self-Diagnosis Method** (SDM) that port representatives can do online by filling a checklist of questions about the environmental management of ports. It helps to identify possible environmental risks and makes the port authorities reflect on these issues.

The result will be further elaborated by an Ecoports expert's analytical review about the strengths, weaknesses, opportunities, and threats of the port's environmental performance. This analysis will identify the gaps in the port's environmental management and offers customized recommendations depending on the port's priorities. Completing the SDM also gives the port access to a port-network where it is possible to share experiences and best practices with each other. (Ecoports 2020.) **EcoOnline** is one of many commercially available general risk analysis tools, but there are open source tools available as well. The **OpenRisk** project has created a toolbox which consists of 20 open source risk assessment tools that are aimed at assessing spill risks from maritime accidents including AISyRisk, IALA Waterway Risk Assessment Programme, Ports and Waterways Safety Assessment, and Next Generation SmartResponse Web among others (Laine et al. 2019, 1035–1036).

The main factors to be considered in risk analysis is the intensity of vessel traffic including the estimated number of ships visiting, vessel types, design and construction (Verbeeck & Hens 2004, 118). Hazardous substances handled by the port should also be studied so the appropriate procedures can be identified and applied as soon as possible if an accident happens. Ports should also analyze the frequency and probability of different kinds of accidents including collisions, groundings, pipeline failure etc. The most important step in risk analysis for ports is the estimation of an incident's consequences. This can be done by trying to come up with a "worst case scenario" and predicting how such an accident would affect the port area and environment. Computational models and consultation of professional engineers will give a realistic and useful estimation.

2.6 Training

Training should aim to slowly change the culture of the port organization so that employees feel that they can improve environmental sustainability by their own actions and behavior. The workforce needs encouraging, supporting and guiding to develop an awareness for sustainable actions. The trainers need to be aware and understand the dynamics of the port organization and impacts of environmental pressures on the workforce to properly activate useful training programs. This can be achieved by implementing work models like recycling, life-cycle analysis or other environmentally beneficial activities to reform the organization structure starting from the micro level. (DiVaio et al. 2018, 25.)

To assist in this cultural restructuring, it is good to apply management innovation by implementing a strategic management instrument. (DiVaio et al. 2018, 21.) One instrument like this is the Balanced Scoreboard performance measurement framework. The scoreboard takes into consideration multiple key performance indicators in addition to financial performance to link environmental objectives to the port's strategy in a functional way. The

indicators discussed in chapter 3 can help in creating these key environmental performance indicators. This multidimensional framework of the supports the monitoring of processes of the business strategy. The Balanced Scoreboard is especially useful in addressing the improvement of environmental performance and cost reduction in ports.
(DiVaio et al. 2018, 22.)

Another well-suited performance measurement framework is Tableau de Bord which represents its users with a "dashboard" of key parameters that support managers in their decision-making processes. Tableau de Bord is best applied by personalizing these dashboard-documents with operational indicators about each sub-unit of the port. This way each manager will have their own Tableau de Bord document that link into each other and as a whole support the local processes. Hence, it is necessary to write down each unit's objectives that are identified as its key performance indicators. By reporting their performance according to these indicators, the managers have useful information to support their decision-making processes.
(DiVaio et al. 2018, 23.)

3 | ENVIRONMENTAL PERFORMANCE MONITORING

3.1 Environmental indicators

To measure a port's environmental performance a comprehensive set of indicators should be created by using numerous different means of measuring. Although automated devices can be used, the method to gain an indication of a port's environmental performance does not always have to be highly technological. An observation of pollution in water, for example, can be done visually or even using one's own sense of smell. Still, automated measuring and predictive calculations do help in achieving representative, objective and trustworthy indicators of a port's environmental performance. The Internet-of-Things (IoT) technology has made it possible to acquire feasible and accurate measurement devices, so the latest commercial sensors, radio frequency communication and mobile computation modules can be integrated into many of the instruments used to measure a port's environment. (Brooke et al. 2020, 167 < Zhong et al. 2016; Cheng et al. 2017.) Examples of environmental indicators are listed below in TABLE 3.

TABLE 3.
Examples of environmental indicators that can be used to evaluate a port's environmental performance. (NEC 2011, 12.)

Tonnes of SO2 released per year
Tonnes of CO2 released per unit of production
MWh's of energy used per month
Litres of water used per year
Kilogrammes of hazardous waste produced per year
Number of legislative breaches per year
Savings achieved through energy efficiency measures
Number of environmental improvement suggestions received and number taken up by management
Number of complaints received about environmentally related matters
Number of employees trained versus number needing training

A port should also keep track of the raw material, energy, resources, products, and waste that is entering, leaving, or held in the port facilities. This kind of an archive over a specific period of time gives a port the ability to assess how much different operations affect the environment and whether the port has reached the objectives it has set for itself in its environmental policy.

All the three main environmental management system standards (ISO 14001, EMAS and PERS) highlight the importance for organizations to use indicators for ensuring environmental protection. The Ports Observatory for Performance Indicator Analysis (PORTOPIA) project has created a methodology for this specific purpose: the **Tool for the identification and implementation of Environmental Indicators in Ports** (TEIP). This tool has been developed by the Polytechnic University of Catalonia (UPC) within the framework of the research project PERSEUS (Policy-oriented marine Environmental Research in the Southern European Seas. (Puig et al. 2017.) This method can be applied to any port regardless of their size or commercial profile to help ports find the most suitable tools for measuring their environmental performance. TEIP is a useful and simple method to boost a port's sustainable development. Currently, a project called PIXEL is developing a Port Environmental Index which uses quantitative real-time data obtained via IoT to integrate a port's main environmental aspects into a single comparable metric (Pixel Ports 2020). DNV GL also has a pilot project called Environmental Port Index that is developing a methodology for quantifying and reporting environmental performance (DNV GL 2020).

3.2 Air quality

Air quality has received more attention during the last years because it is now widely regarded as the measure of public acceptance of a port's activities considering sustainability. It has been the top environmental priority of European ports in 2018 and 2019 and likely continues as such following the International Maritime Organization's limit for sulfur in fuel oil used on ships operating outside designated Emission Control Areas (IMO 2020, 1). **The Environmental Ship Index ESI** can be used to evaluate the amount of nitrogen oxide and sulfur oxide emitted by a ship to indicate the environmental performance of ships and assist in identifying cleaner ships.

Air quality is optimally measured by installing both long-term and temporary monitoring stations in different areas of the port and city including a reference station for background values as well as an action response plan based on the quality levels. Air quality is generally monitored periodically in Finnish ports and rarely continuously. If the monitoring is continuous it is usually related to risk factors in the port's traffic and location (Questionnaire source 2020d). According to the Environmental Protection Act, it is the responsibility of the municipality to enhance air protection within its region, and hence cities provide air quality monitoring for them. In the port of Vysotsky in Russia the air quality is monitored by a third-party organization (Questionnaire source 2020f). It seems the ports in the Eastern Gulf of Finland do not have their own equipment to monitor air quality and rather cooperate with other organizations to gain the relevant information. The Finnish meteorological Institute has started leasing out air quality monitoring stations to ports, from which the data is filtered through the institute before the port receives it. This way the institute can make sure the quality of the information is satisfactory. (Interview source 2020a.) It would be beneficial to upload this data automatically to a port's digital environmental tool whether it is monitored by the port itself or by third party organizations. This would avoid the data to become passive and enable it to be used in analyses for improving ports' sustainability.

One example of air quality measuring in the Baltic Sea Area is The Port of HaminaKotka, which takes part in a regional monitoring of the air quality in which mobile monitoring stations are used periodically. Additionally, the emissions affecting air quality are calculated in the port with models created in the digital environment management tool called Smart Energy Environmental System (SeeS) (See 5.2.1). The emissions from rubber tire traffic is calculated from the amount of traffic at the gates. Emissions of other machines working in the port area have been last estimated in 2018 using the Lipasto calculation model by the Technical Research Centre of Finland. (Questionnaire source 2020a.) The Port of Turku's air quality is also monitored by the city, and an emission calculation system for ships and port operations is also in use (Questionnaire source 2020b). The Port of Rauma also uses the SeeS EMT to calculate its vessel emissions (Questionnaire source 2020c).

Air quality data monitored in Finland is **available online** at the website of the Finnish Meteorological Institute. Russian air quality data can be viewed from **Air Quality Index website** which gathers data from different sources. A large scale analysis of air quality was just completed in Russian cities, after which it was proposed that a control system should be implemented at the facilities with the most negative impact on environment (Federal Service for Supervision of Natural Resources, 2020). Physical barriers can be set up to mitigate the dispersion of dust particles and other materials from spreading with wind. For example, in 2009 Port of Rauma upgraded its unloading funnel and encased the conveyor belt system, which helped the port achieve permitted levels of air quality even during windy weather (ESPO 2012, 16). Sea Port St. Petersburg has installed a vacuum sweeper to suppress the dust from cargo holds, as well as built an ecological bunker to ensure safe handling of bulk cargo (GreenPort 2019).

Although the air quality measured in a port would not exceed the thresholds for EU regulated pollutants (NO2, PM10 and SO2), the amount of non-regulated pollutants might still be high. The polluting potential of these are especially high in ships that use low sulfur but poorly refined oils. High loads of black carbon and ultrafine particles hence exist in port areas. This speaks for an even enlarged set of environmental variables to be taken into consideration to mitigate ports' impact on air quality. (Gobbi et al. 2019, 1–2.)

3.3 Water, soil, and sediment quality

Surface water and sediment quality is usually measured during routine checkups or EIAs. The intensity of measurement depends on whether there are construction works or other projects being done. During a construction project, the monitoring is more intensive as starting values, checkpoints and ending values are compared to find out the environmental impact of the works. (Interview source 2020 a.) Detailed analyses are usually done by hand, taking samples from the port area which are later analyzed. This process can also be automized to a certain degree with CTD measuring devices. These devices can measure the oxygen content and turbidity of water, and even the amount of phytoplankton in the water. The devices can be installed in buoys or gliders depending on what kind of information is wanted. The glider is an autonomous underwater vehicle (AUV) that can measure the water quality from different depths and locations.

Finnish ports prefer joint monitoring systems that give broad information about the water quality. Joint monitoring is done by regional environmental organizations that do the same monitoring procedure in multiple faculties during a certain time span. This makes the operation more efficient and the faculties taking part obtain the information of all participating faculties, not just their own. During the joint monitoring temporary measuring stations are usually founded to give representative results from the port's water area. If the measuring station is deemed to give beneficial information for all participants, it can be changed to a long-term station. (Interview source 2020a.)

The Port of HaminaKotka's water areas have monitoring stations which regularly report the quality of water. Control samples are taken by the Water and Environment Organization of Kymijoki. Runoff water quality is monitored by third-party inspection facilities that analyze samples according to the auditing plan. (Questionnaire source 2020a.) The Port of Turku monitors the underwater areas and waterways with sounding devices regularly. This scanning also helps the port to optimize dredging needs and the optimal amount to dredge. Effects of dredging are not monitored, however. (Questionnaire source 2020b.) Sea Port St. Petersburg is installing a modernized water disposal system and overhauling its sewage system for improved waste treatment (Green Port 2019). In the port of Vysotsky the water quality is monitored by a third-party organization. Also, according to the questionnaire Vysotsky port does not recycle efficiently, which signals that there is a need for environmental management training in Russian ports on the Baltic Sea (Questionnaire source 2020f). The organizational culture should be changed towards a more sustainable direction, so managers and workers feel they have a responsibility towards the environment (See 2.6).

Soil and groundwater quality are measured when a port is doing an EIA to determine old locations of contaminants or potential sources of contaminants. Using GIS-based systems to model the area of the port is helpful in this endeavor. This static data is helpful when planning for dredging as well. Dredging activities should be planned so they create opportunities for improving environmental quality, and in a way that it can enhance the existing ecosystems. The material that has been dredged should be reused in the best possible ways either with or without pre-treatment. Overall, the surrounding environment should be understood very well to use natural processes in maximizing the efficiency of the dredging (PIANC 2014, 32).

To find out the thickness and internal structures of sediment layers, sounding devices can be equipped on ships or automated surface vehicles (AVS). LiDAR technology can be used as well to identify vegetation and seabed quality from bright and shallow areas. Satellite imagery also provides information on water quality. Based on variations of the color of the water, algal abundance and water turbidity can be estimated with the help of neural network algorithms. (Itämeri.fi 2020a; GreenPort 2020b.) Seaport OSX's NCOS ONLINE (see 5.3.1) software's sediment module is aimed to gain more knowledge about the sediment dynamics around a port area and how they can affect the maritime infrastructure. SedNet is a European network aimed at incorporating sediment issues and knowledge into European strategies to support the achievement of a good environmental status and to develop new tools for sediment management.

3.4 Energy usage and climate change mitigation

The solution that makes the biggest difference in mitigating climate change is the shore-side renewable energy that a port can offer the ships at berth (geo-thermal power, wind power, wave power, solar power). The International Association of Ports and Harbors' (IAPH) **Tool Box for Greenhouse Gasses** contains many available actions for ports, and describes the strategy, technical considerations, options for implementation as well as pros and cons for each emission reduction tool.

TABLE 4.
Examples of measures a port can take to mitigate climate change (IAPH 2014).

Performance Standards for On-Road Heavy-Duty Vehicles	Electric Rubber Tired Gantry Cranes (RTG)
Vessel Speed Reduction (VSR)	Electric Yard Tractor
Reduction of At-Berth OGV Emissions	Terminal Equipment Electrification
Main & Auxiliary Engine and Boiler Emis-sions Reduction	Tug Staging Areas
RFID / Terminal Gate Efficiency Measures	Near-Term Zero-Emissions Technologies for Trucks
Electric/Hybrid Electric Vehicles/Plug-ins/ AFVs	Vessel Energy Saving Measures
Employee Commuting	Solar Power Generation
Building Standards/Retrofits/Water Con-servation/Recycling	Renewable Energy Purchase
Operational Efficiency Improvements	Alt. Power Units & Anti-idle for Switching Locomotives
Tree Planting	Hybrid Locomotives
Community Redevelopment – Open Space/ Brownfields	On-Terminal Lighting
	Electric/Hybrid Dray Trucks

Solar panels and geothermal heat are still not used much but are becoming more widely adopted. Many harbors in Finland have carbon neutrality goals for years 2029-2035, which they are likely to achieve. These objectives of course relate to the energy usage of the port – not the ships at berth and waiting access, which are still the biggest contributors of emissions in a harbor. So far options to mitigate the emissions of ships are few, however. They include LNG fuel [4] (better for air quality but is still a fossil fuel) and shore side energy, which is an expensive

[4] Closed-loop scrubbers should be used to wash the liquified natural gas exhaust fumes to achieve the best possible environmental sustainability.

investment and would still have to be produced in carbon neutral way to truly be sustainable. (Interview source 2020a.) It could be said that mitigating the environmental impact of ships has hit a "plateau" in its development regarding fuels and motors, which means other means must be explored. One solution that has proven to cut emissions is the optimization of the vessels routes and speed to achieve a "Just-In-Time" arrival at berth (see 5.3.1).

The Port of HaminaKotka uses SeeS (See 5.2.1) to monitor and control its energy usage. The port uses it to plan the energy usage and production, simulate effects of energy efficiency procedures, monitor emissions and to create reports (Questionnaire source 2020a). By measuring the port's energy use and emissions and synthesizing clear statistical and graphical information of them, it is easier to monitor the port's energy efficiency and emission reduction targets. Port of Turku has installed a remote light adjustment system to optimize the lights of the port area (Questionnaire source 2020b). Port of HaminaKotka also has a selective light control system which enables the ordering of more or less light with a mobile device (PIANC 2014, 39). HaminaKotka also uses air from pipes installed at the harbor bottom to keep quayside clear from ice, so ships can maneuver quicker during wintertime. This helps to avoid unnecessary energy consumption and ship emissions that may occur during lengthy berthing operations caused by ice. (ESPO 2012, 54.)

The IMO and IAPH have also published a very comprehensive **Port Emissions Toolkit** in their project GloMEEP to assist the implementation of energy efficiency measures for shipping. Seaport OPX has also developed additional modules to the **NCOS ONLINE** (see 5.3.1) software aimed at reducing environmental impacts by improving shipping efficiency. The Climate change module determines the risk for sea level change, flood level and severity, storm severity, and storm surge impacts and how these threats might affect physical Port Infrastructure. The Vessel Emission Reduction module provides vessel masters a recommended speed to ensure that vessels arrive on time while minimizing their emissions. (Sustainable World Ports 2019.)

4 | DIGITALIZATION OF ENVIRONMENTAL MANAGEMENT

4.1 Benefits of digitalization

Digitalization is an inevitable part of ports' future as the whole global transport system is digitalizing to help achieve sustainable cost-efficiency. Ports will need knowledge about the options for this transformation so it can be achieved in a phased nature taking steps in the right direction. Ports could take the role as the coordinators and providers of digital services to ensure the smooth flow of information between the many stakeholders. Ports could be trusted to be the central hub for conveying information that is usually not shared between organizations. This way miscommunications, hindrances and overall wasted time that can happen within the tangled networks of communication could be avoided. Digitalization's most important functions in ports are hence the improvement of communication and information flow and the creation of a common "big picture" of port operations. (Saarikoski & Helminen 2019a, 49–50.)

Digitalization is not, however, a passive force that will inevitably change processes into greener alternatives as time passes. It must be actively pursued and implemented for it to make a difference. Often digitalization is thought of as a complex and multifaceted entity that requires big investments and costly time-consuming staff trainings. This does not have to be the case though. To develop the process towards a greener digital port, it is helpful to downscale digitalization into smaller puzzle pieces that can be later put together.

These individual digital EMTs can help to achieve the standards for ports' environmental management systems set out by the ISO. Transforming the collected data to a digital form from the different sensors around the port enables a centralized hub of information that can be viewed in a user-friendly way from a common user-interface. This lets the port workers to produce graphs and statistics automatically without the need for human interaction in inputting this data. This way, for example, the energy consumption profiles of container terminals can be put together to form a scalable timeline to view the effects operational changes and compare the collected data in days, weeks, or years with ease.

Knowing the levels of energy consumption and related emissions gives ports a good to way review its environmental activities and set targets for the next evaluation period. This information is also valuable to know when updating the ports environmental policy since the ports have agreed to implement the measures mentioned in their policies. Realistic, ambitious and achievable targets will affect the PR image and social responsibility factor of ports positively.

4.2 Input of data and connectivity

Although digitalization has made the EMTs more convenient for the end-user, it does not remove the need for the actual data to be recorded either manually by humans or by automated measuring sensors. An archive of previously collected data about port operations can be very helpful when establishing a comprehensive digital EMT in a port. This data can be used in calculating the best options for future investments, for example. Ports are clusters of heterogenous information because of the many stakeholders operating in them, and the integration of this operational data is not yet on the optimal level. Data exchanges are usually provided by the port management information systems, but they are limited to official documents, custom declarations and import and export data etc. At the same time the amount of data that is available is increasing by the day because of developments in the IoT and 5G technologies.

The information that has been recorded and saved can be used in varying levels of detail. Combining multiple information sources into a more downscaled and local point of view will help to assess and plan the port's environmental policy. Digital sources of information can be supplemented by more fit-for-purpose methods of monitoring. Information that is collected during routine activities and inspections would be good to be recorded into a standardized digital format. When this data is available digitally, it can be viewed in comparison with the automated real-time data from sensors and complemented by open source recorded data about environmental changes around the port.

Local data from ports can be collected by different means and one should consider carefully which method should be used in certain areas of the port. When making these decisions, it should be considered how this information will be useful in the future and how much resources are available in the long run. This way data is gained from the most convenient spots around the port while yielding the appropriate level of detail. (Brooke et al. 2020, 166.) Different means of collecting data from the port environment are presented in TABLE 5 with a brief overview of advantages and disadvantages:

TABLE 5.
Different methods of collecting data from the port environment. (Brooke et al. 2020, 166.)

Methodology	Potential advantages	Potential disadvantages
Automated and real-time	• High quality and high frequency of data	• Cost and time to install and maintain • Cost and time to specify the correct equipment or tool, parameter, location etc.
Automated	• High quality of data • Generally high frequency of data	(Same as above)
Manual	• Better than no data, especially if collected regularly	• Can be infrequent or intermittent • Generally lower accuracy (e.g. visually observed data)
Anecdotal (log)	• Better than no data, especially if collected regularly	• Can be infrequent or intermittent • Generally lower accuracy (e.g. visually observed data)

Optimally a port should implement digital EMTs which can be integrated into the port management information system[5] with the other information systems used to oversee the port operations. The system should be usable by all different port operators from truck drivers to harbor management so the "big picture" of the port is the same to all. This integration of systems usually requires additional middleware components that can handle the conversion from legacy systems to the centralized open platform system (Wärtsilä 2020).

Ports of Rotterdam and Amsterdam use Portbase services which include many different solutions that are designed to be integrated into the management information system of a port. This list of software suppliers that Portbase uses is helpful when planning the digitalization of a port's environmental tools and also to review the current standards in ports' information systems. (Brooke et al. 2020, 22.) A comprehensive integration of digital tools requires the implementation of different "modules" to the main system, which the different port operators can use in their specific line of work. This is why the connectivity of different tools that the port

[5] These include but are not limited to: National single windows, Port community systems, Vessel traffic systems, Terminal operating systems, Gate appointment systems, Automated yard systems, Port road and traffic control systems, Intelligent transportation systems and Port hinterland intermodal information systems (Kanellopoulos 2018, 38–48).

uses is currently the main challenge in the digitalization of ports' EMTs. The different layers of connectivity can be summed up into three categories:

• **Data collection layer**: The data collection layer gathers data from the physical port environment. This means port legacy monitoring, control systems, already deployed sensors, open data[6] acquired from the city or other sources as well as personal feedback from the port workers and users. Different communication protocols can be used to transmit this data. If a port is IoT-enabled, a lot of this data is collected automatically and transmitted in real-time.

• **Middleware layer**: The middleware is responsible for gathering all the different data from the sensors and other inputs and pre-process them into a more homogenous form. This layer ensures the connectivity of the data sources and is the key in enabling their integration and interoperability. The data is usually stored on a cloud service provided by an IT-solutions company from where the requested info can be obtained when needed.

• **Application layer:** This is the operational interface that the end-users see. Optimally this interface of the digital environment management tools is merged with the current port management information system so there is only one application layer that is used. This is also why there are usually different modules to account for the many specialized needs of the port. These modules can include logistics platforms, remote management and maintenance platforms, yard operation schedulers, under keel clearance systems, mooring guidance, truck platooning etc. All kinds of data visualizations, analysis tools and decision support systems are also included in the application layer.

IoT and real-time automated data collection should be seen as an opportunity which is essential for ports to boost their sustainable development. At the moment this kind of real-time data collection is rare in Finnish ports and it is very usual that a person writes down a number from a meter regularly each month, after which it is divided to get a value for each day. Automation in these meters combined with IoT technology could improve the level of simulations noticeably which in turn would enforce the decision making on the business side of the port. Many ports seem to be content with a yearly lump sum and its price regarding electricity for example. (Interview source 2020b.) There will be an improvement in the data available for digital EMTs in Finland after the Fingrid Datahub will be opened in the year 2022. This hub will work as a centralized information exchange service for electricity trade after which the transmission information of electricity can be gained faster and in a simpler way. (Fingrid 2020.)

[6] Open data is publicly available and free-to use information content that is machine readable. In ports the most suitable information that is available relates to port transport infrastructure, road and rail data. (Inkinen et al. 2019, 1.)

4.3 Digitalization process

4.3.1 Phased implementation

After sufficient data has been collected and digitized if necessary, it is uploaded into the digital EMT that a port is using. This data input is optimally done automatically straight from the measuring devices via wireless technology[7]. In this example we go through the steps of using a comprehensive digital EMT which can achieve varying levels of analysis from terminal level to the scale of individual vehicles. The idea of digital environment tools is that they are inter-compatible with the port management information system and with the systems used in ships. Hence, they are usually designed uniquely for each client. (Interview source 2020b.) A structured approach to assist ports in achieving a green port transformation is important, so the mission does not seem overwhelming.

1. **On-site terminal inspection and data-source review** – A detailed overview should be compiled of the structural equipment, terminal specific layout, cargo flows, infrastructure conditions, energy consumption data and operational processes of the port. After the overview it should be clear what kinds of information can be gained from the area. Important information from old archived documents should also be either manually uploaded or machine read. This can be done in a single terminal or in the whole port area. Tools such as **SDM**, **TEIP** and **Ecosystem approach** can be used to get a good overview of how environmental issues should be considered during the planning.

2. **Pre-evaluation and pre-selection of measures** – During this evaluation, the feasible measures to improve environmental sustainability are identified, evaluated, and prioritized. Afterwards a pre-selection of potential measures will be done. The catalogue of sustainable measures by GreenPort is helpful during this phase. HPC also has its own catalogue of sustainable measures for ports which it has developed during the project "SuStEnergyPort") in the context of the funding programme "Innovative Port Technologies" (IHATEC).

3. **Detailed analysis** – After the most suitable measures to pursue a green port transformation have been identified, their implications to the port's environmental performance should be assessed. This can be done through simulations that achieve a highly accurate prediction of the changes (See 5.2). Other analyses to be done in this phase include a life-cycle assessment and profitability assessment to know the economic consequences of the sustainability measures. These statements are produced to compare the resulting environmental and cost-saving potential of the changes that can be implemented, including financial and operational resources that might be uncovered during the analysis. This phase is where digital EMTs can offer a lot to ports. Accurate and easy to-use analysis methods which can create clear visual representations of changes in the port's environment are very helpful in aiding decision-making.

[7] Although wireless communication gives a lot of variety and new options to the port, its data transmission reliability has proven challenging. Radio channel conditions can vary rapidly, and a wireless mobile network's coverage can change due to obstacles in the port environment, like cargo containers. Therefore, planning the wireless network with the worst-case-scenario in mind is the best option. The new 5G technology is more suitable for the demanding port environment and will enable the adoption of a comprehensive IoT-based environmental management tool. (Hinkka et al. 2018, 36.)

4. Roadmap – The final step is to create a roadmap for implementing favorable energy sustainability measures that have the most promising measures. This roadmap should provide the port with a phased implementation timeline for the selected measures. The measures with high energy and emission savings potential and low efforts to implement should be prioritized.

5. Implementation – During the implementation phase the selected environmental measures are installed and tested, whether they are operational, technical, or behavioral (sensors, software, new infrastructure, or training courses for example).

After the phased implementation has been done during the agreed upon timeline, a port optimally has made changes in its operations, invested in green technologies and installed sensors that record real-time information about its most economically and environmentally important processes. This new data can be modelled into a digital environment in which the processes of a port can be tracked and analyzed. Creating representative visualizations of information is a good way of integrating the heterogenous information into an easily readable form. A visual and easy-to-use interface also guarantees usability for the different stakeholders in a port. These kind of simulations and analysis tools can predict the profitability of changes made in the port operations or estimate the emissions of a new investment (See 5.2.1).

4.3.2 Data sharing and scale

When planning digitalization of a port's EMTs, the relevant decision-makers should consider involving other nearby ports into the endeavor as well. SeeS has collected information about ships emissions and energy usage for over 10 years into their own database from different ports. Any client port can also add information themselves to the database to enhance the level of analysis the software offers. This is a prime example of how data sharing benefits all parties included. (Interview source 2020b.) The organization NxtPort concentrates on unlocking the potential of sharing existing data between ports' stakeholders. Their Data Utility Platform creates transparency in the shipping process to increase operational efficiency, safety, and revenue. This gathered data can be used to build applications based on the data pools. The applications that have already been developed can be browsed and purchased from the NxtPort API market. Another example of how multi-stakeholder collaboration can decrease environmental impacts is the PIXEL project. It which strives to promote voluntary data exchange between ports and their stakeholders using IoT technologies and a centralized information platform to improve efficient use of resources and sustainable development. ChainPORT is an international partner that connects world's leading ports to co-develop innovations and to learn how to optimally apply the latest technology to ports (World Ports Sustainability Program 2020, 15).

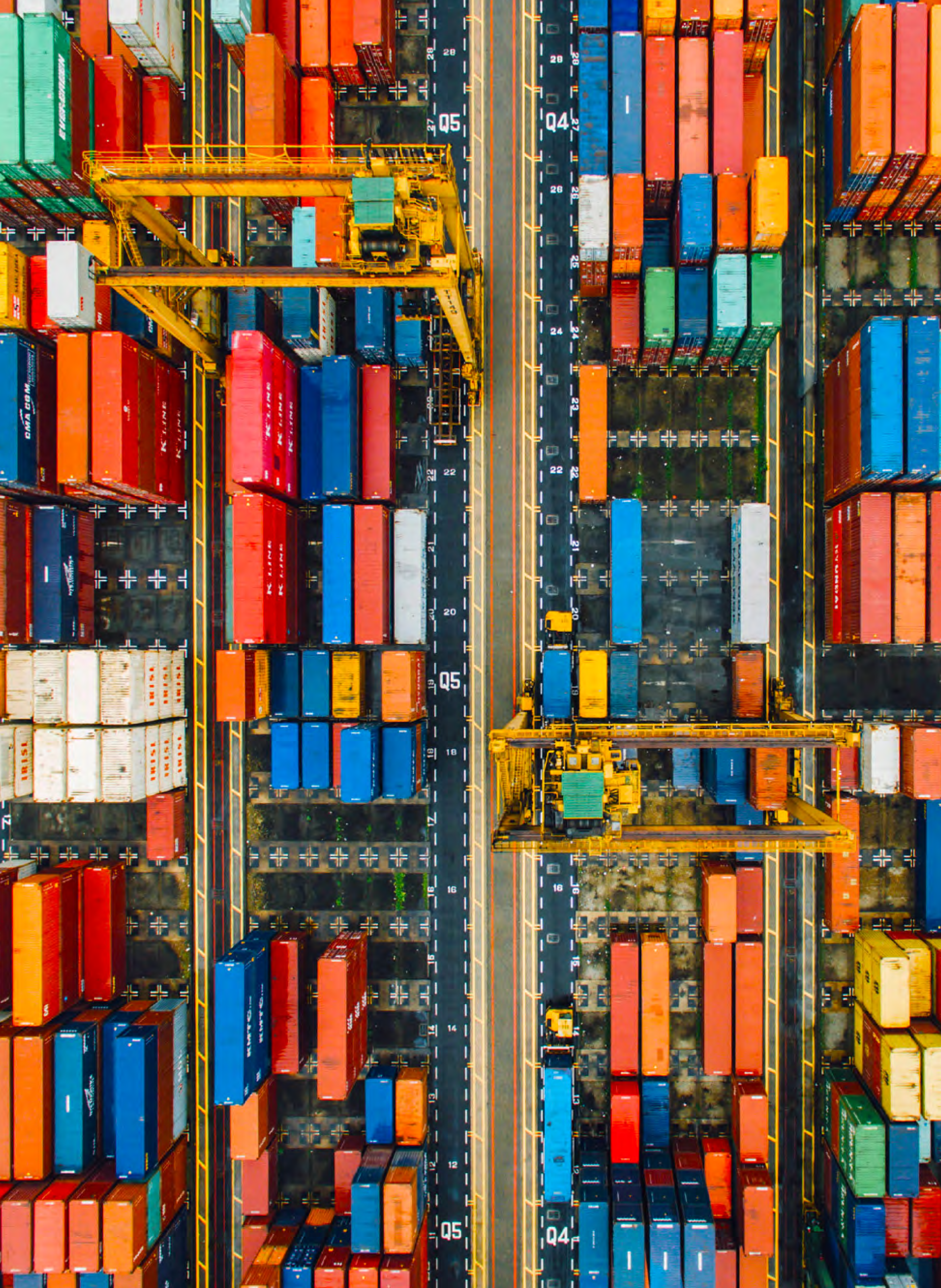
Combining all available data and integrating the possible digital environmental management solutions into one big picture ultimately leads a port to create a digital twin of itself. This kind of a comprehensive digital environment aims to track all aspects of a whole port's life cycle. In Finland, the port of Oulu is creating a digital twin based on the 5G technology. The list of content and features in TABLE 6 that Port of Oulu has gathered for its digital twin can be used as a reference on what such a comprehensive set of data might look like:

TABLE 6.
Example of the content that has been gathered to create a digital twin of a port (Männistö 2019, 13).

3D materials	2D materials	IoT and objects
3D models for the Cranes of the main Port area	Building ID's	IoT data from the STS gantry crane (AZURE-Cloud)
Buildings and structures	Water supply and sewerage plans + their installation depth information	Temperature sensor data in Celcius
Terrain model and an up to date Ortho	Roads & Railroads	Signal strength reading
Surrounding areas of the port,trees and the generic buildings of the Nuottasaari industrial area	Map of container placement	Attachement of a container GPS –location and spatiotemporal visualization
Seafloor scan (Provided by Oulu Port)	Background map	Generic 3D model of a container ship
	Detailed and general plan	Generic 3D models for port objects: Containers, Lightmasts
	Ortho 2017-2018	
	Ship routes	
	Mooring numbers	

It is recommended to proceed with a manageable scale of Big Data[8] that is enough to further the objectives of the port. It is important, however, to use this heterogenous data simultaneously to realize available resources and opportunities. The data gathered from the environment will only give valuable insights if it is used appropriately, and if the interface used to view it is intuitive and visual. (Hämäläinen and Inkinen 2017, 6 < Wu et al. 2016; Belaud et al. 2014.)

[8] The term 'big data' means very large data sets that will have an increasingly significant role in future monitoring systems. Its usage will also have a big impact on how organizations can improve their environmental performance. (Brooke et al. 2020, 168)


Q5
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5 | DIGITAL ENVIRONMENTAL MANAGEMENT TOOLS FOR PORTS

5.1 Land use planning with geographical information systems

5.1.1 Geographical information systems

Land use planning is an aspect that has to be taken into consideration when discussing environmental management, since proper planning of the port's current and future land use helps to avoid future accidents and mitigate risk factors regarding work and the natural environment. This means planning the logistics network in a way that ensures viable long-term operability of the port in regards to traffic intensity, erosion, waves, flooding, sedimentation, river discharges, and possible future places for renewable energy sources (solar, wind, and ocean energies) for example. A port also has to take into consideration the social recreational spaces in the near vicinity in addition to the port's operational needs. To help in this endeavor there are geographic information system (GIS) based spatial and environmental planning and mapping programs. These programs analyze spatial location and organize many types of data gathered from the port area into maps and 3D visualizations. The primary way to view and interact with this data is through a Web GIS in a browser or via a dedicated application. These user interfaces are designed to offer information for end-users in different areas of port (as opposed to only a few GIS-experts).

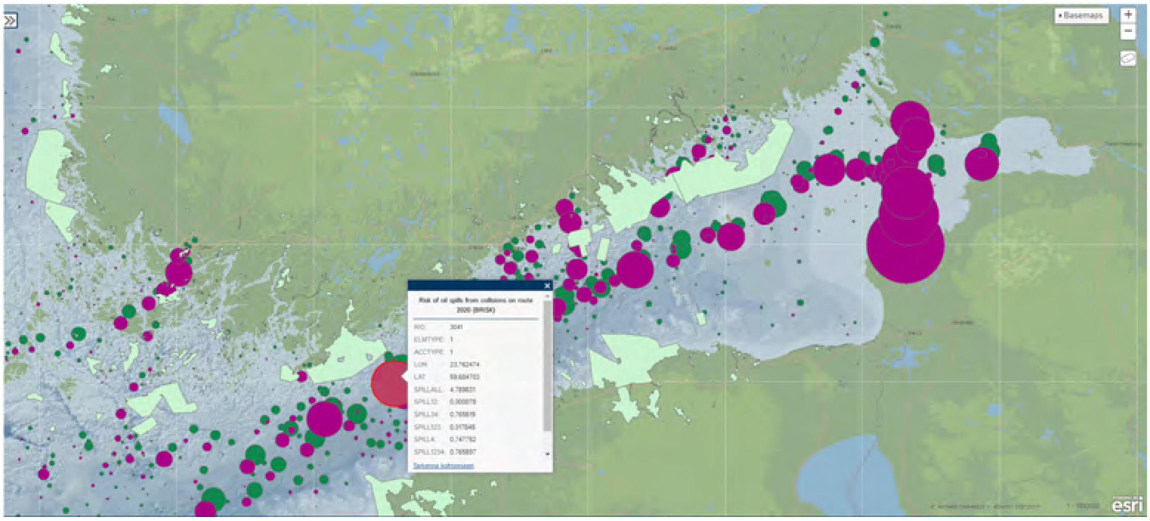
The data gathered from ports usually relates to topography, bathymetry, waterfront infrastructure and legal boundaries (Port Strategy 2019). This kind of static data is usually only measured and updated when needed, for example before a construction project, which is a convenient time to scan the seabed. Environmental regulations require ports in Finland to follow a certain procedure when constructing or dredging, which gives the ports an incentive to geographically aware of their surroundings. In addition to static data, dynamic data in the port area can also be digitalized. This includes vessel location and information, movement of vehicles, people entering buildings, weather, and tides to name a few. Because of this versatility, GIS-based programs can offer solutions for monitoring environmental changes and find possible related problems. This situational awareness has many levels and extends from storm predictions to traffic forecasting, identifying potential underground hazards before excavation or alerting about two hazardous cargos close to each other for example.

5.1.2 GIS-based environmental management tools

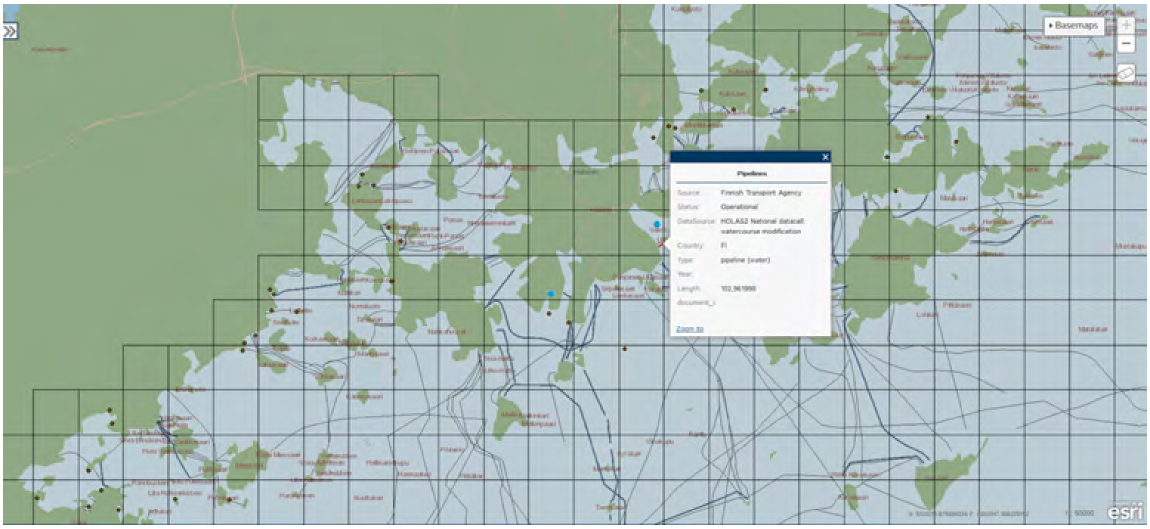
Spatial awareness and a digital archived history of environmental changes enables a port to understand trends on a larger scale and set priorities in their land use accordingly. When deciding on whether to use a GIS-based program it is important to note that the data still has to be measured, collected and uploaded into the program either manually or automatically, although many GIS-programs also include ready-to-use open data from multiple sources. When considering land use planning in ports, the level of measurements should be very local and accurate to achieve predictions and analytics that would be helpful in environmental management.

However, GIS-based online maps can prove to be a valuable asset in following regional and global changes and depending on the scale of data available can also be accurate on a local level. A good example of an open online map that can function as an environmental tool in land use planning is the **HELCOM Map and Data service** (MADS). This Baltic Sea oriented online mapping tool uses different thematic map portals to provide information about: sea environment monitoring stations and assessment units, pollution and its sources in the Baltic Sea, species distribution and protected areas, maritime traffic and accident response and datasets for maritime spatial planning purposes. HELCOM MADS is a good asset to integrate into any GIS-based program used in ports[9]. Datasets and their sources for Finland and Russia can be found from the **HELCOM databases**. Other sources for environmental data are the **open data service** of the Finnish Environment Institute and the **environmental data** provided by the Russian Ministry of Natural Resources. The Russian government has approved that open data about waste placement sites and polluting facilities, recycling, decontamination technologies and pollutant emissions are to be published online starting on January 1st, 2020 (Deloitte Consulting LLC 2018, 16; Federal Service for Supervision of Natural Resources 2020).

[9] HELCOM provides direct access to all HELCOM geospatial datasets by ArcGIS Rest interface or OGC WMS Standards.



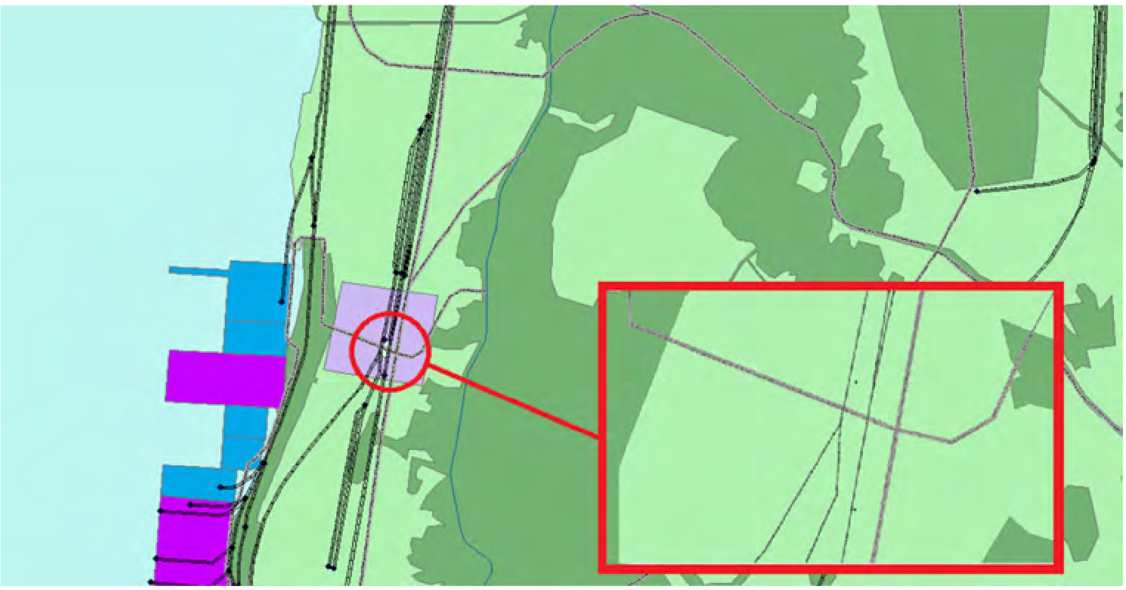
PICTURE 2.
In this map three layers have been chosen: Natura 2000 nature protection sites (light green), Risk of oil spills from collision on route 2020 (purple) and Risk of oil spills from illegal spills 2020 (dark green). (Screenshot of HELCOM MADS available at maps.helcom.fi.)



PICTURE 3.
In this map the layers chosen to be viewed are: dredging sites (brown circles), harbours, (blue circles), cables (thin black lines) and operational pipelines (thicker black lines). The grids represent one square kilometre. (Screenshot of HELCOM MADS available at maps.helcom.fi.)

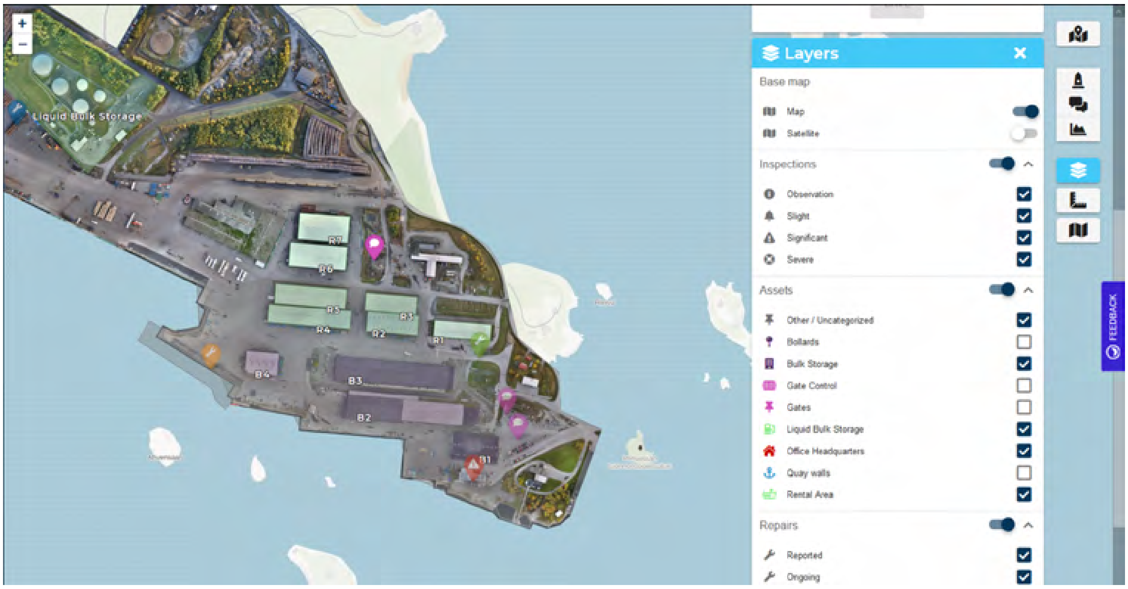
Some GIS-based tools for ports that can create detailed visualizations from multiple data sources include **Gisgro** 3D modelling tool from VRT, **ENESGY for ports** software from North South GIS LLC, and OceanWise's Ocean Database and **Maritime Toolbar** with extensions for environmental samples management, dredging, hydrographic surveys, electric navigational charts and object based image analysis. The market leader in GIS-based solutions is the Environmental Systems Research Institute (ESRI) with its **ArcGIS desktop and online map tools**. These tools are designed with a more general approach but are well suited for port surroundings as well. Other products that offer the same kind of integration of geographical information include Spatial Information Systems from **Cadcorp** and **MapInfo** from PitneyBowes. The Port of HaminaKotka is using the Gisgro system as a tool to maintain its infrastructure and plan land use (Questionnaire source 2020a).

Although the above mentioned are all commercial products, there are also free solutions that rely on open-source data: the Open Geospatial Consortium's (OGC) **OpenGIS** webmap[10] service and OSGeo project's **QGIS**. In sum, there is a plethora of GIS-based tools on the market which can all be used to manage a port's environmental effects with the appropriate data. The ones mentioned here are the most well-known and well-suited for port operations.

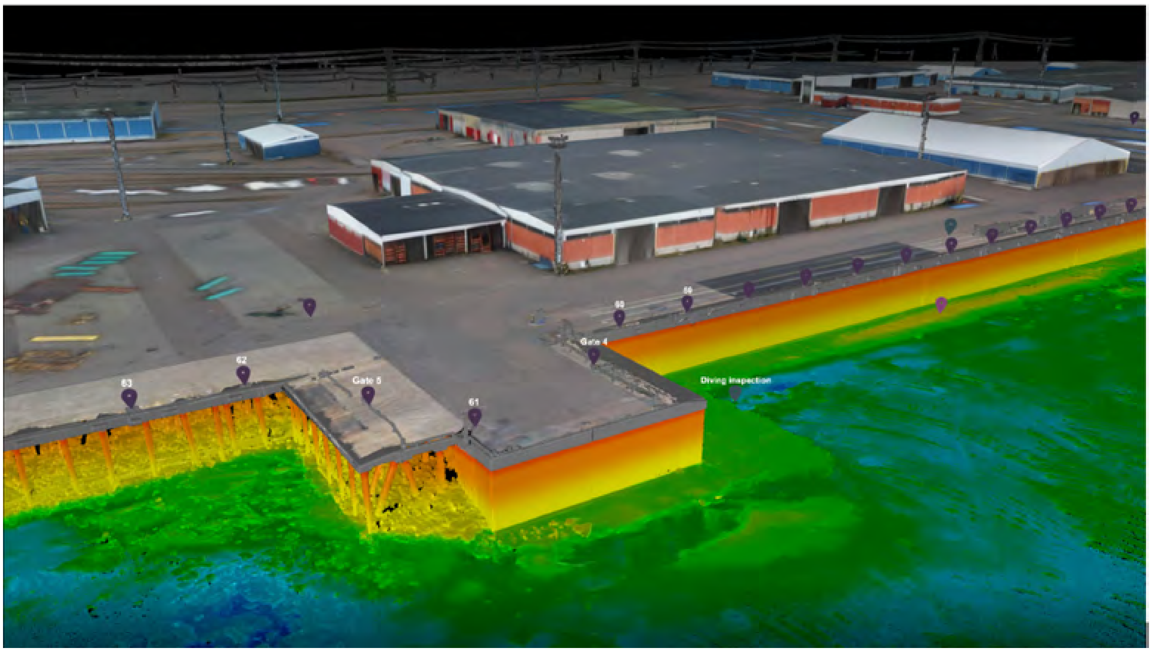


PICTURE 4.
Example of ArcGIS environment being used to model the Ust-Luga Multi Modal Complex (Kotikov 2017, 345).

[10] As has been identified before, most of the ports in Finland have partially achieved level two on the digitalization scale (Helminen & Saarikoski 2019b, 20). To move further up and gain the synergy benefits, the ports will have to share geographic information data with each other. The bottleneck here is the interoperability of different GIS-based programs. The Open Geospatial Consortium (OGC) is working towards making geospatial information and services findable, accessible, interoperable and reusable by creating royalty free and publicly available open geospatial standards.



PICTURE 5.
Gisgro has a clear and easy-to-use interface.
(Screenshot of the Gisgro demo available at demo.gisgro.com)



PICTURE 6.
Example of a multibeam scanned seafloor with underwater infrastructure visible.
(Screenshot of the Gisgro website available at demo.gisgro.com)

It is noteworthy to state that VRT also offers multibeam sounding[11] , laser and drone inspections which make it possible for a port to map large areas accurately, giving information about the depth of the waterway traversed by vessels and the general areas near the port in high detail. A technology that gives similar results to multibeam or oblique sounding[12] is the light detection and ranging [13] (LIDAR) technology which can also be used to create high-resolution digital elevation models with a vertical accuracy of 10 centimeters. Integrating LIDAR maps into GIS-based programs can give highly accurate data of the port area including bare earth, underwater areas, buildings, trees, towers, and powerlines. Laser scanning data covering the entire area of Finland is available for free from the National Land Survey of Finland. This static data can be supplemented by real time data by acquiring LIDAR-sensors[14].

5.2 Simulations and predictive analyses

5.2.1 Detailed analysis of energy usage, waste and emissions

Simulation models used in ports have developed towards general simulation platforms which try to include the port's many operational processes into their calculations (Dragovic et al. 2016). Many simulation tools are already used in ports to boost their cost-efficiency by optimizing logistics and traffic, but simulations to help with sustainable development is a more current trend. TBA among others offer **customized simulation tools** which can be implemented prioritizing environmental management, but there are also prediction tools especially for environmental management purposes available at the market.

The Smart Energy Environmental System (Sees) from Stiia Solutions utilizes real-time and past energy consumption data and production flows to create useful predictions. The energy consumption of the port can be measured and categorized by the energy types used. After the energy consumption of the port has been measured and categorized by energy types, the data is uploaded into SeeS. This enables comparable information on the consumption, production and emissions of electricity, heat, and fuels to be viewed. Because a port's energy usage, working machinery, vessels, and marine traffic as well as their emissions and waste can be calculated and uploaded into the system, it is possible to simulate future energy consumption, production, and emissions. This helps ports to plan their energy usage by noticing opportunities to use energy more efficiently. By improving the energy efficiency of a port, the cost of energy usage is also reduced.

[11] Multi-beam sounding makes it possible to map large areas. The sounding provides very accurate depth information both from the line traversed by the vessel and from a wide strip on both sides of the line. (Itämeri.fi 2020b)

[12] A detailed picture of the surface structures of the seabed as well as its composition can be gained with oblique sonar. This method is also used to locate shipwrecks, for example. (Itämeri.fi 2020a.)

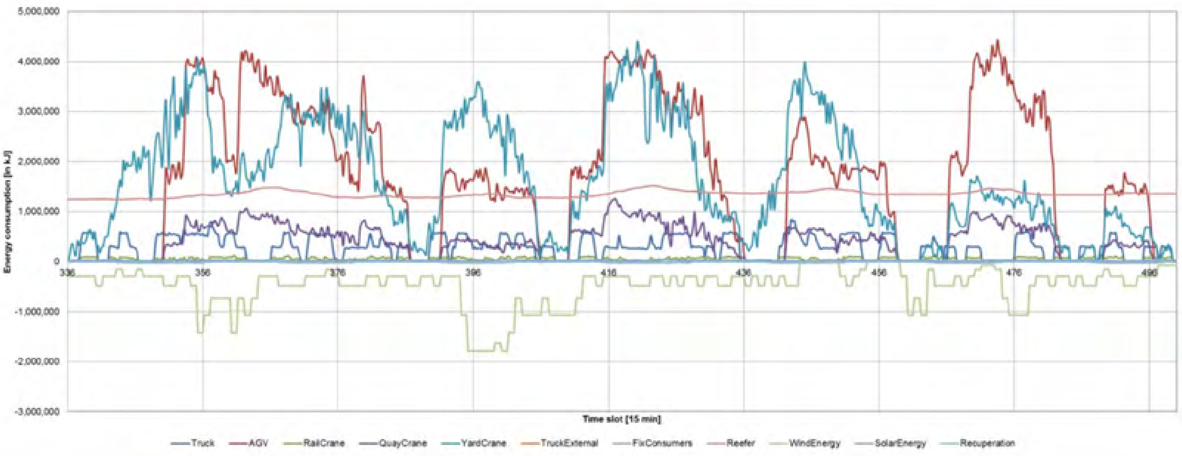
[13] Even urban environment can be made into three-dimensional models with laser scanning data. It can also detect changes in the natural environment. (Maanmittauslaitos 2020.)

[14] LIDAR sensors for outdoor port use are offered at least by Neptec technologies Cor: OPAL LiDAR and Sentek solutions: Hokuyo Outdoor LiDAR Sensors.

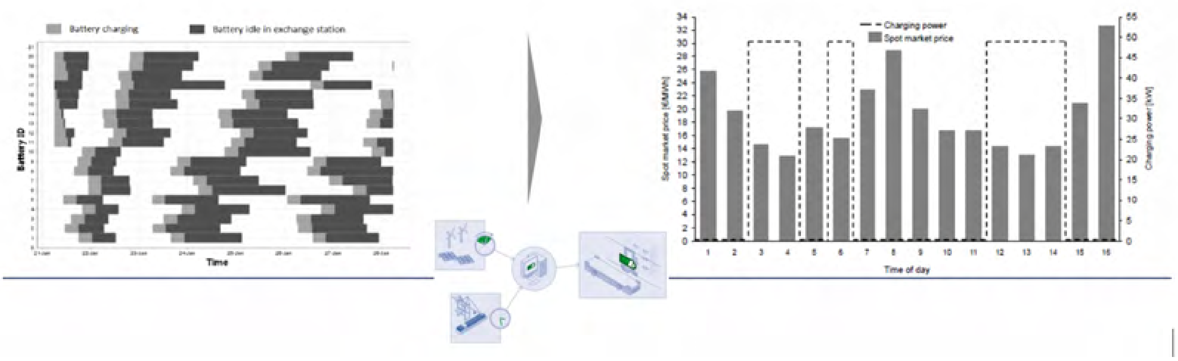
These energy and cost savings as well as emission reductions can be measured by key figures to create a timeline of progress on the port's environmental performance. Information about varying seasonal energy needs can also be identified. This allows for self-learning predictions so ports may plan and shift their energy usage based on the network's load or cost. All of this is dependent on the level of measurement that the port has in place and the quality of information it can provide. If real-time energy consumption and production tracking is installed, faster detection and resolution of failure situations is possible.

Any digital tool used for simulation needs digitized data of the port environment. The port data source review method is wholly dependent on the port and the scale of the data needed. For comprehensive traffic emission predictions, detailed data is needed for each individual vehicle used in the port, for example. The more current information is available about the fuel intake of these vehicles, the more representative the simulation will be. Usually such data is not available, so the yearly fuel usage is divided among the individual vehicles and machinery used in a port by their estimated work hours or average energy usage. (Interview source 2020b.) Predicting energy consumption and production allows a port to plan its energy usage and change its consumption to achieve savings in costs.

HPCsim Energy Consumption Simulation is a tool that models the terminal's operations as well as its energy consumption and emissions. It considers the equipment characteristics, loaded weight, temperature, wind and other energy-relevant aspects. Based on this it provides very detailed simulations of a potential new investment's operational performance compared against the current levels. The benefits of HPCsim is its comprehensive assessment of the environmentally sustainable measures a port may apply, since it uses its Environmental Tool Box to produce life cycle assessments and profitability models alongside the analyses for performance and sustainability. (GreenPort 2018; HPC 2020.) HPCsim Toolbox covers both marine and hinterland providing simulations for marine traffic, quay, terminals, track, and road traffic.



PICTURE 7.
Example of the load profile of a terminal during a one-week period. It can be deduced from the graphic that the largest energy consumers are AGVs and yard cranes, while rail cranes and trucks only consume a little energy when compared. There are also many high peaks in the energy load profile. (HPC 2019, 9.)



PICTURE 8.
Example of utilizing flexible load-shifting in ports or terminals. On the left battery charging and idle times are mapped, and on the right the potential charging times are optimized by energy need and dips in the energy market prize. Renewable energy sources are used to charge the batteries to achieve sustainable cost-efficiency. (HPC 2019, 12.)

These simulations will provide information on a port's potential for energy and cost savings as well as environmental impact reductions. If a validated simulation clearly shows that certain investments would make a port operate more cost-efficiently while also rendering it more environmentally sustainable it is easier to move forward with these investment decisions. This kind of predictive maintenance aims to generate solutions that increase overall equipment effectiveness (OEE). By extracting reliable indicators and patterns from data it is possible to predict possible issues and failures to minimize unscheduled maintenance and maximize productivity and production quality. Real-time holistic understanding of the port's processes not only enables performance optimization but also extends the equipment's lifecycle, which is essential for supporting circular economy and port sustainability. (VTT Technical Research Centre of Finland Ltd. 2020.)

5.2.2 Simulations for decision making

Serious gaming lets port operators to familiarize themselves with high-risk scenarios in realistic settings. Serious gaming is already used in a number of different industries and it has been proven to be an efficient form of training. These simulations can provide the players with high-risk situations with realistic effects on the port's environment, economy, and infrastructure. Playing this sort of a simulation can offer valuable advice on how to take environmental aspects into consideration when developing port processes or planning port expansion.

Port of the Future Serious Game is a digital EMT that gives the port stakeholders the chance to experience aspects of sustainable port development. By applying a fictional environment with unique scenarios and multiple qualitative indicators, the game triggers debate between the players to lead them into constructive conflict about the port's decision-making process. The game's end goal is to demonstrate that successful policy making towards sustainable development requires close cooperation of the port's stakeholders. (Deltares 2020.)

5.3 Optimizing traffic intensity and logistics operations

5.3.1 Just-In-Time arrival and route optimization

According to Wärtsilä, 30% of all bulkers are waiting idle at any given point in time (Wärtsilä 2020 b). For ports this means higher local emissions, higher safety risks and higher coordination needs. Vessels also have a higher fuel consumption because of this and face potential revenue loss because of the waiting times. Hence, the need for a coordinated Just-In-Time arrival to the port is important to improve the overall environmental effect of maritime traffic. Just-In-Time arrival can save a significant amount of fuel by informing the vessel well in advance about and update on the requested time of arrival, after which the ship can slow its speed to accommodate the changes in the port's timetable.

Wärtsilä Navi-Port is a middleware that can be integrated into the Wärtsilä Fleet Operations Solution System[15] and makes it possible for ports and ships to exchange the latest accurate arrival times. With dynamic, real-time data the coordination can be improved to enable more efficient planning of port and terminal operations while reducing congestion and risk of collisions. (Wärtsilä 2020 a.) Exchanging information as early as possible enables a coordinated Just-In-Time arrival which cuts the emissions of vessels as discussed above. By connecting the port navigation system and the vessel navigation system, correspondence can be automated, and the overall workload of different stakeholders lightened. Navi-Port's process works is the following steps:

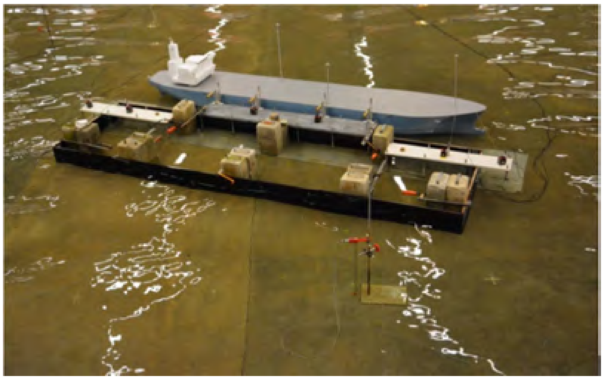
1. Terminal or port has a delay and generates a new requested time of arrival (RTA)
2. RTA is shared with Navi-Port and delivered to Fleet Operations Centre
3. The Fleet Operations Centre and Captain agree to the new RTA
4. The Route and the speed are optimized which results in a new estimated time of arrival (ETA)
5. The new ETA is delivered back to Navi-Port
6. Navi-Port receives the new ETA and shares this with the Terminal or port (Wärtsilä 2020 b.)

NCOS ONLINE is a physics-based online traffic management tool that has been proven to significantly increase a port's capacity to accommodate larger and deeper drafted vessels at berth (Mortensen et al. 2019, 99–105)[16]. This digital under keel clearance tool successfully integrates the different operational user group requirements of multiple port operators by offering a versatile platform to optimize traffic.

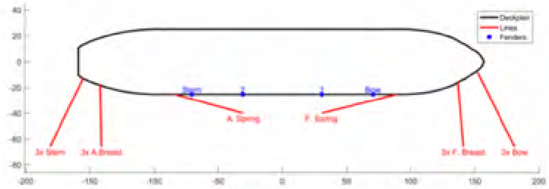
The Seaport OPX's NCOS ONLINE software can forecast a vessel's under keel clearances and the related environmental conditions up to seven days ahead and shows this information on an easy-to-use web interface to allow for more dynamic vessel scheduling. It is said to be the world's most advanced physics-based port traffic management system and the only under keel clearance forecast system in the world that has the same level of accuracy as a bridge ship simulator (Port of Brisbane 2018; Seaport OPX 2020). Because of this incorporation of forecast and real-time environmental data, vessel specifications and transit information, it enables vessels to maximize their cargo, optimize sailing times and maintain optimal safety at all times. NCOS ONLINE considers the forecasted weather conditions, currents, and waves in its physics-based models.

[15] Wärtsilä Fleet Operations Solutions system is an online infrastructure designed for ship-to-shore reporting and fleet performance management. It is integrated into the Electronic Chart Display and Information System (ECDIS) of a ship.

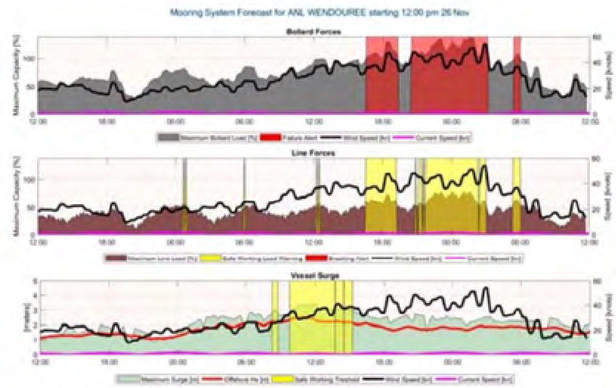
[16] At Port of Brisbane, NCOS tripled the number of deep drafted bulk carriers above 14.0m calling at the Port draft and more than doubled deep drafted containers above 13.0m. This change was during August 2017 to May 2018. (Port of Brisbane 2018.)

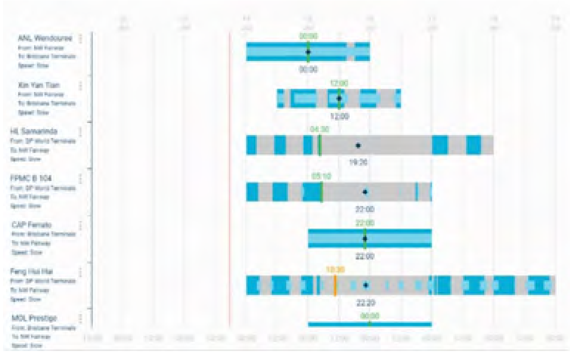


LOA [m]	318.2
Beam [m]	50.6
Draft [m]	12
Displacement [m^3]	133824



PICTURES 9 AND 10.
Example of a sheltered berth 3D physical model and 2D setup in NCOS ONLINE (Mortensen et al. 2019, 102).





PICTURES 11 AND 12.
Example of an operational berth forecast and of the operational planning interface in NCOS ONLINE (Mortensen et al. 2019, 104).

NCOS ONLINE and Navi-Port were raised here as examples of commercially available solutions which improve a port's cost-efficiency and operational capacity while still contributing towards sustainable development by cutting emissions and improving port safety. There are multiple projects in progress to further develop the digital data sharing between ships and ports, and the Sea Traffic Management (STM) organization is connecting the maritime world to speed up this development. Some of the services provided by STM include route optimization, ship-to-ship route exchange, enhanced monitoring, port call synchronization and winter navigation. One example of such a project is the EfficientFlow project implemented in the ports of Rauma and Gävle in the Baltic Sea. The project in question develops digital tools to exchange real-time information of ships to improve maritime traffic flow.

Additionally, MarineTraffic has collected data about ships with a global AIS (automatic identification system) tracking network and used this to create a very comprehensive set of port data. The collected data includes arrival at anchorage, departure from anchorage, arrival at port and departure from port. Using this information MarineTraffic has developed a Port Congestion Tool which shows the estimated waiting times of vessels in different ports worldwide. Waiting times can be viewed weekly depending on the port, market and vessel size class. This tool also lets you benchmark a port's performance based on the waiting and operational times ships experience. MarineTraffic also has an online browser application that shows the real-time location of ships and the density of traffic. It is also possible to view sea currents, wind directions and wave heights among other datasets with the browser application. This information can be used to route incoming vessels into the port, so they can save fuel. The Baltic Sea shipping traffic intensity service also lets you compare traffic by ship type and date during the years 2010–2016, which can be used to analyze trends in marine traffic intensity.

5.3.2 Hinterland logistics optimization

As more cargo will be handled in ports, the hinterland transport system capacity has to grow as well. Here the challenge is to minimize the environmental footprint of the required transport processes. To achieve this, a port can optimize its traffic management and hinterland transport systems to transfer cargo efficiently and to reduce external traffic impacts. (PIANC 2014, 21.)

To avoid trucks that are running half-empty or standing still a digital solution has been created that improves trucks' fill rates, reduces fuel consumption and improves port road capacity: **Truck platooning application** aka Truck Tinder. This digital environmental tool is based on chain-wide real-time data sharing between shippers and transport companies. Simply connecting the right stakeholders and providing them with helpful real-time information sustainable solutions can be achieved.

- **Trailer swapping** uses location tracking of trailers and real-time data sharing between trucking companies to minimize the "empty miles" of the vehicles driven in and out from ports. High-Capacity Vehicles can deploy a second trailer at an intermediate location to be picked up by another transporter on the way back.

- **Cargo bundling** means having multiple shippers load into a single trailer to improve fill rates and reduce empty running. This method uses location tracking and the real-time operational data of different supply chain parties.

- **Truck Platooning** makes it possible to form platoons while trucks are on the road between different trucking companies. A Truck platoon is three to five trucks driving behind each other, which can be combined to form a new modality: a train on the road. The more kilometers are driven as a platoon, the more fuel consumption is reduced. (European Commission, 2018; Port of Rotterdam 2018.)

Also, as discussed above (see 5.2.1) **HPCsim** is a very comprehensive toolbox that offers dry bulk terminal simulation, intermodal hub simulation, terminal planning simulation, terminal simulation analysis and terminal optimization simulation in addition to the energy consumption simulations. These tools can all be used to optimize a multimodal hinterland transport system. Ports of Rotterdam and Amsterdam have developed **Portbase** services that are IT solutions aimed to facilitate exchange of data in the logistics chains of ports. Portbase has its own service for hinterland transport which includes many solutions to optimize the logistics chain. Port of Antwerp also uses smart electronic solutions for transparent logistics flows. The platform they are using is called **C-point**, and it facilitates efficient digital communication around the port to improve the administrative and operational activities.

6 | HINDRANCES OF DIGITAL ENVIRONMENTAL MANAGEMENT

Although the current adoption level of information technology and information systems in ports has certainly made it possible to improve the digitalization of environmental management, there are still hindrances that have to be considered. The more aware different stakeholders are of these factors, the faster they can be overcome.

The degree of digitalization in ports varies a lot and because there are tens of companies operating in a port area, the systems they use are different and often uniquely designed for each organization. Improving operational efficiency and sustainability of ports thus depends a lot on the interconnectivity of the systems used. Although technology already makes this integration possible (API's, middleware and cloud platforms), the work to be done requires time, resources, and expertise in IT-architectural planning. Social acceptance is still the most hindering factor in the digitalization of ports (Kanellopoulos 2018, 74). To begin integrating these systems requires collaboration and leaving behind the mindset of optimizing operations in "silos" (Wärtsilä 2020). Lifecycle and eco-system thinking should be applied to the port operations holistically to connect the many stakeholders under one open system.

Even if the middleware cloud platforms are successfully implemented and work in practice, the stakeholders might not want to share their information. The current idea that ports have about digitalization does not revolve around the idea of "fully open data", and a lot of the information is kept private because it is not clearly understood what kind of data can be shared under the changing legislation. Ports need expertise in the implementation of digitalization and how it should be designed around the concept of open data, so the authorities understand what datasets can be published and which should be prioritized. (Inkinen et al. 2019, 14.)

If the information available from the port area is not automatically measurable or is not machine readable, it will have to be manually typed or uploaded into the digital system. The archives of old information are something that can prove useful in simulations, which is why this labor-intensive work phase is needed. The value of this might not be seen though, and the amount of work related can deter the decision makers because "digitalization" is usually understood as a simple, fast and efficient solution. Automated real-time data gathering from individual vehicles and machines should be more prevalent to truly grasp the benefits that digital prediction and optimization tools can give. There is also a threat that if wireless transfer of information will not be fast and reliable enough in a port environment, IoT technology might not be installed in ports on a sufficient scale.

Digitalization might seem like an overwhelming task, which is why companies and projects that have expertise on the area should be consulted thoroughly to learn the best practices for environmental management. A phased implementation through a clear roadmap that focuses on the most environmentally impactful areas is the best way to move forward without choking on a chunk of big data. This means taking into consideration straight from the beginning how all the small solutions will be integrated into an open platform in the future.

7 | CONCLUSIONS

Incentivized by the environmental regulations and legislation, digital EMTs are becoming widespread in ports of Finland and they are mostly used to calculate emissions from the ships at berth and from the port operations in general. The software are also useful for calculating the usage of energy and producing predictions that show how potential changes would affect the energy usage and emissions. Digital tools make environmental monitoring and reporting easier, while at the same time revealing opportunities for more cost-efficient processes. However, the usefulness of digital EMT's depends on the data that is available. The current state of measurements to gain environmental indicators varies enormously depending on the port in question and real-time automated data is usually only available about the location of ships, air quality of the nearby area and the weather. Although real-time automated measuring per se is not required to benefit from the digital tools, it makes the predictions more accurate and opens the way towards truly sustainable development that goes beyond the current regulations and legislation.

Hence, it is preferable for a port to at least update the reservoir of data when starting the use of a digital EMT if real-time automated data gathering is not an option. Laser, sonar and multibeam scanning services included with the software like GISgro generate good quality static data that will be helpful in implementing a digital EMT. Optimally the port should update the current data with new measurements as well as digitize old archives to enable the simultaneous usage of heterogenous data for the analyses. The importance of using data from different sources is why sharing data is an essential aspect in the future of sustainable development, and why ports should aim towards adopting open platforms where the many stakeholders can exchange data.

Since there are tens of different companies in a port area all using their own information management tools, the interconnectivity of these systems is a challenge that requires expertise and collaboration. This possible hindrance could be overcome more easily if ports take the lead in inviting the stakeholders to share data that improves operational efficiency and sustainability. It is only natural for ports to become central hubs for the exchange of information since they connect organizations and goods to each other by their very nature.

Although certified environmental management systems are already well adopted in the Eastern Gulf of Finland along with their required processes and audits, there is still a lot ports can do to improve their environmental performance, and the tools described in this survey helps to inform about the different possibilities. The most noticeable difference in sustainability can be achieved by optimizing marine and hinterland traffic. One of the solutions with the biggest impact seems to be the Just-In-Time approach, which is achieved by improving the communication between ports and ships by integrating their information management systems. Further route optimization with next generation under keel clearance systems will also mitigate environmental impacts by maximizing the capacity of ports' shipping channels and minimizing the need for large-scale dredging. The possibilities that digital EMTs already offer signals how useful they will prove to be in achieving sustainable and cost-efficient growth for ports.

For the testing of these new investments, simulations are preferred to be used. Both SeeS and HPCsim can predict how the operational changes made from using Naviport and/or NCOS ONLINE could affect the port's revenue and environmental impact. Although all methods towards sustainability are encouraged, Just-In-Time arrival and route optimization of ships are the best solutions to mitigate ports' impact on the environment. This of course asks for more cooperation between shipping companies and the ports as well as the many related stakeholders. A tool to help in this is also available, as the Port of the Future Serious Game simulates the multifaceted decision-making process towards sustainability.

Real-time data gathering is endorsed to support the current methods of environmental management and to create training materials that promote innovativeness in digital environmental management. Technology and automation have proved to be enablers of digitalization if we look at ports like Rotterdam, Amsterdam and Hamburg, while social acceptance is the main barrier in the way of sustainable and cost-efficient development. This barrier will hopefully be overcome since the solutions will also increase revenues and cut costs of ports. This economic incentive is important to get ports invest their time and resources into the adoption of digital EMTs.

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