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A novel approach for assessing the ports' environmental impacts in real time – The IoT based port environmental index

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ABSTRACT

In recent years, exchange of goods around the world has mostly been done by the sea, which increased the pollution coming from the port areas. Activities connected with shipping and handling of goods in ports may harm both human health and the environment. These activities include different (mostly diesel-fueled) machinery used in ports, resulting in air emissions including GHG, NO_X, SO_X, PM, etc. Besides air pollution, port activities affect noise, light, and odor emission, waste accumulation and water pollution. Existing methodologies for estimating environmental impacts of port activities are mostly qualitative and include self-assessment methods which can often lead to biased results. Because of that, there is a need for a quantitative, industry-validated, and cohesive method that would give more accurate results. In this article, the Port Environmental Index (PEI) which has all the attributes described above will be presented. The PEI mission is to integrate all of the main environmental aspects of port such as air emission, waste production, water pollution, noise, light, and odor pollution into one metric that can then be used to assess the port performance and make comparison between ports. The PEI is made as a quantitative composite index based on aggregations of individual indicators for significant aspects of port operations. It includes different indices according to the source of the emission; the Ship Environmental Index (SEI), the Terminal Environmental Index (TEI), and the Port Authority Environmental Index (PAEI). While designing the PEI, correctly choosing the environmental impacts is paramount to properly identify port activities and associated environmental aspects. After their identification, for each significant aspect, a set of representative environmental key performance indicators (eKPIs) is identified. Afterwards, a series of mathematical operations are to be applied: normalization, weighting and aggregation. In this short communication, those methods are outlined yet not definitively chosen. The main idea behind the PEI is to use quantitative, data-based information collected automatically leveraging Internet of Things (IoT) techniques making it possible to assess the environmental impacts of port operations in real-time. The advantages of having such metric in the environmental management plan of a port are numerous. Amongst the most remarkable, it allows inter-port comparison and it can be used for decision making to estimate the impacts using one single metric rather than having many disperse values. Moreover, it can be used by ports for estimating their environmental performance and progress. Since it is based on information collected using IoT technologies provided in real-time, ports can make immediate corrections in their activities.

1. Introduction

Maritime transport is considered to be the most cost-effective way for moving goods and materials (IMO, 2020) with data showing that more than 90% of the world's trade is carried by sea (GloMEEP and IAPH, 2018). The shipping industry in general and port activities in particular, can have significant adverse effects on the environment. Ports rely heavily on a wide range of machinery that run on diesel engines which emit several pollutants into the atmosphere, including greenhouse gasses, particulate matter, nitrogen oxides, sulphur oxides and other chemicals that have the potential to cause serious adverse effects, to both human health and the environment. According to the latest ESPO report, the European port sector considers air pollution the top environmental priority, followed by energy consumption and climate change (ESPO, 2019). Because of this, many communities have raised concerns regarding adverse environmental and health outcomes that they are experiencing due to exposure to emissions related to port operations. Although a significant fraction of the maritime trade is

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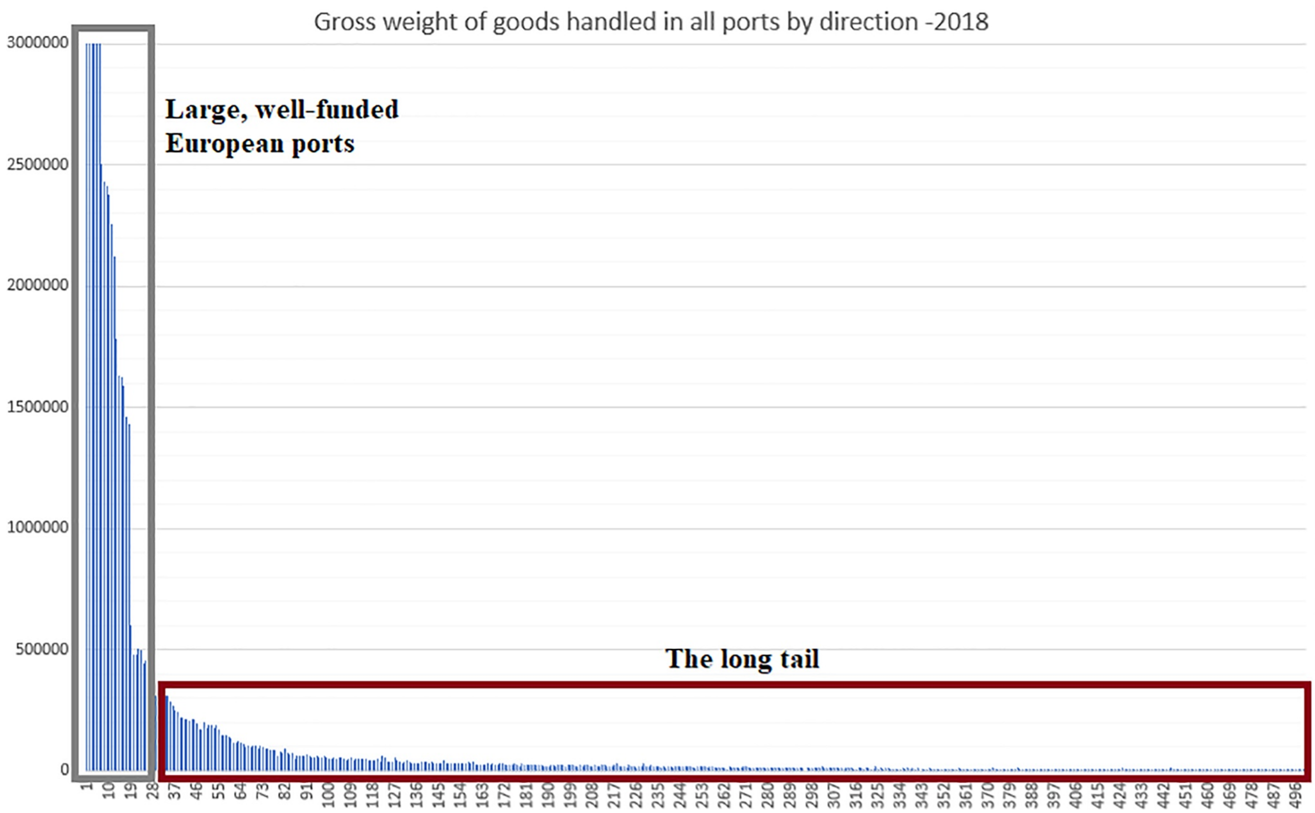

Fig. 1. Gross weight of goods transported in European ports in 2018 (in tonnes), data from Eurostat (2020).

carried out by large ports there is a long tail of registered ports in Europe which have a significant environmental impact, very often not assessed due to budgetary and organizational constrains (Fig. 1).

There are several initiatives for addressing the environmental performance of ports. For example, one of the best-known environmental initiative for assessing the environmental performance of a port is the European EcoPorts initiative. It includes methods such as the Self Diagnosis Method (SDM) that serves port managers to self-assess the environmental management of port activities concerning the performance (EcoPorts, 2019b). The second tool is the Port Environmental Review System (PERS) which is a standard of best practice for reviewing and reporting on significant environmental aspects of port processes (EcoPorts, 2019a). Another initiative often used is the Green Marine Programme, which offers a "*detailed framework for maritime companies to first establish and then reduce their environmental footprint*" (Green Marine, 2019). The main limitation of the above approaches is that they are based on qualitative indicators and are not able to quantitatively assess how well ports are managing environmental issues. Although, as we have seen, several methodologies for estimating environmental impacts exist (EcoPorts, 2019ab; Green Marine, 2019) an industry-endorsed, comprehensive and Internet of Things (IoT)-based methodology able to provide comparable results in real-time is currently lacking, both for small and medium sized ports as well as larger ones. Traditional methods require extensive sampling campaigns and data processing initiatives that are nor time efficient nor cost effective. As a result, current estimates of the port's environmental impacts are usually expensive, impossible to compare between the ports and properly interpret.

Here we present a new development (a part of the project: PIXEL) that addresses the above problem financed under the EC-H2020 topic Mobility for Growth 2017. The development of an IoT leveraged, comprehensive and standardized Port Environmental Index (PEI) which aims at integrating all of the main environmental aspects and their impacts into a cohesive, transparent and standardized metric that can be used to assess the ports performance in time as well as perform inter-port comparisons with respect to their environmental impact.

2. The port environmental index (PEI)

The PEI is a quantitative composite index based on aggregations of individual indicators for significant aspects of port operations. The PEI algorithm is based upon the composite index methodology, which includes statistical methods for data processing and integration (Nardo et al., 2005). PEI is built by integrating three indices: the Ship Environmental Index (SEI), the Terminal Environmental Index (TEI), and the Port Authority Environmental Index (PAEI) (Fig. 2). These indices were so selected according to the various origins into which environmental impact in a port can be divided: (i) from the ships berthing at the port, (ii) from the terminals loading/unloading cargo and from the (iii) Port Authority. The responsibility on the environmental impact in a port is, thus, shared among different agents that may not be managed under the same institution. However, in this paper it is assumed that the management of a port is conducted in a centralized fashion.

Composite indicators are frequently used for both the policymaking and communication, as they are considered to be much easier to interpret and deploy than to analyze indicators across several different domains. They have been widely adopted in medicine (Smith et al., 2009) but according to the best of our knowledge this is the first time that such an approach has been deployed in the port domain.

PEI encompasses the idea to serve as a benchmark that ports can use to evaluate their environmental performance in an inclusive, compositional fashion and to be able to compare it to the other ports. What makes PEI innovative is that methodology used for its construction is quantitative, data-based rather than qualitative. Besides, the main idea behind PEI is to be using IoT to a maximum possible extent, which makes it possible to assess environmental impacts of port operations in real time. IoT consists of connecting objects – typically, sensing equipment – to a network with the purpose of sharing information to

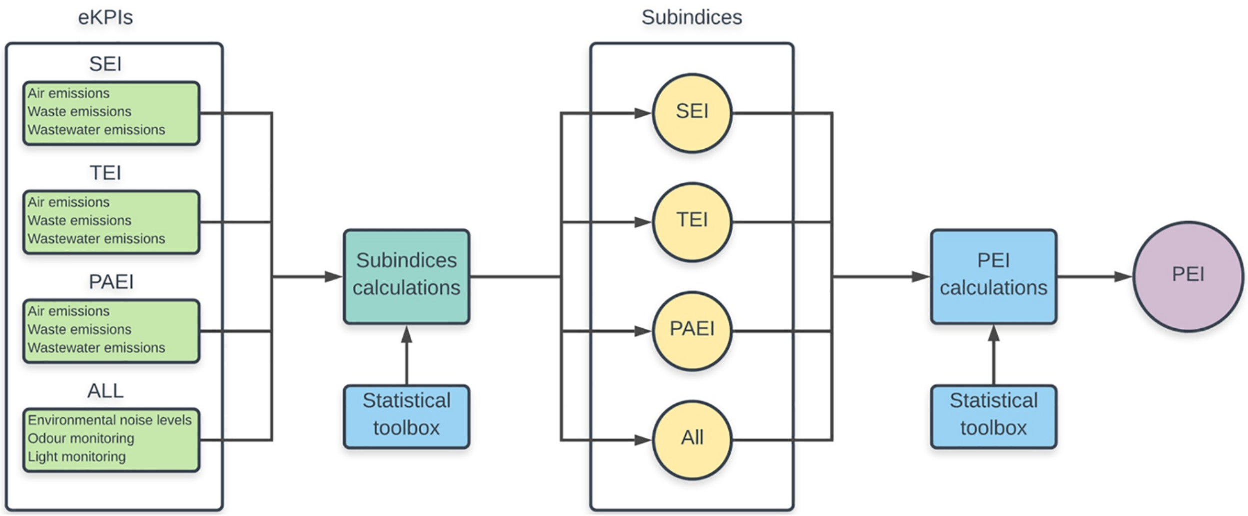

Fig. 2. Generalized methodology for executing the PEI calculation.

conduct some actions towards exploitation of data and other benefits. IoT entails a series of methods (devices connection, data acquisition, data storage, centralization and presentation of data) oriented to have more complete and actionable information about real events (Patel et al., 2016).

2.1. Significant environmental aspects of port operations

To correctly identify and describe the environmental impacts it is paramount to properly identify port activities and the associated environmental aspects. According to ISO 14001, environmental aspects are defined as an element of activities, products, or services that can interact with the environment (ISO, 2015). Amongst those aspects, the most relevant are consider to conform the so-called SEA – "Significant environmental aspects" – (Darbra et al., 2005). The SEAs for the PEI have been identified based on a questionnaire provided by the PIXEL pilot ports (port of Bordeaux – France, port of Monfalcone – Italy, port of Thessaloniki – Greece and port of Piraeus – Greece) as well as by searching the relevant scientific and technical literature. The environmental aspects deemed significant were emissions to the atmosphere, emissions of wastewater, noise emissions, production of waste, light pollution, and odor levels.

2.2. Environmental key performance indicators (EKPIS)

After the identification of SEAs, a set of representative eKPIs were identified for each aspect, assuming that the indicators must be representative and generally available in small and medium sized ports. The most relevant indicators of port processes' impacts on the environment were assessed based on the following features; significance, measurability (meaning the feasibility of having them measured in real-time by IoT systems or using already existing data produced by the ports), representativeness (differentiate the effects of port activities from any other "outside" effect) and their correlation.

The list of the eKPIs that are used to build the PEI is given in Table 1.

2.3. PEI statistical toolbox

In order to integrate the chosen eKPIs, that can be measured in different units and on different scales, a valid normalization method has to be selected. Different normalization (and weighting and aggregation) methods, described in works such as European Commission (2008) and Nardo et al. (2005), are being tested and the most robust will be chosen for the final calculation of the index, according to the final scope of the on-going project. For the sake of this paper, it is assumed that a min–max normalization is used.

The issue of robustness is extremely important in the creation of the PEI. In the context of composite indicators, the term "robustness" refers to the handling of outliers and possible small variations in the input parameters (European Commission, 2008). If the indicator is considered to be "robust", it means it is not affected by those variations and outliers. Considering the PEI, the methods were chosen based on simple analysis of pros and cons of each normalization, weighting and aggregation method. No testing with larger amount of data has been performed yet, and it is considered to be a subject for analysis in future papers.

The next step in the calculation consists of selecting the most robust weighting procedure. This is an extremely important step, as it should assess the relative difference in importance between the selected eKPIs. As stated in Gan et al. (2017) article, there is no definite answer which weighting method is the most optimal one. Like with the choice of the normalization method, several different approaches are being tested and the best one would be selected. The choice must be done in a clear and transparent way. For the sake of this paper, it is assumed that an equally weighting method is selected.

Once the normalization and weighting methods are successfully chosen, there is an issue of the aggregation of those values. The methods include additive and geometric aggregation methods, as well as non-compensatory methods. Several of them are, likewise, being tested and the one that satisfies the needs of the PEI in the best way possible would be selected for use. For the sake of this work, additive aggregation is the option considered.

To ensure the quality of the final results, sensitivity of the PEI (composite index calculation) to the input data has to be done, according to Saisana et al. (2005). It will be done by conducting a sensitivity analysis, which will determine the data that has the most significant influence on the PEI.

It is worth remarking that the usage of these mathematical tools are obliged steps that are not yet definitively defined. To conclude unequivocally on the techniques to be applied (e.g. min–max normalization, equally weighting and additive aggregation), a set of test experiments using enough historical data (there is the estimation that 2 years would be considered as so) must be conducted. It is likely that different combinations may emerge afterwards. Those actions will entail huge amounts of careful planning and execution, employing techniques of data science with its own metrics. While it is planned, the authors consider that the testing and selection task will be candidate to

Table 1
eKPIs for the calculation of the ship, terminal and port authority environmental index Ship index.

	eKPI name	Associated index	eKPI description	Subindex	Units
SHIPS	CO2	ships	C02 emissions by ships	emissions to air	kg or tonnes
	NOx	ships	NOx emissions by ships	emissions to air	kg or tonnes
	PM10	ships	PM10 emissions by ships	emissions to air	kg or tonnes
	PM2.5	ships	PM2.5 emissions by ships	emissions to air	kg or tonnes
	SO2	ships	S02 emissions by ships	emissions to air	kg or tonnes
	HC	ships	HC emissions by ships	emissions to air	kg or tonnes
	CO	ships	C0 emissions by ships	emissions to air	kg or tonnes
	N20	ships	N20 emissions by ships	emissions to air	kg or tonnes
	CH4	ships	CH4 emissions by ships	emissions to air	kg or tonnes
	Plastics	ships	Plastics wasted by ships	waste	kg or tonnes
	Food waste	ships	Food wasted by ship crew and passengers	waste	kg or tonnes
	Domestic waste	ships	Domestic waste created by ship crew and passengers	waste	kg or tonnes
	Cooking oil	ships	Cooking oil used by the ship crew and passengers	waste	kg or tonnes
	Incinerator ashes	ships	Incinerator ashes created	waste	kg or tonnes
	Operational waste	ships	Waste created during maintenance or ship operations	waste	kg or tonnes
	Animal carcass(es)	ships	Self-explanatory	waste	kg or tonnes
	Fishing gear	ships	Self-explanatory	waste	kg or tonnes
	E-waste	ships	Electronic waste (from electronic devices)	waste	kg or tonnes
	Cargo residues (harmful)	ships	Self-explanatory	waste	kg or tonnes
	Cargo residues (non-harmful)	ships	Self-explanatory	waste	kg or tonnes
	Passively fished waste	ships	Waste caught in the next during fishing	waste	kg or tonnes
	other substances	ships	All waste not covered with other categories	waste	kg or tonnes
	Oily bilge water	ships	Water accumulated in the bilge	wastewater	m3
	Oily residues (sludge)	ships	mixture of oily residues created by ships	wastewater	m3
	Oily tank washings	ships	Washing out the residue using crude oil	wastewater	m3
	Dirty ballast water	ships	Seawater pumped in fuel tanks for ship stability	wastewater	m3
	Scale and sludge from tank cleaning	ships	Self-explanatory	wastewater	m3
	Other – oil	ships	Oil substances not covered above	wastewater	m3
	Noxious liquid substances (NLS) – type X	ships	Present major hazard to marine resources or human health, prohibited from discharging	wastewater	m3
	NLS – type Y	ships	Present hazard to marine resources or human health, limited discharging allowed	wastewater	m3
	NLS – type Z	ships	Minor hazard to marine resources or human health, more discharging allowed	wastewater	m3
	NLS – other	ships	No harm to marine resources or human health	wastewater	m3
	Sewage	ships	Domestic wastewater created by crew and passengers	wastewater	m3

Port Authority/Terminal Index

	eKPI name	Associated index	eKPI description	Subindex	Units
Terminals/Port Authority	CO2	terminals/Port Aut	C02 emissions by terminals	emissions to air	kg or tonnes
	NOx	terminals/Port Aut	NOx emissions by terminals	emissions to air	kg or tonnes
	PM10	terminals/Port Aut	PM10 emissions by terminals	emissions to air	kg or tonnes
	PM2.5	terminals/Port Aut	PM2.5 emissions by terminals	emissions to air	kg or tonnes
	SO2	terminals/Port Aut	S02 emissions by terminals	emissions to air	kg or tonnes
	HC	terminals/Port Aut	HC emissions by terminals	emissions to air	kg or tonnes
	CO	terminals/Port Aut	C0 emissions by terminals	emissions to air	kg or tonnes
	N20	terminals/Port Aut	N20 emissions by terminals	emissions to air	kg or tonnes
	CH4	terminals/Port Aut	CH4 emissions by terminals	emissions to air	kg or tonnes
	Sanitary wastewater	terminals/Port Aut	Wastewater created by usual domestic activities	wastewater	m3
	Technological wastewater	terminals/Port Aut	Wastewater created by industry and ship maintenance	wastewater	m3
	Storm water	terminals/Port Aut	Water resulting from rain, snow, etc.	wastewater	m3
	Municipal solid waste	terminals/Port Aut	garbage (“everyday items discarded by the public”)	waste	kg or tonnes
	Inert waste	terminals/Port Aut	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes
	Hazardous waste	terminals/Port Aut	Waste hazardous for public health or environment	waste	kg or tonnes
All	Noise pollution (Lden)	terminals/Port Aut	Noise levels calculated from day, evening and night levels	noise	dB
	Noise pollution (Lnight)	terminals/Port Aut	Noise levels during the night	noise	dB
	Odour	terminals/Port Aut	Self-explanatory	odour	ouE/m3
	Light pollution	terminals/Port Aut	Self-explanatory	light pollution	lx

different publications in the future.

2.4. PEI data requirements

The idea behind PEI is to be based on IoT data sources meaning that all data should ideally come from automated and precise sources such as sensors, legacy systems with proper integration or from updated databases or remote services. This idea is strongly powerful when applied to small and medium sized ports, as it has been presented in Section 1. According to the survey conducted by ESPO at late 2017, more than 50 ports from 18 European countries recognized that more than 4% of their investment projects for forthcoming years will be devoted to Information and Communication Technologies (ICT), ranking second overall in perceived importance (just below road transport connection)[1]. ICT are the basis for the PEI adoption (computing servers, wireless connection and sensing equipment), then

[1] https://sectormaritimo.es/wp-content/uploads/2018/03/Port-Investment-Study-2018_FINAL_1.pdf

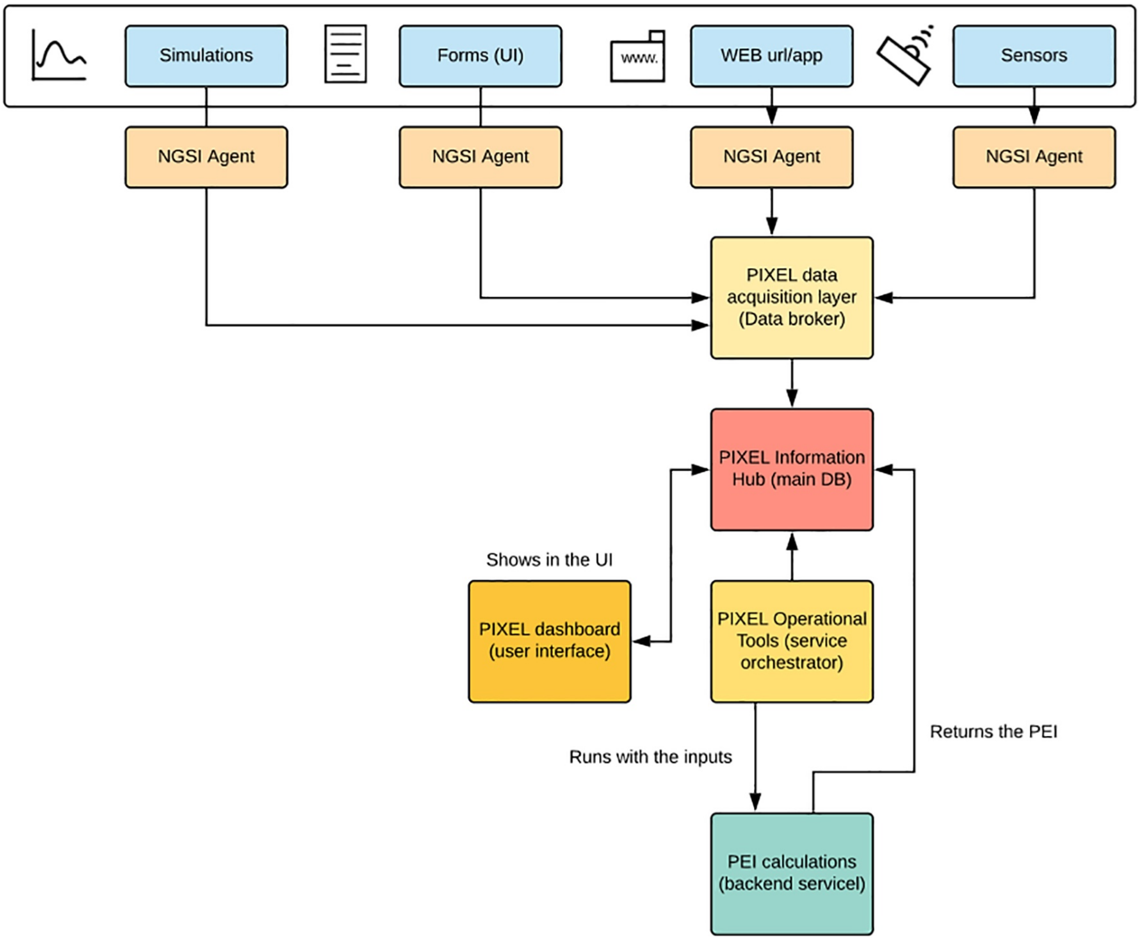

Fig. 3. The implementation steps needed for PEI calculation.

assuming all ports are driving towards digitalization, authors feel safe saying that PEI will be able to be used by small and medium ports. No clear cost structure has been defined yet (also planned under the project PIXEL), but it is the intention of its creators to keep it affordable, especially after realizing how investments in ICT are growing at ports worldwide (2.5 million US dollars in the next three years in average per port)[2]. However, in order to provide economic flexibility to the ports, mechanisms have been put in place to minimize the number of actual IoT devices that a port must invest into to run the PEI. Thus, the index will be built upon quantitative data measured directly or by data derived through proxy indicators such as mapping of the supply chain, operational data, machine specification, emission factors etc.

The main IoT data sources and the flow of data through the PIXEL platform is shown in Fig. 3.

3. Concluding remarks

Advantages of introducing the PEI into the ports are several. First of all, environmental problems are usually multidimensional, and it is thus very difficult for decision-makers to act based on environmental data that come from a large, heterogeneous, multi-owned number of different data sources. It is much easier for them to act on complex environmental issues by addressing a single metric which integrates all environmental impacts that a port is having. The Port Environmental Index is that metric. PEI has been devised as a composite indicator representing a multidimensional phenomenon. The impact of the port as a whole is represented by the PEI while the specific contribution of that impact from the various agents involved is encapsulated in the SEI, TEI and PAEI subindices. Whereas a single metric may entail loss of information, it will allow external entities (public, government bodies, municipalities, etc.) to have a clear view of the current impact, establishing rankings, timely analysis, comparison between different scenarios and among ports and to build policies upon that single value. This is the way that a port as a whole may be accountable and better accepted by the society without getting too detailed and technical, losing its focus.

The metric will be a useful tool for assessing trends in the overall environmental performance of the ports. By using the metric, the ports will be able to address whether they are making progress in terms of their overall environmental performance through time, or they are deteriorating. Since the index will be leveraged using IoT technologies, the information will be provided in real-time. By using the PEI, the ports will have immediate feedback on the environmental effects of their operations and will be able to take instantaneous corrective actions to mitigate adverse environmental situations.

Using current approaches, comparing the environmental performance between ports is unfortunately not possible due to a lack of a standardized practice and because of data sharing concerns (security, privacy, business issues). To that aim, the methodology for calculating the Port Environmental Index will be fully transparent and we hope it will be widely adopted. By using this metric, it will be possible to make inter-port comparisons and rank the ports based on their overall environmental performance, always guaranteeing the maximum compliance with applying regulations. Also, in the case that the ports will decide to disclose the PEI to the public, they will be able to showcase their commitment towards a sustainable and environmentally friendly

[2] https://internetofbusiness.com/inmarsat-report-maritime-iot-adoption/

management of their operations.

Finally, the metric will enable the ports to address "what if "scenarios and asses the overall environmental return on financial investments. For example, assuming that a port would decide to invest in energy-efficient lighting, it will be possible -by using the index – to quantify the effect that such an investment would have on the overall environmental performance of the port. If it does not affect the Port Environmental Index much, there is no environmental benefit to be gained and there are maybe other ventures that are providing more environmental return on investment.

In conclusion, the PEI will be an IoT-leveraged comprehensive indicator of the overall environmental performance of a port delivered in real-time. By using the metric, the ports will receive immediate feedback on the environmental effects of their operations and will thus be able to take instantaneous mitigation measures including testing what-if environmental scenarios in a comprehensive manner across different environmental dimensions.

CRediT authorship contribution statement

Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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