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PEI Definition and Algorithms v2

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Description	This deliverable describes the methodology for PEI computation including the eKPIs to be used, the statistical algorithms as well as a description of the data sources which will be used.		
Work Package	WP5		

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Key Data

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Abstract

This document is a direct follow-up to the Deliverable 5.2 and expands on the ideas and conclusions presented in that document. Continuing the work done in sections 5 and 7 in D5.2, various means of the data retrieval mechanisms (web-based, sensors, web forms and external data) are presented and described in more detail. Likewise, an exhaustive review of the minimum data needed for the PEI calculation is laid out. The review is done for all four pilot ports of the PIXEL project and deals with the data linked to ships, port terminals and port authorities in each of these ports.

Considering the eKPIs listed and defined in the previous deliverable, the work was done to relate those indicators to the three subsidies of the PEI (Ship, Terminal and Port Authority Environmental Indices). In addition to that, the list of eKPIs was further refined and modified to represent the subsidies in the best way possible. To achieve that, the eKPIs related to noise, light and odour pollution are now treated as eKPIs directly related to all subsidies and are not treated separately for each subsidy (unlike the eKPIs representing air and water pollution and waste production). Methods for estimating the eKPIs from data sources are presented for each of those eKPIs. Those are divided into (i) the indicators based on direct measurements and (ii) the indicators whose calculation requires the use of proxy data. The latter include eKPIs related to air pollution and include both those related to ships and port authorities/terminals.

Although the data analysis will be fully addressed in WP7 (pilot trials), this deliverable nevertheless includes a study of the impact that different methods used for the calculation of composite indicators, described in D5.2, have on the calculation of the PEI. In order to perform the analysis, a mock-up database consisting of several different ports was created. Also, uncertainty analysis was performed. Based on those analyses, additional conclusions and guidelines were provided.

The last section deals with the technological implementation of the PEI. It presents an insight on how the technological basis of the PEI implementation was (described in the D5.2) followed to obtain a working PEI calculation tool. The section addresses the position of the PEI in the global PIXEL architecture and the process of the development of the code for the PEI computation. At the very end, some outlines for the upcoming PEI manual are provided.

With this deliverable, the task T5.3 comes to an end, as all its objectives are successfully achieved.

Statement of originality

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List of acronyms

Acronym	Explanation
AIS	Automatic Identification System
API	Application Programming Interface

ASPM	L'Azienda Speciale per il Porto di Monfalcone - Special Authority for the Port of Monfalcone
BAL	Budget Allocation
CH_4	Methane
CI	Composite indicator
CO	Carbon monoxide
CO_2	Carbon dioxide
DAL	Data Acquisition Layer
DB	Database
DWT (dwt)	Deadweight Tonnage
EC/BC	Elemental or Black Carbon
EF	Emission Factors
eKPI	Environmental Key Performance Indicator
END	Environmental Noise Directive
ESPO	European Sea Ports Organisation
ETA	Estimated Time of Arrival
EU	European Union
EWC	European Waste Catalogue
FAL	Facilitation of International Maritime Traffic
FTP	File Transfer Protocol
GA	Grant Agreement
GHG	Greenhouse Gas
GIS	Geographic Information System
GPMB	Grand Port Maritime de Bordeaux - Port of Bordeaux
GWP	Global Warming Potential
HC	Hydrocarbon
HTTP	Hyper Text Transfer Protocol
IH	Information Hub
IMO	International Maritime Organization
IoT	Internet of Things
IT	Information Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
L_{ae}	A-weighted, Sound Exposure Level
L_{DEN}	Overall day-evening-night Noise Level
L_{eq}	Equivalent Continuous Noise Level

L_{max}	Maximum Noise Level
L_{min}	Minimum Noise Level
L_{night}	23:00 - 7:00hrs Noise Level
MARPOL	Maritime Pollution
MCR	Maximum Continuous Rating
MMSI	Maritime Mobile Service Identity
MQTT	Message Queuing Telemetry Transport
N_2O	Dinitrogen Oxide
NGSI	Next-Generation Sensors Initiative
NLS	Noxious Liquid Substances
NMVOCs	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen oxides
OC	Organic Carbon
OT	Operational Tools
PA	Port Authority
PAEI	Port Authority Environmental Index
PAN	Peroxyacetic Nitric Anhydride
PAS	Port Activity Scenario
PCA	Principal Components Analysis
PCS	Port Community System
PEI	Port Environmental Index
PIXEL	Port IoT for Environmental Leverage
PM	Particulate matter
PMIS	Port Management Information System
PPA	Piraeus Port Authority
REST	Representational State Transfer
RTG	Rubber-tired gantry
SaaS	Software as a Service
SEI	Ship Environmental Index
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxides
TEI	Terminal Environmental Index
TEU	Twenty-foot Equivalent Unit
ThPA	Thessaloniki Port Authority
TOE	Tonnes of oil equivalent
TOS	Terminal Operator System

TSP	Total Suspended Particles
UA	Uncertainty Analysis
UI	User Interface
URL	Uniform Resource Locator
VOCs	Volatile Organic Compounds
WP	Work Package

About this document

This deliverable builds upon the Deliverable 5.2 and expands the procedure described in it, as well as provides some new insights and conclusions. The beginning of the document deals with the data acquisition, with the emphasis being on the data sources and the availability of data (and data acquisition methods) in the four pilot ports. Following that, there are two sections dealing with environmental Key Performance Indicators (eKPIs). The first of them contains the description of eKPIs and relates them to ship-, terminal- and port authority-related activities. The second one focuses more on the estimation of the eKPIs' values from the data sources described in the beginning. The fourth chapter deals with the statistical analysis related to the PEI calculation process. It includes comparisons between various mathematical methods used for the creation of the PEI. The closing chapter describes the technological implementation of the PEI and includes both the description of the PEI's position in the PIXEL architecture and some guidelines for its further implementation and use.

Deliverable context

Keywords	Lead Editor
Objectives	The main objectives of the deliverable are the following: (a) description of the data retrieval mechanism and the review of minimum data in the pilot ports; (b) finalization of the eKPI list and the methods for their estimation; (c) analysis of the PEI calculation methods and their impacts; (d) description of the technological implementation of the PEI
Exploitable results	The results of this deliverable will be exploited during the PEI implementation in WP7 (Task 7.5). More specifically, the PEI development is presented in this document and it will be implemented in the four pilot ports during the course of the T7.5. In addition, WP6 will exploit the results of this deliverable for the development of a PEI model and dashboard to be included in the PIXEL platform.
Work plan	This deliverable is the result of the work performed from M19 to M26 and is related to the task 5.3 PEI development.
Milestones	This deliverable is a final verification of the milestone MS6 under WP5 PEI "Development completed".
Deliverables	The deliverable is a direct follow-up to the D5.2 and expands on the ideas and conclusions presented in it. It also builds upon the content of D5.1, especially the parts dealing with the identification of significant environmental aspects and the definition of eKPIs.
Risks	WP5#10. Data availability – the needed data/KPIs for computing PEI will not be available (for pilot ports). WP5#11 Data standardization and interoperability– different pilot ports will have different types of data, or the same type of data measured with different methods which makes comparisons difficult. This deliverable expands on the previous one (D5.2) and presents additional methods for the eKPIs estimation, as well as the methods for data imputation and normalisation. WP6#12 KPIs weighing - weighing environmental indicators is hard

	The deliverable will discuss different weighting approaches with the aim of minimizing the inherent biases which are a part of the weighing procedure.

The rationale behind the structure

The deliverable encompasses the work done on the PEI development from the submission of D5.2 (M18) until the submission of this deliverable (M26). It is directly built on the previous deliverable and follows a similar logical succession.

In the first section after the introduction, data sources are described, including data retrieval mechanisms and the minimum data that the pilot ports can provide. After that, eKPIs are described and related to the activities of ships, terminals and port authorities. Based on these two sections, methods for estimating eKPIs from the available data sources are presented in the next section. This part deals both with the data acquired from the direct measurements and the eKPIs based on proxy data.

Once the methods for eKPIs estimation are presented, a procedure for statistical analysis of the indicators and the calculation procedure is laid out. This section is itself divided in a logical sequence that follows a standard procedure used for the construction of composite indicators, such as the one described in Joint Research Centre-European Commission (2008).

The deliverable is finalized with the last chapter, dealing with the technological implementation of the PEI. The chapter was put at the end because it presents a continuation on all the previous sections and it also gives some conclusions and guidelines that will be used in the future work in WP5 and WP7.

Version-specific notes

This deliverable presents an overview of the work done under task T5.3 (PEI development) during M19 – M26. It follows D5.2 and provides a full description of the data sources and algorithms for PEI calculation including the executable code to be implemented and deployed in the PIXEL IT infrastructure.

1. Data sources

The relevance of the data for calculating the Port Environmental Index is paramount. PEI must be a quantitative value drawing from operations over quantitative data representing actual values of real elements in a port. Thus, this deliverable (D5.3) is highly biased by the data availability in ports and the possibilities that those will offer.

According to definitions in the PIXEL GA, the objective in WP5 is not to force ports to gather all data about environmental impact in their port, but rather making them be able to have a methodology to run the PEI and showing them the ideal data they must have to obtain a totally reliable value. From the proposal stage of PIXEL, it was identified that current European ports would have difficulties on having all data so one of the actions in the task is to come with a clear report on those difficulties to gather the data needed (*guidelines and best practices recommendation for his adoption by ports outcome of T5.5)*, and extrapolate this to other ports (with clear reasoning). Therefore, the work on this regard has consisted of creating a bare minimum of mandatory data and envision strategies to cover the part of data/methodology that the ports will have difficulties about. Later in the project (WP7 – T7.5), ensuring this bare minimum of data is covered by all four ports in PIXEL, the tool will be validated and tested in real life environments. Meanwhile, in WP5 one of the works being done is to decide and describe: how to calculate and deploy PEI for a port in case some data will not be available (e.g.

missing data imputation, skipping values and stating that into a report, including a percentage of data coverage in the result, inferring some values, using averages) and creating the code to compute the PEI over the data.

In the previous version of documented work in WP5 (deliverable D5.2), several pieces were explained and the global context of the data usable in the PEI procedure was stated.

In D5.2 – Section 5, the WP5 team described all the pieces of data with links to real phenomena that would be used for the calculation of eKPIs from the point of view of an extensive literature analysis. This was elaborated with the aim of being a reference of the different data associated to the most relevant environmental aspects identified for maritime ports (section 3 of D5.2). With that information, during last months of execution, the team dug deeper into the real data availability in small, medium and large European ports and finally came up with a list of minimum mandatory data to compute the PEI. It was decided that: as many that a port could offer, the better accuracy and the richer information could be observed, but the bare minimum pieces of data were immutable. Therefore, any port wishing to apply the PEI, should comply and provide it.

In D5.2 – Section 7, data collection was analysed generically from a technologically-oriented view. Different ways of retrieving data complying with PIXEL's IoT schema were lightly explained and the methodology to calculating the PEI was outlined. During these last months of T5.3 execution, these modes of data retrieval have been fine-tuned and particularised for the four ports participating in PIXEL.

Some objectives for D5.3 were to put those pieces together, to analyse the data gathering capacity of current European ports by extrapolating the scenario of the stakeholders involved in the project and to come up with a strategy for integrating those data into a single technological framework for computation.

With that in mind, this section is divided in two sub-sections, aiming at covering the spectrum of data availability and data requests in the future for potential external ports acquiring PEI (and PIXEL).

- Section 1.1 analyses in deep the data retrieval mechanisms discovered (and present) and offered by the ports in order to comply with the bare minimum dataset for PEI computation. In this section, different ways of having the data reaching PIXEL infrastructure are detailed: through own IoT services, making use of external data provision, retrieving it from remote servers and periodically imputing them.
- Section 1.2 makes a thorough review (with illustrations and clear samples) of the bare minimum data for the PEI calculation available in all four ports participating in PIXEL. For each one of the ports, a separated sub-section is created and in each of them the following documentation strategy is followed:
    - Detailed report on the data available assigned to the ships environmental impact domain.
    - Detailed report on the data available assigned to the terminals environmental impact domain.
    - Detailed report on the data available assigned to the Port Authority domain.
    - Summary table and conclusion. For all the data pieces related, the way of retrieval (one among those informed in section 1.1) is described.

1.1. Data retrieval mechanisms for the needed PEI dataset

Realising PIXEL title: "Port IoT for Environmental Leverage", the reader can directly drill down the concepts: (i) for environmental leverage – the PEI (Port Environmental Index) aims at monitoring environmental impact in order to let ports tackle green policies to improve their performance while being able to quantify this improvement with a clear metric, and (ii) "port IoT". The whole PIXEL idea is to take advantage of the IoT.

Differently to what is generally internalised by people, IoT is far more than sensors transmitting data to a platform. IoT encompasses a series of techniques, concepts, procedures, tools, technological architecture, and (finally) hardware such as sensors. As per definition[1], the purpose of IoT is "to describe and materialise a network of software, and other technologies with the aim of connecting and exchanging data with other devices and systems over the Internet".

[1] https://www.oracle.com/internet-of-things/what-is-iot.html

Therefore, being able to say that a system is indeed IoT does not necessarily means everything must come from a sensor in a lighting post or from small (handheld or not) devices moving around. Applying the software, techniques and spirit of IoT is what actually matters on this regard.

For the case of the PEI, several information needed to compute the designed single metric indicator cannot be extracted directly from such data sources (e.g. supply chain definitions, MARPOL annexes information or details on operational information of a vessel). Additionally, one of the traits of PIXEL/PEI is the scalability, then no overdependence should be created with physical-devices data sources recommendable to reach it.

The IoT feature that is crucial for PEI is the automation and connectivity[2], as per applying seamless communication among the interrelated components of the IoT ecosystems (sensors, compute engines, data hubs, etc.). Added to the aforementioned scalability, automation will make PEI usable, useful and practical.

Another basic IoT idea behind the PEI is the fact of having different heterogeneous data integrated and available under a common understandable semantics in a single system and database. According to what has been decided in WP6 and WP7, a PIXEL deployment will be single-instanced and centralised in a server within port premises.

Following the previous, the technical team discussed lengthy with the ports in the Consortium to discover in which way could the different pieces of data be gathered and collected in order to respect IoT principles and properly reach the PIXEL infrastructure to feed the eKPIs' slots and PEI calculation.

1.1.1. Web-based

This is one of the preferred ways of data acquisition for the PEI. It is usually smooth, it allows straightforward conversion to PIXEL data formats and it is based on a dynamic, ubiquitous nature. This data retrieving form embeds the integration with own legacy systems as long as they will offer a reachable access point. Generically, it covers every way of communication based and/or powered on a HTTP exchange.

Own APIs/URLs:

Wherever deploying PEI in a port, there will usually be a series of previous data information systems in place. For instance, a Terminal Operator System (TOS), a Port Management Information System (PMS or PMIS) or different proprietary software helping manage daily port operations. PEI would be interested on retrieving and taking advantage of some data pertaining to those systems, such as, per most common, vessel calls, operations schedule or traffic information at the gates of the port.

Several ways of interconnecting both worlds may appear, but, as per general case, systems in the port have a procedure for being queried to retrieve data. Therefore, the PEI will be able to gather it using HTTP calls:

- Through the built-in API of the original software system
- Through an API developed by the IT department of the port
- Through a URL the port uses for informing of that data (see 1.2.2.1)
- Public data from the ports or related-to-ports agents available via website and/or API

In the case of PIXEL ports, this situation has appeared with high frequency (see section 1.2). This is a very useful and valid way of data gathering for the PEI as the NGSI agent will make easily collect and filter the data.

PIXEL tools:

PIXEL aims at developing additional tools apart from the PEI. With the purpose of bringing the ports closer to the Port of the Future concept, improving digitalisation and use of operational data, PIXEL is developing tools for modelling different aspects of the port functioning (e.g. energy, intermodal transport, parking occupancy), for visualizing different data under a single dashboard and enabling certain intelligence for predicting the estimated time of arrival (ETA) of ships, among others.

It has been made evident that using tools embedded in the PIXEL platform, the ports may take advantage of their results incorporating part of them as input data for the PEI calculation:

[2] https://www.educba.com/iot-features/

- **“Port Activity Scenario” (PAS**). It will be used as a tool for getting data to feed the PEI. More details on this proxy data and the whole process designed can be found later in section 3.2.2
- **AIS processing:** It will be used as a tool for obtaining the data of berthing and manoeuvring time of vessels in the port area for some ports of the Consortium. Details can be found later in section 3.2.1

Manual upload to remote servers:

Usually, the legacy management systems in ports will not allow an HTTP request, peer-to-peer connection, REST query or simply an automated direct access to the data. Likewise, often the personnel at the port only has at its disposition Excel files with the information (e.g. the registers of waste collected by the company who handles garbage), and no automatic operation is included in all the process.

For those cases, one of the accepted data retrieval ways for the PEI is the access to remote FTP (or similar protocols) servers where the port staff uploads periodically the different files with clear naming instructions in order to automate the process from the point of view of the composite index calculation.

1.1.2. Sensors

This is the ideal way of data retrieval in PIXEL (and PEI). As commented in the introduction of this section, not all the data included in the PEI input dataset is subject to be collected through a sensor. Therefore, the normal case of PEI deployment will be only a percentage of the data being collected using this way.

However, during WP5 course, the team has identified - a minimum of - three sources that can (and should) be collected by ports (in all cases) using IoT sensors: (i) noise pollution, (ii) light pollution and (iii) odour pollution levels. An example of sensor for getting those values is described in section 1.2.1.3.

1.1.3. Forms

During WP5 execution, the team realised that for certain ports (extrapolating it, many ports in Europe) are not even measuring/recording certain data, such as the energy consumption of certain activities, the wastewater produced or the waste spilled by certain entity. PEI must be prepared for deployments in “harsh” scenarios in which these situations appear. Therefore, several web forms are being developed and included within the PIXEL UI for the ports to manually type the different values (e.g. see section 1.2.4.3). Especially considering lack of technological investment in small and medium ports, it is an obligation of the tool to put the means to retrieve the minimum information needed even though having to use this retrieval option.

1.1.4. External data

This sub-section relates to the data that is not coming directly from the port, but from external entities. This kind of data source could have been placed in section 1.1.1, as in the majority of cases the data are provided via web APIs or simple HTTP requests to URLs in Internet, but it is worth mentioning them in a different section as they present certain particular characteristics:

- Less control on the data: the port (and PIXEL IT owners) don’t have control of the data, therefore it could change its policies, its update frequency or the service could be denied or even stopped.
- Usually, this external data access has a cost. Sometimes it can be high, and this could become a problem for the ports. See the AIS case in section 3.2.1.6.

1.2. Data in PIXEL ports for PEI implementation

1.2.1. GPMB

1.2.1.1. Data of ships (GPMB)

IMO number and gross tonnage moved of all the ships arriving at the port

GPMB uses (actually own as the product creator) a software tool (enhanced PCS) named VIGIESip[3] that stores all the information related to the port management, including the forthcoming vessel calls, the ships operated by the port in the past, and other details such as the amount of cargo, type of vessel, type of operation, etc. VIGIESip has the capacity to be interconnected with external systems (API-like connector with a particular technological configuration) in an automated way. The technical team in PIXEL has developed an NGSI agent capable to connect with VIGIESip and to retrieve the data needed for the PEI in this regard.

In the next image (Figure 1.1) there is an extract of the vessels that were operated in the port of Bordeaux in order to show the data that is provided by VIGIESip to PIXEL. Among those fields, the most interesting (and the ones to be filtered) for the atmosphere emissions by ships in GPMB are the IMO code (in this case, MMSI, which is equivalent and for the PEI makes the same function), the operation date, the type of ship and the total tonnage operated in the port.

Terminal	MMSI	N° Vigie	Vessel name	Date	Goods categories		Tonnage	Load/unload
FR_BAS	9123960	20198391	AYLA	2019-09-08 20:00:00	449	E.BLE VRAC	27000	Loading
FR_BAS	9173226	20198392	AM LARAFALE	2019-09-09 19:30:00	417	E.PNEUS BROYES	3550	Loading
FR_BAS	9224104	20198396	FRI RIVER	2019-09-09 16:00:00	449	E.MAIS VRAC	3100	Loading
FR_BAS	9235488	20198397	HC BEA LUNA	2019-09-09 16:00:00	431	E.TALC	5000	Loading

Figure 1.1 IMO number and gross tonnage GPMB vessels

GPMB pushes new data in VIGIESip as soon as new vessels are operated or a new vessel call is received. Every hour the database in VIGIEsip is updated with regards to forthcoming vessel calls and the database associated to already operated ships is refreshed every 10 days. Historic data from 2017 to 2019 is available.

Then, the procedure that is followed for having this information ready for the calculations of the PEI is: (i) VIGIEsip data are updated (each hour or 10-days), (ii) the NGSI agent is subscribed to that data and updates PIXEL immediately, (iii) extracting the data relevant for the corresponding time period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) grouping, filtering and counting the vessels and the total cargo processed in that period, (v) make those data available for the next calculations.

Main and auxiliary engine power of all the ships for calculating emissions

This procedure is explained in detail in section 3.2.1, but in a glance, it consists of inferring the main and auxiliary engines power from the vessel type of each ship. This information is available for all vessels arriving or departing to/from GPMB as it can be observed in Figure 1.1.

Berthing and manoeuvring time of all vessels in the port docks:

Using the data out of the execution of the PAS (see section 3.2), PIXEL is able to know how much time a vessel has been operated, which for the sake of PEI calculation will constitute the "berthing time".

Drawing from the information provided through the API and that is available in VIGIESip, GPMB provides the other piece of data needed for obtaining the berthing and manoeuvring time for each ship: the difference between *"exit_time"* and *"entry_time"* constitutes the time a vessel remains in the port area. Following that, the difference between the total time and the "berthing time" will give PEI the manoeuvring time.

Then, the procedure is: (i) NGSI agent retrieves data from VIGIEsip API for the period requested, (ii) NGSI agent retrieves from the latest PAS execution the "berthing time" corresponding to the ships on that period (iii) (iv) make the berth and manoeuvring time data of each field available for further integrations in formulae.

[3] http://www.vigie-ports.fr/index.php/service-portuaire-numerique/vigiesip/

MARPOL Annexes for retrieving ships waste:

Like the IMO number and tonnage per vessel, the information related to waste from ships to be handled by the port is as well recorded, managed and stored via VIGIESip. Similarly, the technical team of PIXEL developed and NGSI agent capable to connect under a publish/subscribe schema to the VIGIESip database containing information relative to MARPOL annexes.

The functioning is as follows: every time a vessel (before anchoring in the dock of GPMB) sends a request to the port for handling residues (waste), a new entry (or a set of entries) is created in the database. Then, according to the information issued to GPMB through the MARPOL annexes, it is recorded. Each single residue is recorded, including the current stock on board of that residue, the maximum stock allowed on board of that type of waste, the quantity deposited in GPMB, a description (e.g. oily bilge water) and the code of that residue.

An extract of the database that is already integrated in PIXEL is depicted in Figure 1.2**¡Error! No se encuentra el origen de la referencia.**. Regarding past data, the history available ranges from 2017 to 2019. Current data is being updated in VIGIEsip with direct connection with PIXEL, therefore a "real-time" request of those data will return the most updated information.

lloyd	nom_navire	e_t_a	dem_dec_qt	dem_dec_stock_max	dem_dec_a_bord	dem_dec_port	dem_dec_qt_prod	dem_dec_qt_deposee	description	code_t2k	dem_dec_port_libelle
9734848	YARA NAUMA	01/01/2019 19:00	0	100	0	null	0	0	null	2300	null
9734848	YARA NAUMA	01/01/2019 19:00	0	200	0	null	0	0	null	2300	null
9734848	YARA NAUMA	01/01/2019 19:00	0	6100	100	null	100	0	null	2300	null
9734848	YARA NAUMA	01/01/2019 19:00	0	11700	2900	null	100	0	null	1100	null
9734848	YARA NAUMA	01/01/2019 19:00	0	15400	2700	null	200	0	Oily Bilge / waste Oil	1301	null

Figure 1.2 MARPOL annexes information – waste of ships operated by GPMB

Then, the procedure followed for having this information ready for the calculations of the PEI is: (i) VIGIEsip data is updated (altogether with vessel calls, each hour), (ii) the NGSI agent is subscribed to that data and updates the PIXEL platform (DAL) immediately, (iii) checking the vessels operated in the period of interest (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) extracting the data relevant (description, code and quantity to be handled in GPMB, (v) grouping, filtering and counting the vessels and the total cargo processed in that period, (vi) make those data available for the next calculations.

1.2.1.2. Data from terminals (GPMB)

Energy consumed by the machines functioning in the port:

In this context the PEI will take advantage of three relevant pieces of information that will be combined with emission factors (see section 3.2.2) in order to obtain the emissions to the atmosphere by the terminals of the port.

The pieces of information that will be provided are:

- Resources used to operate each ship at the terminal: machines, time used by each machine, consumption of each machine.
- Energy consumption for operating each vessel (in kWh)
- Nature of the energy source of each machine used: electricity, gas, etc.

This information will be extracted from the result of PAS (Port Activity Scenario) model executions, which will provide this information in a raw format that will need to be processed before synthesizing the data relevant for PEI. For instance, the values are provided within a long JSON stored in the IH result of the PAS execution. A tiny example of part of the info contained in those containers is illustrated in Figure 1.3.

The procedure for obtaining the data is the following: (i) members of the port should have introduced through a web form interface the description of the supply chains applying to the port. Again, this is well explained in section 3.2.2. (ii) PAS model is scheduled to be executed with a certain periodicity, the results (JSON aforementioned including the three relevant pieces of data) are stored in the IH, (iii) NGSI agents explore that results and will select the ships corresponding to the sought period (depending on the PEI calculation request:


```
"activities_list":[
  {
    "ID":0,
    "ressources_accounts_list":
    [
      {
        "energy_consumed":[
          {
            "nature":"gazol",
            "value":238.84979
            423750002
          }
        ],
        "ressource_ID":"machine
        _17"
      }
    ],
    "step_ID":"step_1",
    "timespan_scheduled":{
      "duration":623.08641975,
      "end":"2018-01-
      02T05:13:05.185185",
      "start":"2018-01-
      01T18:50:00"
    }
```


Figure 1.3 PAS relevant data

daily, weekly, fortnightly, monthly), (iv) the sum of that period is made, (v) the corresponding eKPI are populated, (vi) fulfilled data is made available for the next calculations.

<u>Waste produced by the terminals:</u>

GPMB keeps a record of the waste consumed by the terminal each month. This recording is made following manual registers and currently there is no possibility to have an automated access from PIXEL.

Observing this situation, and considering the willingness from GPMB to comply with all the minimum data for computing the PEI, the only option left for the technical team was to create a web form to be included within the PIXEL UI that will allow the user of the platform to introduce the values. This will be requested to be fulfilled before executing PEI (if not done before) and the planned periodicity for completion of these values **is monthly**.

Figure 1.4 depicts the interface provided via the PIXEL UI and the different representations of the information that will be stored (in that very format) in the PIXEL database for the usage of the data in the PEI.

Figure 1.4 Waste of terminals GPMB – web form filling data

<u>Wastewater produced by the terminals and spilled to the sea:</u>

Therefore, the same option as before has been opted for by GPMB in order to provide the information for the PEI's eKPIs related to wastewater produced by the terminals. The web form in Figure 1.5 will be fulfilled by the GPMB staff **once per year**, and the value of the different fields will be introduced: (i) sanitary wastewater, (ii) technological wastewater and (iii) storm water.

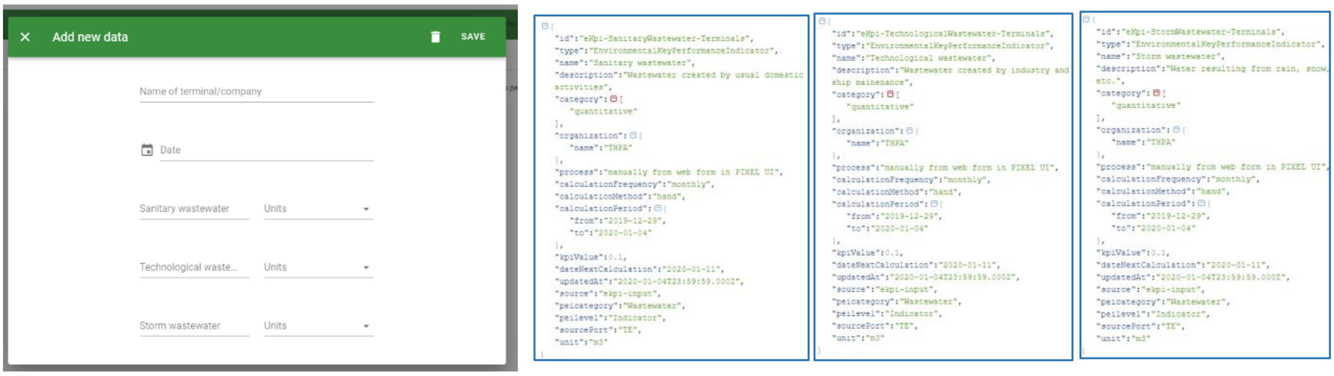


Figure 1.5 Wastewater of terminals GPMB – web form filling data

1.2.1.3. Data from port authorities (GPMB)

According to GPMB, it is of their interest to deploy a PEI that will only take into account the contributions to the atmosphere from ships (SEI) and from the terminal of Bassens (TEI). The PAEI will not be interesting, therefore GPMB has not been able to provide data associated to the port authority itself.

However, like in the previous sub-section, and as it can be checked in 1.2.2.3, a series of web forms have been prepared (that can be integrated in the whole PIXEL UI) in case GPMB will decide to deploy and measure a whole PEI.

1.2.1.1. Data associated to the port as a whole (GPMB)

Noise and light levels registered in the area of the port:

For this data, as advanced in section 1.1.2, the members of the WP5 team claimed that the use of sensors is possible and advisable. In that sense, several searches in the market were tackled. A detail of the options that were explored can be found at Appendix A.

Finally, the decision made was to purchase the Smart Spot of the provider HOPU[4] (see Figure 1.6). The main reasons that conducted this decision were:

- Simplicity: having embedded noise and light (and odour, if needed) in a single device reduces efforts of integration, installation, tender procedures and bureaucracy.
- The data provided is already in the units sought for the associated eKPIs.
- Competitive price.

Figure 1.6 Noise and light sensor device

Regarding the data that will be used for the PEI calculation we use the following values/parameters:

- L_{DEN} (dB)
- L_{night} (dB)
- L_{eq} (dB)
- Luminosity (lux)
- Odour (Volatile Organic Compounds) – GPMB marked odour as “not relevant” for their environmental performance.

More details on the characteristics of the sensors and the “station” are also enclosed in appendix A. The procedure to follow to effectively incorporate this data into PIXEL (thus into PEI calculation) is: (i) NGSI agent with MQTT server active is running in the port, (ii) the Smart Spot sends the information to the MQTT server each minute, (iii) the NGSI agent processes the information and filters and summarises it per day, (iv) the data per day is then stored in the IH and thus ready to be used in the PEI calculation, (v) the data for the corresponding time period are filtered (depending on the PEI calculation request: daily, weekly, fortnightly, monthly (vi) the sum of the corresponding values for that specific period is made, (vii) feeding the corresponding eKPIs both for noise and light, (viii) make those data available for the next calculations.

1.2.1.2. Summary of data retrieval in GPMB for PEI deployment

In the previous sub-chapters, a detailed reference of all the data that is (and will be) available in the Port of Bordeaux has been done. Nevertheless, this part aims at being a quick summary to realise at a quick glance of the coverage for the PEI deployment that is already taking place under the scope of task T7.5:

[4] https://smartcities.hopu.eu/smart-spot.html

Table 1.1 Summary of data retrieval at GPMB

Origin entity	*e of data needed for calculating PEI el*	*Existing*	*Obtained through*	*Mechanism*	*Historic*
Ships	IMO number of all the ships arriving at the port	Yes	VIGIESip - agents push every 10d	Web - push to PIXEL	2017, 2018 and 2019
Ships	Gross tonnage moved by all ships in the port	Yes	VIGIESip - agents push every 10d	Web - push to PIXEL	2017, 2018 and 2019
Ships	Main engine power of all the ships for calculating emissions	Yes	Vessel type of each ship - VIGIE	Web - push to PIXEL	2017, 2018 and 2019
Ships	Auxiliary engine power of all the ships for calculating emissions	Yes	Vessel type of each ship - VIGIE	Web - push to PIXEL	2017, 2018 and 2019
Ships	Berthing time of all vessels in the port docks	Yes	PAS results and VIGIEsip data	PIXEL tool - PAS Web - push to PIXEL	2017, 2018 and 2019
Ships	Maneuvering time of all vessels within the port area	Yes	PAS results and VIGIEsip data	PIXEL tool - PAS Web - push to PIXEL	2017, 2018 and 2019
Ships	MARPOL Annexes for retrieving ships waste	Yes	VIGIESip - agents push every 10d	Web - push to PIXEL	2017, 2018 and 2019
Terminals	Energy consumed by the machines functioning in the port	Yes	Results of executing PAS model	PIXEL tool - PAS	None
Terminals	Waste produced by the terminals	Yes	Form in PIXEL UI	Form filled periodically	None
Terminals	Waste water produced by ther terminals and spilled to the sea	Yes	Form in PIXEL UI	Form filled periodically	None
Port Authority	Not interested, only the terminal of Bassens is within the scope of PIXEL project.				
Global	Noise levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	None
Global	Light levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	None

Conclusions:

GPMB is a very technological port. VIGIESip counts with an architecture that includes information gathered from sensors (e.g. weather station, tide level sensors). Furthermore, having developed VIGIESip (being sold to many other French ports) spots it as a very advanced port with regards to data retrieval.

However, certain data needed for the PEI is being difficult to track down, as until today, no procedures were established where those data were of interest. For instance, information about waste and wastewater produced by the Port Authority and the terminals were not being collected beforehand. This has conducted the team to opt for the manual input form option, which is always the less convenient and less preferable. This way, GPMB will be able to fulfil the data they are being able to gather by asking the related departments and staff and manually type it in order to compute the PEI with all minimum data.

On the other hand, despite noise and light were not of interest of being monitored (in real-time) till now, GPMB acquires a Smart Spot station in order to feed the PEI with those values.

To sum up, GPMB is not yet reaching a remarkable status of data collection for the PEI. Nonetheless, both the technical team and the port believe they will be ready to deploy the PEI in GPMB during the task T7.5. However, a note is done in this regard. According to GPMB, it is of their interest to deploy the PEI that will only take into account the contributions to the atmosphere from ships (SEI) and from the terminal of Bassens (TEI). The PAEI will not be interesting, therefore GPMB will end task T7.5 having relevant values of a partially limited PEI (SEI and TEI but not PAEI). Technically, this will have sense as the calculation is made modularly, and the values of indices will be available.

1.2.2. ASPM

1.2.2.1. Data of ships (ASPM)

IMO number and gross tonnage moved of all the ships arriving at the port

ASPM makes public the information of the last vessels operated and the next ships to be berthing in the port through its website: http://www.monfalconeport.it/eng/sailinglist.asp . This can be accessed at any moment. In this website, the information provided especially relevant for the PEI calculations is time of arrival and departure, IMO number of the vessel and gross tonnage. This data is published daily on the website manually by the ASPM staff and the information comes behind from the storage database of the PMIS.

In Figure 1.7, there is a screenshot of the information that can be obtained. PIXEL partners have received permission for scraping the website for retrieving the data. The members of the technical team developed a NGSI agent with this purpose.

Arrival Departure	Ship's Name	IMO	Flag	G.T.	Draught	Cargo Descr.	Type	Wharf	Last port of call	Next port	Ship. Agent
14/04/2020 17/04/2020	SU	9116084	TR	5447	7.82 m	CEREALI	SBARCO	CASILLO	VARNA	ISTANBUL	CATTARUZZA
14/04/2020 16/04/2020	OSHIMANA	9249295	SG	36324	9.3 m	CELLULOSA	SBARCO	7_8	SETE'	GIBILTERRA	MARTERNERI
15/04/2020 16/04/2020	PHOENIX	9558490	BG	11927	8 m	BRAMME	SBARCO	22-32	MARIUPOL	ISTANBUL	ADRIATICA

Figure 1.7 IMO number and gross tonnage for PEI – ASPM website data source

Historic of this information is available in PMIS. PIXEL members have 2018 and 2019 in a .xls file.

Then, the procedure that is followed for having this information ready for the calculations of the PEI is: (i) website is updated daily, (ii) the NGSI agent queries the website each morning to keep PIXEL database updated, (iii) the data relevant for the corresponding time period is extracted (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) data is grouped and filtered and the vessels and the total cargo processed in that period are counted, (v) those data are made available for the next calculations.

Main and auxiliary engine power of all the ships for calculating emissions

As it can be seen in Figure 1.7, the type of vessel arriving at the Port of Monfalcone is always available via the connected interface with the public website of ASPM. On that regards, and not being the preferred option (due to making several assumptions in the procedure), ASPM will (initially) implement the PEI by using the procedure in 3.2.1. This way, the process is: (i) the NGSI agent retrieves the vessel type field, (ii) calculations and relations are made to infer the main and auxiliary engine power of ships, (iii) both are available for more calculations.

The procedure of obtaining this data from vessel type is explained in detail in section 3.2.1 (tables for obtaining main and auxiliary engine information from vessel type).

Berthing and manoeuvring time of all vessels in the port docks:

For the case of Monfalcone, the PIXEL team (courtesy of partner XLAB) has gained access to AIS data of the vessels arriving to ASPM. This way, with the defined polygon of the port, and after running the AIS processing module of PIXEL, the time each vessel is berthed and moving will be available as input data for the PEI.

This way, the procedure is as follows: (i) polygon of port area is provided by port staff, (ii) vessels of the period selected for PEI calculation are identified (IMO numbers, MMSI if possible) (ii) AIS processing model is requested to be run, introducing as input the needed data (vessel number, area of the port, (iii) results of the model execution are inserted into the central data storage of PIXEL (IH), (iv) NGSI explores those results and selects the values (berthing and manoeuvring time), (v) those data are made available for the next calculations.

The procedure of collection of this data is explained in detail in section 3.2.2.

MARPOL Annexes for retrieving ships waste:

As well as the IMO number and tonnage per vessel, the information related to waste from ships to be handled by the port is recorded, managed and stored via the PMIS: Unfortunately, this information is not made public through the website and up to today ASPM (as organisation) does not have the permissions to directly access (under an automated fashion – such as DB query or API) the information, as it is managed by the Port of Trieste.

Nevertheless, the Port of Monfalcone keeps a record in a .xls file of the waste generated by each ship being operated in the port. The functioning is as follows: every week, ASPM staff checks the registers of PMIS and fulfils new rows in the .xls file. Then, according to the information issued to ASPM through the MARPOL annexes, ASPM creates a new row per vessel and introduces the different values for waste. Per each row, there are columns that are fulfilled with the tons of each residue that is requested to be managed in the port: (E) oily bilge water, (F) waste water, (G) other types of waste, (H) paper rags glass, metals, bottles, etc., (I) sludge, (J) plastic, (K) food waste, (L) incinerator ashes. Naturally, each row has columns (A to D) for identifying to which vessel corresponds the introduced data.

This .xls is shared with the PIXEL team using an FTP server, where each week, and following a clear naming procedure, ASPM uploads the data. In the future (planned during task T7.5), the PMIS will be automatically reachable and there will be no need of this procedure, augmenting the level of IoT-ness of the PEI in ASPM.

An extract of the .xls file used in ASPM is shown in Figure 1.8.

ID	Type of cargo	Amount of cargo (tonnes/m3/TEU)	Ship type	Bilge water/Acqua di Sentina MC	Waste water/Acqua di scarico MC	Other types of waste/Altri rifiuti MC	Paper Rags Glass, Metals, Bottles etc/Carta Stracci Vetri, Metalli, Bottiglie etc. MC.	Sludge/Fanghi MC	Plastic/Plastica MC	Food Waste/Rifiuti	Ash from incineration/C
S	STRUTT. METALLIC	2500	9 566								
R	VERGELLA	3200	9 348								
EG	BILLETTE	7705	9 013								
NA	BRAMME	23299	9 769			0.4	0.5		0.6		

Figure 1.8 Form used by ASPM to assess the ship-generated waste

Similarly, the technical team of PIXEL developed and NGSI agent capable to be connected under a client/server schema to the FTP remote server containing information relative to MARPOL annexes.

1.2.2.2. Data on terminals (ASPM)

Energy consumed by the machines functioning in the port:

Same as in GPMB, in this context the PEI will take advantage of three relevant pieces of information that will be combined with emission factors (see section 3.2.2) in order to obtain the emissions to the atmosphere by the terminals of the port.

The pieces of information that will be provided are:

- Resources used to operate each ship at the terminal: machines, time being used each machine, consumption of each machine.
- Energy consumption for operating each vessel (in kWh)
- Nature of the energy source of each machine used: electricity, gas, etc.

This information will be extracted from the result of PAS executions, which will provide this information in a raw format that will need to be processed before synthesizing the data relevant for PEI. See little diagram of it in Figure 1.9.

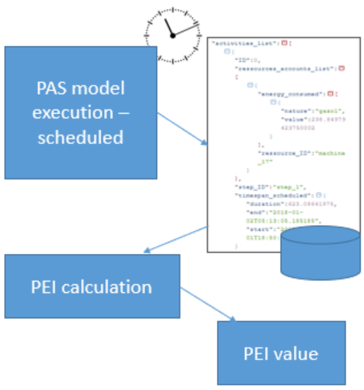


Figure 1.9 PAS-PEI diagram

Like GPMB, the procedure for obtaining the data is the following: (i) members of the port should have introduced through a web form interface the description of the supply chains applying to the port. Again, this is well explained in section 3.2.2, (ii) PAS execution model is scheduled to be executed with a certain periodicity, the results (JSON aforementioned including the three relevant piece of data) are stored in the IH, (iii) NGSI explore that results and will select the ships corresponding to the sought period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) the sum of that period is made, (v) feeding the corresponding eKPI are populated, (vi) those data are made available for the next calculations.

Waste produced by the terminals:

The Port of Monfalcone presents a scenario where a myriad of heterogeneous entities is involved, in one form or another, in the management of the operations. In this sense, ASPM (as organisation) only has access and control over certain part of the activities happening in the port, and therefore has no access to a good stake of the data that could be available. The situation is no different with regards to terminals. The Port of Monfalcone embeds four different entities that were granted with a concession for exploiting a certain area of the terminal of the port: CEPAL, CPM, MarterNeri and Midolini. Thus, in order to have the information on waste, energy consumption and wastewater ASPM must collect the information from different independent agents that have no obligation nor established procedures to gather data about the waste and wastewater that they produce.

The only information that was available for 2019 is what is reflected in Figure 1.10. The water consumption of ASPM regards also the consumption of some port operators connected to ASPM's water line. ASPM fuel consumption regards the gas used to heat ASPM's buildings expressed in cubic meters.

Port of Monfalcone - resources consumption in 2019	CETAL	CPM	MarterNeri	Midolini	ASPM*
Water (cm)	-	14.618	-	-	26.520
Energy (Kw)	378.000	118.576	-	-	64.914
Fuel (l)	3.000	777.127	-	-	27.062

Figure 1.10 Terminal entities waste 2019 Port of Monfalcone

Observing this situation, and considering the willingness from the Port of Monfalcone staff to comply with all the minimum data for computing the PEI, the only option left for the technical team was to create a web form to be included within the PIXEL UI that will ask the user of the platform for introducing the values. This will be requested to fulfil before executing PEI (if not done before) and the planned periodicity of completion of these values is monthly. More information on the need of using this data origin can be found at section 1.1.3.

Figure 1.11 depicts the interface provided via the PIXEL UI and the different representations of the information that will be stored (in that very format) in the PIXEL database for the usage of the data in the PEI.

Figure 1.11 Waste of terminals – web form filling data

Wastewater produced by the terminals and spilled to the sea:

The same procedure as before applies for the wastewater. In this case, different values will be requested to be fulfilled, particularised as (i) sanitary wastewater, (ii) technological wastewater and (iii) storm water (Figure 1.12).

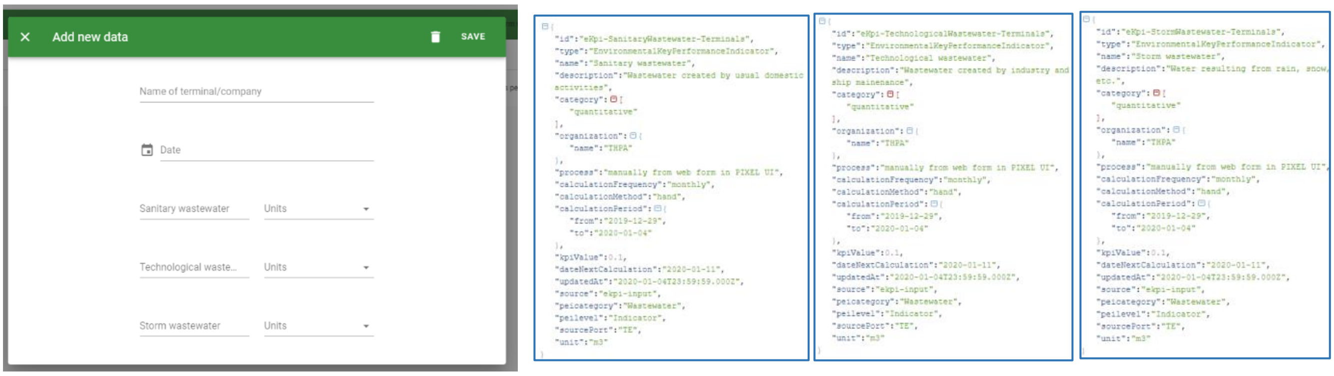


Figure 1.12 Wastewater of terminals – web form filling data

1.2.2.3. Data on port authorities (ASPM)

Energy consumed by the Port Authority in a period of time:

The same procedure as before applies for the energy consumption of the Port Authority (as it can be seen in Figure 1.13, this is one of the values that is available, but periodicity will be improved with this data collection strategy). In this case, different values will be requested to be fulfilled, which are: (i) period of time referring, (ii) energy consumed (and units) and the type of energy used (electricity, natural gas).

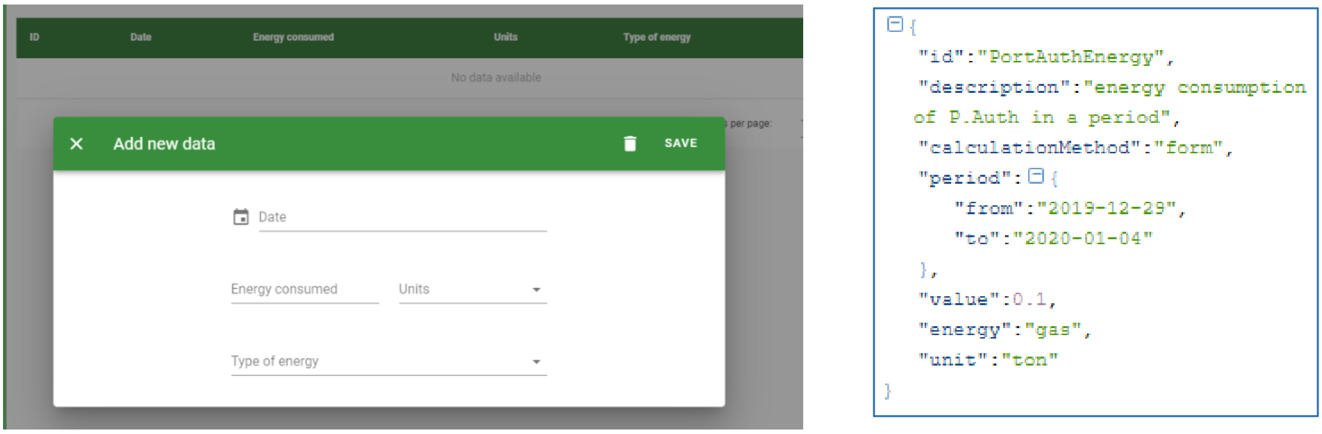


Figure 1.13 Energy consumed by the Port Authority – web form filling data

Waste and wastewater produced by the Port Authority (garbage, usual residues):

Following the same line of thought, and as it can already be checked in Figure 1.14 and Figure 1.15Figure 1.10, the values (that will directly feed eKPIs) relate to waste and wastewater. For **waste**, the data requested (and its period) is: (i) municipal solid waste, (ii) inert waste. For **wastewater**: (i) sanitary wastewater, (ii) technological wastewater, (iii) storm water.

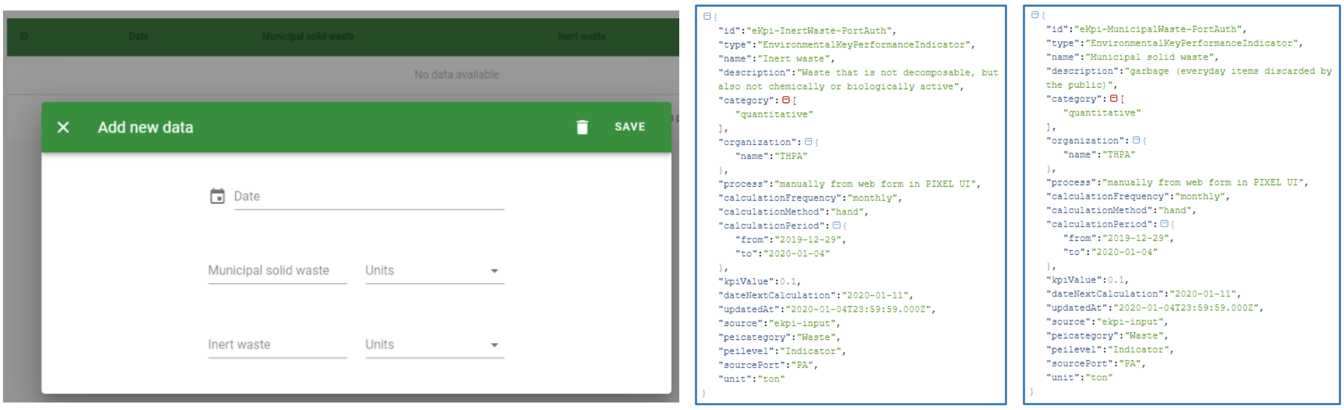


Figure 1.14 Waste residues by the Port Authority – web form filling data

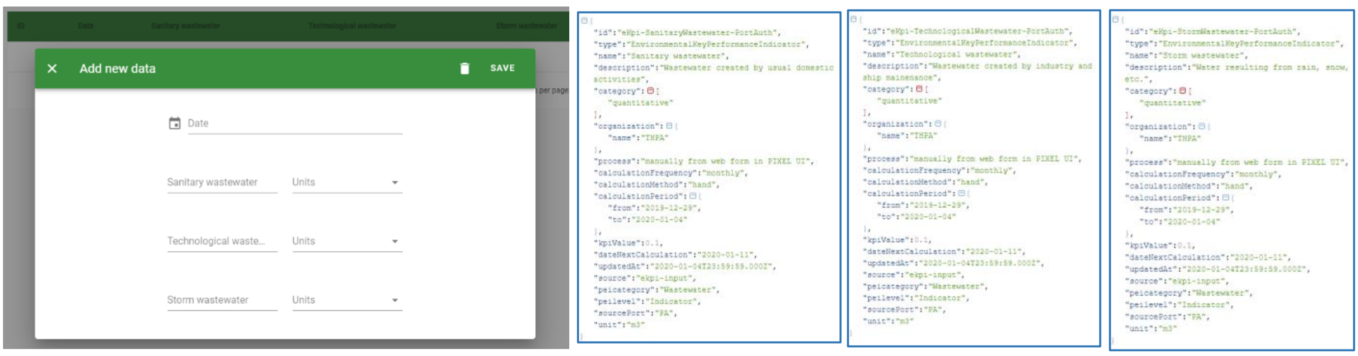


Figure 1.15 Wastewater by the Port Authority – web form filling data

1.2.2.1. Data associated to the port as a whole (ASPM)

Noise and light levels registered in the Port Authority area of the port:

For these two (odour was discarded as it is not reported as a problem in ASPM), the procedure is the same as for GPMB. The Smart Spot device is used for feeding PEI calculations on noise and light data.

1.2.2.2. Summary of data retrieval in ASPM for PEI deployment

In the previous sub-chapters, a detailed reference of all the data that is (and will be) available in the Port of Monfalcone has been done. Nevertheless, this part aims at being a quick summary to realise at a quick glance of the coverage for the PEI deployment that is already taking place under the scope of task T7.5.

Table 1.2 Summary of data retrieval ASPM

Origin entity	*Piece of data needed for calculating PEI eKPIs*	*Existing*	*Obtained through*	*Mechanism*	*Historic*
Ships	IMO number of all the ships arriving at the port	Yes	ASPM's official website	Web - own web	Yes 2019 from .xls file
Ships	Gross tonnage moved by all ships in the port	Yes	ASPM's official website	Web - own web	Yes 2019 from .xls file
Ships	Main engine power of all the ships for calculating emissions	Yes	ASPM web and assumptive tables	Web - own + proxy data	Yes 2019 from .xls file
Ships	Auxiliary engine power of all the ships for calculating emissions	Yes	ASPM web and assumptive tables	Web - own + proxy data	Yes 2019 from .xls file
Ships	Berthing time of all vessels in the port docks	Yes	AIS data vi XLAB AIS antenna	PIXEL tool - AIS	June - December 2019
Ships	Maneuvering time of all vessels within the port area	Yes	AIS data vi XLAB AIS antenna	PIXEL tool - AIS	June - December 2019
Ships	MARPOL Annexes for retrieving ships waste	Yes	ASPM to weekly upload to FTP	Upload to remote server	None
Terminals	Energy consumed by the machines functioning in the port	Yes	Results of executing PAS model	PIXEL tool - PAS	None
Terminals	Waste produced by the terminals	Yes	ASPM reads PMIS and types	Form filled periodically	None
Terminals	Waste water produced by ther terminals and spilled to the sea	Yes	ASPM reads PMIS and types	Form filled periodically	None
Port Authority	Energy consumed by the Port Authority in a period of time	Yes	ASPM reads PMIS and types	Form filled periodically	None
Port Authority	Waste produced by the Port Authority (garbage, usual residues)	Yes	ASPM reads PMIS and types	Form filled periodically	None
Port Authority	Waste water produced by the Port Authority	Yes	ASPM reads PMIS and types	Form filled periodically	None
Global	Noise levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	None
Global	Light levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	None

Conclusion: PMIS is the software management system of the port of Monfalcone and Trieste. This software is not owned by ASPM, but rather by the Port of Trieste. The issue in this regard is that no access has been granted yet to automatically query the database of PMIS. This will be received during the course of Task 7.5. This has affected enormously the capacity for providing automated data for the PEI from this organisation. However, access is supposedly to be granted during the execution of T7.5, therefore the less-convenient current retrieval ways (remote servers, form to be filled periodically) will be substituted by automated connectors that will incorporate the data into PIXEL (and PEI) in a smoother way.

At this moment, the PEI could be executed in ASPM as soon as T7.5 members will confirm total integration and the start of collecting real time data (no whole set of 2019 past data is yet available in ASPM). This also assumes supply chains have been defined and that the different data to be introduced through web forms will be typed by ASPM staff periodically into the system.

1.2.3. THPA

1.2.3.1. Data of ships (THPA)

IMO number and gross tonnage moved of all the ships arriving at the port

These data are provided by THPA and are served by the IT department of the Port of Thessaloniki via a web API created explicitly for the PIXEL project. Internally, these data are managed by a TOS (for container ships) and the Statistics DB software (for conventional cargo).

The query to the API returns all the vessels that were operated (one API per year) in a JSON format including very rich information and details of every single vessel in a year. This information is only timestamp-referred by including fields of "*imo_code*" and "*cf_tonnage*" of each ship, therefore certain data pre-processing after acquisition was needed.

In the API created by THPA, data can be queried both for past operations of vessels (history from 2015 to 2019 and 2020 so far is available) and for the ships that will arrive to the port during next week (vessel calls). The PEI being a retrospective calculation, the computation will only use the past data initially.

The procedure to be followed is: (i) have the NGSI agent retrieving data from this web API, (ii) extracting the data relevant (IMO and tonnage) for the corresponding time period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) grouping, filtering and counting the vessels and the total cargo processed in that period, (v) make those data available for the next calculations.


```
{
  "imo_code":"9659749",
  "ship_descr":"BUNUN CHAMPION ",
  "date_katapl":"Dec 27 2019 10:30:00:000AM",
  "date_apopl":null,
  "time_prosdesi":"Dec 28 2019 08:55:00:000AM",
  "start_work":"Dec 28 2019 11:00:00:000AM",
  "end_work":"Dec 31 2019 06:00:00:000PM",
  "time_apodesi":"Jan 4 2020 05:00:00:000PM",
  "departure_date":"Jan 4 2020 05:50:00:000PM",
  "work_descr":"\u0391\u03a0\u039f\u0392\u0399\u0392\u0391\u03a3\u0397-\u0395\u039a\u03a6\u039f\u03a1\u03a4\u03a9\u03a3\u0397 ",
  "work_latin_descr":"DEMBARKATION-UNLOADING ",
  "empr_descr":"SLABS \u03a3\u0399\u0394\u0397\u03a1\u039f\u03a0\u039b\u0391\u039a\u0395\u03a3 ",
  "empor_latin_descr":"SLABS ",
  "cf_empty":"0",
  "cf_emforta":"0",
  "cf_value":17147,
  "cf_tonnage":17147
},
```


Figure 1.16 IMOs and cargo ships THPA

Main and auxiliary engine power of all the ships for calculating emissions

As it can be seen in Figure 1.16 (second field *"ship_descr"*), the type of vessel arriving at the Port of Thessaloniki is always available via the connected interface with the public website of ThPA. On that regards, and not being the preferred option (due to making several assumptions in the procedure), ThPA will (initially) implement the PEI by using the procedures explained in chapters 3 to 5 in this deliverable.

This way, the process is: (i) the NGSI agent retrieves the vessel type field, (ii) calculations and relations are made to infer the main and auxiliary engine power of ships, (iii) both are available for more calculations.

The procedure of obtaining this data from vessel type is explained in detail in section 3.2.1 (tables for obtaining main and auxiliary engine information from vessel type).

Berthing and manoeuvring time of all vessels in the port docks:

Drawing from the information provided through the API (see Figure 1.16), THPA provides indirectly these two needed data pieces for PEI calculation. The difference between *"time_prosdesi*" (ship on dock) and *"time_apodesi"* (ship leaves the dock) constitutes the time a vessel is berthed (berthing time). Additionally, the filed *"date_katapl"* indicates the moment the ship enters the port area, while "time_departure" goes for the contrary (leaving the port area). The time space between those minus the berthing time will provide the PEI the data needed for "manoeuvring time".

Then, the procedure is: (i) NGSI agent retrieves data from this web API, (ii) the data relevant (three fields) is extracted, making the pre-processing for the corresponding time period and (iii) the berth and manoeuvring time data of each field are made available for further integrations in formulae.

MARPOL Annexes for retrieving ships waste:

Data on waste discharged from vessels is collected manually (filled forms), then transferred to an Excel file and then provided to PIXEL (and PEI) via the web API that ThPA's IT department has developed. Data is categorized under MARPOL standards. 2016 to 2019 data are available both from container and conventional cargo terminals.

The structure followed is particular. There is a "reference" Excel sheet that masters the codification of fields to represent the ship number and the different waste types (MARPOL types). Below, in Figure 1.17, there is the reference "template" of row and columns. The example takes the top of the page of 2019's waste from ships:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
1	ΠΛΗΡΟΦΟΡΙΕΣ ΚΑΤΑΧΩΡΗΣΗΣ			ΗΜΕΡΟΜΗΝΙΕΣ - ΒΕΒΑΙΩΣΕΙΣ		MARPOL Annex I - Oil		MARPOL Annex V - Garbage							MAI
2	A/A	Agency	Vessel	Date of receipt (liquid)	Date of receipt (solid)	bilge water	oil cargo residues	plastic	Food waste	Domestic waste	cpooking oil	incrinator ashes	operational waste	cargo residues	
3	1	MSC	MSC ……		03/01/2019			1,000	0,100	0,900					
4	2	ARKAS	A………	03/01/2019	03/01/2019	1,000	5,000	0,200	0,100	0,600					
5	3	CMA CGM		03/01/2019	03/01/2019	9,000	4,000	0,375	0,400	0,250					

Figure 1.17 Ships waste from MARPOL Annexes ThPA

The different rows (from 3 on) represent ships that have been operated by ThPA in a particular period and that have issued any of the MARPOL Annexes to the port beforehand announcing that some residues should be handled in port premises:

- Column A: ship number per order of arrival.
- Columns B and C: Shipping agency and name of the vessel.
- Columns D and E: Date of receipt (liquid and solid residues)
- Columns F and G: Annex I (Oil) – bilge water (F) and oil cargo residues (G)
- Columns H to N: Annex V (Garbage) – plastic (H), food waste (I), domestic waste (J), cooking oil (K), incinerator ashes (L), operational waste (M), and cargo residues (N):
- Column O: Annex IV - Sewage
- Columns P to U: Annex I (other oils) – oil tank washings (P), dirty ballast water (Q), tank cleaning waste (R), dirty oil (S), waste oils (T), and other (U)
- Columns V to X: Annex V (other garbage) – animal carcasses (V), fishing gear (W), and other (X)
- Columns Y to AB: Annex II (Noxious Liquid Substances – NLS) – substances of X category (Y), substances of Y category (Z), substances of Z category (AA), and other (AB)
- Columns AC and AD: Annex VI (Air pollution) – substances affecting Ozone (AC), and gas cleaning residues (AD).

At the moment to be inserting the information of these files into the DB (JSON) of the web service, the information is stored the way it is reflected in Figure 1.18, using the columns letters as the information pieces.

This way, by retrieving the API and having the reference template, all ships waste of a certain period of time can be obtained and directly feed the corresponding eKPIS for the PEI computation.

The procedure to follow is: (i) have the NGSI agent retrieving data from this web API, (ii) filtering the data for the corresponding time period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iii) analysing the meaning of each field mapping them to the reference rows and columns, (iv) making the sum of certain residue for that specific period, (v) feeding the corresponding eKPI, (vi) make those data available for the next calculations.


```
"5":{
  "A":6,
  "B":"MSC",
  "C":"MSC INGF
  "D":"01-08-18
  "E":"01-08-18
  "F":null,
  "G":"1.500",
  "H":"0.300",
  "I":"0.100",
  "J":"0.400",
  "K":null,
  "L":"0.100",
  "M":"1.500",
  "N":null,
  "O":null,
  "P":null,
  "Q":null,
  "R":null,
  "S":null,
  "T":null,
  "U":null,
  "V":null,
  "W":null,
  "X":null,
  "Y":null,
  "Z":null,
  "AA":null,
  "AB":null,
  "AC":null,
  "AD":null
},
```


Figure 1.18 JSON ships waste ThPA

1.2.3.2. Data from the Port Authority and Terminals (ThPA)

In the case of ThPA, the team has decided to make a joint review of the data for terminals and for the Port Authority. According to that, the eKPIs and the PEI will be calculated considering the terminals and the Port Authority as a single entity, and not having three different "areas" of origin but just two (ships and PA). This is because for all the aspects related to energy, waste, wastewater and common information on functioning, ThPA collects, stores, pays and handles the services (and the data associated) under the scope of a single entity, in spite of the varying sublets and customers within the area of the port that are operating every day (even other public bodies, located in the port such as the Maritime Police, go through ThPA's networks). This way, it is impossible to decouple which part of (for instance) the gas waste reported by the gas station is associated to the machines of the terminal, which was derived to trucks and which is for building maintenance operations. Therefore, in contrast with the methodology of the other ports, ThPA will report data jointly for terminals and Port Authority. The eKPIs calculated will be associated to the PA but will need to be interpreted as the sum values from both "origin entities".

Energy consumed by the machines functioning in the port and by the Port Authority and other services in the area managed by THPA:

THPA gathers, stores, and provides data to PIXEL related with the energy consumption due to the activities of the Port Authority and the terminals. Before describing the data sources, a little context is needed. THPA uses both electricity (from substations) and natural gas for powering their various buildings and activities that can be directly pinpointed and attributed to the Port Authority and terminals (all activity in the port area, actually).

Regarding the **electricity supply**, there are nine substations (mid-voltage) that provide electricity for nine different areas of the port (see one example in Figure 1.19). THPA is invoiced by the Energy Service Provider for the consumption registered in the different substations. Each time an invoice is received, ThPA personnel insert the information into a .xls file indicating the period and the corresponding power supply number of entry point.

The .xls currently existing in ThPA covers the bills issued to ThPA from 2012 to 2019. An extract of the .xls file is represented in Figure 1.20. As it can be observed, the total energy consumption of a certain period can be obtained retrieving information from that file. A finer filtering per area could as well be done if needed.

Figure 1.19 Example of area substation

A/A	power supply number	Type of charge	Date (start)	Date (end)	das	TOTAL ENERGY CONSUMPTION (kWh) * active	TOTAL ENERGY CONSUMPTION (kVarh) *inactive	MZ (kW)	MZA (kW)	MZN (kW)	KMZ (kW)	tanφ	cosφ	Σ.ΠΡΣ	A	X.Z	C	Agreed power (kVA)	installed power (kVA)	Transormation Factor	Power (kW)	Day (kWh)	Night (kWh)
1	82010113	B2	01/01/2012	01/02/2012	31	108000	30000	272	272	227	272	0,2777	0,964	0,893	1,0333	251,0	53,3%	2000	1270	6000	251,0	56613	51387
2	82010113	B2	01/02/2012	01/03/2012	29	108000	30000	307	290	235	307	0,2777	0,964	1,000	0,9667	296,8	50,5%	2000	1270	6000	296,8	61346	46654
3	82010113	B2	01/03/2012	01/04/2012	31	120000	42000	300	309	309	309	0,3500	0,944	1,000	1,0333	310,0	52,2%	2000	1270	6000	310,0	66871	53129
4	82010113	B2	01/04/2012	01/05/2012	30	84000	24000	226	224	181	226	0,2857	0,962	1,000	1,0000	226,0	51,6%	2000	1270	6000	226,0	39319	44681
5	82010113	B2	01/05/2012	01/06/2012	31	90000	24000	241	189	224	241	0,2666	0,966	1,000	1,0333	249,0	50,1%	2000	1270	6000	249,0	48901	41099
6	82010113	B2	01/06/2012	01/07/2012	30	108000	36000	417	383	275	417	0,3333	0,949	1,000	1,0000	417,0	35,9%	2000	1270	6000	417,0	58029	49971
7	82010113	B2	01/07/2012	01/08/2012	31	138000	54000	313	313	231	313	0,3913	0,931	1,000	1,0333	323,4	59,2%	2000	1270	6000	323,4	78213	59787
8	82010113	B2	01/08/2012	01/09/2012	31	126000	54000	343	343	269	343	0,4285	0,910	1,000	1,0333	354,4	49,3%	2000	1270	6000	354,4	69696	56304
9	82010113	B2	01/09/2012	01/10/2012	30	120000	42000	293	304	304	304	0,3500	0,944	1,000	1,0000	293,0	54,8%	2000	1270	6000	293,0	62465	57535
10	82010113	B2	01/10/2012	01/11/2012	31	102000	36000	226	226	199	226	0,3529	0,943	1,000	1,0333	233,5	60,6%	2000	1270	6000	233,5	57204	44796
11	82010113	B2	01/11/2012	01/12/2012	30	138000	48000	374	350	356	374	0,3478	0,944	1,000	1,0000	374,0	51,2%	2000	1270	6000	374,0	74690	63310
12	82010113	B2	01/12/2012	01/01/2013	31	120000	36000	288	299	299	299	0,3000	0,958	1,000	1,0333	297,6	55,7%	2000	1270	6000	297,6	54715	65285
					ΣΥΝΟΛΟ	1362000	456000																

Figure 1.20 File containing bills and electricity consumption per substation ThPA 2012-2019

Regarding **natural gas**, a similar procedure takes place. Seven natural gas connections are distributed throughout the port area. Once per month, the invoiced bills from Energy Service Provider are received and the amount and details are inserted into an .xls file (Figure 1.21), again power supply number of entry point.

A/A	Client code	Category	Correction Factor	From	To	days	Sum (m^3)	Sum (kWh)	$1m^3$ σε kWh
1	197899	T3A	1,30000	01/01/2012	24/01/2012	24	12659,62	141859,40	11,20565
2	197899	T3A	1,30000	25/01/2012	21/02/2012	28	15700,10	176020,00	11,21140
3	197899	T3A	1,30000	22/02/2012	23/03/2012	31	12789,50	143462,00	11,20932
4	197899	T3A	1,30000	24/03/2012	23/04/2012	31	10511,80	117845,00	11,21072

Figure 1.21 File containing bills of natural gas consumption per entry point ThPA 2012-2019

However, ThPA has decided to include all the information in the Excel files into their own-built API as well.

The procedure to follow here is: (i) the file is made available to PIXEL partners (for PEI) via the API, (ii) the NGSI agent retrieves data from those remote excels, (ii) the data are filtered for the corresponding time period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iii) the meaning of each column is analysed, (iv) the sum of certain residue for that specific period is made, (v) the corresponding eKPI is populated, (vi) those data are made available for the next calculations.

Waste and wastewater produced by the terminals:

Data on waste and wastewater produced by the terminals and the Port Authority in ThPA is collected manually upon delivery from the Env Dep., being able to be extracted as an Excel file whose information is afterwards provided to PIXEL (and PEI) via the web API.. Data is categorized under the EWC (European Waste Catalogue) codes[5]. 2018 and 2019 data are available for container and conventional cargo terminals (whole port actually).

The structure followed is particular. There is a "reference" Excel sheet that masters the codification of fields to represent the waste type (respecting EWC codes). The extracted Excel file mentioned above has a clear structure: the first tab reflects the total (in kgs) amount of each waste handled by the terminal in a year. Then, a series of tabs (one per each waste code) are created including the details of the day that the residue was informed and its quantity (in kgs). Below, in Figure 1.22, there is the example of 2019, with certain parts selected in order to clarify the data origin:

EKA code no	Quantity
20 03 01	447,42
13 02 05*	20,070
20 01 21*	0,222
20 01 21*	0,025
16 02 16	0,370
20 01 33*	0,042

SUM | end-of-life tyres | Oils | mxd municip waste | Lamps | Electr. | Toner | Sludges | Oily water | Batteries

A/A	EWC code no	Description	Date	Quantity (Kg)	Type
1	***20 01 21****	***fluorescent tubes and other mercury-containing waste***	18/01/2019	78,1	Solid
2	***20 01 21****	***fluorescent tubes and other mercury-containing waste***	28/03/2019	64,5	Solid

Figure 1.22 Terminals waste THPA following EWC codes

At the moment of inserting the information of these files into the DB (JSON) of the web service, the information is stored the way it is reflected in Figure 1.23, indicating the tab (EWC code) and the period.

The data provided is coded using EWC, and for ThPA the following types are included. Code W is for the waste eKPIs and WW for the wastewater eKPIs:

- W -16 01 03 - end-of-life tyres
- WW - 13 02 05 – mineral-based non-chlorinated engine, gear and lubricating oils
- W - 20 03 01 – mixed municipal waste
- W - 20 01 21 - fluorescent tubes and other mercury-containing waste
- W - 20 01 36 - discarded electrical and electronic equipment other than those mentioned in 20 01 21, 20 01 23 and 20 01 35
- W - 16 02 16 - components removed from discarded equipment other than those mentioned in 16 02 15
- WW - 13 05 02 - sludges from oil/water separators
- WW - 13 05 07 - oily water from oil/water separators
- W - 20 01 33 - batteries and accumulators and unsorted batteries and accumulators containing those
- W - 15 01 04 – metallic packaging
- W - 15 01 03 – wooden packaging
- W - 16 06 01 – lead batteries


```
"activities_list":[
    {
        "ID":0,
        "ressources_accounts_list":
        [
            {
                "energy_consumed":[
                    {
                        "nature":"gazol",
                        "value":238.84979
                        423750002
                    }
                ],
                "ressource_ID":"machine
                _17"
            }
        ],
        "step_ID":"step_1",
        "timespan_scheduled":{
            "duration":623.08641975,
            "end":"2018-01-
            02T05:13:05.185185",
            "start":"2018-01-
            01T18:50:00"
        }
```


Figure 1.23 Terminals waste data

[5] https://www.sepa.org.uk/media/163421/ewc_guidance.pdf

- W - 15 02 02 - absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances
- W - 16 01 07 - oil filters
- W - 17 04 05 – iron and steel
- W - 17 04 11 - cables other than those mentioned in 17 04 10

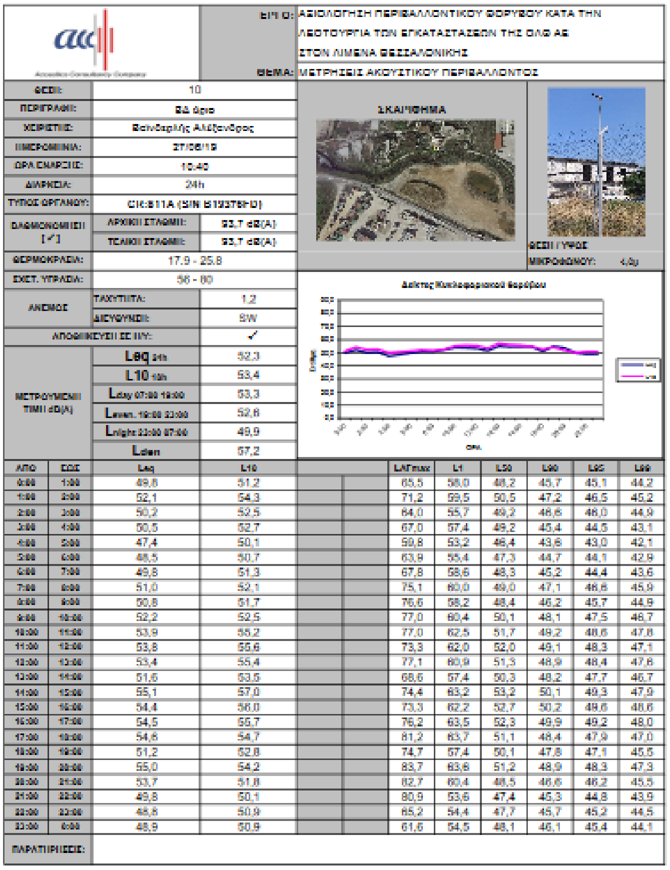
The procedure to follow is: (i) the NGSI agent retrieves data from this web API, (ii) the data for the corresponding time period is filtered (depending on the PEI calculation request: daily, weekly, fortnightly, monthly), (iii) the meaning of each field is analysed, mapping them to the reference rows and columns, (iv) the sum of certain residue for that specific period is made, (v) the corresponding eKPIs are populated both for waste and for wastewater, (vi) those data are made available for the next calculations.

1.2.3.1. Data associated to the port as a whole (THPA)

Noise and light levels registered in the Port Authority area of the port:

For these two (odour was discarded as it is not reported as a problem in ThPA), the procedure is the same as for GPMB and ASPM. The Smart Spot device is used for feeding PEI calculations on noise and light data.

Regarding historic data, ThPA does (mandatorily by the Greek authorities) a noise report once per year (Figure 1.24). The action consists of spotting at eight points of the port one noise measuring station in each and leaving them retrieving data along one day (24 hours). Thereafter, the different data collected by the eight stations are included in a detailed report that is recorded by the port. In the image below there is an example of the record of year 2018. Initially, this data will not be useful for WP5 as what is aimed in the PEI is to have as many measurements as possible (ideally: real-time) in order to have the most accurate values to incorporate into the composite index calculation. Therefore, a translation, gathering and integration effort has not been done in this case.



ΕΡΓΟ: ΑΞΙΟΛΟΓΗΣΗ ΠΕΡΙΒΑΛΛΟΝΤΙΚΟΥ ΘΟΡΥΒΟΥ ΚΑΤΑ ΤΗΝ ΛΕΙΤΟΥΡΓΙΑ ΤΩΝ ΕΓΚΑΤΑΣΤΑΣΕΩΝ ΤΗΣ ΟΛΘ ΑΕ ΣΤΟΝ ΛΙΜΕΝΑ ΘΕΣΣΑΛΟΝΙΚΗΣ

ΘΕΜΑ: ΜΕΤΡΗΣΕΙΣ ΑΚΟΥΣΤΙΚΟΥ ΠΕΡΙΒΑΛΛΟΝΤΟΣ

ΘΕΣΗ:	10	
ΠΕΡΙΓΡΑΦΗ:	26 όριο	
ΧΕΙΡΙΣΤΗΣ:	Βελιδαρλής Αλέξανδρος	
ΗΜΕΡΟΜΗΝΙΑ:	27/06/19	
ΩΡΑ ΕΝΑΡΞΗΣ:	10:40	
ΔΙΑΡΚΕΙΑ:	24h	
ΤΥΠΟΣ ΟΡΓΑΝΟΥ:	CK:811A (S/N B19376FD)	
ΒΑΘΜΟΝΟΜΗΣΗ [✓]	ΑΡΧΙΚΗ ΣΤΑΘΜΗ:	93,7 dB(A)
	ΤΕΛΙΚΗ ΣΤΑΘΜΗ:	93,7 dB(A)
ΘΕΡΜΟΚΡΑΣΙΑ:	17.9 - 25.8	
ΣΧΕΤ. ΥΓΡΑΣΙΑ:	56 - 80	
ΑΝΕΜΟΣ	ΤΑΧΥΤΗΤΑ:	1,2
	ΔΙΕΥΘΥΝΣΗ:	SW
ΑΠΟΘΗΚΕΥΣΗ ΣΕ Η/Υ:		✓
ΜΕΤΡΟΥΜΕΝΗ ΤΙΜΗ dB(A)	Leq 24h	52,3
	L10 18h	53,4
	Lday 07:00 19:00	53,3
	Leven. 19:00 23:00	52,6
	Lnight 23:00 07:00	49,9
	Lden	57,2

ΣΚΑΡΙΦΗΜΑ

ΘΕΣΗ / ΥΨΟΣ ΜΙΚΡΟΦΩΝΟΥ: 4,0μ

Δείκτης Κυκλοφοριακού Θορύβου

ΩΡΑ

ΑΠΟ	ΕΩΣ	Leq	L10			LAFmax	L1	L50	L90	L95	L99
0:00	1:00	49,8	51,2			65,5	58,0	48,2	45,7	45,1	44,2
1:00	2:00	52,1	54,3			71,2	59,5	50,5	47,2	46,5	45,2
2:00	3:00	50,2	52,5			64,0	55,7	49,2	46,6	46,0	44,9
3:00	4:00	50,5	52,7			67,0	57,4	49,2	45,4	44,5	43,1
4:00	5:00	47,4	50,1			59,8	53,2	46,4	43,6	43,0	42,1
5:00	6:00	48,5	50,7			63,9	55,4	47,3	44,7	44,1	42,9
6:00	7:00	49,8	51,3			67,8	58,6	48,3	45,2	44,4	43,6
7:00	8:00	51,0	52,1			75,1	60,0	49,0	47,1	46,6	45,9
8:00	9:00	50,8	51,7			76,6	58,2	48,4	46,2	45,7	44,9
9:00	10:00	52,2	52,5			77,0	60,4	50,1	48,1	47,5	46,7
10:00	11:00	53,9	55,2			77,0	62,5	51,7	49,2	48,6	47,8
11:00	12:00	53,8	55,6			73,3	62,0	52,0	49,1	48,3	47,1
12:00	13:00	53,4	55,4			77,1	60,9	51,3	48,9	48,4	47,6
13:00	14:00	51,6	53,5			68,6	57,4	50,3	48,2	47,7	46,7
14:00	15:00	55,1	57,0			74,4	63,2	53,2	50,1	49,3	47,9
15:00	16:00	54,4	56,0			73,3	62,2	52,7	50,2	49,6	48,6
16:00	17:00	54,5	55,7			76,2	63,5	52,3	49,9	49,2	48,0
17:00	18:00	54,6	54,7			81,2	63,7	51,1	48,4	47,9	47,0
18:00	19:00	51,2	52,8			74,7	57,4	50,1	47,8	47,1	45,5
19:00	20:00	55,0	54,2			83,7	63,8	51,2	48,9	48,3	47,3
20:00	21:00	53,7	51,8			82,7	60,4	48,5	46,6	46,2	45,5
21:00	22:00	49,8	50,1			80,9	53,6	47,4	45,3	44,8	43,9
22:00	23:00	48,8	50,9			65,2	54,4	47,7	45,7	45,2	44,5
23:00	0:00	48,9	50,9			61,6	54,5	48,1	46,1	45,4	44,1

ΠΑΡΑΤΗΡΗΣΕΙΣ:

Figure 1.24 Noise reports ThPA

1.2.3.2. Summary of data retrieval in THPA for PEI deployment

In the previous sub-chapters, a detailed reference of all the data that is (and will be) available in the Port of Thessaloniki has been done. Nevertheless, this part aims at being a quick summary to realise at a quick glance of the coverage for the PEI deployment that is already taking place under the scope of task T7.5:

Table 1.3 Summary of data retrieval in THPA

Origin entity	*Piece of data needed for calculating PEI eKPIs*	*Existing*	*Obtained through*	*Mechanism*	*Historic*
Ships	IMO number of all the ships arriving at the port	Yes	API offered to PIXEL by THPA	Web - own API	From 2015 till today
Ships	Gross tonnage moved by all ships in the port	Yes	API offered to PIXEL by THPA	Web - own API	From 2015 till today
Ships	Main engine power of all the ships for calculating emissions	Yes	API THPA and assumptive tables	Web - own API + proxy data	From 2015 till today
Ships	Auxiliary engine power of all the ships for calculating emissions	Yes	API THPA and assumptive tables	Web - own API + proxy data	From 2015 till today
Ships	Berthing time of all vessels in the port docks	Yes	API offered to PIXEL by THPA	Web - own API	From 2015 till today
Ships	Maneuvering time of all vessels within the port area	Yes	API offered to PIXEL by THPA	Web - own API	From 2015 till today
Ships	MARPOL Annexes for retrieving ships waste	Yes	API offered to PIXEL by THPA	Web - own API	2016 to 2019
PA&Terminals	Energy consumed by Port Authority and terminals	Yes	Electricity bills by Energy Provider	Web - own API	From 2012 till today
PA&Terminals	Waste produced by the Port Authority and Terminals	Yes	API offered to PIXEL by THPA	Web - own API	2018-2019
PA&Terminals	Waste water produced by the Port Authority and Terminals	Yes	API offered to PIXEL by THPA	Web - own API	2018-2019
Global	Noise levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	2012-2019
Global	Light levels registered in the Port Authority area of the port	Will be	Sensor being installed	Sensor	None

Conclusions:

ThPA is an exceptional case within PIXEL as per the operational scenario of managing together services of Port Authority, terminals and other has led the team to not divide the different data to be provided in the same way as for the other three ports in PIXEL. This also affects the eKPIs but will not affect calculations nor the validity of the PEI value for the port.

About the data, the WP5 team has been able to gather all the data needed to run the PEI for ThPA. The effort has conducted both to have a full dataset for 2019 (so tests and sensitivity analysis can be conducted over them) and also to have the means to integrate (close to-) real-time data into the PIXEL infrastructure so that the PEI can be calculated per request, daily, weekly or monthly, **always in a retrospective way**.

Regarding the ways of collection, the overview is rather optimistic. No need of manually inputting data has been identified. The 80% of the sources come directly from an own-built API service which is already integrated in the platform, two data sources come from an IoT sensor and, on the bad note, there is dependency on assumptions for getting some data: assuming manoeuvring time is twice the entry *hotelling time* and using tables mapping vessel type to main and auxiliary engine power information. This is mainly due to the raw data needed on those cases about vessels details (engines used, etc.) that had not been managed by the port before PIXEL. More accurate options do exist (see section 3), and they are being studied for the short future, but with the current data availability the PEI can be calculated.

To sum up, ThPA has been able to gather enough data to become a ready-to-test port in task T7.5.

1.2.4. PPA

1.2.4.1. Data on ships (PPA)

PPA has acquired a subscription to Marinetraffic[6] in order to have reliable information of the vessels that arrive and depart from the Port of Piraeus. Vessel calls data are already managed by a private PCS system in Piraeus, however the port decided to acquire this subscription to have access to the AIS data transmitted by the ships. This will allow PEI (and PIXEL) to have real time information on the current position, future moves and technical characteristics of the vessels operated in Piraeus.

<u>IMO number and gross tonnage moved of all the ships arriving at the port</u>

For what regards these two values, their retrieval for every PEI calculation request done for April 2020 on will be obtained from the AIS data gained via the aforementioned subscription. The PIXEL technical team is developing an NGSI agent that will be able to (periodically) retrieve data querying the API and will feed the PEI procedure calculations (with IMO, type and tonnage moved) following a format as indicated in Figure 1.25. The AIS subscription allows more fields, but in the following image there is an extract of the relevant data that will be used:

Vessel Name	Port Call Type	Ata/atd	Mmsi	Imo	Voyage Origin Port Atd	Vessel Type - Generic	Capacity - Dwt
[illegible]	ARRIVAL	2019-03-15 15:50:00	[illegible]	[illegible]184	2019-03-15 15:20:00	High Speed Craft	
	ARRIVAL	2019-03-15 15:45:00		278	2019-03-15 15:36:00	Special Craft	383
	DEPARTURE	2019-03-15 15:43:00		786	2019-03-15 08:53:00	Passenger	1896
	DEPARTURE	2019-03-15 15:40:00		579	2019-03-14 23:23:00	Passenger	2651
	ARRIVAL	2019-03-15 15:12:00		978	2019-03-15 07:46:00	Passenger	1147
[illegible]	DEPARTURE	2019-03-15 15:10:00	[illegible]	[illegible]700	2019-03-15 14:03:00	High Speed Craft	16
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 1.25 MarineTraffic useful data for PEI – PPA subscription

Regarding historical data, the information about all the vessels that berthed in PPA during 2019 is available. In this occasion, no automated process has been able to be put in place, as the information is stored in non-compatible legacy databases. This fact has led the team to establish a procedure foreseen as an option for PEI data provision: web-based but using a remote repository to upload static documents (see section 1.1). The whole information about 2019 vessels have been provided via four different files, corresponding to the ships operated by the three different terminals in the Port of Piraeus:

- Container cargo terminal
- Passengers terminal
- High speed craft vessels
- Cruise terminal

An extract of one of those files can be observed in Figure 1.26. The relevant fields to be used for this part of data provision to the PEI are the IMO number, date, and tonnage (dwt).

Vessel Name	Port Call Type	Ata/atd	Imo	Vessel Type -	Capacity - Dwt
[illegible]	DEPARTURE	2/21/2020 15:04	[illegible]	Cargo	139335
	ARRIVAL	2/21/2020 13:59		Cargo	51671
	DEPARTURE	2/21/2020 13:37		Cargo	11433
ANEO	DEPARTURE	2/21/2020 13:18		Cargo	18427
	DEPARTURE	2/21/2020 12:41		Cargo	15511
	DEPARTURE	2/21/2020 10:24	[illegible]	Cargo	24095
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 1.26 Vessel calls data PPA

<u>Main and auxiliary engine power of all the ships for calculating emissions:</u>

Drawing from what has been explained at the beginning of PPA explanation, the subscription to the AIS-based MarineTraffic API will allow PPA to have available valuable information of the ships arriving and departing to/from the port.

The vessel type (standardised) is available in the reduced set of information that has been selected for the PEI. With this piece of information, PPA will be able to forward to the PEI data on main and auxiliary engine power

[6] https://www.marinetraffic.com/es/ais-api-services

by using the procedure in 3.2.1. However, the AIS subscription already includes data on the main engine power of the vessel, therefore there also exists the possibility of just inferring auxiliary engine and forward those data.

This way, the process is: (i) the NGSI agent retrieves the vessel type field, (ii) calculations and relations are made to infer the main and auxiliary engine power of ships, (iii) both are available for more calculations.

<u>Berthing and manoeuvring time of all vessels in the port docks:</u>

For the case of Piraeus, as explained before, access has been gained to AIS data of the vessels arriving to PPA This way, with the defined polygon of the port, and after running the AIS processing module of PIXEL, the time each vessel is berthed and moving will be available as input data for the PEI.

This way, the procedure is as follows: (i) polygon of port area is provided by port staff, (ii) vessels of the period selected for PEI calculation are identified (IMO and MMSI numbers possible) (ii) AIS processing model is requested to be run, introducing as input the needed data (vessel number, area of the port), (iii) results of the model execution are inserted into the central data storage of PIXEL (IH), (iv) NGSI explores those results and selects the values (berthing and manoeuvring time), (v) those data are made available for the next calculations.

The procedure of collection of this data is explained in detail below in chapter 3.

<u>MARPOL Annexes for retrieving ships waste:</u>

Data on waste discharged from vessels is collected by an old legacy database after being filled manually, then downloaded as an Excel file and then provided to PIXEL (and PEI) via the remote web repository option commented before. Data is separated in two Excel files corresponding to the vessels that announce waste to be processed by the port. The two Excel files correspond to: (i) waste categorized under MARPOL standard Annex V (Figure 1.27 MARPOL Annexes data for PEI calculation - PEI – PPA (I)and (ii) waste categorized under MARPOL Annex IV (Figure 1.28). Historical data of 2019 is already totally available for PIXEL (and PEI).

Delivery date	Name of ship	IMO Nunber	Food waste from cmeters	Plastic waste	Other garbage description	Other waste amount	Dangerous	Functionally	type
1/1/2019 0:00:00	[illegible]	[illegible]	0,90	1,50			0,00	3,00	
1/1/2019 0:00:00	[illegible]	[illegible]	0,00	0,00		26,00	0,00	0,00	WASTE
1/1/2019 0:00:00	[illegible]	[illegible]	11,30	13,00		0,00	0,00	2,50	WASTE
1/1/2019 0:00:00	[illegible]	[illegible]	0,00	0,00		0,00	14,06	2,14	WASTE
2/1/2019 0:00:00	[illegible]	[illegible]	0,00	0,00		0,00	0,00	35,00	Container
2/1/2019 0:00:00	[illegible]	[illegible]	2,00	4,00		3,00	0,00	3,00	WASTE
2/1/2019 0:00:00	[illegible]	[illegible]	1,00	2,00		4,00	0,00	3,00	CONTAINER

Figure 1.27 MARPOL Annexes data for PEI calculation - PEI – PPA (I)

Delivery date	Name of ship	IMO number	Oil residues	Water collector waters	Quantity of other waste oils	Quantity related waste	Quantity of cargo residues	Dangero us
02/1/2019 0:00:00	[illegible]	[illegible]	10,00	0,00	0,00	0,00	0,00	0,00
02/1/2019 0:00:00	[illegible]	[illegible]	0,00	4,44	0,00	0,00	0,00	0,00
02/1/2019 0:00:00	[illegible]	[illegible]	4,70	0,00	0,00	0,00	0,00	0,00
02/1/2019 0:00:00	[illegible]	[illegible]	2,00	0,00	0,00	0,00	0,00	0,00
02/1/2019 0:00:00	[illegible]	[illegible]	0,00	2,85	0,00	0,00	0,00	0,00
02/1/2019 0:00:00	[illegible]	[illegible]	5,00	4,00	0,00	0,00	0,00	0,00

Figure 1.28 MARPOL Annexes data for PEI calculation - PEI – PPA (II)

The procedure to follow is: (i) the NGSI agent retrieves data from the FTP remote repository with proper credentials, (ii) the data for the corresponding time period is filtered (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iii) the meaning of each field is analysed, mapping them to the reference rows and columns, (iv) making the sum of certain residue for that specific period, (v) feeding the corresponding eKPI, (vi) make those data available for the next calculations.

1.2.4.2. Data on terminals (PPA)

Energy consumed by the machines functioning in the port:

In this context the PEI will take advantage of three relevant pieces of information that will be combined with emission factors (see section 3.2.2) in order to obtain the emissions to the atmosphere by the terminals of the port.

The pieces of information that will be provided are:

- Resources used to operate each ship at the terminal: machines, time being used each machine, consumption of each machine.
- Energy consumption for operating each vessel (in kWh)
- Nature of the energy source of each machine used: electricity, gas, etc.

This information will be extracted from the result of the PAS (Port Activity Scenario) model executions, which will provide this information in a raw format that will need to be processed before synthesizing the data relevant for PEI. For instance, the values are provided within a long JSON stored in the IH as a result of the PAS execution. A tiny example of part of the info contained within those is illustrated in Figure 1.29. More details about this JSON and the whole PAS procedure are provided in section 3.2.2.


```
"activities_list":[
    {
      "ID":0,
      "ressources_accounts_list":
      [
        {
          "energy_consumed":[
            {
              "nature":"gazol",
              "value":238.84979
              423750002
            }
          ],
          "ressource_ID":"machine
          _17"
        }
      ],
      "step_ID":"step_1",
      "timespan_scheduled":{
        "duration":623.08641975,
        "end":"2018-01-
        02T05:13:05.185185",
        "start":"2018-01-
        01T18:50:00"
      }
```


Figure 1.29 PAS relevant data

The procedure for obtaining the data is the following: (i) members of the port should had introduced through a web form interface the description of the supply chains applying to the port. Again, this is well explained in section 3.2.2. (ii) PAS execution model is scheduled to be executed with a certain periodicity, the results (JSON aforementioned including the three relevant pieces of data) are stored in the IH, (iii) NGSI agent explores that results and will select the ships corresponding to the seeked period (depending on PEI calculation request: daily, weekly, fortnightly, monthly), (iv) the sum of that period is made, (v) he corresponding eKPI is populated, (vi) those data are made available for the next calculations.

Waste produced by the terminals:

The port of Piraeus is not able to provide an automated way to retrieve the data. The approach adopted has been to fulfil the different values using an Excel file each certain time and afterwards uploading an it to the already settled FTP server. This option (see section 1.1.1) has been considered as valid for the PEI, as long as an NGSI agent is capable to retrieve the information and make it ready to feed the PEI as eKPI values.

Table 1.4 Terminals waste PPA

Period	*Type of cargo*	*Amount of cargo (tonnes/m3/TEU/passengers)*	*Muncipal solid waste (tonnes)*	*Inert waste (tonnes) (recycable)*	*Hazardous waste (tonnes)*
2019	CRUISE TERMINAL	2.000.000 passengers	161, 44	25,69	551
2019	PASSENGER SHIPPING TERMINAL	18. 000.000 passengers	205,1	31,27	
2019	GENERAL CARGO TERMINALS	500.000 vechicles	142,6	12,66	
2019	CONTAINER TERMINALS	800.000 TEUs	32,08	6	

In Table 1.4, the data of 2019 is indicated. This file will be updated by PPA every three months, for all the four terminals in the port (cruise, passengers, general cargo and container). The values will be extrapolated from the files if the need for that arises (in case of the shorter calculation period).

Wastewater produced by the terminals:

Same procedure as per the waste applies. Values map directly to eKPIs. 2018 and 2019 (one registry per year) are available and are shown in Table 1.5. Three months will be also the refreshing frequency.

Table 1.5 Terminals wastewater PPA

Period	*Amount of cargo (tonnes/m^3/TEU/passengers)*	*Sanitary wastewater (m^3)*	*Technological wastewater (m^3)*
2018	587	57349	43011,75
2019	481	64922	64922,75

1.2.4.3. Data on port authorities (PPA)

Energy consumed by the Port Authority in a period of time:

Same way as for the waste and wastewater for the terminals.

The way (and tool) to be used to provide this data can be seen at Table 1.6. Port of Piraeus staff will provide these values for the calculation of the PEI every three months (three-monthly periodicity). In the table one can observe the historical data as well available: 2018 and 2019 with one registry per year.

Table 1.6 Energy consumed Port Authority PPA

Period	*Fuel type*	*Fuel quantity (lt)*	*Electricity consumption (kWh)*	*Primary energy (solar station) production of energy kWh per annum*
2018	Diesel	1.468.177	59.154.497,02	674.644,00
2019	Diesel	1.204.331	71.577.716,15	676.150,00

The energy consumption includes all the following Electricity consumption (kWh):

- Container terminal machinery
- Car terminal
- Offices
- All lighting indoor/outdoor

Waste produced by the Port Authority (garbage, usual residues):

Exactly the same procedure as for waste and wastewater of the terminals is going to be followed. PPA will update the Excel file in the FTP repository every three months with the most recent values. The data to be provided maps (see Table 1.7) directly to the eKPIs of waste of a Port Authority, therefore the procedure is straightforward.

Table 1.7 Waste produced Port Authority PPA

Period	*Muncipal solid waste (tonnes)*	*Inert waste Recycable (tonnes)*	*Hazardous waste (tonnes)*
2018	903	81	423
2019	940	118	551

Wastewater produced by the Port Authority (garbage, usual residues):

Same procedure as just above applies. The different columns of the Excel file also map directly to the wastewater eKPIs of Port Authorities. Historic data is available except for sanitary wastewater.

PPA is in the process of gathering further information in order to obtain the numbers of sanitary wastewater of 2018 and 2019. For the future, these values will be included in the 3-monthly updates.

Table 1.8 Wastewater produced Port Authority PPA

Period	*Sanitary wastewater (m^3)*	*Technological wastewater (tn) - oil water from the workshops*	*Water consumption (m^3)*	*Coefficient factor for sewage calculation (75%)*
2018	-	587	57349	43011,75
2019	-	481	64922	64922,75

1.2.4.1. Data associated to the port as a whole (PPA)

Noise and light levels registered in the Port Authority area of the port:

PPA has used the budget reserved for the equipment to acquire a noise sensor that is in the procedure of being purchased and installed in the port. According to the specifications provided by the WP5 team, the values of L_{DEN}, L_{night} and L_{eq} (in dB) will be available and accessible for future PEI calculation requests. Regarding historical data, the only information available are the results of a noise study report that took place during June-July 2018 through which PPA was able to realise the average values in the port of the following values: L_{eq}, L_{max}, L_{min}, L_{ae}, L_5. This is not useful for the PEI, so the integration of this data was discarded.

1.2.4.2. Summary of data retrieval in PPA for PEI deployment

In the previous sub-chapters, a detailed reference of all the data that is (and will be) available in the Port of Piraeus has been done. Nevertheless, this part aims at being a quick summary to realise at a quick glance of the coverage for the PEI deployment that is already taking place under the scope of task T7.5:

Table 1.9 Summary of data retrieval PPA

Origin entity	*Piece of data needed for calculating PEI eKPIs*	*Existing*	*Obtained through*	*Mechanism*	*Historic*
Ships	IMO number of all the ships arriving at the port	Yes	Agent and MarineTraffic subscrip.	External data	FTP own 2019
Ships	Gross tonnage moved by all ships in the port	Yes	Agent and MarineTraffic subscrip.	External data	FTP own 2019
Ships	Main engine power of all the ships for calculating emissions	Yes	Agent and MarineTraffic subscrip.	External data	None
Ships	Auxiliary engine power of all the ships for calculating emissions	Yes	Agent and MarineTraffic subscrip.	External data	None
Ships	Berthing time of all vessels in the port docks	Yes	MarineTraffic + PIXEL tool AIS	External data PIXEL tool - AIS	June 2019 - April 2020
Ships	Maneuvering time of all vessels within the port area	Yes	MarineTraffic + PIXEL tool AIS	External data PIXEL tool - AIS	June 2019 - April 2020
Ships	MARPOL Annexes for retrieving ships waste	Yes	PPA uploads .xls monthly	Upload to remote server	2019
Terminals	Energy consumed by the machines functioning in the port	Yes	Results of executing PAS model	PIXEL tool - PAS	None
Terminals	Waste produced by the terminals	Yes	PPA uploads every 3 months	Upload to remote server	2018, 2019 - yearly
Terminals	Waste water produced by ther terminals and spilled to the sea	Yes	PPA uploads every 3 months	Upload to remote server	2018, 2019 - yearly
Port Authority	Energy consumed by the Port Authority in a period of time	Yes	PPA uploads every 3 months	Upload to remote server	2018, 2019 - yearly
Port Authority	Waste produced by the Port Authority (garbage, usual residues)	Yes	PPA uploads every 3 months	Upload to remote server	2018, 2019 - yearly
Port Authority	Waste water produced by the Port Authority	Yes	PPA uploads every 3 months	Upload to remote server	2018, 2019 - yearly
Global	Noise levels registered in the Port Authority area of the port	Yes	Sensor bought - installing	Sensor	Report 2019
Global	Light levels registered in the Port Authority area of the port	-	-	-	None

Conclusions:

The AIS subscription acquired by PPA will feed different data needed for PEI calculation and the noise sensor to be installed will also contribute actively. Conclusion here is that the budget planned is properly carried out and that ports will be able to increase their options to execute PEI with affordable investments in IoT.

Regarding the deployment, PPA is ready to start the PEI pilot (T7.5) as soon as the NGSI agents (WP6-WP7) start getting data and storing eKPIs into the IH in PPA. However, no 2019 nor 2018 retrospective complete PEI will be able to be tested. Only partially, for the sake of selecting mathematical methods (section 4).

2. Environmental KPIs (eKPIs)

Based on the available scientific and technical literature, a list of all existing eKPIs was compiled and presented in the Deliverable 5.1 (Environmental aspects and mapping to pilots). In the Deliverable 5.2 (PEI Definition and Algorithms v1), they were correlated with port activities and categorized according to different environmental aspects: emissions to the atmosphere, wastewater emissions, noise emissions, waste production, odours, and light emissions (D5.2).

In this chapter, the focus is to demonstrate and analyse how the environmental aspects and the associated eKPIs relate to the three subsidies of the PEI: the Ship Environmental Index, the Terminal Environmental Index, and the Port Authority Environmental Index as well as to provide environmental and toxicological contexts of each identified eKPI.

2.1. Ships

Ship generated pollution, such as air emissions, waste, and wastewater have a direct impact on the human community and the ecosystem. There are many regulations, such as the MARPOL Convention and several EU legislations, putting in place to monitor and mitigate the negative environmental impact of the maritime industry. The International Maritime Organisation (IMO) MARPOL Convention defines the on-board handling of ship-generated waste through six annexes (IMO 2020), as seen in Table 2.1.

Table 2.1 MARPOL Annexes for on-board ship-generated waste

Annex	*Regulations for:*	*Related eKPIs:*
I	the prevention of pollution by oil	Wastewater emissions
II	the control of pollution by noxious liquid substances in bulk	Wastewater emissions
III	the prevention of pollution by harmful substances carried by sea in packaged form	All
IV	the prevention of pollution by sewage from ships	Wastewater emissions
V	the prevention of pollution by garbage from ships	Waste emission
VI	the prevention of air pollution from ships	Emissions to the atmosphere

2.1.1. Emissions to the atmosphere

Air quality is recognized as the major environmental priority in the European port sector independently from the size of the port and of the type of the port since 2013. This environmental issue is very important in European ports because of its direct relationship with the health of people who work or live around the harbour. The issue of climate change, which is directly connected with air quality, appeared for the first time in 2017 and rose to the third position in 2019 which makes reducing carbon emissions a high priority for European ports. Air quality in ports must be in line with the international and European political agenda (ESPO/EcoPorts 2019). Atmospheric emissions that affect air quality are caused by several activities within the port area. Ship movement, as one of them, negatively impacts the ambient air. By burning hydrocarbon fuels, ships contribute to air pollution, affect human health, endanger ecosystems, and add to climate change.

Fuel in ships

The ratio between the emissions coming from various activities might vary significantly from port to port. Frequently, it is difficult to know how much each activity contributes to the total air pollution within the port territory. The PEI can be a helpful tool for estimating how high the contribution of each activity is. To calculate the emissions from ships five eKPIs are taken into account (Figure 2.1).

Figure 2.1 Air pollution eKPIs for ships

2.1.1.1. SO_X and NO_X emissions

Sulphur oxides and nitrogen oxides are the main two culprits that contribute to air pollution from ships. Because of chemical reactions in the air, NO_X and SO_X are converted into fine particles, nitrate aerosols, and sulphates. These gasses have damaging effects on the Earth's ozone layer which results in the global warming and greenhouse effects.

The emission of NO_X comes from fuel combustion in internal engines, boilers and incinerators needed for the normal functioning of a ship. For combustion to take place, there is a need of mixing the fuel with air which is mostly composed of oxygen (about 21%) and nitrogen (about 78%) with some traces of gases and water vapour. Regarding the NO_X emissions from ships, there are some adjustments that engine manufactures can make to reduce the emissions (Ship Insight 2020).

Sulphur oxides (SOx) are products coming purely from combustion processes and because of that, the resulting pollution is only an issue for ships that burn residual fuels in engines and boilers. In order to mitigate SO_X emissions from ships two things can be done, the reduction of the sulphur level in fuel or Exhaust Gas Cleaning systems need to be employed (Ship Insight 2020). The regulation of ship exhausts is regulated by the VI annex of MARPOL.

2.1.1.2. CO_2 emissions

CO_2 emissions originate from fuel combustion by burning carbon in that fuel. The Third IMO GHG Study (2014) concluded that in 2012 international shipping emitted 796 million tonnes of CO_2 making the shipping industry accountable for about 2.2% of the total global CO_2 emissions in 2012. Emissions from ships could grow between 50% and 250% by 2050 mainly due to the growth of the world maritime trade.

2.1.1.3. PM emissions

Similar to the other pollutants and their total influence on the atmosphere, particulate matter (PM) emissions from ships significantly contribute to the anthropogenic burden of PM. Particulate matter consists of elemental or black carbon (EC/BC), organic carbon (OC), compounds containing sulphate, inorganic substances, some other metals and associated water. Physical and chemical properties may vary based on fuel type, engine type and operating mode (Moldanová et al. 2013).

2.1.1.4. HC/VOC emissions

During combustion, not all of the fuel oil gets burned. A small fraction of it, consisting of hydrocarbons, passes through the engine unburned, nevertheless most of the HC emissions come from combustion process. Another source of hydrocarbons emission comes from lubrication oils (Green Ship 2020).

The final air emissions eKPIs along with their impacts and cause can be found below, in Table 2.2 (Clear Seas 2020, ESPO).

Table 2.2 Air emission eKPIs for ships and their impacts

Matrix	eKPI	Description and impact	Cause/resulting from:
AIR	NO_X	When breathed, it causes lung inflammation, and with long time exposure could lead to eventual heart and lung failures. It can interact with volatile organic compounds (VOCs) and create ground-level ozone. O_3 contributes to shortness of breath, eye, nose, and throat irritations. Contributes to over-abundance of nutrients to coastal waters which cause toxic algal to bloom and decreases water oxygen levels	Burning fuel for energy
AIR	PM	A key component of smog. It can be inhaled and therefore absorbed in the bloodstream, causing heart and lung diseases. Forms "black carbon" that darkens ice surfaces and snow which reduce solar energy reflected into the space (the albedo effect) - accelerates melting	Burning fuel for energy
AIR	SO_2	When breathed, it causes lung inflammation, and with long time exposure could lead to eventual heart and lung failures.	Burning fuel for energy
AIR	HC	Reduce the photosynthetic ability of plants. Increase the risk of respiratory illness and cancer rates in humans and animals.	Burning fuel for energy
AIR	CO_2	It contributes to the climate change and therefore plays a significant role in extreme weather conditions such as floods, heatwaves, and violent storms. All that has a major impact on human health and the ecosystem. When absorbed into seawater it makes it more acidic. Acidification weakens coral structures and damages the shells of mussels and clams.	Burning fuel for energy

The PEI only takes into the calculation ships located in the port territory, which means air pollution generated while the ships are at sea is omitted. The ships' manoeuvring and berthing modes are essential for the estimation of the emissions to the atmosphere.

2.1.2. Waste emissions

In the past few years, marine litter has become a huge problem in oceans and a great concern for local communities. ESPO Environmental Report from 2019 shows that the ship waste is in sixth position and port waste in the seventh position of the top 10 environmental priorities of the port sector (ESPO/EcoPorts 2019). The implementation of the EU Directive on Port Reception Facilities for ship waste is the priority of ports since waste is the most monitored indicator for more than five years. For waste production, a difference must be done between wastes produced by port or terminal activities and wastes generated by ships, because priorities and legislation are not similar.

Ship-generated waste includes, for example, plastics, food waste, domestic waste, and operation waste. In the Mediterranean, a variety of it have been found on the seafloor along most used shipping lanes with plastics being the most common one. About 20% of plastics found in the oceans/seas originate from maritime activities. That plastic endangers aquatic animals causing serious harm as they may drown or suffer wounds from it. (Jägerbrand et al. 2019)

Annex V of the MARPOL convention contains regulations to prevent waste emissions from ships. Its main aim is to reduce and eliminate the amount of garbage discharged into the sea.

Figure 2.2 Waste emissions eKPIs for ships

Ships of 100 gross tonnage and above must carry a garbage management plan on board, which includes written procedures for minimizing, processing, storing, collecting, and disposing of garbage. Ships of 400 gross tonnages and above must provide a Garbage Record Book. For the PEI, these waste management plans and books are very important as they contain the needed data for the calculation of the waste emissions.

The eKPIs (Figure 2.2) contained in these documents along with their impacts and cause can be found below, in Table 2.3 (IMO 2020, Jägerbrand et al. 2019).

Table 2.3 Waste emission eKPIs for ships and their impacts

Matrix	*eKPI*	*Description and impact*	*Source/resulting from*
WASTE	**Plastics**	Includes plastic garbage bag, bottles, ropes, synthetic fishing nets, sheets, wrapping, drums, synthetic ropes, and empty chemical cans. Endanger marine life if discharged	Originates from supplies used for ship operations
WASTE	**Food waste**	Food substances that include meat products, fruits, poultry, vegetables, dairy products, etc.	Food generated onboard
WASTE	**Domestic waste**	Waste from domestic spaces on-board that is not plastic, food waste or cooking oil. Includes lids, paper, foils, cardboard, fluorescent lamps, glass, metal cans, synthetic material, etc.	From crew and passenger hoteling on board
WASTE	**Cooking oil**	Oils form cooking activities	Generated on-board during food preparation
WASTE	**Incinerator ashes**	Ashes from burning sludge, domestic, operational waste and other types of waste	From burning several types of waste
WASTE	**Operational waste**	Includes machine room waste, chemical remains, old ropes, jerry cans, wood, refrigerators, aerosols, fireworks, flares, etc.	Generated during normal operations or maintenance of a ship
WASTE	**Animal carcass(es)**	Remains of deceased livestock	Deceased livestock
WASTE	**Fishing gear**	Only generated on fishing vessels	Generated when fishing gear wears and tears beyond repair
WASTE	**E-waste**	Electrical and electronic equipment from the accommodation spaces or used for the normal ship operation of the ship	Electrical and electronic equipment
WASTE	**Cargo residues (harmful)**	Contain components which are known to be mutagenic, carcinogenic, or reprotoxic	During ship operations
WASTE	**Cargo residues (non-harmful)**	Remnants of any cargo which are not covered other categories	During ship operations, loading or unloading excess or spillage
WASTE	**Passively fished waste**	Waste collected in nets during fishing activities	From fishing operations

2.1.3. Wastewater production

The eKPIs are similar to the prevention of waste emissions MARPOL enforced regulation to mitigate wastewater emissions from ships – defined in Annex IV (Figure 2.3).

Figure 2.3 Wastewater production eKPIs for ships

Wastewater pollution can cause significant damage to marine life. For example, ballast water that is often filled from one region and discharged to another contains microorganisms and microbes that endanger local species and marine life. Ship wastewater can be categorized as black- or greywater. Blackwater, also known as sewage, consists mostly of discharges of onboard toilets. Blackwater contains viruses, bacteria, nutrients and it is more concentrated as less water is used for flashing. Gray water, or non-sewage wastewater, includes drainage from onboard kitchens, laundry facilities, and showers (Jägerbrand et al. 2019).

Ships have to carry wastewater management plans and books, which again are useful for the PEI calculations. The eKPIs are shown in Table 2.4. (IMO 2020, Jägerbrand et al. 2019).

Table 2.4 Wastewater production eKPIs for ships and their impacts

Matrix	*eKPI*	*Description*	*Cause*
WATER	Oily bilge water	A mixture of water, oil, and lubricants	Generated during normal ship operations
WATER	Oily residues (sludge)	*Residual* waste *oil* products	Generated during normal ship operations
WATER	Oily tank washings	Wastewater from tank washing	Generated by tank washings,
WATER	Dirty ballast water	It is necessary to improve balance, stability, and trim. Oil tanks used to carry ballast water, contaminate it with oil	Carried in ships' ballast tanks
WATER	Scale and sludge from tank cleaning	Semi-liquid or solid matter remaining in a tank from the fuel	From tank cleaning
WATER	Other - oil	Other oily substances	Generated during normal ship operations
WATER	Noxious liquid substances (NLS) - type X	Substances that present a major hazard to either human health or marine resource. It is prohibited to discharge into the marine environment;	Tank cleaning or deballasting operations
WATER	NLS - type Y	Substances that present a hazard to either human health or marine resource. It is prohibited to discharge into the marine environment; The discharge of such substances is limited to the quality and quantity of it;	Tank cleaning or deballasting operations
WATER	NLS - type Z	Substances that present a minor hazard to either human health or marine resource. It is prohibited to discharge into the marine environment; The discharge of such substances is limited to the quality and quantity of it;	Tank cleaning or deballasting operations
WATER	NLS - other	Substances outside the X, Y or Z categories	Tank cleaning or deballasting operations
WATER	Sewage	Blackwater (sewage) includes any waste contaminated by human excrement and other effluents.	From urinals and toilets

2.2. Port Terminals

In this section, pollution resulting from port terminals is presented. The main pollutants are various types of port machinery, including cargo handling equipment.

2.2.1. Emissions to the atmosphere

Numerous articles, including the one from Darbra et al. (2005), concluded that significant environmental aspect in seaports is emissions to the atmosphere. Most of the reviews are focusing upon emissions from fuel combustion since these are the main source of pollution and the majority of the machinery used for cargo handling use diesel as the fuel of preference (Saharidis and Konstantzos 2018, Villalba and Gemechu, 2011). The main pollutants considered for diesel fuel combustion are included in eKPIs, as shown in Figure 2.4.

Since the indicators are very hard to measure directly because of difficulty to equip all emission sources with sensors, in the PIXEL project indirect indicators based on the calculation or indirect data will be used in air emission quantifications. If the supply chain or the port activities are well described, emissions can be obtained by simple calculation, using indicators of activities and information drawn from the literature showing emission factors, or engine manufacturer data, cargo's supply chain, fuel's sulphur content, etc. Due to the diversity of cargo handled by the port terminals, there is a wide range of equipment types but as said before most of the equipment runs on diesel so calculations of the emissions of these engines run by diesel will be based on the emission factors of diesel engines.

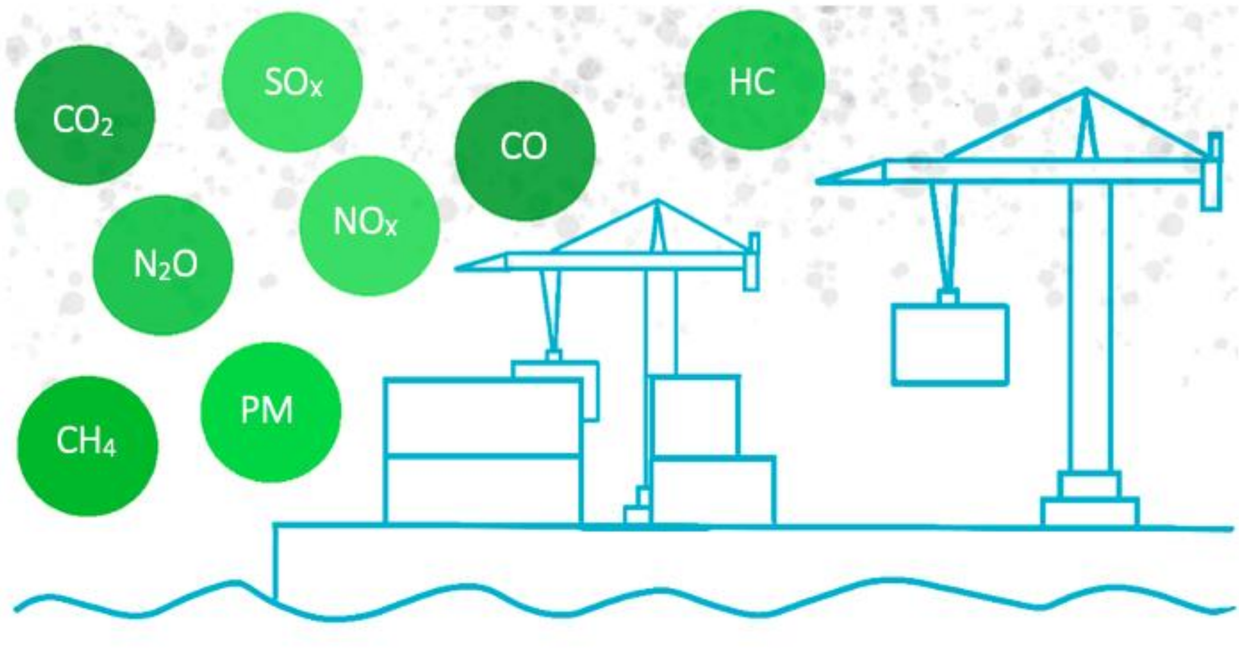


Figure 2.4 Air pollution eKPIs for port terminals

2.2.1.1. Carbon dioxide

The emissions from the port terminal activities can be directly measured by the amount of exhaust produced by the equipment but as said before this method is not going to be used here. The method that will be used is the indirect determination of emissions by measuring the amount of fuel needed for the processes. Therefore, understanding energy consumption indirectly provides a picture of CO_2 emissions. Finally, the total CO_2 emissions of ‘a port terminal can be calculated as the total sum of emissions provided by combinations of various types of equipment and their contribution to the port operations (Geerlings and Van Duin 2011).

Ports consume a vast amount of energy, especially in terms of fossil fuels. Since fulfilling all terminal operations requires high energy it makes port container terminals huge energy consumers. For that reason, CO_2 emissions in ports depend on the energy consumption of the individual terminals it consists of. The CO_2 emissions are a direct consequence of the burning of fossil fuels to generate the energy needed to operate terminal processes. The type of equipment and the use of this equipment determines the energy consumption, and consequently the amount of CO_2 emissions. CO_2 is one of the GHG which reduces the loss of heat into space and together with other GHG contributes to global climate change and warming. Activities that release CO_2 into the air and therefore GHG include those that take place during the usual operations of a container terminal (Martínez-Moya et al. 2019).

In Martinez-Moya et al. (2019) article, CO_2 emissions of port container terminal equipment of Port of Valencia were examined. Emission factors, both for electricity and diesel fuel have been obtained to calculate the CO_2 emissions generated from the use of each of the two types of energy. The emission factor for electricity expressed in CO_2 tonnes per kWh and the emission factor for diesel fuel expressed in CO_2 tonnes per TOE were used. CO_2 emissions have been calculated applying the following formula in the equation, which considers fuel consumption, in tonnes of oil equivalent, or TOE, and electricity consumption, in kWh:

$$CE_X = \sum_{i=1}^{4} (a_i \cdot f_f) + \sum_{j=1}^{4} (b_j \cdot f_e),$$

where:

CE_X – total weight of CO_2 emissions produced at terminals (tonnes)

a_i – yearly consumption of fuel with equipment i (TOEs)

f_f – emission factor in tonnes of CO_2 emission per TOE

b_j – yearly consumption of electricity with equipment j (kWh)

f_e – emission factor in tonnes of CO_2 emission per kWh

2.2.1.2. N_2O and CH_4

CH_4 and N_2O are also found in the scientific literature as an important part of air emissions in ports but they can be expressed as CO_2 equivalents using the global warming potential (GWP). GWP is used to compare GHGs emissions from different sources obtaining the CO_2 equivalent emissions. GWP is the ability of a GHG to capture heat in the atmosphere compared to an equivalent amount of CO_2 (Weisser 2007). GWP takes a value of 1 for CO_2, 23 for CH_4 and 296 for N_2O. Emission factors for CH_4 and N_2O are 137 g/tonnes fuel for N_2O and 15 g/tonnes fuel for CH_4. Following the same equation as above, the total CO_2 equivalent (CO_{2eq}) emissions were obtained and results show that CO_2 represents 99.99% over total CO_{2eq} emissions. Findings show that the contribution of fuel consumption to the total CO_2 emissions is notably larger than the electricity contributions and that yard terminal tractor and RTGs are responsible for 68.1% of total CO_2 emissions in Port of Valencia (Martínez-Moya et al. 2019).

Nitrous oxide is a consequence of burning of the fuels and its amount depends on the type of fuel and combustion technology, maintenance, and operating practices. Nitrous oxide is also one of the main stratospheric ozone depleting substances (EPA 2019).

Methane is typically hydrocarbon gas in outdoor ambient air. It is a colourless, odourless, and highly flammable gas, and the main component in natural gas, which is used to generate electricity and heat. Methane is much more efficient at absorbing heat than carbon dioxide making it a very potent greenhouse gas. (Curtis et al. 2006)

2.2.1.3. Particulate Matter (PM)

Numerous articles include PM as an important indicator of air emissions in port areas (Bailey and Solomon 2004, Bachvarova et al. 2018, Donateo et al. 2014, Sorte et al. 2018). PMs that are relevant to health are particles with a diameter of fewer than 10 µm (PM_{10}) and with a diameter of fewer than 2.5 µm ($PM_{2.5}$). PM_{10} can penetrate and lodge deep inside the lungs but even more health-damaging particles are $PM_{2.5}$ that can penetrate the lung barrier and enter the blood system. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer (World Health Organization 2013, Sorte et al. 2018). $PM_{1.0}$ and $PM_{0.1}$ (Ultra Fine Particles) are PM with diameter of less than 1.0 and 0.1 micrometers (µm) and can remain in the atmosphere for days or weeks and thus be subject to long-range transboundary transport in the air (World Health Organization 2013). There is a natural concentration of PM in the atmosphere that consists of aerosol components like dust, marine salt or polls but it is enhanced by diverse anthropogenic effects like the burning of fuels or handling of goods. Especially the combustion of diesel and heavy fuel oil leads to a comparatively high amount of PM emissions (Bachvarova et al. 2018).

Air quality in a port area can be affected by dust and particles from traffic (Gupta et al. 2005). Some of the port activities related to the emission of particles include storage, loading, and unloading of bulk solids, as well as handling and transformation of bulk solids (Peris-Mora et al. 2005). The impact on air quality of harbor operations is presented in Viana's (2003) article. The article showed that handling operations (loading and unloading of tankers and cargo vessels) had an impact on the ambient PM_{10} and $PM_{2.5}$ concentrations in the form of resuspension of mineral dust (road dust coming from road transport).

Primary particles are directly emitted into the air and secondary ones are formed in the atmosphere from gaseous precursors such as SO_2, NO_X, ammonia, and NMVOC. Primary PM emissions are the consequence of the fossil fuels consumption and can be calculated using estimation methods, provided the quantity and type of fuel combusted is known, along with the type of boiler or engine (Bachvarova et al. 2018).

2.2.1.4. NO_X and SO_X emissions

Nitrogen Oxides (NOx) arise during fuel combustion within the engines of ships, construction machinery, locomotives, and trucks. Increasing combustion time and temperature ends up in the increase of NOx emissions (Bachvarova et al. 2018). Studies have shown that NOx can cause lung irritation similarly to lowering people's resistance to pneumonia and bronchitis and other respiratory infections. NOx is additionally acidification precursor and also the commonest eutrophication precursor which both have effects on biodiversity. NOx is a smog precursor that, combined with sunlight, creates a reaction which is producing ground-level ozone which is, together with peroxyacetic nitric anhydride (PAN) and particulate matter, the main component of photochemical smog known as a health hazard. Processes that emit smog precursors are fuel combustion, as an example in road transport and electricity generation. NOx emission may be derived using proxy data i.e. using emission factors.

Sulphur oxides (SOx) are produced from the burning of sulphur-containing fuels like diesel and particularly from high sulphur marine fuels. Their emissions from shipping and port activities may be transported by the wind and pollute coastal and hinterland regions. When SO and SO_2 are oxidized in SO_4, they form sulphate aerosols which are sufficiently little that they may be classified to the group of PMs (Bachvarova et al. 2018). SOx react with the vapour within the air and creates acidic aerosols that irritate the airways, sometimes causing discomfort and coughing in healthy people and sometimes causing severe respiratory symptoms in asthmatics. Several studies indicate that the mixture of SOx and NOx within the air is especially noxious because these compounds appear to act together to extend allergic responses to common allergens like pollen and mud mites (Bailey and Solomon 2004). These emissions arise from the consumption of fossil fuels and can be calculated using standard emissions factors, provided the quantity and type of fuel combusted is known, along with the type of boiler or engine.

2.2.1.5. Carbon Monoxide

Carbon monoxide (CO) port related sources come from the exhaust of engines that power landside equipment and vehicles, non-renewable energy generation and other industrial and commercial sources that burn fuel. Larger amounts of CO can be emitted as a result of incomplete combustion. It has an atmospheric half-life of 1– 2 months and can also travel thousands of kilometres away from its source (Curtis et al. 2006). Even though CO emissions have declined significantly since the introduction of catalytic converters for motor vehicles in 1975 which resulted in a decrease of 76.3% in CO emissions, brief elevations in ambient CO concentrations can still occur during times of higher automobile volume. Consequently, the impact of CO exposure continues to be a public health concern (Chen et al. 2007).

CO emissions can be derived using emission factors based on proxy data which includes fuel consumption, fuel type and technical specifications of the engine.

2.2.1.6. HC

Hydrocarbons are compounds that consists of carbon and hydrogen atoms. They are the main component of crude oil, natural gases, gasoline, petroleum, coal, kerosene etc. All these substances contribute to the greenhouse effect by the incomplete combustion of this hydrocarbon fuels, the depletion of the ozone layer and act as major contributor to smog. They also reduce the photosynthetic ability of plants, increase cancer rates in humans and animals, and increase the risk of respiratory illness.

2.2.2. Waste production

Waste accumulation in ports is affected by several activities such as administrative and planning activities of the port authorities, cargo handling operations, port industry, shipbuilding and repair, cruise ships or ferries garbage, etc. (Darbra et al. 2005). Harbour operations also produce sewage, bilge wastes, a variety of solid wastes, oil discharges and leakages of harmful materials both from shore and ships (Mohee et al. 2012). Handling of that waste usually happens in two phases - collection and treatment. The collection takes place on ships and in ports whereas treatment is done only partially on ships and in ports. Olson's (1994) article shows the categorization of waste generated by the ships and ports like following: oily waste, bulk chemical waste, noxious substances in packaged form, sewage waste and garbage that includes all kinds of waste that is generated during the usual ship and port operation (Olson 1994).

The indicators identified in PIXEL are all based on the actual production of port’s activities and on several studies on the environmental impact of port activities or environmental management in the seaport, which ensures that they are significant and representative (Trozzi & Vaccaro 2000, Puig et al. 2014, González Laxe et al. 2017, Roos & Kliemann Neto 2017, Saeedi Pash et al. 2017). None are measurables by real-time sensors.

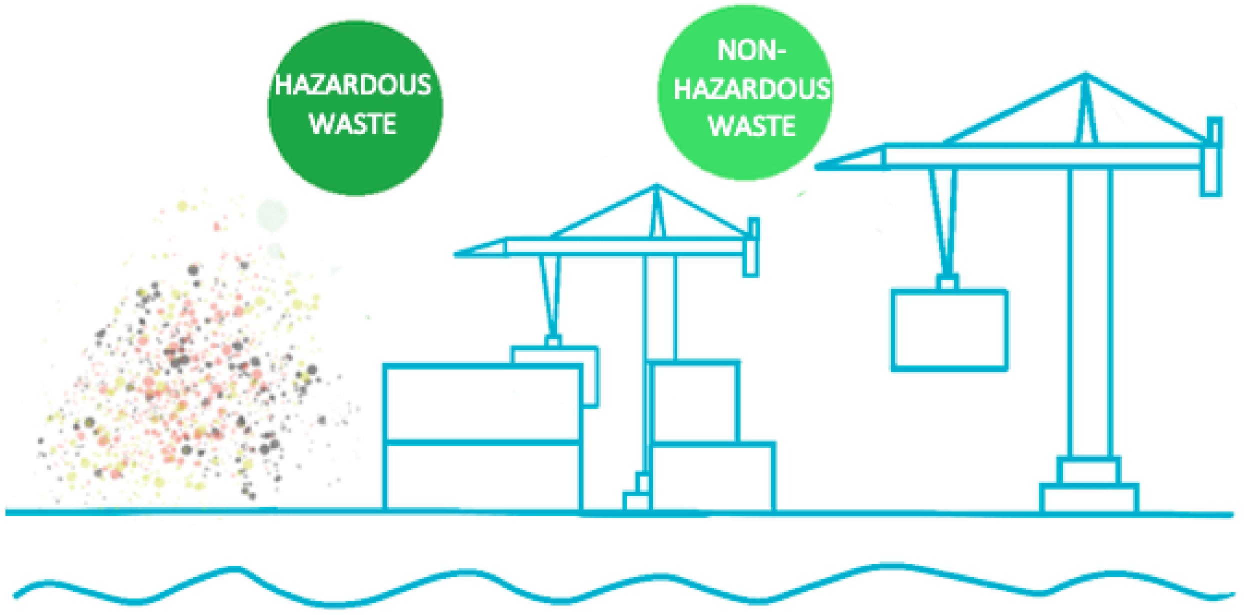


Figure 2.5 Waste production eKPIs for port terminals

2.2.2.1. Generation of hazardous waste (waste hazardous for public health or environment)

Waste produced in port terminals can generally be divided as hazardous and non-hazardous. By the definition of the Waste Framework Directive, hazardous wastes present considerable risk both to the environment and human health and it requires stricter control than non-hazardous waste. The properties of hazardous waste can be found in Annex III of the Directive, which also defines hazardous waste as a waste that displays one or more of the fifteen hazardous properties listed. The Directive also provides additional labelling, record keeping, monitoring and control obligations from the hazardous waste production to the final disposal or recovery (Waste Framework Directive). The volume or weight data can be extracted from the waste management plan for the ports.

2.2.2.2. Generation of non-hazardous waste

Non-hazardous waste from port terminals includes municipal solid waste, also referred to as garbage, described as everyday items discarded by the public. Secondly, it includes inert waste that is described as waste that is not decomposable but not chemically or biologically active. Therefore, it can be seen as the sum of all solid urban waste as well as inert waste produced by terminal operators. The study presented in the article by Mohee et al. (2012) shows that types of wastes generated from industries and buildings in port areas were mostly food and green wastes followed by paper waste.

2.2.3. Wastewater emissions

Water pollution is identified as a part of the top 10 environmental priorities of the port sector (ESPO/EcoPorts, 2019). Water pollution in seaports can be a result of numerous different emissions connected with port activities.

These activities are listed in Gómez et al. (2015) article and include: management wastes activities (collection, transportation, and storage of wastes), vessel/port interface (includes abandoned vessels, mooring, vessel repairs, oil- supplying installations and manipulation of dangerous cargos), cargo terminals activities (exterior and interior storage and distribution, residues of cargos), passenger terminals (parking/land traffic), urban activities (storage urban residues, construction, and demolition, sewage waters), industrial activities (storage industrial residues and raw materials, contaminated surfaces and sediments, waters used in refrigeration systems, sewage and process waters), maritime activities (antifouling activities, ballast water, waste from ships, invasive species in hulls, etc.). The Article from de la Lanza Espino et al. (2010) lists vessel construction, maintenance, and repair, as the main runoff sources.

Contaminant sources can be divided by the method of discharge and by its origin (Gómez et al. 2015). By the method of discharge, we can distinguish point contamination through some fixed point (i.e. channelled run-off, storm relief, and sewage) and diffuse source of contamination (i.e. dredging and filtrations). Origins of the contamination can be external (contaminant source whose area or point of discharge is located outside of the port area) or internal (contaminant source whose area or point of discharge is located inside of the port area and produced by port activity) (Gómez et al. 2015). In Ondiviela et al. (2012), in the case of Port of Gijon, most of the diffuse sources originate from the loading of solid bulk and liquids, fuel supply and handling of the containers. In Puig and Darbra (2019), oil chemical spills and the spreading of invasive species by the exchange of ballast waters are listed as the main environmental impacts in the realm of water pollution.

The indicators identified for the assessment of wastewater emissions to seawater include indicators that are related to port operational activities like sanitary and technological wastewater, and the indicator related to the port treatment systems efficiency which are limiting the discharge of pollutants into seawater. That indicator includes percentage of the port area equipped with a system for the collection and treatment of rainwater.

Figure 2.6 Wastewater production eKPIs for port terminals

2.2.3.1. Sanitary wastewater

This eKPI shows the amount of wastewater coming from various port activities that are collected by the sanitation network in ports. It can be measured using IoT connected flow meters positioned on the sanitation network. The second way of measuring would include measuring flow from the different sources in ports to the wastewater treatment plant if it exists. In case treatment plan does not exist on the port that has to be noticed since untreated wastewaters have a higher impact if they are directly dumped in seawater.

2.2.3.2. Storm water network on port

Rainwater falls on hard and impermeable surfaces and, in that way, collects pollutants. If the ports are lacking good storm water network majority of this rainwater eventually ends up in port waters bringing suspended solids, nutrients, but also heavy metals, hydrocarbons or faecal bacteria. Major environmental impacts of polluted runoff are related to lack of oxygen in water bodies, microbial and toxic pollution, eutrophication, turbidity, aesthetic pollution, contamination, etc. This indicator is used to calculate the area of the port equipped with a storm water collection network. The larger the network is the fewer pollutants are emitted into the marine environment. To collect data for this eKPI it is important to know if the storm water is collected and discharged into the natural environment or if it's treated. The percentage (%) of the port area that has a system for the collection or/and treatment of rainwater can be obtained by processing the aerial photos of the harbour and the map of the rainwater collection network.

2.2.3.3. Technological wastewater

This term presents water coming from operational activities in the port. Sources of soil or seawater pollution in ports usually come from terminal operations and fuel deposits. Some events include accidental discharge of oil in the soil or water, loss from deposit tankers and pipeline, spill from the bulk handling device and dust spread during the handling. Even though Olson's (1994) article categorized oily spills like waste instead of source for water pollution in this context it can be used to support the idea of taking this eKPI as relevant for water pollution. As described in the article, oily waste comes from oil terminals and tank farms from either accidental oil spills or operational (predictable) oil spills. The second category affecting this eKPI is bulk chemical waste generated during the handling of oil products in bulk in the ports and terminals and during the release of ballast and tank wash water in chemical tankers. This type of waste is considered to be very harmful both to humans and to the environment. Another one, called noxious substances in packaged form (dangerous goods), usually happens because of the defective or inadequate packaging of the substances and occur during the handling in the terminals (Olson 1994). Considering oil spills, it is very important to have in mind that around 80% of all oil spills occur inside the port and harbour (Ball 1999).

2.3. Port authorities

In the previous two subsections, pollution resulting from ships and activities in port terminals were described. Unlike them, the influence of port authorities on total pollution levels consists mainly of activities from people working in the authority and no significant industrial activities are conducted, and the traffic is limited to personal vehicles with which the workers come to work. Also, it was decided to use the same eKPIs for port terminals and port authorities (aside from the storm water and technological wastewater, which were eliminated in port authorities), so the accent would be on the activities contributing to pollution and the eKPIs were described in the previous subsection.

2.3.1. Emissions to the atmosphere

The main source of air pollution in port authorities is the energy consumption used in the workplaces. The energy is used mostly for electricity and heating.

In order to calculate the values of each eKPI, the port would need data on which type of power plant is used for electricity generation and which type of fuel is used for heating. Some emission factors for the calculation of air pollution of power plants can be found in works such as Cai et al. (2012), Czachorski and Leslie (2009), Deru and Torcellini (2007), Trozzi et al. (2019) and Nielsen et al. (2018). Similarly, if something other than electricity is used for heating, emissions to the atmosphere can be calculated using emission factors provided in the works such as in the previously mentioned Trozzi et al. (2019).

To put values into perspective, in Martínez-Moya at al. (2019), electricity consumption was calculated for various types of "consumer centres", including STS cranes, yard lightning, offices and container reefers. Offices contributed only 5.5% of the total electricity consumption. When taking into account both CO_2 emissions resulting from electrical consumption and diesel consumption, offices represented only 1.6% of total emissions. It should be noted that ships were not considered in the study. Although the figure may vary from port to port and from eKPI to eKPI, it is clear that port authorities have a much smaller influence on air pollution that port terminals.

2.3.2. Waste production

Considering the waste production, the only waste category relevant for port authorities in usual situations is the municipal solid waste, which consists of "food wastes, paper, plastic, rags, metal and glass, with some hazardous household wastes such as electric light bulbs, batteries, discarded medicines and automotive parts" (Magutu and Onsongo 2011). This type of waste is, like the waste produced by terminals, represented by two eKPIs – non-hazardous waste and hazardous waste, representatives of which were both listed above.

Since there are no industrial activities conducted by port authorities, those types of waste represent the entirety of waste produced by them. The only possible exception is during the conduction of out of the ordinary activities, such as renovations and construction works during expansion.

2.3.3. Wastewater emissions

There is only one eKPI used to define the negative influence that port authorities have on the environment - sanitary wastewater. It represents wastewater created by usual domestic activities (in this case, the activities of port authority employees). Everything written on the measurement and treatment of this type of wastewater in the terminals also applies to the port authorities.

2.4. All (ships/port terminals/port authorities)

Contrary to the previously described eKPIs, the influence of ships, port terminals and authorities on the following three aspects are extremely complicated to differentiate. Having that in mind, they are described as indicators that represent all those influences (Figure 2.7).

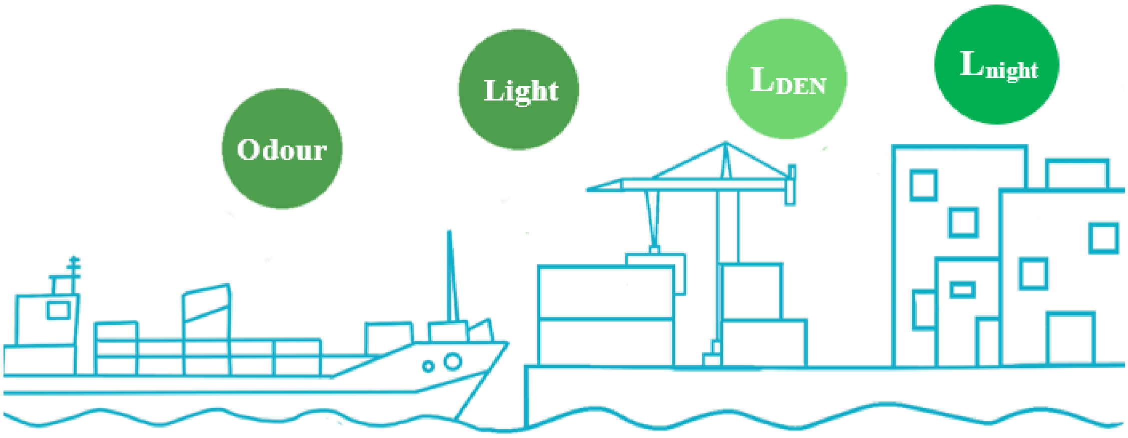


Figure 2.7 eKPIs representing the environmental influence of a whole port

2.4.1. Environmental noise levels

Noise pollution is regularly listed among the most important port environmental aspects. As seen from ESPO (2018), the noise was listed as the third most important environmental priority for years 2016 – 2018. In 2009, it was ranked even higher, as the most important environmental aspect. The first subject was, as previously stated, air pollution and the second one was energy consumption. In the context of the PEI, the latter is considered as a proxy to calculate emissions to the atmosphere and not as a separate environmental aspect. Considering that, noise can be seen as the second most important port environmental aspect. As such, it should be given a great deal of attention.

The main reason for the importance of noise as a major environmental aspect is the fact that ports are usually located near large urban areas (Van Breemen 2008). In Deliverable 5.1, the four pilot ports were asked to rate the significance of different environmental aspects. It was listed as the second most important aspect in three of the ports and as the third most important aspect in the remaining port.

While the previously described environmental aspects are "covered" with many eKPIs, there are only two eKPIs chosen to represent the noise pollution and both are listed in Table 2.5.

Table 2.5 Environmental noise eKPIs

Matrix	*eKPI*	*Description and impact*	*Source/resulting from*
NOISE	L_{DEN}	Day-evening-night noise level	All port activities and ships
NOISE	L_{night}	Night (23:00 – 7:00) noise level	Mainly ships, some port activities

The difference between those two indicators is in the way they are calculated and in the noise sources having a direct influence on them.

In the Deliverable 5.2, the sources were separated into two groups, based on those provided by Van Breemen (2008) and other literature:

- Industrial noise sources
- Traffic noise sources

The industrial noise sources include port services, facilities, terminals, industrial areas, machinery, etc. Additionally, berthed ships are also categorized in this group. Traffic noise can result from road traffic, railways and air traffic, with the first two being relevant for the pilot ports. However, despite the categorization, those two groups are closely related and cannot be treated separately.

It can be assumed that all sources, regardless of the group it belongs, depend on ports' working hours. Indeed, all traffic in the port is either a part of the cargo handling process (trucks coming and exiting ports) or workers' arrival/departure from work (personal cars coming to and exiting ports). As most of the ports do not work during the night, all traffic sources are absent in that period and only a small fraction of industrial noise sources is "active" – berthed ships.

2.4.2. Odour monitoring

Odour pollution differs from all other environmental aspects described here in a way that it does not apply to every port. For example, none of the pilot ports rated it as a significant environmental aspect. Nevertheless, as stated in the deliverable 5.2, it is significant in certain types of ports, such as fish ports (Chirmata and Ichou 2016, Wibowo et al. 2017).

More complete list of possible sources of odour pollution is as follows:

- handling and transforming perishable bulk solids (Peris-Mora et al. 2005)
- MARPOL V waste treatment (Peris-Mora et al. 2005)
- fish handling (Peris-Mora et al. 2005, Paipai 1999)
- odours from water purifiers (Peris-Mora et al. 2005)
- bank disposal when the material has significant organic matter (Paipai 1999, African Development Fund 2008)
- demolition works (the level of odour pollution depends on the previous use of a building) (Paipai 1999)
- handling of chemicals with a bad odour (Paipai 1999)
- loading of bunker oil (Gothenburg Port Authority 2017)
- diesel exhaust caused by the port equipment and ships (Corson and Fisher 2009)
- vapour resulting from liquid bulk transport (Corson and Fisher 2009)
- livestock transportation (McCarthy 2003, Townsville Ocean Terminal 2007)

The list is not meant to be exhaustive, but it should give the reader a clear insight into how complicated odour pollution can be and that it is not simply an issue of "fish ports", but can depend on a significant amount of factors.

There will be only one eKPI describing odour pollution, simply called "odour pollution". The unit for odour pollution is "European odour unit per cubic metre" (ouE/m^3). If odour level is 1 ouE/m^3, it means that 50% of the population can detect the smell ("detection point") (Nicolay 2006). Another characteristic of odour pollution is that, unlike for noise pollution, it is not possible to set one, definitive, threshold above which the pollution is considered to be significant. In Table 2.6 and Table 2.7, hedonic scores and recommended thresholds are provided for some cases, including general odours (given for orientation purposes) and possible odours in ports. Hedonic scores represent how pleasant or unpleasant the odour is ("odour offensiveness"), with the more unpleasant odours requiring lower threshold.

Table 2.6 Hedonic scores for various odours (Environmental Agency 2011, Dravnieks et al. 1984)

Odour	Hedonic score
Bakery (fresh bread)	3.53
Coffee	2.33
Hay	1.31

Raw potato	0.26
Rope (hemp)	-0.16
Kippery-smoked fish	-0.69
Paint	-0.75
Mothballs	-1.25
Disinfectant, fresh tar	-1.60
Fish	-1.98
Wet wool, wet dog	-2.28
Fecal (manure)	-3.36
Sewer odour	-3.68
Cadaverous (dead animals)	-3.75

Table 2.7 Thresholds for hedonic scores (Environment Agency 2011, Carruthers and Kāla 2012)

Odour level	Threshold (ouE/m^3)	Examples
Most offensive odours	1.5	Wastewater treatment, brickworks, oil Refining, decaying animal or fish remains
Moderately offensive odours	3	Sugar beet processing, intensive livestock rearing
Less offensive odours	6	Brewery, chocolate manufacture

While hedonic scores are available in the literature for some odours, they can be determined by survey, such as the one done in Dravnieks et al. (1984). In Table 2.8, some values for perceived intensity are provided.

Table 2.8 Perceived intensities for various hedonic scores (Carruthers and Kāla 2012)

Threshold (ouE/m^3)	Description
1	Point of detection
3	Usual recognition threshold
5	Faint odour
10	Distinct odour

2.4.3. Light monitoring

As stated back in the Deliverable 5.2, light pollution can be defined as "the brightening of the night sky caused by streetlights and other man-made sources that hinder the observation of stars and planets" or "any adverse effect of artificial light" (Elsahragty and Kim 2015). Despite not being recognised as an important environmental aspect by the pilot ports in the Deliverable 5.1, it was nevertheless decided to use it as one of the sub-indexes of the PEI.

In Deliverable 5.2, many sources of light pollution in ports were mentioned. Some of them include light towers, traffic (both sea and land traffic), crane lighting, gate technologies, lights in public areas and many more. Just by looking at these sources, it is pretty clear that it is a similar situation to noise pollution, as it is very hard, if not impossible, to determine the contribution of every single source to the total levels of pollution, hence the inclusion in this section.

Similar to odour pollution, there is only one indicator of light pollution, labelled simply as “light pollution”. The unit of measurement is lux (symbol: lx) and the values can be achieved with the use of relevant sensors, called “light meters” or “lux meters”. Some examples of values are provided in Table 2.9.

Table 2.9 Example of the intensities for various light sources (Bedrosian and Nelson 2017, Schubert 2006)

Light source	Intensity (lux)	Distance
Overcast night sky	0.00003 – 0.0001	At the surface of Earth
Clear starry night	0.001	At the surface of Earth
Full moon	0.1 – 0.3	At surface of Earth
Urban sky glow	0.15	At the surface of Earth
Residential side street	5	Unknown
Lighted parking lot	10	Unknown
Main road street lighting	15	Unknown
ICU step-down unit	1.3 – 47.3	Unknown
Intensive care unit (ICU)	190.5	Unknown
Most homes	30 – 300	Unknown
Office desk lighting	100 – 1000	Unknown
Surgery lighting	10 000	Unknown
Direct sunlight	100 000	At the surface of Earth

As it is pretty hard to determine the human perception of light pollution, those values should provide some orientation.

3. Methods for estimating eKPIs from data sources

Thanks to numerous exchanges with the ports, it was possible to establish a precise list of data available or not which could be included in the calculation of the PEI. The inventory of all the data available by the different port stakeholders (Port Authority, ships and terminals) therefore makes it possible to obtain, by different methods, the numerical values for each of the eKPIs described in the previous chapter. The methods of obtaining as well as the typology of the sources used are described in the following chapters. Two methods are finally employed:

- one based on direct measurements obtained by sensors or other records done on the port,
- and the second one based on proxy data which allow emissions to be estimated by calculation methods or indirect parameters describing port activity and its impact on the environment.

3.1. Direct measurements

3.1.1. Ships

3.1.1.1. Waste production

Regulations for the prevention of pollution by garbage from ships are contained in Annex V of MARPOL. MARPOL Annex V seeks to eliminate and reduce the amount of garbage being discharged into the sea from ships. All ships of 100 gross tonnage and above, every ship certified to carry 15 persons or more, and every fixed or floating platform must carry a garbage management plan on board, which includes written procedures for minimizing, collecting, storing, processing and disposing of garbage. And all ships of 400 gross tonnage and above and every ship which is certified to carry 15 persons must provide a Garbage Record Book to record all disposal and incineration operations. The date, time, position of the ship, description of the garbage and the estimated amount incinerated or discharged must be logged and signed. The Garbage Record Book must be kept for a period of two years after the date of the last entry.

Estimation of each eKPIs mentioned in the previous chapters can be done by summing all data recorded by MARPOL categories (Table 3.1) for all ships arriving at the port for a period.

Table 3.1 Estimation of eKPIs for the generation of waste by ships

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
SHIPS	S.06	Plastics	Plastics wasted by ships	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.07	Food waste	Food wasted by ship crew and passengers	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.08	Domestic waste	Domestic waste created by ship crew and passengers	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.09	Cooking oil	Cooking oil used by the ship crew and passengers	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.10	Incinerator ashes	Incinerator ashes created	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.11	Operational waste	Waste created during maintenance or ship operations	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.12	Animal carcass(es)	Self-explanatory	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.13	Fishing gear	Self-explanatory	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.14	E-waste	Electronic waste (from electronic devices)	waste	kg or tonnes	Sum per vessels and by MARPOL convention category

	S.15	Cargo residues (harmful)	Self-explanatory	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.16	Cargo residues (non-harmful)	Self-explanatory	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.17	Passively fished waste	Waste caught in the next during fishing	waste	kg or tonnes	Sum per vessels and by MARPOL convention category
	S.18	other substances	All waste not covered with other categories	waste	kg or tonnes	Sum per vessels and by MARPOL convention category

3.1.1.2. Wastewater emissions

As with waste from ships, the management of used discharges from ships is regulated by the Annex IV of MARPOL convention. This appendix indicates the different types of discharges that can be generated and unloaded at the port by vessels. Annex IV to the International Convention for the Prevention of Marine Pollution from Ships contains a series of rules related to the discharge at sea of sewage from ships, in particular rules concerning on-board equipment and discharge control systems of wastewater, the establishment of reception facilities for wastewater in ports, and prescriptions relating to inspections and the issue of certificates.

The Annex requires that ships be fitted with either an approved wastewater treatment facility, a grinding and disinfection system, or a storage tank.

This annex contains requirements to prevent pollution to the sea by waste water: discharge of waste water into the sea is prohibited, except when the ship uses an approved waste water treatment plant or discharges waste water, after grinding and disinfection using an approved device, more than three nautical miles from the nearest land.

Untreated and non-disinfected wastewater must be discharged at a distance of more than 12 nautical miles from the nearest land because it is generally considered that on the high seas, the action of microorganisms makes it possible to assimilate and neutralize untreated wastewater.

So, regulations allow ships to unload part of their wastewater supply at sea under certain conditions of treatment and distance to the coast. And finally, sewage reception facilities at ports and terminals are not often used. The values included in the PEI calculation will therefore only be based on discharges from ships, which are either collected at the port or rejected within the port.

For more convenience, the eKPIs are based on the different categories of releases from the MARPOL convention as shown in the previous chapter. **For each of them, the value can be obtained by adding all the discharges done by vessels over a period.** Indeed, these data are collected by the ports when the latter is equipped with collection system for these discharges.

For example, none of the data presented in Table 3.2 is currently available on the different ports included in the PIXEL project, requiring the use of data imputation algorithms, as presented in section 4.4

Table 3.2 Estimation of eKPIs for the generation of wastewater by ships

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
SHIPS	S.19	Oily bilge water	Water accumulated in the bilge	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.20	Oily residues (sludge)	mixture of oily residues created by ships	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.21	Oily tank washings	Washing out the residue using crude oil	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.22	Dirty ballast water	Seawater pumped in fuel tanks for ship stability	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.23	Scale and sludge from tank cleaning	Self-explanatory	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.24	Other - oil	Oil substances not covered above	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.25	Noxious liquid substances (NLS) - type X	Present major hazard to marine resources or human health, prohibited from discharging	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.26	NLS - type Y	Present hazard to marine resources or human health, limited discharging allowed	wastewater	m^3	Sum per vessels and by MARPOL convention category

	S.27	NLS - type Z	Minor hazard to marine resources or human health, more discharging allowed	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.28	NLS - other	No harm to marine resources or human health	wastewater	m^3	Sum per vessels and by MARPOL convention category
	S.29	Sewage	Domestic wastewater created by crew and passengers	wastewater	m^3	Sum per vessels and by MARPOL convention category

3.1.2. Port terminals

3.1.2.1. Waste production

To consider the quantity of waste produced by port terminals, waste amount produced values are needed. The production of waste by the ports can be declined in different typologies based on the environmental and health impacts of waste, and their mode of management more or less constrained:

- hazardous waste is a waste with properties that makes it dangerous or capable of having a harmful effect on human health or the environment: The annex III of the Waste Framework Directive gives a definition of hazardous waste as a waste that displays one or more of the fifteen hazardous properties listed
- non-hazardous waste

Waste designated as hazardous based on Commission notice on technical guidance on the classification of waste (2018/C 124/01) triggered a number of important obligations, for instance on labelling and packaging but also in terms of monitoring and treatment. The volume or weight data can, therefore, be extracted from the waste management plan for the ports in tons or in cube meters.

This data cannot be obtained by sensors or automatically, but ports keeps manual registers with records of this values each month. Each value of the two eKPIs for waste production by terminals have to be fulfilled in a specific interface, and the **eKPIs are obtained by summing the total amount of waste produced by port terminals for a period**.

Table 3.3 Estimation of eKPIs for the generation of waste by port terminals

	ID	*eKPI name*	*eKPI description*	*subindex*	*units*	*Calculation from data sources*
TERMINALS	T.13	Non hazardous waste	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes	provided by the terminals/port authorities and summed for a period
	T.14	Hazardous waste	Waste hazardous for public health or environment	waste	kg or tonnes	provided by the terminals/port authorities and summed for a period

3.1.2.2. Wastewater emissions

To obtain each specific value for wastewater produced by the terminals, a distinction is made between different categories generated. For all of them, data are available but not automatically, and values are filled periodically by ports (Table 3.4). Each **eKPIs values can be obtained by summing the total amount of wastewater emission produced by port terminals for a period.** The issue of storm water has to be addressed having in mind the general precipitation in the port area.

Table 3.4 Estimation of eKPIs for the generation of wastewater by port terminals

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
TERMINALS	T.10	Sanitary wastewater	Wastewater created by usual domestic activities	wastewater	m^3	provided by the terminals/port authorities and summed for a period
	T.11	Technological wastewater	Wastewater created by industry and ship maintenance	wastewater	m^3	provided by the terminals/port authorities and summed for a period
	T.12	Storm water	Water resulting from rain, snow, etc.	wastewater	m^3	provided by the terminals/port authorities and summed for a period

3.1.3. Port authorities

3.1.3.1. Waste production

The quantities of waste produced by the port authorities will be obtained in the same way as for the terminals. The data cannot be obtained automatically but will be transmitted by the port authorities periodically.

The values of the different eKPIs be obtained by summing the total quantities of waste by category and over a given period.

Table 3.5 Estimation of eKPIs for the generation of waste by port terminals

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
TERMINALS	T.13	Non hazardous waste	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes	provided by the terminals/port authorities and summed for a period
	T.14	Hazardous waste	Waste hazardous for public health or environment	waste	kg or tonnes	provided by the terminals/port authorities and summed for a period

3.1.3.2. Wastewater emissions

The quantities of wastewater produced by the port authorities will be obtained in the same way as for the terminals. The data cannot be obtained automatically but will be transmitted by the port authorities periodically.

The values of the different eKPIs will be obtained be obtained by summing the total quantities of wastewaters emitted by category and over a given period.

Table 3.6 Estimation eKPIs for the generation of wastewater by port terminals

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
PORT AUTHORITIES	P.10	Sanitary wastewater	Wastewater created by usual domestic activities	wastewater	m3	provided by the terminals/port authorities and summed for a period

3.1.4. All (ships/port terminals/port authorities)

3.1.4.1. Environmental noise levels

For these data, as advanced in section 2, the use of sensors is possible and recommended. Research on the sensor market shows that sensors can be quickly deployed and used to collect port data by systems.

The eKPIs will therefore be obtained thanks to the automatic collection of data from the sensors. The data collection being continuous over a different time step according to the typology of sensors. This large amount of data will have to be subject to quality control to avoid any aberrant measurement or drift of sensors. Once this control processing has been carried out, the data may be used in the calculation of the eKPI.

The values of each eKPI (L_{DEN} and L_{night}) will have to be calculated over a precise period.

Table 3.7 Estimation of eKPIs for noise pollution

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
ALL	A.01	Noise pollution (Lden)	Noise levels calculated from day, evening and night levels	noise	dB	Raw data provided by sensors, and calculation of L_{DEN} indicator
	A.02	Noise pollution (Lnight)	Noise levels during the night	noise	dB	Raw data provided by sensors, and calculation of L_{night} indicator

The L_{DEN} is a global indicator harmonized on a European scale (Directive 2002/49/EC relating to the assessment and management of environmental noise) which takes into account the fact that noise is perceived as more disturbing at night than during the day. This indicator is calculated with equivalent sound levels over the three basic periods: day, evening and night, to which major corrective terms are applied, taking into account a criterion of increased sensitivity depending on the period. Thus, 5 dB (A) is added in the evening and 10 dB (A) at night.

This indicator therefore requires the calculation of:

- the noise level over the day (L_{day}) which is an average of the measurements carried out on the time slot between 07.00 to 19.00 (twelve hours);
- the noise level on the evening ($L_{evening}$) which is an average of the measurements carried out on the time slot between 19.00 to 23.00 (four hours);
- and the noise level of the night (L_{night}) which is an average of the measurements carried out on the time slot between 23.00 to 07.00 (eight hours).

The day-evening-night level L_{DEN} in decibels (dB) is defined by the following formula available in the Annex I of the Environmental Noise Directive (END):

Indicator L_{DEN} is calculated using the following formula (Kephalopoulos et al. 2012):

$$L_{DEN} = 10 \cdot \log\left[\frac{12}{24} \cdot 10^{\frac{L_{day}}{10}} + \frac{4}{24} \cdot 10^{\frac{L_{evening}+5}{10}} + \frac{8}{24} \cdot 10^{\frac{L_{night}+10}{10}}\right],$$

where:

L_{day} – A-weighted noise level during the day (7:00-19:00) (dB (A))

$L_{evening}$ – A-weighted noise level during the evening (19:00-23:00) (dB (A))

L_{night} – A-weighted noise level during the night (23:00-7:00) (dB (A))

The END indicate that these indicators are relevant for a period of a year.

3.1.4.2. Odour monitoring

The odour nuisance assessment is now integrated into the PEI calculation. Although this aspect is not always cited as a problem by ports, the new sensors available on the market would make it possible to carry out a global monitoring on noise, odours and light. Odour tracking was therefore integrated into the PEI using an eKPI. The value of this eKPI can be obtained directly with directs measurements done by sensors.

Table 3.8 Estimation of eKPIs for odour monitoring

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
ALL	A.03	Odour	VOCs detection	odour	ppb	Raw data collected by sensors and average values over a period

The European Standard for olfactometry, EN13725, was published in 2003, specifies a method for the objective determination of the odour concentration of a gaseous sample using dynamic olfactometry with human assessors and the emission rate of odours emanating from point sources, area sources with outward flow and area sources without outward flow. The primary application is to provide a common basis for evaluation of odour emissions in the member states of the European Union. The unit is European Odor Unit (ouE) normally associated at a masse measurement (m^3). But this methodology is not well addressed for the PIXEL projects issues.

The sensor station selected for PEI/PIXEL purposes have a metal oxide gas sensor for the detection of Volatile Organic compounds only. It gives a volatile compounds concentration in ppm per m^3. This instrumental odour monitoring gives no information about odour intensity. However, conversions can be carried out by typology of molecules with conversion factors between olfactometry, and concentrations in the air.

As for the noise data, this large amount of data will have to be subject to quality control to avoid any aberrant measurements or drift of sensors. Once this control processing has been carried out, the data may be used in the calculation of the eKPI.

The eKPI value will be obtained by taking an average of the values obtained during a given time step for the PEI calculation.

3.1.4.3. Light pollution

Light pollution can be assessed through the implementation of direct measurements on the port. The envisaged sensors will make it possible to obtain luminescence data expressed in Lux. These data collected continuously by the sensors will provide a reference value for the eKPI on the light. As for the noise and odour data, this large amount of data will have to be subject to quality control to avoid any aberrant measurements or drift of sensors. Once this control processing has been carried out, the data may be used in the calculation of the eKPI.

This value can be obtained by averaging the values obtained over a period fixed for the PEI calculation.

Table 3.9 Summary of the calculation of eKPIs for odour monitoring

	ID	eKPI name	eKPI description	subindex	units	Calculation from data sources
ALL	A.04	Light pollution	Self-explanatory	light pollution	lx	Raw data collected by sensors and average values over a period

3.2. Proxy data -Emissions to the atmosphere and energy consumption

3.2.1. Ship emissions

The methodology for estimation emission from ships is an activity-based approach. It involves the application of emission factors to a particular ship activity. After a vessel enters the port the following steps need to be taken for quantifying air emissions:

1. Register a ship enering the port
2. Categorize ship by type, engine type/ fuel class

3. Obtain the engine specifications
4. Obtain the appropriate emission factor for each pollutant eKPI, the emission factors will be selected by engine type/fuel class, based on the values provided in Table 3.10 (auxiliary engines) and Table 3.11 (main engines)

Table 3.10 Emission factors for auxiliary engines using HFO with 2.7% sulphur content, g/kWh (GEF-UNDP-IMO GloMEEP 2018)

Engine category	***Model year range***	***NO_x***	***PM_{10}***	***$PM_{2.5}$***	***SO_2***	***HC***	***CO***	***CO_2***	***N_2O***	***CH_4***
Medium speed auxiliary (Tier 0)	1999 and older	14.7	1.44	1.35	11.98	0.4	1.1	722	0.03	0.01
Medium speed auxiliary (Tier I)	2000 to 2010	13.0	1.44	1.35	11.98	0.4	1.1	722	0.03	0.01
Medium speed auxiliary (Tier II)	2011 to 2016	11.2	1.44	1.35	11.98	0.4	1.1	722	0.03	0.01
Medium speed auxiliary (Tier III)	2016+	2.8	1.44	1.35	11.98	0.4	1.1	722	0.03	0.01
High speed auxiliary (Tier 0)	1999 and older	11.6	1.44	1.35	11.98	0.4	0.9	690	0.03	0.01
High speed auxiliary (Tier I)	2000 to 2010	10.4	1.44	1.35	11.98	0.4	0.9	690	0.03	0.01
High speed auxiliary (Tier II)	2011 to 2016	8.2	1.44	1.35	11.98	0.4	0.9	690	0.03	0.01
High speed auxiliary (Tier III)	2016+	2.1	1.44	1.35	11.98	0.4	0.9	690	0.03	0.01

Table 3.11 Emission factors for auxiliary engines using HFO with 2.7% sulphur content, g/kWh (GEF-UNDP-IMO GloMEEP 2018)

Engine category	***Model year range***	***NO_x***	***PM_{10}***	***$PM_{2.5}$***	***SO_2***	***HC***	***CO***	***CO_2***	***N_2O***	***CH_4***
Slow speed main (Tier 0)	1999 and older	18.1	1.42	1.34	10.29	0.6	1.4	620	0.03	0.01
Slow speed main (Tier I)	2000 to 2010	17.0	1.42	1.34	10.29	0.6	1.4	620	0.03	0.01
Slow speed main (Tier II)	2011 to 2016	15.3	1.42	1.34	10.29	0.6	1.4	620	0.03	0.01
Slow speed main (Tier III)	2016+	3.6	1.42	1.34	10.29	0.6	1.4	620	0.03	0.01
Medium speed main (Tier 0)	1999 and older	14.0	1.43	1.34	11.35	0.5	1.1	683	0.03	0.01
Medium speed main (Tier I)	2000 to 2010	13.0	1.43	1.34	11.35	0.5	1.1	683	0.03	0.01
Medium speed main (Tier II)	2011 to 2016	11.2	1.43	1.34	11.35	0.5	1.1	683	0.03	0.01
Medium speed main (Tier III)	2016+	2.8	1.43	1.34	11.35	0.5	1.1	683	0.03	0.01

Gas turbine	All	6.1	0.06	0.06	16.10	0.1	0.2	970	0.08	0.00
Steam main engine and boiler	All	2.1	0.93	0.87	16.10	0.1	0.2	970	0.08	0.00

5. Obtain the loading factor for the main and auxiliary engine (we provide this database from the literature, as shown in Table 3.12)

Table 3.12 Engine load factors for ship activities (Whall et al. 2002)

Activity	*Summer engine load factors*				*Rest of year load factors*			
	Cruise ships		*Coastal passenger ships*		*Cruise ships*		*Coastal passenger ships*	
	ME	*AE*	*ME*	*AE*	*ME*	*AE*	*ME*	*AE*
Manoeuvring	0.20	0.75	0.20	0.75	0.20	0.60	0.20	0.60
At berth	0.00	0.60	0.00	0.45	0.00	0.40	0.00	0.30

6. Determine total hotelling and maneuvering time for each ship category and engine type/fuel class

7. Calculate the ship' s emissions from with the gathered data from the **steps 2-6** using the following equation:

$$E_M = T_M \times [(ME \times LF_{ME,M} \times EF_{ME})] + [(AE \times LF_{AE,M} \times EF_{AE})] \times 10^{-6}$$

And:

$$E_B = T_M \times [(ME \times LF_{ME,B} \times EF_{ME})] + [(AE \times LF_{AE,B} \times EF_{AE})] \times 10^{-6}$$

Where:

E_M and E_B = ship emission during manoeuvring or at berth receptively [tons]

T_M and T_B = time spent manoeuvring and a at berth [h]

ME and *AE* = main engine MCR power and auxiliary engine MCR power [kW]

$LF_{ME, M}$ and $LF_{ME, B}$ = Load factor of main engine in manoeuvring or at berth, respectively

$LF_{AE, M}$ *and* $LF_{AE, B}$ = Load factor of auxiliary engine in manoeuvring or at berth, respectively

EF_{ME} and EF_{AE} = Emission factor of main and auxiliary engine and for each of the emitted species (g kWh^{-1}).

calculate ships emissions:

$$E_T = \sum E_i = E_M + E_B$$

To do build an emissions inventory some key data is needed. More often than not this data is not readily available, and many approximations need to be done.

The main data needed for calculating ship missions are:

- Engine and fuel type
- Main engine and auxiliary engine power
- Emission factors
- Manoeuvring and berthing time

3.2.1.1. Engine and fuel type

The knowledge of the vessel's engine and fuel type is needed for calculating the MA and AE data. If this is not available, the engine type can be approximated based on the vessel's category.

Table 3.13 Engine and fuel type approximations based on ship categories (Trozzi and De Lauretis 2019)

Ship category	SSD MDO /MGO	SSD BFO	MSD MDO /MGO	MSD BFO	HSD MDO /MGO	HSD BFO	GT MDO /MGO	GT BFO	ST MDO /MGO	ST BFO
Liquid bulk ships	0.87	74.08	3.17	20.47	0.52	0.75	0.00	0.14	0.00	0.00
Dry bulk ships	0.37	91.63	0.63	7.29	0.06	0.02	0.00	0.00	0.00	0.00
Container	1.23	92.98	0.11	5.56	0.03	0.09	0.00	0.00	0.00	0.00
General cargo	0.36	44.59	8.48	41.71	4.30	0.45	0.00	0.10	0.00	0.00
Ro Ro cargo	0.17	20.09	9.86	59.82	5.57	2.23	2.27	0.00	0.00	0.00
Passenger	0.00	3.81	5.58	76.98	3.68	1.76	4.79	3.29	0.00	0.02
Fishing	0.00	0.00	84.42	3.82	11.76	0.00	0.00	0.00	0.00	0.00
Others	0.48	30.14	29.54	19.63	16.67	2.96	0.38	0.20	0.00	0.00
Tugs	0.00	0.00	39.99	6.14	52.80	0.78	0.28	0.00	0.00	0.00

Where:

GS – Gas turbine

SS – Speed turbine

SSD – slow speed diesel engine

MSD – middle speed diesel engine

HSD – high speed diesel engine

BFO – bunker fuel oil

MDO – marine diesel oil

MGO – marine gas oil

GS – Gas turbine

3.2.1.2. ME and AE Engine power

Main engine data is easier to obtain than auxiliary. It may be available in ship calls or trackable through the vessel's IMO number. If not, approximations based on vessel type are available to fill the missing data (Table 3.14).

Table 3.14 Main engine power estimation based on the ship category (Trozzi and De Lauretis 2019)

Ship category	Main engine power	
	1997 fleet	2010 fleet
Liquid bulk ships	6.695	6.543
Dry bulk ships	8,032	4,397

Container	22.929	14.871
General cargo	2.657	2.555
Ro Ro cargo	7.898	4.194
Passenger	3.885	10.196
Fishing	837	734
Others	2.778	2.469
Tugs	2.059	2.033

The main engine's power can be calculated with the installed engine power as a function of gross tonnage (Table 3.15)

Table 3.15 Approximated main engines power based on the vessel's gross tonnage (Trozzi and De Lauretis 2019)

Ship categories	2010 world fleet	1997 world fleet	Mediterranean Sea fleet (2006)
Liquid bulk ships	14.755*GT0.6082	29.821*GT0.5552	14.602*GT0.6278
Dry bulk carriers	35.912*GT0.5276	89.571*GT0.4446	47.115*GT0.504
Container	2.9165*GT0.8719	1.3284*GT0.9303	1.0839*GT0.9617
General Cargo	5.56482*GT0.7425	10.539*GT0.6760	1.2763*GT0.9154
Ro Ro Cargo	164.578*GT0.4350	35.93*GT0.5885	45.7*GT0.5237
Passenger	9.55078*GT0.7570	1.39129*GT0.9222	42.966*GT0.6035
Fishing	9.75891*GT0.7527	10.259*GT0.6919	24.222*GT0.5916
Other	59.049*GT0.5485	44.324*GT0.5300	183.18*GT0.4028
Tugs	54.2171*GT0.6420	27.303*GT0.7014	

Reliable auxiliary engine data is a very hard finding. Even with paid subscriptions, it is often incomplete. To bypass this obstacle, auxiliary engine power can be approximated with the help of the main engine power and vessel type (Table 3.16).

Table 3.16 Average ratio of Auxiliary engine/ main engine by ship type (Trozzi and De Lauretis 2019)

Ship category	1997 fleet	2010 fleet
Liquid bulk ships	0.30	0.35
Dry bulk ships	0.30	0.39
Container	0.25	0.27
General cargo	0.23	0.35
Ro Ro cargo	0.24	0.39
Passenger	0.16	0.27
Fishing	0.39	0.47
Others	0.35	0.18
Tugs	0.10	

Both ME and AE information show only the Maximum continuous rating of the engines which does not picture the real data. To correct that Load factors for the main engine based on the ships' mode are introduced into the emissions quantification equation (Table 3.17).

Table 3.17 Estimated % load of MCR of Main and Auxiliary during different ship activities (Trozzi and De Lauretis 2019)

Phase	*% load of MCR Main Engine*	*% time all Main Engine operating*	*% load of MCR Auxiliary Engine*
Cruise	80	100	30
Manoeuvring	20	100	50
Hotelling (except tankers)	20	5	40
Hotelling (tankers)	20	100	60

3.2.1.3. Emission factors

Emission factors are the key part in calculating emissions from a source as they are needed for translating the used power into emissions (mass). They are usually based on the type of fuel used in the engines. Some factors (e.g. SO_2) depend on the fuel quality and it may vary from batch to batch. The main pollutants, in the case of PEI also called eKPIs, needed for building for a ship emission inventory are shown in Table 3.18.

Table 3.18 Emission factor for the chosen eKPIs (Trozzi and De Lauretis 2019)

Eng	*Phase*	*Fuel type*	*Eng type*	*Nox EF 2000 [g/kWh]*	*Nox EF 2005 [g/kWh]*	*Nox EF 2010 [g/kWh]*	*NMVOC EF [g/kWh]*	*TSP PM10 PM2.5 EF [g/kWh]*	*Specific fuel consumption [g fuel/kWh]*
ME	Cruise	GT	BFO	6.1	5.9	5.7	0.1	0.1	305.0
			MDO/ MGO	5.7	5.5	5.3	0.1	0.0	290.0
		HSD	BFO	12.7	12.3	11.8	0.2	0.8	213.0
			MDO/ MGO	12.0	11.6	11.2	0.2	0.3	203.0
		MSD	BFO	14.0	13.5	13.0	0.5	0.8	213.0
			MDO/ MGO	13.2	12.8	12.3	0.5	0.3	203.0
		SSD	BFO	18.1	17.5	16.9	0.6	1.7	195.0
			MDO/ MGO	17.0	16.4	15.8	0.6	0.3	185.0
		ST	BFO	2.1	2.0	2.0	0.1	0.8	305.0
			MDO/ MGO	2.0	1.9	1.9	0.1	0.3	290.0
	Manoeuvring Hotelling	GT	BFO	3.1	3.0	2.9	0.5	1.5	336.0
			MDO/ MGO	2.9	2.8	2.7	0.5	0.5	319.0
		HSD	BFO	10.2	9.9	9.5	0.6	0.9	234.0
			MDO/ MGO	9.6	9.3	8.9	0.6	0.9	223.0
		MSD	BFO	11.2	10.8	10.4	1.5	0.9	223.0
			MDO/ MGO	10.6	10.2	9.9	1.5	0.9	223,0
		SSD	BFO	14.5	14.0	13.5	1.8	2.4	215.0

			MDO/ MGO	13.6	13.1	12.7	1.8	0.9	204.0
		ST	BFO	1.7	1.6	1.6	0.3	2.4	336.0
			MDO/ MGO	1.6	1.6	1.5	0.3	0.9	319.0
AE	Cruise Manoeuvring Hotelling	HSD	BFO	11.6	11.2	10.8	0.4	0.8	227.0
			MDO/ MGO	10.9	10.5	10.2	0.4	0.3	217.0
		MSD	BFO	14.7	14.2	13.7	0.4	0.8	227.0
			MDO/ MGO	13.9	13.5	13.0	0.4	0.3	217.0

Emission factors like SO_2 can be calculated with the following equation:

$$SO_2\left(\frac{g}{kWh}\right) = 20 * S\left(\frac{kg}{tonne}fuel\right) * sfc * 0{,}00{,}1$$

Where:

S- sulphur content in fuel

Sfc- specific fuel consumption

3.2.1.4. Berthing and manoeuvring time

Berthing and manoeuvring time can be derived from a GIS system if one is available in the port. Another way is documenting when the vessel enters the port territory and subtracting it from when its berths. The same rule principle applies when the vessel leaves the port. As with most of the other data, for manoeuvring and berthing time, there are available approximations (Table 3.19).

Table 3.19 Approximated ship activity durations based on ship category (Trozzi and De Lauretis 2019)

Ship category	Ave.Cruise Speed (km/h)	Manoeuvring time (hours)	Hotelling time (hours)
Liquid bulk ships	26	1.0	38
Dry bulk ships	26	1.0	52
Container	36	1.0	14
General cargo	23	1.0	39
Ro Ro cargo	27	1.0	15
Passanger	39	0.8	14
Fishing	25	0,7	60
Others	20	1.0	27

3.2.1.5. Manoeuvring and berthing time-AIS

When all the other data is collected, the precise time that vessels spend in manoeuvring and berthing (hotelling) has to be obtained for the calculation of ship air emissions. For that purpose, a GIS system installed in the ports is very useful, such as the Automatic Identification System (AIS). AIS is an automatic tracking system that tracks the ships' position and movement via the installed GIS system or with the help of an internal sensor built into an AIS unit onboard. Apart from the location information, AIS collects data like the vessel name, the MMSI number (Maritime Mobile Service Identity), destination and cargo type. If a GIS system is not available at the port the needed manoeuvring/berthing data can be calculated otherwise: the proposed approach is to use the time stamps for entering/exiting the port area and the time at berth to calculate the different operation modes of the vessel inside the port.

3.2.1.6. Vessels characteristics from external private providers

One of the biggest obstacles in gathering data for the PEI calculations is the availability of vessel characteristics. Such data can be obtained from private providers like Lloyds Register, Vesseltracker or Fleetmon. Data for these subscriptions include vessel main engine characteristics, type of cargo, type of vessel and type of fuel used. In most of the case, the data on auxiliary engines is not provided and it has to be approximated.

3.2.2. Terminal emissions and energy consumption- Port Activity Scenario

The Port Activities Scenario (PAS), combined with the energy model and emission factors, is a transferable and applicable tool for small and medium European ports that allows to model port supply chains. This model is explained in detail in Deliverable 4.2. The output of this model can be used as an input for evaluating the energy consumption and (with the use of emissions factors) to provide an estimation of pollutants emissions. A specific composition of cargo's transition operations (involving different machines, work shifts and operators) is called supply chain. Port activities or port operations involve: loading and unloading of cargo to and from ships; transfer of cargo inside the port (docks, storage areas, gates) and supportive operations (warehouses and docks lighting, reefer areas energy supply, etc.).

The modelling of supply chains applying to different cargo types can help to correctly identify the energy sources involved, the types of equipment used, the sources of pollution and the frequency with which these cargoes enter and leave the port. The previous helps to build emission inventories that catalogue the various port-related emissions sources and their activities, translate those activities into energy consumption levels and then translate energy consumption into emissions.

The Port Activity Scenario (PAS) model back casts and forecasts energy consumption of ports based on the ports supply chain, vessel calls and activities. PAS is an automated tool which by-passes traditional data collection procedures and can provide energy consumption estimation close to real-time. In port activities, cargoes are considered to be functional unit as activities are connected to incoming or outgoing cargoes. For that reason, input data are based on: vessel planning (arrival date, cargo type and tonnage), activity data (details related to the transition of a cargo), operational data (refer to the technical specifications of engines and equipment used) and emission source data (related to emissions factors of engine and equipment). Every cargo that is transhipped in the port has its own sequence of operations happening in given time and these time series are used as an input for the PAS model. A hypothetical combination of those transition operations can be seen as a scenario that can be designed by port operators and the end-users of modelling and data analysis tools.

With this approach it is possible to evaluate scenarios according to optimization metrics. For each of these operations in sequence of duration, the machine’s energy type and their unit consumption values are available, which makes it possible to calculate the energy cost and to get total consumption by summing all the operations. In the PAS model, four main data types are used: activity, cargo, area and machine (equipment).

Activity data considers all the details about the transition of a cargo such as duration of the operation, type of machine used, distance travelled, etc.

Operational data/Machine specification considers all the machinery and equipment used in the supply chain and its technical specifications such as the type of energy used, the consumption according to the mode of operation, the status of the machine, its operating limitations, etc.

Emission source data / Emissions factors data is based on emission factors that translate the consumption of energy into quantity of pollutants emitted. For each machine, engines or other sources used in the transition of a cargo, the sources of emissions are linked to it.

Vessel planning data includes all vessels arriving in the port with the type of cargo, the tonnage, their expected date of arrival and departure. This makes it possible to predict flow rate for each type of cargo.

Important data are also vessel calls which gives the specific time for handling of the specified amount of cargo. Input for this data contains information like ship's name and IMO number, the ship's estimated time of arrival and departure to the port and to a specific dock, the category or type of cargo that will be unloaded and/or loaded and the stakeholders related to that operation. This data comes from the vessels' call list and by the FAL forms. The output information contains the data about port activities that will take place for the handling of the cargo of the input.

Area data can be generic or more detailed depending on the level of detail required by the user (port). More detailed examples would include for example, describing only one area per use, i.e. pier for cereals carrying ships, pier for container ships, etc., liquid cargo storage area, container storage area, etc. and generic describing only one shore / ship unloading area and one warehousing area.

Collection of the data

All the data contains the information related to physical items used for operational port activities. The sources of this kind of data are usually port's inventories, meaning the port itself: equipment manuals and brochures and areas descriptions can be provided mainly by the Facilities Management and logistics chains, stakeholders mapping, cargo cataloguing, and port operations rules can be provided mainly by the Operations Management. Data such as emissions factors or machinery emissions can be obtained from relevant literature (GloMEEP) or from databases.

Usage of PAS for the PEI calculation

Apart from the above explained functioning of the PAS, what is most interesting on the scope of this deliverable is how can it be used to help calculate the PEI in an automated fashion. As commented, the PAS model can be executed in the context of a port if certain input data is granted: vessel calls (vessels to arrive/depart to/from the port), area specifications, work shift specifications, supply chain description and rules.

Assuming that one port has installed enough infrastructure for collecting the data and has incorporated the needed specifications, a scheduled execution of the PAS can be set. Considering that, for example, the PAS can be run periodically each week, certain valuable data can be used towards the PEI. According to the PAS nature, for a specific timeframe, if all pre-conditions are met, results can be stored in a database (in the PIXEL architecture, the Information Hub – IH). This way, a PIXEL user may have weekly information about the energy consumed in that week associated to each vessel operated in the port, a time that the vessel has been operated and other relevant information such as which machinery was used (including the type of fuel/power) with a reasonable accuracy basis.

Thus, the PEI can hugely benefit from those data stored in a reachable database. Following the previous, the usefulness of the PAS for the PEI can be understood two-fold:

- Providing information on the **berthing time.** Ideally, a port will provide the values of the time a vessel is being berthed, hoteling and manoeuvring within port maritime area. In a lesser-preferred scenario, AIS data can be used and processed to infer those time durations. However, there will very often be cases in which the port is not able to provide any of the previous. For those situations, the PAS outputs can be used to obtain a (approximated) value of how much time is a vessel operated (loaded/unloaded), which can be considered a basis for the berthing/manoeuvring ratio.

- Providing information of **energy consumption of the terminal to calculate air emissions.** Energy consumption is, usually, a complex metric to quantify, in contrast of what logical thinking would indicate. PAS output allows to know, with a simulation perspective, the total amount of energy consumed by the machinery needed to operate one vessel. Using that information, altogether with the type of fuel/power used, can be leveraged by the PEI to estimate the air emissions attributable to the terminal activity in a period of time.

Regarding the materialization, the technology for getting it done should be easily implemented. The flexibility of the PIXEL architecture allows a seamless interaction of both models (PAS and PEI). Additionally, the dual structure of processing for computing the PEI is prepared for such interaction.

Section 5 digs deeper into the details of the technological composition of the PEI. However, in order to ease readability, it should be enough to understand the big picture. PEI has two clearly differentiated "data processing spots". Meaning that, in a simplified way, raw data comes from the left block in Figure 3.1, it is converted into eKPIs through the NGSI agents (Data Acquisition Layer in PIXEL stack), it is stored and then it is retrieved from the PEI mathematical model to obtain the subindices and a final single metric.

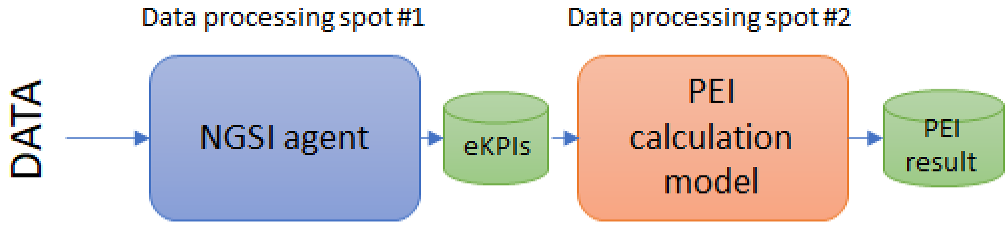


Figure 3.1 PEI Data processing

When introducing the PAS, the concepts remain the same and the technology adapts in favour of usefulness. In particular, as it is illustrated in Figure 3.2, a new NGSI agent must be developed to: (i) read the PAS results from the storage database as if they were raw data inputs, (ii) apply advanced conversions – processing – such as the mapping with emission factor literature tables, reference to normalized cargo, etc., (iii) convert those data into eKPIs, using the agreed JSON formats and (iv) storing the results (again) in the Information Hub database, in this case prepared to be consumed by the PEI calculation model.

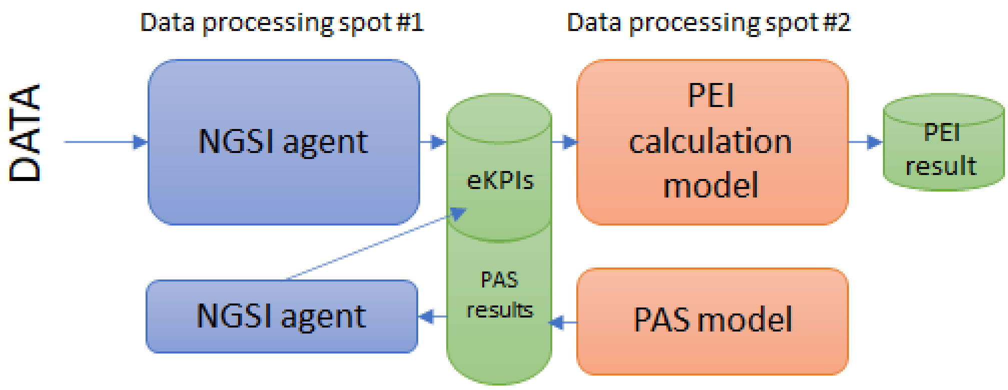


Figure 3.2 Data processing including PAS

4. Statistical analysis of the indicators

In this section, a brief description about the data collected from the ThPA use case is given as example. The data analysis will be better addressed in WP7 when all eKPIs from all ports will be fully available. In this deliverable, first insights observed from the ThPA data related to ships are provided. The data structure is explained and the way the eKPIs are calculated and obtained can have a huge impact on the PEI values.

Then, the impact of the different methods to build a composite indicator on the final PEI values is studied. As described in deliverable D5.2, different methods can be applied for normalization of eKPIs, weighting and aggregation of sub-indexes in order to calculate PEI values. These methods have a direct impact on the way the PEI is understandable and explainable. To do so, a mock-up database composed of six different ports is built. The objective here is to give clear answers on how the different methods impact the final PEI values, give some recommendations and guidance for the PEI algorithms and its analysis.

Finally, a simple uncertainty propagation analysis is provided in order to show how the PEI values evolves when uncertainty on eKPIs values is considered.

4.1. Descriptive statistics of the data

In the following subsection, a brief data analysis on the eKPIs related to ships that have been obtained and calculated for ThPA is provided. Since all eKPIs values will be gathered as part of the WP7 for the four ports of the PIXEL project, it is not yet possible to give a full data analysis for the whole eKPIs database. The main analysis that can be provided, based on this data set, is to perform a correlation analysis of the eKPIs related to ships. The conclusions drawn in the following section must be validated when more data will be available.

4.1.1. Correlation analysis

Based on the data related to the ships that have been collected from ThPA a first correlation analysis has been done. This step is important to better understand the structure of the data and thus adapt the way the PEI values are calculated. Indeed, it is desirable to avoid double counting and be sure not building a PEI on highly correlated data.
The work done here will be completed when all data from ports will be available. Some first insights about the data structure are drawn in the following but must be validated with a better data set.

4.1.1.1. Emissions to air for ships

Table 4.1 shows the correlation factors between the different eKPIs related to emissions to air for the ships. It can be observed that all the eKPIs are strongly correlated. This can be explained by the approach used to calculate the eKPIs: for a specific ship the eKPIs are all calculated based on the same berthing and manoeuvring time and with the same characteristics of the main and auxiliary engines (consumption per hours, type of fuel, …). Only the emissions factor changed to calculate eKPIs value related to emissions to air.

Table 4.1 Correlation matrix for eKPIs related to the emissions to air for ships

	CO_2	NOx	PM	SOx
CO_2	1,00	0,99	0,99	1,00
NOx	0,99	1,00	0,99	0,99
PM	0,99	0,99	1,00	0,99
SOx	1,00	0,99	0,99	1,00

This means that after the normalisation process (independent of the applied method) the eKPIs values that have been defined for the emissions to air for ships will always have the same values. This also means that the sub-index “emission to air” can be obtained just by considering one of the eKPIs related to the emissions to air. Moreover, if some eKPIs for emissions to air by ships are missing, they can easily be obtained them from only one value.

Since for calculating the emissions to air due to terminals and port authority at this point, mainly the Port Activity Scenario will be used (to obtain the type and quantity of energy used), combined with emissions factors, it can be assumed that the same correlation matrix will be obtained.

Thus, just one eKPI related to the emissions to air can be considered to calculate the PEI. Readers should keep in mind that this is a first analysis based only on the ThPA data and the conclusion about correlation is mainly due to the way the eKPIs are calculated.

4.1.2. Waste and wastewater for ships

Table 4.2 and Table 4.3 show the correlation matrix for some eKPIs related to waste and wastewater for ships. It can be observed that plastic, food waste and domestic waste are highly correlated. This means that in order to calculate PEI it is possible to only consider one of them, or that it is possible to easily input them if one of them is known. This analysis must be consolidated with other data coming for the other ports in order to confirm it or not. The other eKPIs related to waste of ships do not seem to be correlated.

Table 4.2 Correlation table for some eKPIs related to waste for ships

	Plastic	*Food waste*	*Domestic waste*	*Cooking oil*	*Incinerator ashes*	*Operational waste*	*Cargo residues (non-harmful)*
Plastic	1,00	0,99	0,97	0,04	0,49	0,84	-0,13
Food waste	0,99	0,01	0,97	0,01	0,49	0,83	-0,11
Domestic waste	0,97	0,97	1,00	0,01	0,53	0,81	-0,15
Cooking oil	0,04	0,01	0,01	1,00	0,05	0,08	-0,07
Incinerator ashes	0,49	0,49	0,53	0,05	1,00	0,38	0,06
Operational waste	0,84	0,83	0,81	-0,01	0,38	1,00	-0,11
Cargo residues (non-harmful)	-0,13	-0,11	-0,15	-0,02	0,06	-0,11	1,00

Table 4.3 Correlation table for eKPIs related to waste for ships

	Oily bilge water	*Oily residues*	*Sewage*
Oily bilge water	1,00	0,93	0,00
Oily residues	0,93	1,00	-0,06
Sewage	0,00	-0,06	1,00

4.2. Principal component and cluster analysis

Based on the first data analysis performed on the ThPA data, it seems that some eKPIs are highly correlated. Thus, it will be very interesting to perform a principal component analysis in order to: 1) better understand and visualize data, 2) decorrelate variables (the new base after the PCA will be constituted with uncorrelated data). This method could also help us to decrease the number of eKPIs needed to calculate the PEI values. This analysis will be done in WP7 and will let the project partners to consolidate their knowledge of the data structure of eKPIs.

4.3. Outliers identification and treatment

Outlier identification is an important pre-processing step, since the PEI values can be sensible to them. To detect outliers, the most basic method is the Extreme Value analysis. By knowing the mean value and the standard deviation of each eKPIs before their normalisation (based on all values obtained by each port), some criteria to detect outliers can be defined.

If it is supposed that the eKPIs have a Gaussian distribution, it can be considered that values outside the mean plus or minus three times the standard deviation are outliers. If it is supposed that eKPIs are normally distributed, the quantiles have to be calculated.

Then outliers can be automatically treated, or an alert could be set up in order to inform a port agent to check the value. In the PEI context, outliers will be mainly due to problem during measurement, human or mechanical error obtaining the data. Thus, outliers can be considered and treated like missing data.

In WP7, the analysis will be deepened, and the focus will be on the detection of outliers that can appear in the dataset.

4.4. Data imputation algorithms

Data imputation is required in cases when there are missing values in the available data. In order to proceed with the data imputation, several questions need to be addressed:

- Which values are missing?
- How many values are missing?
- With which frequency the data are missing?
- If the data are missing completely at random or not at random?
- A statistical description of missing values (mean, median, variance, …).

The objective is to understand:

- What do we know about the mechanism behind the missing value?
- Do the missing values contain information?
- What happens if we ignore the missing values?

4.4.1. Hot deck imputation

The missing value is completed using a "similar" value that is already registered in the data set. For example, missing values for CO_2 emissions of one vessel may be replaced with CO_2 emissions of another vessel with similar characteristics available in the internal database of the port (*e.g.* engine, length, type of fuel, …).

4.4.2. Cold deck imputation

The missing value is replaced with a constant value from an external source. This value can come from literature, expert knowledge or similar studies. For example, a missing value for fuel consumption of crane in the GPMB can be replaced by the fuel consumption of a crane considering the manufacturer value.

4.4.3. Unconditional mean/median/mode imputation

The missing value is replaced by the mean/median of recorded values. If a port is not able to provide its lighting consumption, mean of lighting consumption observed for the other ports in the same period can be used. This approach leads to underestimation of the true variance of the missing value. Thus, the uncertainty in the PEI will be underestimated.

4.5. Overview of how PEI values are calculated

PEI is divided in four indices where environmental impacts are attributed to a specific entity: port authority, terminals, ships or to a global category (all). Table 4.4 shows this attribution and how eKPIs are related to a sub-index.

Table 4.4 Relation between eKPIs and sub-indexes

	eKPI name	Associated index	eKPI description	Sub-index	Units
SHIPS	CO_2	ships	C02 emissions by ships	emissions to air	kg or tonnes
	NOx	ships	NOx emissions by ships	emissions to air	kg or tonnes
	PM	ships	PM10 emissions by ships	emissions to air	kg or tonnes
	SO_2	ships	S02 emissions by ships	emissions to air	kg or tonnes
	HC	ships	HC 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
TERMINALS	CO2	terminals	C02 emissions by terminals	emissions to air	kg or tonnes
	NOx	terminals	NOx emissions by terminals	emissions to air	kg or tonnes
	PM10	terminals	PM10 emissions by terminals	emissions to air	kg or tonnes
	PM2.5	terminals	PM2.5 emissions by terminals	emissions to air	kg or tonnes
	SO2	terminals	S02 emissions by terminals	emissions to air	kg or tonnes
	HC	terminals	HC emissions by terminals	emissions to air	kg or tonnes
	CO	terminals	C0 emissions by terminals	emissions to air	kg or tonnes
	N2O	terminals	N2O emissions by terminals	emissions to air	kg or tonnes
	CH4	terminals	CH4 emissions by terminals	emissions to air	kg or tonnes
	Sanitary wastewater	terminals	Wastewater created by usual domestic activities	wastewater	m3
	Technological wastewater	terminals	Wastewater created by industry and ship maintenance	wastewater	m3
	Storm water	terminals	Water resulting from rain, snow, etc.	wastewater	m3
	Non-hazardous waste	terminals	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes
	Hazardous waste	terminals	Waste hazardous for public health or environment	waste	kg or tonnes
ALL	Noise pollution (Lden)	all	Noise levels calculated from day, evening and night levels	noise	dB
	Noise pollution (Lnight)	all	Noise levels during the night	noise	dB
	Odour	all	Self-explanatory	odour	ouE/m3
	Light pollution	all	Self-explanatory	light pollution	lx
PORT AUTHORITIES	CO2	port authorities	C02 emissions by port authorities	emissions to air	kg or tonnes
	NOx	port authorities	NOx emissions by port authorities	emissions to air	kg or tonnes
	PM10	port authorities	PM10 emissions by port authorities	emissions to air	kg or tonnes
	PM2.5	port authorities	PM2.5 emissions by port authorities	emissions to air	kg or tonnes

	SOx	port authorities	S0x emissions by port authorities	emissions to air	kg or tonnes
	VOC	port authorities	VOC emissions by port authorities	emissions to air	kg or tonnes
	CO	port authorities	C0 emissions by port authorities	emissions to air	kg or tonnes
	N2O	port authorities	N2O emissions by port authorities	emissions to air	kg or tonnes
	CH4	port authorities	CH4 emissions by port authorities	emissions to air	kg or tonnes
	Sanitary wastewater	port authorities	Wastewater created by usual domestic activities	wastewater	m3
	Non-hazardous waste	port authorities	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes
	Hazardous waste	port authorities	Waste hazardous for public health or environment	waste	kg or tonnes

In order to be able to calculate PEI values (for ships, terminals, port authority and all), several steps have to be followed:

1) **Normalisation of each eKPIs:** In this step, each eKPI is normalised in order to transform it in a pure and dimensionless number. This is of huge importance since it is a necessary step in order to be able to sum up eKPIs expressed in different units and different order of magnitude. The same normalisation method must be applied to all eKPIs. In the following it is explained how the normalisation method directly impacts the PEI values, their signs and range of variation. Three different normalisation methods are investigated (Standardisation (Z-scores), re-scaling and distance to a reference). These methods have been already described in deliverable D5.2.

2) **From eKPIs to sub-indexes:** In this step, each eKPI is assigned to a specific sub-index (as described in Table 4.4). Each sub-index can be considered as a composite indicator on its own. Indeed, in each sub-index must be weighted and different eKPIs must be aggregated. In this document, it is assumed that an equal weighting method for the weighting process is used as well as an additive method for the aggregation. Thus, each eKPI is summed using the arithmetic mean. Doing so the normalised eKPIs and their associated sub-index have the same variation range.

   These assumptions were made since at this point, only the eKPIs related to the same sub-index and thus to the same environmental impact are added. Equal weighting can be used if it is considered that all the indicators are equally important. Moreover, since some eKPIs related to the same sub-index are highly correlated (as shown for the eKPIs related to emissions to air) there is no need to have a complex weighting and aggregating process to calculate sub-indexes. Indeed, when there is a strong correlation between eKPIs their normalised values are almost equal. The following formulas are used to calculate sub-indexes.

$$Emissions\ to\ air\ (ships) = \sum eKPIs\ /5$$

$$Emissions\ to\ air\ (terminals) = \sum eKPIs\ /9$$

$$Emissions\ to\ air\ (port\ authority) = \sum eKPIs\ /9$$

$$Waste\ (ships) = \sum eKPIs\ /13$$

$$Waste\ (terminals) = \sum eKPIs\ /2$$

$$Waste\ (port\ authority) = \sum eKPIs\ /2$$

$$Wastewater\ (ships) = \sum eKPIs\ /11$$

$$Wastewater\ (terminals\ ) = \sum eKPIs\ /3$$
$$Waste\ (port\ authority) = \sum eKPIs\ /1$$
$$Odour\ (all) = \sum eKPIs\ /1$$
$$Noise\ (all) = \sum eKPIs\ /2$$
$$Light\ pollution\ (all) = \sum eKPIs\ /1$$

3) **Weighting of sub-indexes:** In this step, a weight for each of the sub-indexes must be defined in order to calculate PEI values. Contrary to what is done in step 2, in this step values (normalised ones) that represent different environmental impacts are compared. That is why two different weighting methods are compared: equal weighting method and budget allocation method. Using equal weighting it is assumed that each sub-index has the same impact on the port's environment. Using the budget allocation (based on expert knowledge or even on public opinion) it is assumed that some sub-indexes have much more impact (based on expert knowledge) or are considered as much important (based on public opinion) than other ones.

4) **Aggregation of sub-indexes into PEI values:** In this last step sub-indexes are aggregated into PEI values. In the following, the additive aggregation (using weighted arithmetic mean) is compared with the geometric aggregation (using the weighted geometric mean).

4.6. Methodology used to compare methods to build PEI

In order to study the impact of normalisation of eKPIs, weighting and aggregation method of sub-indexes on the PEI values and their understanding, a mock-up database composed of six different ports with different eKPIs values has been defined. The objective here is not to give realistic PEI values, but rather study how they change depending on the method used to calculate them.

Table 4.5 gives the description of this mock-up database. Firstly, a reference port (best performance in every eKPIs) with a data structure that reflects what has been observed for the ThPA data (mainly the high correlation of eKPIs related to the emissions to air) has been designed. Then, five data sets of eKPIs that differ between them and the reference port have been defined.

Table 4.5 Description of ports

	Port #1	***Port #2***	***Port #3***	***Port #4***	***Port #5***	***Port #6***
Description	Reference port with best performance on every eKPIs	eKPIs related to waste (ships, terminals, port authority) are 30% higher than the ones from the reference port. All the other eKPIs are 5% higher than the reference port.	Every eKPIs are 25% higher than the reference port. Port with the mid performance on every eKPI	eKPIs related to emissions to air (ships, terminals, port authority) are 50% higher than the reference port (equal to the worst performance) eKPIs related to wastewater (ships, terminals,	eKPIs related to emissions to air (ships, terminals, port authority) are 50% higher than the reference port (equal to the worst performance). All the other eKPIs are the same as port #3 (equal to	All eKPIs are 50% higher than the reference port. Port with the worst performance on every eKPI

				port authority) are 5% higher than port #1 (close to the best performance). All the other eKPIs are the same as port #3 (equal to the mid performance)	the mid performance)	
Objective	To give a reference for comparison. This port is the best one in every eKPIs and can be considered as a goal to achieve.	To study the effect on PEI values if one sub-index is under the mid performance and the other one close to the reference.	To study the effect on PEI values. Do we always obtain PEI values 25 % higher than the reference PEI values?	To study the effect on PEI values if one sub-index is close to the best performance, one index close to the worst and all other indexes have a mid-performance	To compare PEI values obtained by port #4.	This port is the worst case in terms of impact.

Then, for each of these six defined ports, the associated PEI values depending on the method used for normalisation of eKPIs, weighting and aggregation of sub-indexes have been calculated. In the following text, the effect of each method and the cross effects between methods is studied and shown. In deliverable D5.2, state of the art method for normalization of eKPIs, weighting and aggregation of sub-indexes have been described. Based on this work, three methods for normalization, two methods for weighting and two methods for aggregation have been selected. Table 4.6 sums up the selected methods.

Table 4.6 Selected method for normalization of eKPIs, weighting and aggregation of sub-indexes

Normalization of eKPIs	***Weighting of sub-indexes***	***Aggregation of sub-indexes***
Standardisation (Z-scores)	Equal Weighting	Weighted Arithmetic mean
Re-scaling	Budget Allocation	Weighted Geometric mean
Distance to a reference (port)		

In order to be able to show the impacts of the different methods on the PEI values, all the possible combinations have been studied. Table 4.7 describes these 12 combinations.

Table 4.7 Possible combinations of applied methods

Name of the combination	Methods that are applied
#111	Z-Scores – Equal Weighting – Weighted Arithmetic mean
#112	Z-Scores – Equal Weighting – Weighted Geometric mean
#121	Z-Scores – Budget Allocation – Weighted Arithmetic mean
#122	Z-Scores – Budget Allocation – Weighted Geometric mean
#211	Re-Scaling – Equal Weighting – Weighted Arithmetic mean
#212	Re-Scaling – Equal Weighting – Weighted Geometric mean
#221	Re-Scaling – Budget Allocation – Weighted Arithmetic mean
#222	Re-Scaling – Budget Allocation – Weighted Geometric mean
#311	Distance to a reference port – Equal Weighting – Weighted Arithmetic mean
#312	Distance to a reference port – Equal Weighting – Weighted Geometric mean
#321	Distance to a reference port – Budget Allocation – Weighted Arithmetic mean
#322	Distance to a reference port – Budget Allocation – Weighted Geometric mean

4.7. Normalization algorithms

4.7.1. Standardisation (Z-scores)

In this method for each environmental indicators (eKPIs) the average and the standard deviation across ports are calculated. The normalisation formula is:

$$Nomalised\ value\ (t) = \frac{[Observed\ value(t) - Average\ value(t)]}{Standard\ deviation(t)}$$

The min and max of the normalised value depend on each eKPI. This method is the most used because all indicators have the same scale (average of zero and standard deviation of one). An average of zero avoid introducing distortions in the aggregation step due to difference of indicator means.

Table 4.8 Examples of PEI values using the Z-scores normalization (combination #111)

111	PEI (Ships)	PEI (Terminals)	PEI (Port Authority)	PEI (all)
Port #1	-1,290	-1,290	-1,290	-1,218
Port #2	-0,504	-0,504	-0,504	-0,937

Port #3	0,029	0,029	0,029	0,187
Port #4	0,032	0,032	0,032	0,187
Port #5	0,385	0,385	0,385	0,187
Port #6	1,348	1,348	1,348	1,592
#6	1,534	1,534	1,534	1,744

The main drawback of this normalization method for PEI values is that it generates negative and positive values (this is observed for all the combination involving the standardisation method). Negative and positive values could be more difficult to analyse for external users and not easy to communicate. That is why it is suggested not to use this normalisation method for the PEI calculation.

4.7.2. Re-scaling

The objective here is to obtain a normalised eKPI with value between 0 and 1. Each eKPI is transformed using the following formulae:

$$Normalised\ value\ (t) = \frac{[Observed\ value\ (t) - \min value(t)]}{[\max value - \min value]}$$

where min and max values are the minimum and the maximum values across all ports at a specific time. Using the above formulae in the PIXEL context will lead to have PEI values were the worst case equals to one and the best case equals to 0. If it is wanted to have the best case equal to 1 and the worst case equal to 0, the following formula must be followed:

$$Normalised\ value\ (t) = \frac{[\max value(t) - Observed\ value\ (t)]}{[\max value - \min value]}$$

This choice directly impacts on how PEI values evolve. In the following, it is considered that worst values for PEI are reached when PEI equal to 1 and best values when PEI equal to 0. Using this approach, the lower the PEI values are the lower the impact of the port on the environment is.

Table 4.9 Examples of PEI values using the re-scaling normalization (combination #212 and 221)

211	*PEI (Ships)*	*PEI (Terminals)*	*PEI (Port Authority)*	*PEI (all)*
#1	0,000	0,000	0,000	0,000
#2	0,267	0,267	0,267	0,100
#3	0,500	0,500	0,500	0,500
#4	0,533	0,533	0,533	0,500
#5	0,667	0,667	0,667	0,500
#6	1,000	1,000	1,000	1,000
212	*PEI (Ships)*	*PEI (Terminals)*	*PEI (Port Authority)*	*PEI (all)*
#1	0,000	0,000	0,000	0,000
#2	0,182	0,182	0,182	0,100
#3	0,500	0,500	0,500	0,500
#4	0,368	0,368	0,368	0,500
#5	0,630	0,630	0,630	0,500
#6	1,000	1,000	1,000	1,000

4.7.3. Distance to reference

In this approach, the normalised value takes the ratio between the value of an eKPI and the value of the eKPIs of a reference port. A good method is to consider that the reference port is a target to be reached in a given time frame. By doing this the reference port will have normalised value equal to 0 and the normalised eKPIs for a port will represent the effort to do to achieve the targeted improvement.

This normalisation method gives a result that is easily understandable where the high values of PEI meaning that the port is far away from the reference.

Table 4.10 Examples of PEI values using the distance to a reference normalization (combination #212 and 221)

311	*PEI (Ships)*	*PEI (Terminals)*	*PEI (Port Authority)*	*PEI (all)*
#1	0,000	0,000	0,000	0,000
#2	0,133	0,133	0,133	0,050
#3	0,250	0,250	0,250	0,250
#4	0,267	0,267	0,267	0,250
#5	0,333	0,333	0,333	0,250
#6	0,500	0,500	0,500	0,500
312	*PEI (Ships)*	*PEI (Terminals)*	*PEI (Port Authority)*	*PEI (all)*
#1	0,000	0,000	0,000	0,000
#2	0,091	0,091	0,091	0,050
#3	0,250	0,250	0,250	0,250
#4	0,184	0,184	0,184	0,250
#5	0,315	0,315	0,315	0,250
#6	0,500	0,500	0,500	0,500

Readers should have in mind that in this work, distance to a reference considering the same port as the reference is used. By doing so, the ports are allowed to compare themselves and their PEI values on a common basis (which is one aim of the PIXEL project). Taking as a reference not the same port for all cases but specify a reference for each port can be considered. This approach will allow ports to compare to a reference they want to achieve but doing so it will never be possible to compare ports together. That is why it was chosen to consider a common reference.

4.8. Weighting algorithms

4.8.1. Equal Weighting

This approach is the most used one. It can be used if it is considered that all the indicators are equally important or if there is no statistical or empirical evidence supporting a different scheme. This strategy is also recognised as the simplest one and is easily replicable. However, equal weighting can lead to combining variables with high degree of correlation and thus introducing an element of double counting.

This approach works well if all dimensions (water pollution, air pollution, biodiversity, …) are represented in the composite indicator with the same number of sub-indicators. If this is not the case, it will imply a higher weight to the dimension represented with the highest number. In this context, every dimension has only one associated sub-index, so there is no theoretical contradiction to use it.

Table 4.11 Equal weighting for PEI (ships, terminals, port authority)

Sub-index	Weight
Emission to air	1
Waste	1
Wastewater	1

Table 4.12 Equal weighting for PEI (all)

Sub-index	Weight
Noise	1
Odour	1
Light Pollution	1

4.8.2. Budget Allocation

Budget allocation (BAL) approach or expert opinion is a method where experts with extensive knowledge and experience are joined together to distribute a budget of “n” points over the indicators. Based on experts’ judgment, indicators that are judged to be more important are given a larger proportion of the budget. Then the weighting is done according to the budget distribution. The method follows four steps:

i) Selection of the experts for the valuation
ii) Allocation of budget to the indicators (sub-indexes in PIXEL)
iii) Calculation of the weights
iv) Iteration of the budget allocation until convergence is reached (optional)

BAL is useful for its transparency and explicitness, but the weighting process could reflect local specific conditions and not transferable from one area to another. Moreover, it could measure the urgency of the situation or need of political intervention rather than measure the importance of each indicator (e.g. more weight on wastewater emission if the expert considers that nothing has been done to reduce them).

This type of approach is used when it is essential to bring experts with a wide spectrum of knowledge and experience and is optimal for a maximum number of sub-indicators equal to 10 – 12. If the number of sub-indicators is higher, a cognitive stress can lead to a biased allocation.

In the following, it is assumed that experts have been consulted and that they have converged to define weights for each sub-indexes. In the tables below an example of weights for the budget allocation approach is given.

Table 4.13 Equal weighting for PEI (ships, terminals, port authority)

Sub-index	Weights
Emission to air	3
Waste	1
Wastewater	2

Table 4.14 Equal weighting for PEI (all)

Sub-index	Weights
Noise	2
Odour	1
Light Pollution	2

4.9. Aggregation algorithms

4.9.1. Additive aggregation

In all additive aggregation methods, the normalised values of indicators are summed up using a specific function. The most used function is the weighted arithmetic mean: the normalised values of indicators are summed up using their respective weight. Additive aggregation methods should be used carefully since these methods imply two main features:

i) Preferential independence: Indicators must be independent, meaning that the contribution of all indicators can be added together implying that no synergy or conflicts exist among different indicators. If the assumption is not respected this will result in a biased composite indicator in which the dimension and the direction of the error will be difficult to determine. In the previous section, it is observed that some eKPIs are highly correlated. As explain this means that just one of the correlated eKPIs to be included in the PEI value can be considered.

ii) If there is a substantial interaction between indicators, additive methods should not be used since these methods intrinsically imply a compensatory logic. Weights in additive methods have the meaning of substitution rates and do not indicate the importance of the indicator associated.

This approach is useful when sub-indicators have the same measurement units and when scale effects are neutralized. It also has trade-offs between sub-indicators, meaning that the deficit in one indicator can be neutralised by the surplus of another one. In additive (linear) aggregation method the compensability is linear.

In order to calculate PEI values, sub-indexes that seem to be independent (this point will have to be confirmed when all eKPIs will be available from every ports) are dealt with. The following formulae are used to calculate the different PEI values:

$$PEI\ (ships) = \frac{\alpha * \ Emissions\ to\ air\ (ships) + \beta * Waste(ships) + \gamma * Wastewater(ships)}{\alpha + \beta + \gamma}$$

$$PEI\ (terminals) = \frac{\alpha * \ Emissions\ to\ air\ (terminals) + \beta * Waste(terminals) + \gamma * Wastewater(terminals)}{\alpha + \beta + \gamma}$$

$$PEI\ (port\ authority) = \frac{\alpha * \ Emissions\ to\ air\ (port\ authority) + \beta * Waste(port\ authority) + \gamma * Wastewater(port\ authority)}{\alpha + \beta + \gamma}$$

$$PEI\ (all) = \frac{\alpha' * \ Odour\ (all) + \beta' * Noise\ (all) + \gamma' * Light\ Pollution(All)}{\alpha' + \beta' + \gamma'}$$

where α, β and γ are the weights associated with emissions to air, waste and wastewater, and where α', β' and γ' the weights associated to odour, noise and light pollution.

Using the additive arithmetic mean for aggregation the range of variation of eKPIs, sub-indexes and PEI values are the same.

4.9.2. Geometric aggregation

Geometric aggregation methods use multiplicative functions. The most used function is the weighted geometric mean. Geometric mean-based methods only allow compensability between indicators within certain limitations. When using geometric aggregation methods, the measurement scale must be the same for all indicators in order to remove the scale effects. The normalisation method should take this into account. That is why using geometric aggregation combined with a standardisation method for normalisation is not appropriated.

There are also limitations to such approaches. First, geometric methods are not fully non-compensatory techniques and like the additive method are preferentially dependent. Second, it is not possible to analyse sensitivity and uncertainty quantification using measurement errors of indicators. This will be discussed in the following section.

PEI values are calculated using the following formulas when the weighted geometric means method is used:

$$PEI\ (ships) = [\alpha *\ Emissions\ to\ air\ (ships) * \beta * Waste(ships) * \gamma * Wastewater(ships)]^{\frac{1}{\alpha+\beta+\gamma}}$$

$$PEI\ (terminals) = [\alpha *\ Emissions\ to\ air\ (terminals) * \beta * Waste(terminals) * \gamma * Wastewater(terminals)]^{\frac{1}{\alpha+\beta+\gamma}}$$

$$PEI\ (port\ authority) = [\alpha *\ Emissions\ to\ air\ (port\ authority) * \beta * Waste(port\ authority) * \gamma * Wastewater(port\ authority)]^{\frac{1}{\alpha+\beta+\gamma}}$$

$$PEI\ (all) = [\alpha' * Odour\ (all) * \beta' * Noise\ (all) * \gamma' * Light\ Pollution((all)]^{\frac{1}{\alpha'+\beta'+\gamma'}}$$

4.10. Impact of the normalisation of eKPIs, weighting and aggregation of sub-indexes the PEI values

In this section the impact of the way PEI values are obtained is analysed and some recommendations on the PEI algorithms were made. Table 4.15 shows all the PEI values for ships, terminals, port authority and all and for the different combination of methods.

Table 4.15 PEI values obtained for each port and each combinations of methods

	PEI (Ships)											
	111	112	121	122	211	212	221	222	311	312	321	322
#1	-1,243	-1,224	-1,209	#####	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
#2	-0,493	0,000	-0,719	1,048	0,274	0,184	0,183	0,578	0,133	0,091	0,217	0,406
#3	0,046	0,048	0,011	0,295	0,509	0,508	0,500	0,961	0,250	0,250	0,250	0,674
#4	0,001	0,000	0,167	0,898	0,521	0,359	0,617	0,807	0,235	0,157	0,119	0,534
#5	0,354	-0,352	0,520	#####	0,654	0,613	0,750	1,056	0,301	0,268	0,186	0,698
#6	1,335	1,282	1,231	1,526	1,000	1,000	1,000	1,348	0,500	0,500	0,500	0,953
	PEI (Terminals)											
	111	112	121	122	211	212	221	222	311	312	321	322
#1	-1,290	-1,262	-1,233	#####	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
#2	-0,504	0,582	-0,725	1,028	0,267	0,182	0,183	0,575	0,133	0,091	0,092	0,406
#3	0,029	0,158	0,002	0,029	0,500	0,500	0,500	0,953	0,250	0,250	0,250	0,674
#4	0,032	0,316	0,182	0,757	0,533	0,368	0,617	0,818	0,267	0,184	0,308	0,579
#5	0,385	0,385	0,535	#####	0,667	0,630	0,750	1,070	0,333	0,315	0,375	0,757
#6	1,348	1,294	1,238	1,534	1,000	1,000	1,000	1,348	0,500	0,500	0,500	0,953

	PEI (Port Authority)											
	111	112	121	122	211	212	221	222	311	312	321	322
#1	-1,290	-1,262	-1,233	#####	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
#2	-0,504	0,582	-0,725	1,028	0,267	0,182	0,183	0,575	0,133	0,091	0,092	0,406
#3	0,029	0,158	0,002	0,536	0,500	0,500	0,500	0,953	0,250	0,250	0,250	0,674
#4	0,032	0,316	0,182	0,757	0,533	0,368	0,617	0,818	0,267	0,184	0,308	0,579
#5	0,385	-0,251	0,535	#####	0,667	0,630	0,750	1,070	0,333	0,315	0,375	0,757
#6	1,348	1,294	1,238	1,534	1,000	1,000	1,000	1,348	0,500	0,500	0,500	0,953

	PEI (All)											
	111	112	121	122	211	212	221	222	311	312	321	322
#1	-1,218	-1,218	-1,218	-1,485	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
#2	-0,937	-0,937	-0,937	-1,269	0,100	0,100	0,100	0,331	0,050	0,050	0,050	0,219
#3	0,187	0,187	0,187	0,483	0,500	0,500	0,500	0,871	0,250	0,250	0,250	0,574
#4	0,187	0,187	0,187	0,483	0,500	0,500	0,500	0,871	0,250	0,250	0,250	0,574
#5	0,187	0,187	0,187	0,483	0,500	0,500	0,500	0,871	0,250	0,250	0,250	0,574
#6	1,592	1,592	1,592	1,744	1,000	1,000	1,000	1,320	0,500	0,500	0,500	0,871

By analysing the PEI values that have been obtained, the following conclusions can be drawn on the choice of normalisation, weighting and aggregation methods:

- All the combinations including the standardisation method for normalisation lead to obtain positive and negative values for PEI. It is considered that this can make understanding the PEI more difficult for external users. The use of these combinations is thus not recommended for the final understanding of the PEI index.
- The combination of standardisation for normalisation and geometric method for aggregation (combination 112) can lead to a mathematically undefined PEI value. This is explained simply by the fact that the mathematical expression $(- a) \wedge (1 / c)$ $(a > 0)$ exists only and only if c is odd. In this budget allocation example, the value is $c = 6$. This possibility of combination is therefore to be excluded as a possibility for calculating PEI.
- The combinations #211, #212 and #221 lead to PEI values between 0 and 1. This is something interesting in order to be able to compare PEI values in an easy way. Port with the best performance are close to zero and ports with bad performance are close to one. Using the re-scaling normalisation method, it is possible to compare PEI values between ports but there is no common reference. That means that if eKPIs change over time the PEI values will not be comparable over time since the scale of eKPIs will have changed. Thus, using the combination #211, #212 and #221 only the ports at a certain point in time can be compared and it is not possible to follow the evolution of PEI values over time.
- The combination #311, #312 and #321 allow to quickly reflect the deviation from the reference. If a PEI value equals 0.3 this can be understood as an environmental impact 30% higher than the reference.

Moreover, if the same reference port (the goal to achieve) is used over time, using this approach, it will be possible to follow the PEI evolution of port over time. Considering all of this it is recommended to use distance to a reference as a normalization method.

- Comparing combinations #311 and #322, the effect of the additive or the geometric aggregation is observed. The geometric aggregation leads to lower PEI values when the sub-index is close to the reference. Indeed, if a sub-index is close to the reference, its associated value is close to zero. Thus, PEI values are also close to 0. Geometric aggregation is mainly used to avoid compensatory effect but in the PEI context it will be in favour of ports with one good sub-index even if the other sub-index is not so good. This is clearly observed when port #3 and port #4 are compared. Port #4 has one sub-index close to the reference (waste), one close to the mid-performance (wastewater) and one close to the worst performance (emissions to air). All sub-indexes of port #3 are equal to the mid-performance. When additive aggregation is used, port #3 has better PEI values than port #4 but using a geometric aggregation port #3 has higher PEI values. Since using a geometric aggregation can send a misleading information and can be difficult to interpret, it is suggested not to use it for calculating PEI values.

4.11. Uncertainty analysis and effects on the PEI values

Uncertainty analysis (UA) studies how uncertainty in the input factors (eKPIs or inputs for calculating eKPIs for the PEI) propagates through the structure of the composite indicator. In the following text, some first results about how PEI values evolves when eKPIs are subject to uncertainty are provided.

At the time of writing of this deliverable, there is no clear idea of the structure of the uncertainty associated with each eKPIs (normal or Gaussian distribution? standard deviation? …) . A deeper analysis has to be done in WP7 on this point by 1) interviewing the port agent to have their feedback on the confidence they have on the eKPIs values, 2) better understanding the error of measures associated with each sensor 3) evaluating the error due to the use of emissions factors or models like PAS. However, it is clear that the uncertainty on each EKPIs is rather independent and mainly due to measurement or modelling errors.

In order to be able to perform an uncertainty propagation analysis, it is assumed that the error on each eKPI is considered to be Gaussian and independent (errors on eKPIs are mainly due to measurement errors). Thus, for all the ports of our mock-up database and for all the eKPIs, their associated uncertainty law has been defined. These laws have been built considering a Gaussian distribution and with a standard deviation equal to (port #3 value)/20 (assumption to model the errors). Figure 4.1 shows some examples.

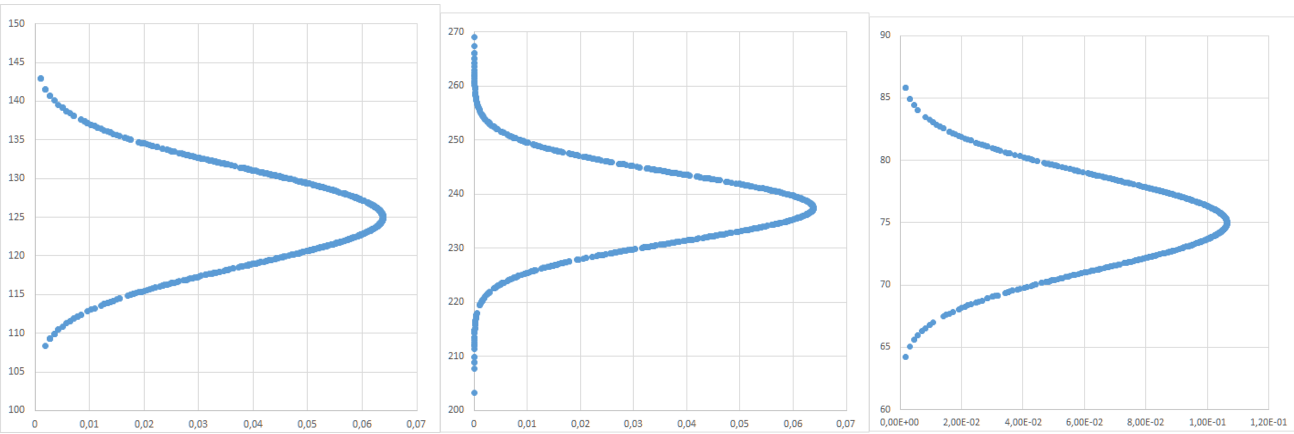


Figure 4.1 Example of incertitude low for eKPIs

A Monte-Carlo approach has been followed in order to perform the uncertainty analysis. This approach is a well-known strategy for uncertainty analysis and can be easily used in the PEI context. To obtain the distribution of PEI values, these steps were followed:

1) Definition of the uncertainty laws associated to each eKPI.
2) An experience plan has been built for each port of the mock-up database. We chose at random in the uncertainty lows the value of eKPIs. This results in 250 values for each eKPIs associated to one port.
3) The PEI values are calculated for all the values in the experience plan.

The methodology that has been set up for this simple uncertainty propagation analysis is easily reproducible and can be used in WP7 or even integrated in the PEI calculation to obtain PEI values and their associated error. This is doable only if it is possible clearly know or model the error associated to each eKPIs. This can be a difficult and time-consuming work.

In the following figures, the results obtained for the different combination of methods to build PEI values that use distance to a reference port as normalisation method are presented. Figure 4.2 and Figure 4.3 show that using an additive method the PEI value (for ships) have a similar standard deviation. This means that there is no distortion of error using additive method. On the contrary, Figure 4.4 and Figure 4.5 show that the geometric aggregation lead to have PEI values with different standard deviation: PEI with low values have a higher standard deviation with PEI with high value. This reflects the fact that a geometric method for aggregation makes not possible to analyse uncertainty quantification using measurement errors of indicators.

Thus, it seems preferable to use an additive method for aggregation in order to be able to link errors of eKPIs with errors on PEI values (only the results about PEI for ships were shown since the same conclusion will be observed for PEI (terminals) and PEI (port authorities)). That is why it is suggested to use an additive methods for aggregation.

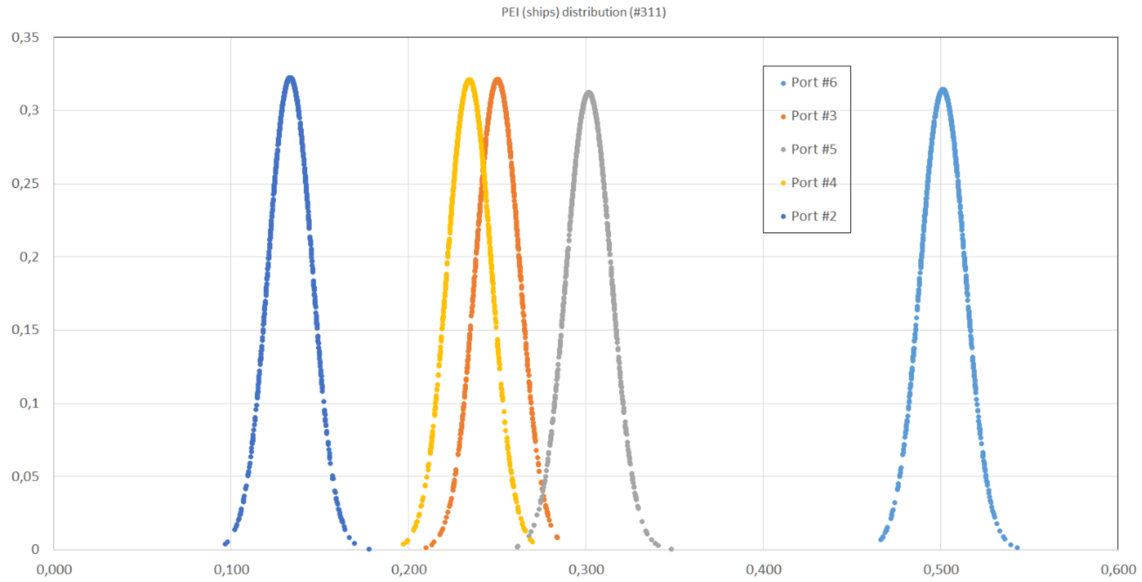


Figure 4.2 PEI (ships) distribution for the combination #311

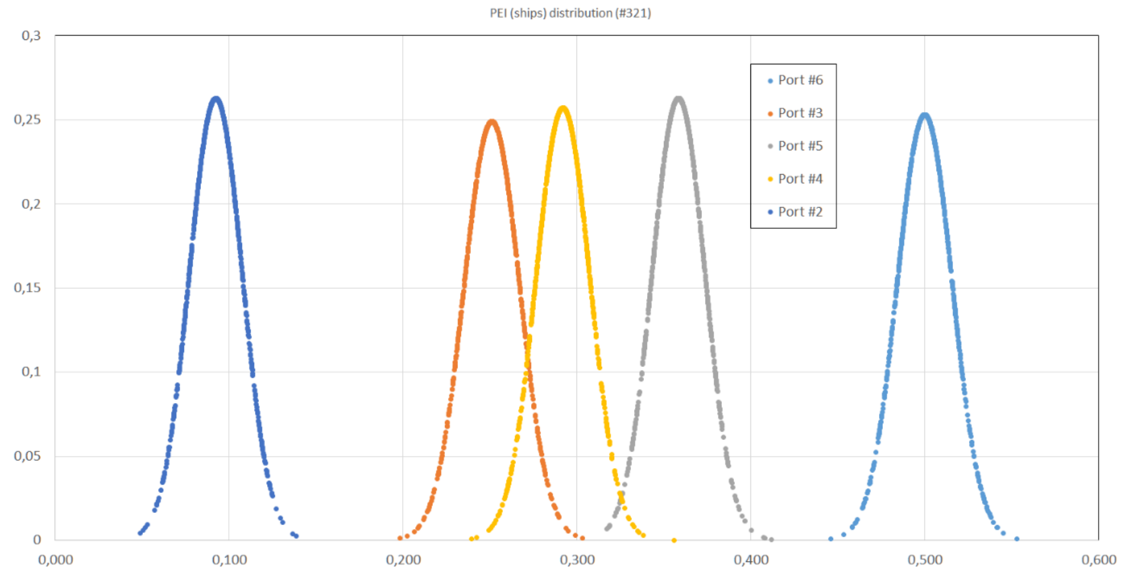


Figure 4.3 PEI (ships) distribution for the combination #311

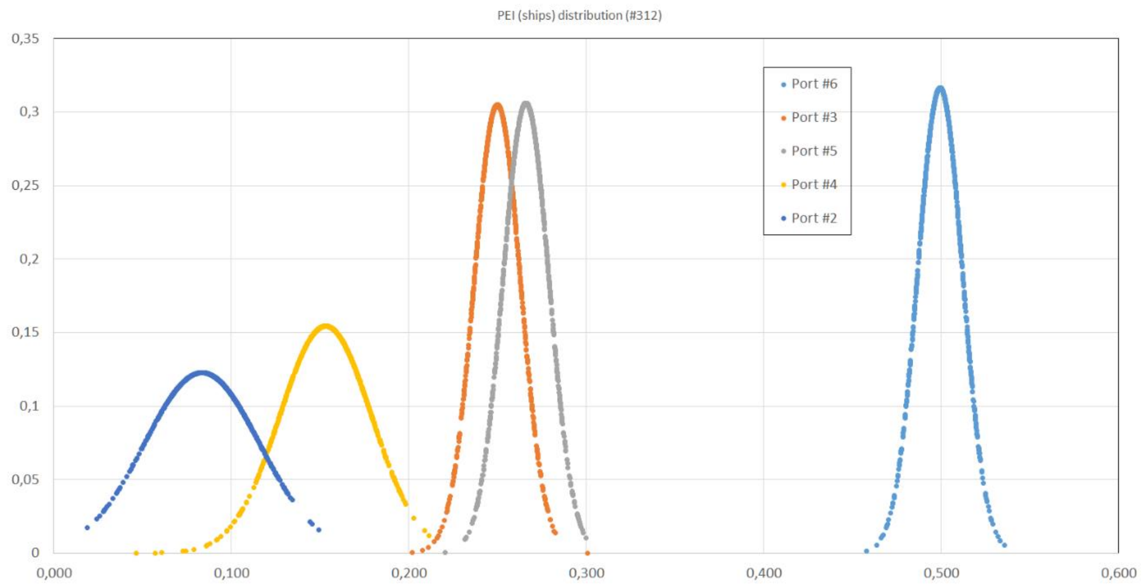


Figure 4.4 PEI (ships) distribution for the combination #312

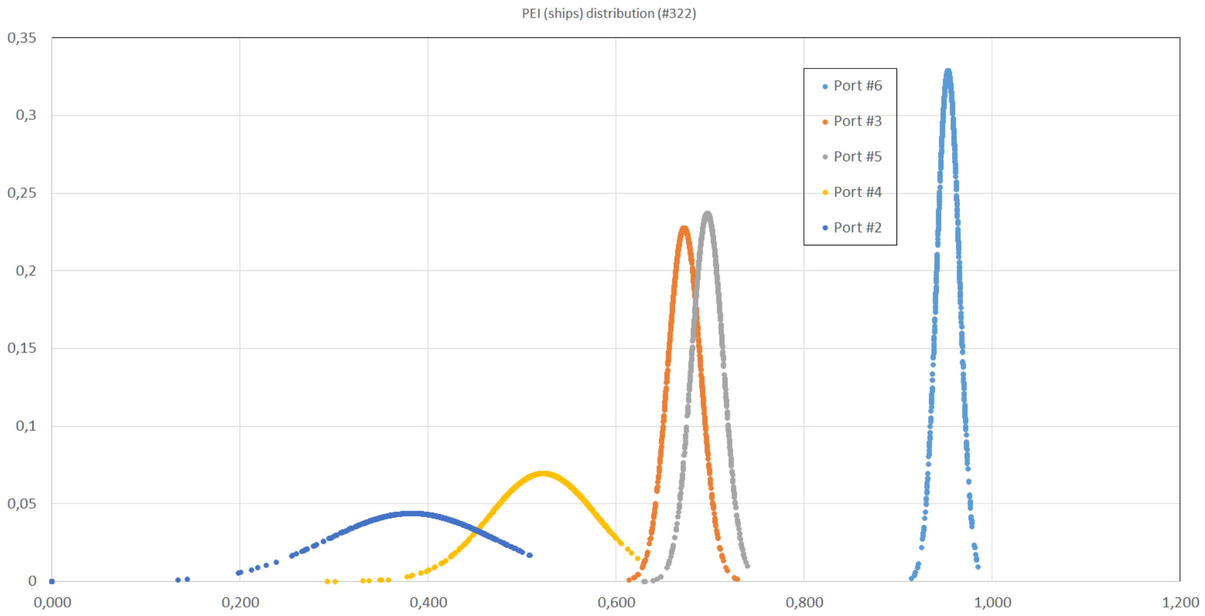


Figure 4.5 PEI (ships) distribution for the combination #312

5. Technological implementation of PEI

While deliverable D5.2 established the technological basis for the PEI implementation, this section in deliverable D5.3 aims at explaining how those lines have been followed in such a way to (already) obtain a running version of the PEI calculation tool.

During the last months of T5.3, the team has used the information of the data available provided from ports (see section 1), the KPIs that form the basis for the calculation (see sections 2 and 3) and the different mathematical operations involved (see section 4), conjugating them into a technological program aligned with the PIXEL architecture. This has supposed an exhaustive, coordinated work by several partners from various expertise.

This section is aimed at describing the design processes and the results obtained from those activities. At this point of the project, a functioning PEI backend code is available in the code repository of the project. At the same time, the visualization interfaces and accessory tools for actually deploying the PEI in a real port are being integrated in the final PIXEL UI (v2 on-going). With the previous, it is expected that very soon will start the real development in the PIXEL ports, constrained and limited to the scope of data available in each case (ports (see section 1). It is also expected that, during the pilots' phase (task T7.5), the PEI technological implementation will evolve to be adapted to ports' reality embedding progressively more advanced options such as the outcomes of tasks T5.4 and T5.5.

With the content exposed below, altogether with the explanations in D5.2, the task T5.3 comes to an end. According to the WP5 team, the objectives of this task have been achieved. Those objectives were: (i) *careful documentation of the methodology for PEI construction/computation* and (ii) *a web-based software for PEI computation, tracking and reporting will be developed*.

Regarding the content below, in section 5.1 the final global position of the PEI within PIXEL architecture is explained. Details on the whole execution design are provided, as well as information is included addressed to the technical teams in the project (designers, developers, and integrators) in order to completely embed PEI in the whole PIXEL solution in later stages of the project (mainly WP7 and T8.4).

In section 5.2, the backend program (PEI as a model) that has been developed is explained. The Java asset was converted into a Docker so that it is ready to be used. Usual software engineering documentation is provided as well in the sub-section such as class and flow diagrams to better explain the program to the reader.

The most useful and illustrative view of what a port staff member should do in order to have the PEI properly running at their port is provided in 5.3. There, the user-interface interaction is described. This section is believed to serve as baseline for the forthcoming PEI manual (at the end of WP5) and PEI installation guidelines (WP7, embedded in the work to be done in task T7.5).

5.1. PEI position within PIXEL architecture

5.1.1. Overview of final landscape

The spot of the PEI component within the PIXEL architecture was outlined in section 7 of the deliverable D5.2, which constituted the first element including a technological approach to the PEI calculation. Deliverable D5.2, which had due date in M18 (October 2019) was properly submitted to the European Commission. During the mid-term review, that took place in Brussels in January 2020, the deliverable was approved and the materialisation of the concepts thereof exposed was also validated via a short in-situ demonstration.

As a short summary, the spot of the PEI within the PIXEL architecture is exactly as the rest of the models/predictive algorithms developed and to be integrated in a final deployment in a port.

The Operational Tools (OT) module analyses the input data required by the PEI software, the OT executes the PEI by informing where the relevant data are, and the PEI executes after retrieving that data from the Information Hub (IH). Afterwards, the PEI module is run in a SaaS (Software as a Service) fashion and its outcome (in a specific format) is also stored in the Information Hub to feed the Dashboard and, in particular, the PEI visualization interface within the PIXEL UI.

Global vision:

As mentioned in D5.2, PEI must be "*provided as a packed piece of software to be run by the Operational Tools*". This means that it was a duty of WP5 team to develop a program able to transform the conceptual environmental calculations into actionable instructions materialized as code. The design for implementing that software started by answering the following questions:

How many things need to be developed?

First, the conversion from data into eKPIs according to section 3. Second, what needs to be calculated are the different indices (emissions to air, waste, wastewater, noise, light, odour) by the different entities of a port. Finally, the user will need to interact with the system by observing the results and configuring the tool.

Within which components/modules must those things run?

The data available (section 1) are provided in heterogeneous formats (inter and intra ports). Additionally, what is really interesting for the PEI are eKPIs (not raw data), that according to sections 2 and 3 do not directly map 1:1 to the data sources. On most occasions, an eKPI is constructed by applying certain processing to raw data. On the other side, PEI must be understood as a model (from D5.2), which means that PEI must be conceived as a "black box" that needs an indication of an input and that provides an output. According to the previous, the technical team decided to **split the computation of the PEI in two clearly differentiated parts**. The conversion from raw data to eKPIs must be done at the agents, in order to insert the eKPIs info in the context broker and into the I.H. as so. This is because it will be easier and more flexible to change/correct/adapt in the future any modification/addition of eKPIs in that part of the architecture, leaving the calculation from eKPIs to the PEI (and subindices) as a fixed code that is not supposed to be changing throughout the time (expect for metadata parameterisation – explained later). Finally, regarding the visualization, it must be fitted into the Dashboard.

How must the information be exchanged among those modules?

Following the descriptions made at the proposal stage, PIXEL is committed to use, if possible, standardised interfaces to communicate modules among them. Taking advantage of the use of the open-source reference for IoT solutions, all data formats have been designed to follow (as much as possible) FIWARE NGSI data models[7].

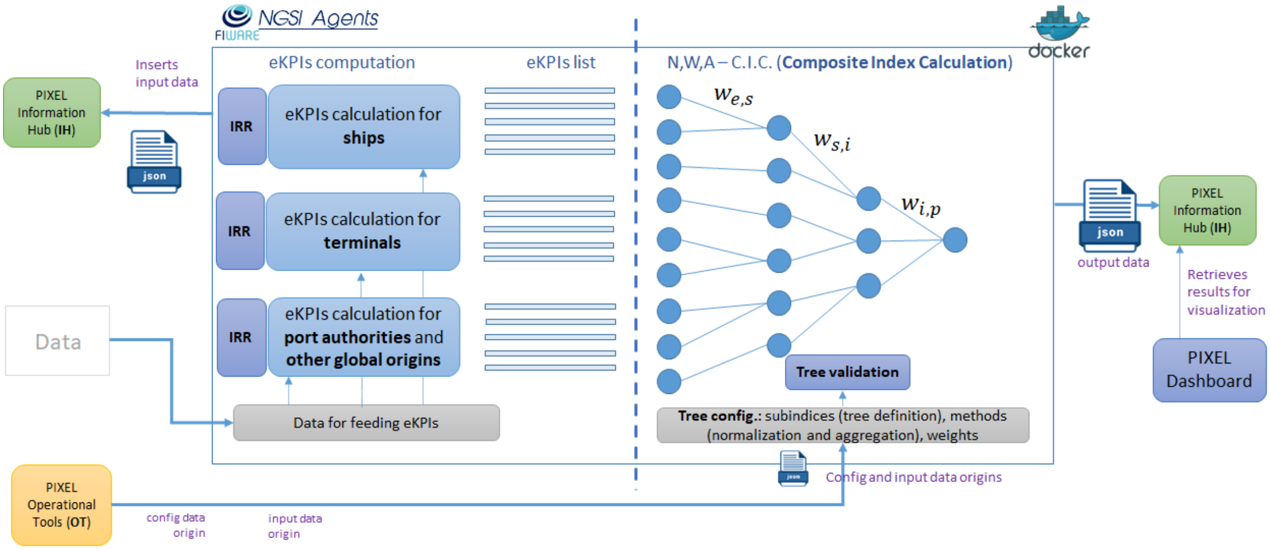


Figure 5.1 Global vision of PEI computation in PIXEL

Figure 5.1 represents with certain level of detail the "structure" of the PEI calculation that was designed by the expert team. As it can be observed, the calculation of the eKPIs and the IoT-Readiness-Level (see D5.2) is calculated by NGSI agents. A set of eKPIs is then used by the Composite Index Calculation (Dockerised backend software) that processes the inputs and produces a result, to be stored in the IH. The Operational Tools

[7] https://fiware-datamodels.readthedocs.io/en/latest/index.html

act as an orchestrator, indicating different configuration parameters. The format selected to communicate all components is JSON. A further explanation of the main blocks of this "sub-architecture", are detailed below.

Agents block: NGSI agents converting data to eKPIs.

This block constitutes the basis of the PEI functioning schema. One cannot calculate the PEI nor its indices and subindices without having the eKPIs put in place and reachable. Assuming the data for fulfilling those eKPIs are available, the technological solution for converting data into actionable KPIs and make them ready to use is what the NGSI agents aim at performing. NGSI prefix is used to explicitly state PIXEL-FIWARE compliance.

It is worth to mention that the NGSI agents' development is an action that will deviate from one port to another. As data will be different, the treatment at this level will vary and it is responsibility of each port aiming at deploying PEI to handle the development of the agents. In PIXEL, to conduct this action, the project has assigned technical supporters (PRO, UPV, CATIE/ORANGE and INSIEL) to each port to help them having the NGSI agents developed and deployed.

Figure 5.2 clearly shows the functionality of the agents, entities involved and process:

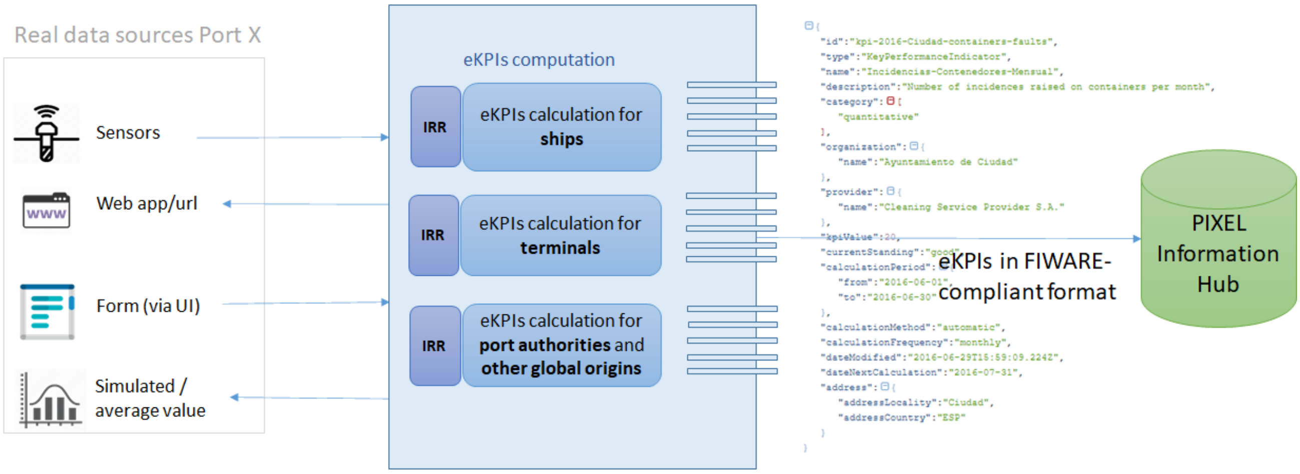


Figure 5.2 PEI calculation picture (I): Agents block

The functions that all NGSI agents must provide are the following:

1. **To retrieve the data from the original source**. This connection be: a) the agent actively queries the data source origin to retrieve the data following a periodic pattern. This case is the most common, and mainly used whenever the data source is a web service with a callable API/URL. This is also used if the value to be used for the calculations comes from a static table or from averaged values. Or b) the agent implements a data broker service (e.g. implementing FIWARE ORION, Apache Kafka or others) so that the active data origin entity points to the agent by publishing new data. With this, the agent embeds a subscriber client inside that has access to the newest data to proceed with calculation.
2. **To coarsely clean the data**: From WP6 (T6.2) it was decided to include data cleansing in the agents. For the case of PEI-related agents, this cleaning means just to obviate irrelevant parts of the data and identifying potential spurious values or outliers.
3. **To fulfil data for the IRR calculation**: The fields *"process"* and *"calculationMethod"* are completed.
4. **To process the data and convert it into eKPIs**: Each NGSI agent has been/ is being / will be developed according to the established in sections 2 and 3. Depending on which eKPIs are targeted, the calculations will be different. They might range from a simple format conversion to a complex data relation, combination and construction. Each NGSI agent may also have different number of inputs and outputs. As it is illustrated in Figure 5.3, one single agent may have multiple data feeds and generate multiple eKPIs at the same time. The relations that may exist are: 1:1:1, N:1:1, N:1:N, 1:1:N.
5. **To update the entity in the PIXEL Data Acquisition Layer (DAL)**: The main purpose of the agent is to send data upwards in the IoT stack of PIXEL. For doing so, the eKPIs obtained will be submitted to the PIXEL Context Broker (ORION) via a PUT HTTP message in order to update the "eKPI entity"

that should have been created before by the technical team. This responds to a publish-subscribe schema.

6. **To act periodically and systematically**: All NGSI agents will be pre-configured to be executed (same execution every time) each certain period. This will be changeable in the future. This periodicity option will be the source to feed the fields "*calculationFrequency*" and "*calculationMethod*" (see Figure 5.4).

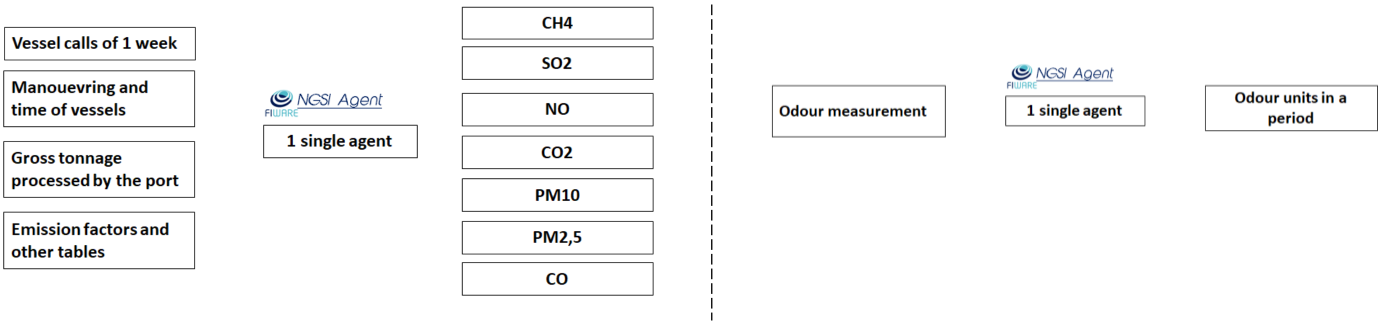


Figure 5.3 Two examples of agents converting data into eKPIs for illustrating N:1:N possibilities

For sending upwards the eKPIs' data to the DAL, the team has opted for selecting and extending one of the FIWARE Data Models: *KeyPerformanceIndicator*. Below there is the example and the reasoning behind:


```
{
  "id": "eKpi-AnimalCarcasses-ships"
  "type": "EnvironmentalKeyPerformanceIndicator",
  "name": "Animal carcass(es)",
  "description": "Animal carcass(es) of the vessels",
  "category": ["quantitative"],
  "organization": {
    "name": "THPA"
  },
  "process": "MARPOL annexes issued by vessels",
  "calculationFrequency": "fortnightly",
  "calculationMethod": "automatic",
  "calculationPeriod": {
    "from": "2019-12-29",
    "to": "2020-01-04"
  },
  "kpiValue": 0.1,
  "dateNextCalculation": "2020-01-11",
  "dateModified": "2020-01-04T23:59:59.000Z",
  "source": "ekpi-input",

  "peicategory":"Waste",
  "peilevel":"Indicator",
  "sourcePort": "SH",
  "unit":"ton"
}
```


Figure 5.4 eKPI input JSON

Fields *"id"*, *"type"*, *"name"* and *"description"* aim at describing the eKPI created each time. "organization" is the name of the port that is implementing the PEI.

As commented, *"process"* and *"calculationMethod"* are intended to allow IRR calculation, describing how "good" in terms of IoT readiness has this retrieval method been.

Depending on each eKPI, the fields "peicategory" (index), "peilevel" (always indicator) and "sourcePort" (origin entity) will be different. In the example, it is Animal Carcasses belonging to ships waste.

All previous values would remain the same for all the updates of the value of an eKPI.

The values that will be changed (updated to DAL) will be:
- *"kpiValue"* (self-explanatory)
- *"calculationPeriod":* the period that is covered.
- *"dateModified"*: when this agent was executed and provided this kpiValue.
- *"dateNextCalculation"*: dependant of the frequency of update.

Finally, a value that might change (even though not very likely) is the *"unit"* field (self-explanatory).

Composite index block: Calculating PEI.

This is the part that constitutes the "PEI as a model" component. This block consists of a series of calculations that will be invariant, following a clear algorithm. These calculations will be only known by the PEI technical designers, while remaining as a "black box" for the rest of PIXEL architecture. A black box that takes some inputs, process them and provides an output (result of the execution).

According to the PEI methodology (deliverable D5.1), and enhancing the operations described there, the backend model program performs a 4-step mathematical operation procedure:

- **From single periodical eKPIs to global eKPIs for the time frame selected for calculation:** Each eKPI produced by the previous block may have different periodicities, referring to a certain time period over that they were calculated (e.g. plastics waste requested by ships to be processed by the port during the month of April). These eKPIs are also attributable to an entity of the port (port authority, terminals or ships) or to a global category. On the other hand, the PEI calculation has a clearly associated global time frame (e.g. the PEI of last month of February).

- **From eKPIs to subindices**: Six subindices have been selected: Emissions to the atmosphere, water, noise, waste, odour and light. At this step, the operations will be (in that order):
    - **Normalization**: each eKPI must be normalised against one value. The program developed has been prepared to accept various normalization methods. It has been established that the same normalization method must be used for all eKPIs in a single execution of the PEI. Further explanation can be found in section 4.7.
    - **Weighting:** all eKPIs feeding one subindex (e.g. CH_4, CO_2, etc. feeding Air emissions of ships) will have an assigned weight. The program developed has been prepared to accept various weighting assignment methods. More info in section 4.8.
    - **Aggregation:** The program developed has been prepared to accept two aggregation methods**.** More info in section 4.9.
- **From subindices to indices**: The result here will be four indices attributable to an entity of the port (port authority, terminals or ships) or to a global category.
- **From indices to the PEI**: This final step will merge the different indices (which already contain meaningful information themselves) into a single quantified metric, that has been the objective of all the work package: The Port Environmental Index.

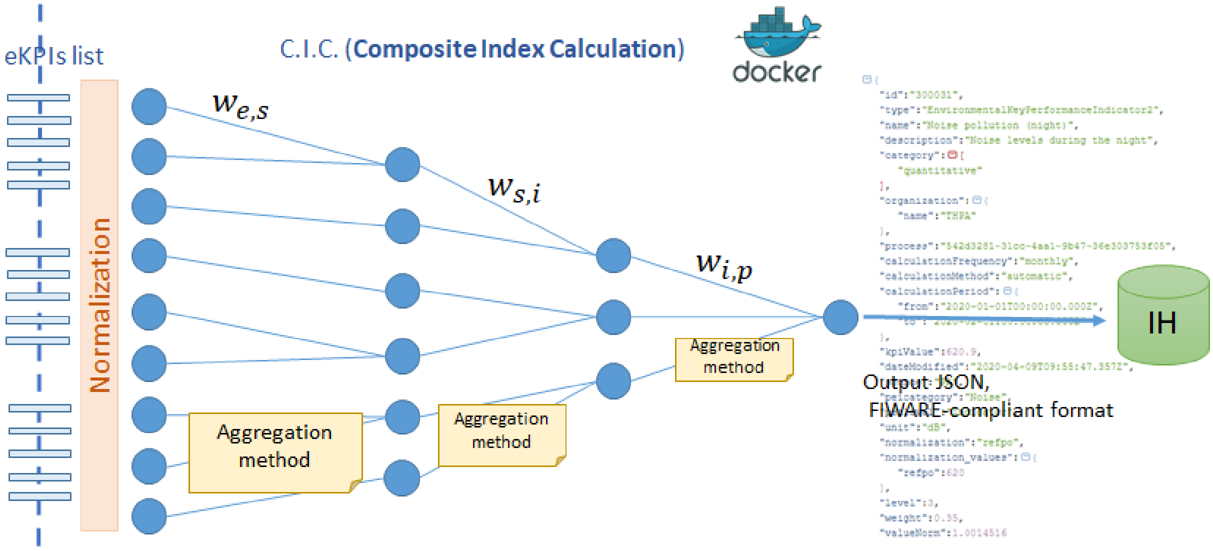


Figure 5.5 PEI calculation picture (II): Composite index Agents block

```
{
  "id": "300031",
  "type": "EnvironmentalKeyPerformanceIndicator2",
  "name": "Noise pollution (night)",
  "description": "Noise levels during the night",
  "category": ["quantitative"],
  "organization": {
    "name": "THPA"
  },
  "process": "542d3281-31cc-4aa1-9b47-36e303753f05"
  "calculationFrequency": "monthly",
  "calculationMethod": "automatic",
  "calculationPeriod": {
    "from": "2020-01-01T00:00:00.000Z",
    "to": "2020-02-01T00:00:00.000Z"
  },
  "kpiValue": 620.9,
  "dateModified": "2020-04-09T09:55:47.357Z",
  "source": "PA",

  "peicategory": "Noise",
  "peilevel": "Indicator",
  "unit": "dB",

  "normalization": "refpo",
  "normalization_values": {
    "refpo": 620
  },
  "level": 3,
  "weight": 0.35,
  "valueNorm": 1.0014516
}
```


Figure 5.6 PEI output JSON

The program (in Java) developed to perform the previous is described in section 5.2. Figure 5.5 aims at representing graphically the methodology explained.

At the left of this text, Figure 5.6 represents the format (JSON) that has been designed by the team to store the results of the computation of the PEI into the Information Hub.

Like for the agents' output, the KeyPerformanceIndicator data model has been used and extended for this purpose.

The idea is that, with this format, the PEI program constructs an output including all nodes of the calculation tree as if they were expressions of eKPIs, differentiated with the field "*type*" and the "*level*", which indicates the position within the tree of that JSON.

With this, the PEI-node JSON will only indicate "level" 0 (zero) the aggregation method and the value. JSONs of the subindices and indices will include aggregation and weighting methods used, as well as the final value of each. Finally, the most extended JSON (figure at the left) will contain the normalization information (method and values used), the origin, weight, units and PEI category of each eKPI.

5.1.2. Operational Tools

As commented in deliverable D5.2 (section 7.1), the PEI is considered, from PIXEL technological framework viewpoint, as a model. Like any model, the PEI is scheduled and executed by the Operational Tools. Besides, it can be recognised in Figure 5.1 that the OT are a needed enabler in order to provide the links between the southbound module (Information Hub) and the application (northbound) service, which is the PEI.

Conceptually, the Operational Tools (OT) module acts as the orchestrator providing the intelligence to the procedure. In the next figure, the procedure that the Operational Tools follow for all models is indicated. A more detailed explanation of the Operational Tools can be found at deliverable D6.3. Additionally, a full reference of Operational Tools configuration, deployment and associated UI is already available (in its version v2) and will be documented via deliverable D6.4 and D6.5 (month M26).

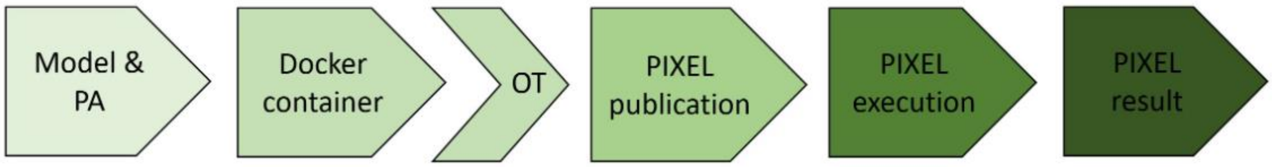


Figure 5.7 Operational Tools as manager of PEI model execution

The process that the PEI has experienced / will experience with regards to Operational Tools interaction is:

- The PEI was first drafted (during first months of T5.3) and finally has been implemented as program (last months of task T5.3). Details of the program developed are explained in the next sub-section 5.2.
- PEI "model part (backend)" has been encapsulated into a Docker container to convert it into a portable component. The current version is available in the internal Git repository of the project[8], so that any partner can at this moment have access to the PEI calculation module. Additionally, an OT adaptor is attached to this Docker container to be integrated into the PIXEL platform.
- Through the publication process the PEI becomes aware into the PIXEL platform. The Docker image is pulled from the private Git repository or from an open GitHub repository (the exploitation task T9.4

[8] https://gitpixel.satrdlab.upv.es/ravagar/PEI_dev

is analysing the licensing and publishing structure for each PIXEL asset at this moment) and can be used internally. This means that, once PIXEL will be single-instance installed in the on-premises servers in a port, PIXEL personnel will publish PEI as an available service within the platform to be used by that port. This publication is effective because the OT adaptor contains a clear explanation of PEI model: type of model, the type of execution it allows and what the PEI requires to be run. This information has been created using the template established by the Operational Tools leader (UPV), and it is informed via a JSON file named *GetInfo*. The PEI file of *GetInfo* is attached in B.1 (Appendix B).

- After published, the PEI can be executed by the Operational Tools by passing the appropriate arguments (parameters) as JSON file. This means that, each time the OT module runs the PEI, certain parameters are indicated (as input) for allowing PEI having enough knowledge of the environment to retrieve needed information, mainly: from where to retrieve data, normalization values, where to store the results. This parameterisation of the PEI is done through another JSON file named *Instance*. The PEI file of *Instance* is attached in B.2 (Appendix B) at the end of this document.
    - For the PEI, it has been established that the execution may run per-request (real time) or under a scheduled fashion. The planned executions for the PEI are weekly and monthly.

```
docker run pixelh2020/pei '{"id":"5e3d7ghae2cabc05ec59a25t","idRef":"5e99b5ad44fce835ce6a9f73","name":"pei-execution1","d
```

- The results of the PEI are stored into the PIXEL Information Hub with the format explained in Figure 5.6, which can be queried by the PIXEL Dashboard to visualize them in form of particular graphs depending on the model or predictive algorithm. This is clearly observed as well at the right part of Figure 5.1.

5.2. Structure of the computation

The previous sub-sections have provided all valuable information enough to instantiate the PEI calculation methodology into an actionable tool. This means, converting theoretical design into executable code.

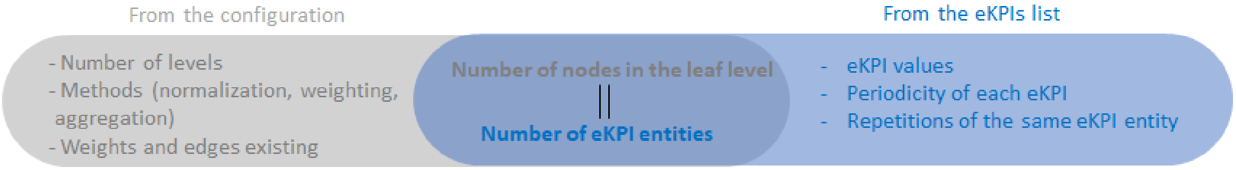
The options for the implementations were varied. Regarding the agents, as it is stated below, it is up to each port and technical supporting partner assigned to decide (nonetheless, what is currently being used is the Python library specifically designed in T6.2 for NGSI agents implementation[9]). Regarding the composite index computation, several discussions were held. While Python remained valid, the technical team decided to develop the code in Java because of (i) previous works on tree and binary decision trees (similar to network functioning), (ii) knowledge and expertise of the team and (iii) benefits of object-oriented paradigm for this case.

According to the previous, the software was developed following an iterative approach. To explain the software, in 5.2.1 a diagram class is provided, for 5.2.2 the team created sequence diagrams and here below there is an explanation of the execution flow:

1 - Read properties from the PEI_instance.json file generated by the Docker image (via OTs)

- URL (within the same virtual server where PIXEL is installed) where the Information Hub is located.
- Indices of the database (IH) where – one for each- (i) the eKPIs data are, where (ii) the Configuration information is, where (iii) the logging must be stored and where (iv) the output of the PEI computation must be stored.
- URL (web service) of the API where the normalization values are (if the normalization used indicated is REFPO).

2 – Retrieve and validate the tree structure



[9] https://pypi.org/project/pyngsi/

Figure 5.8 Software structure (2) – Tree validation

3 – Build tree structure

With the information retrieved of the tree structure, the program uses proper classes (Node and Edge), to build the tree. This is done following the classical approach of **downward generation,** starting from the root node:

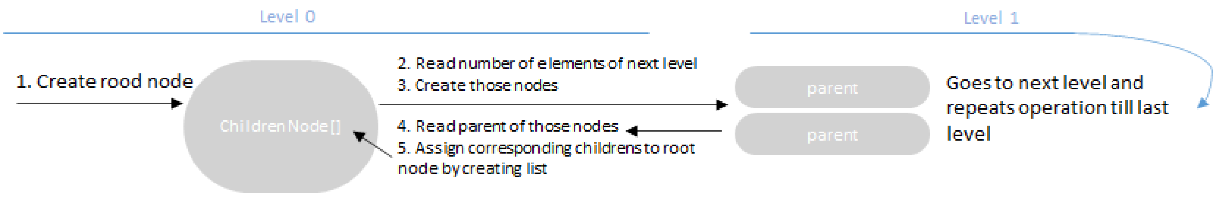


Figure 5.9 Software structure (3) – Tree creation

4 - Retrieve all inherited eKPIs for the calculation period

This step consists of querying the IH with the global period info and of reading and filtering the JSONs obtained.

5 - Calculate global eKPIs for the corresponding period and normalize them

6 – Run the PEI calculation drawing from the values of the global eKPIs for that period

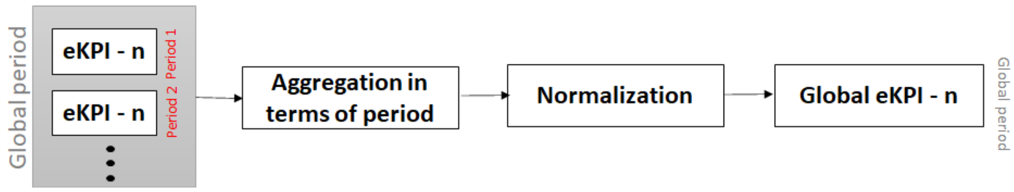


Figure 5.10 Software structure (5) – Normalization

Once the previous is available, the next step is to update the values of each node considering all operations needed: weighing and aggregation, always respecting the direction of the edge arrows in the tree and the inheritance relations (parent-children). In this regard, all nodes (except leaves) must have a method in order to aggregate the weighted values of children nodes. In order to properly conduct this "fulfilment" of values, the approach to be followed is the upwards propagation, starting by the leaf nodes (eKPIs):

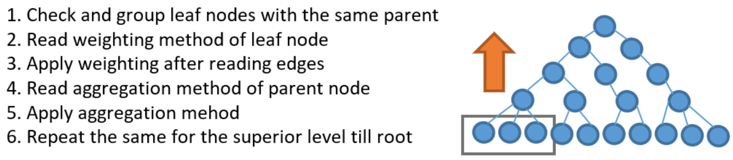


Figure 5.11 Software structure (6) –Calculation of values

7 - Build the output JSON with the results and the required global values

Afterwards, according to the explanations attached to Figure 5.6, the program creates different JSONs for the different level nodes depending on the level of the tree they are located. Some information is extracted directly from the input eKPIs and some other information (mainly, the value of each node) from the results within the program.

8 – Storage of the output in the Information Hub

The last step is to make an insert query request to the index of the database (IH) where the output of the PEI computation must be stored.

5.2.1. Class diagram

The technical structure of calculation that has been exposed above is, in code terms, governed by a main class (usual practice in Java programs) that has been named "CIC calculator" by the T5.3 team. One useful resource to understand how instructions are translated into executable code is to include a class diagram.

Class diagrams aim at reflecting the relation of the different software classes (Java language, again) used to implement the software. It means, indicating the different objects of the reality (in an object-oriented paradigm) created, fulfilled and manipulated to perform the PEI calculation.

The figure below represents a summarised version of the class diagrams that are present in the code developed. Appendix C contains all the class diagrams. Those diagrams have been generated with the tool ObjectAid UML[10] (plugin of the Eclipse IDE).

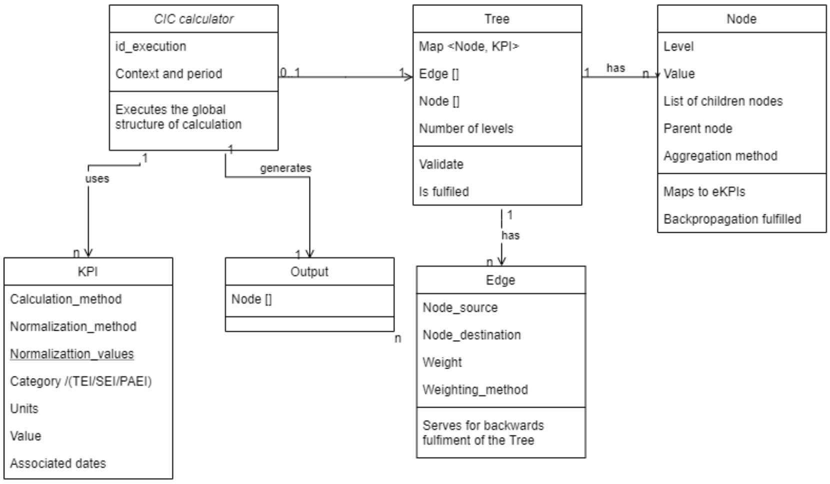


Figure 5.12 Class diagram summary of PEI calculation

5.2.2. Flow diagrams

Another interesting visual resource to understand the steps of the program coded are the flow (or sequence) diagrams. For documenting this part, the T5.3 team has found useful to provide two flow diagrams to illustrate (i) how and by which module is data processed and (ii) what is really the structure of the calculation of the PEI with its different indices and subindices in the "model backend" part of the PEI computation.

[10] https://www.objectaid.com/home

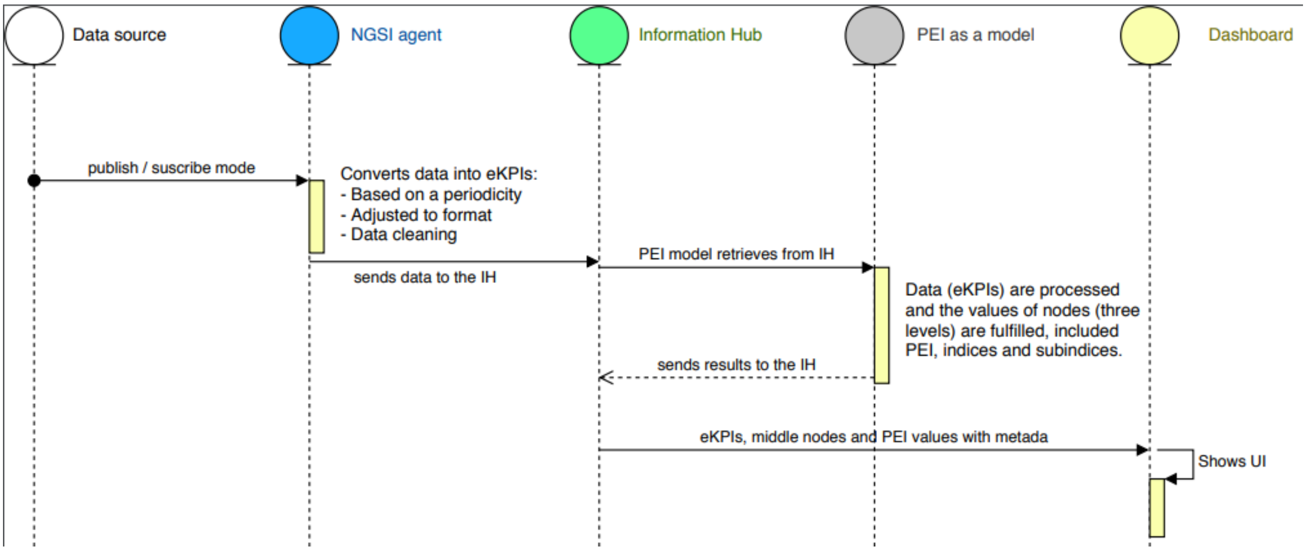


Figure 5.13 Diagram of the data flow in PEI and relation with PIXEL modules

As it can be observed, almost every PIXEL module is involved in the whole data handling procedure of PEI data. The NGSI agents (see section 5.1.1) are in charge of the conversion data-eKPIs, the Information Hub stores both the “baseline data” (eKPIs) and the results, the Operational Tools are the module responsible for orchestrating the (periodic) execution and the Dashboard (PIXEL UI) shows the results of the calculation. The only module not included in the sequence is the security, which is a transversal tool with no direct intervention in the data flow.

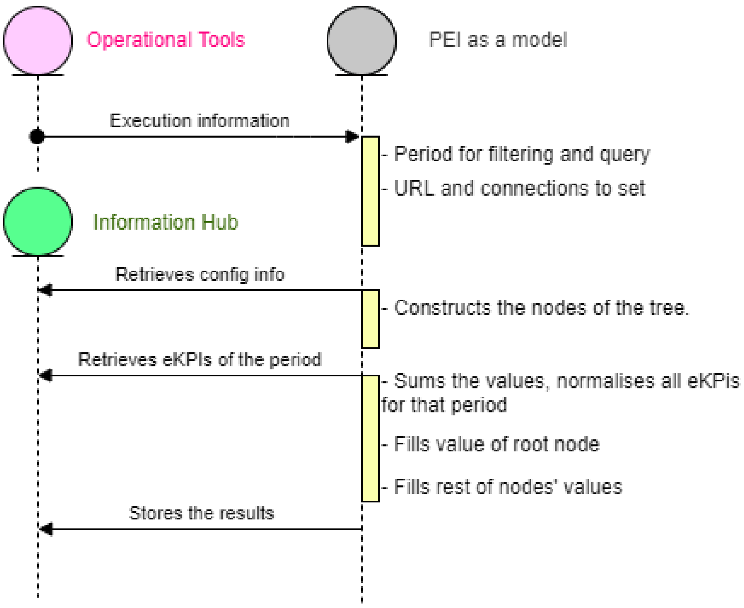


Figure 5.14 Flow of PEI calculation and actors involved

5.3. User-interface interaction (PEI in PIXEL)

The program that has been explained in the previous section is developed, available and works perfectly as long as a solid set of eKPIs are properly stored in one instance of the Information Hub. However, for the real deployment of PIXEL in a port, the software explained above is only one a slice of the cake of the whole actions and interactions needed.

This section aims to be a quick, incomplete, WP5-constrained, technical guide of the PEI use. It encompasses, mainly, what technical staff should do, what the port environmental staff would encounter, the different options and configurations available and how the results would be provided to all of them.

First action: *Technical staff* installing the PIXEL platform

The guidelines for the installation of all PIXEL architecture components in the on-premises (or cloud) servers of the port are being elaborated right now by the WP6 and WP7 team. The idea is that one assigned person (currently, the responsible is one member of the partner ORANGE) will integrate all modules of PIXEL in the selected server, will make all needed connections and will set the security permissions right.

Second action: *Technical staff* with *Port staff:* Linking data sources to PIXEL

This second action is crucial for the accuracy of the PEI calculation. It is sub-divided in three stages:

- *Stage 1 of second action: Available data*

A table like Table 1.1 (or Table 1.2Table 1.3 orTable 1.9) must be created by the Port staff before implementing PEI. This table will allow the technical team to know how to integrate all data needed for the PEI calculation (thus, having all eKPIs). According to the final look of that table, the options are:

a) Some data will come in an automated way. This is tackled in the next stage.
b) Some data will need the enablement of forms for manual input.

- *Stage 2 of second action*: *Linking the data*

At this stage, the technical staff will analyse the mentioned table and will proceed with the developments of the NGSI agents to properly connect the data to the PIXEL platform. A guide on how to develop and integrate an NGSI agent can be found at the deliverable D6.3 available in PIXEL website.

For the pieces of data that will not be automated, the technical team will enable in the platform the options for manual input (see section 1.2.2.2 to check examples of how to introduce that data).

- *Stage 3 of second action: Checking linkage*

Technical and port staff will check that the stage 2 has achieved its objective. Using the map functionality within the PIXEL UI (see in deliverable D6.3), both users and technicians will be able to check if the data sources selected have been properly integrated. If the values are updated and can be seen referenced in the map, there will be the certainty that the eKPIs will be up-to-date in the Information Hub.

Third action: *Port Environment Department / user*: Static information before running the PEI for the first time

According to section 1.1.1, the system has been designed to leverage certain PIXEL tools (AIS, PAS) for having inputs for the PEI. Here is when the port staff must introduce the needed information to enable that leveraging:

- A map of the port must be uploaded to the platform. The map must contain a point-defined polygon with the coordinates that define the sea area of the port. This will feed the **AIS module** that, with that information, will return manoeuvring and berthing time of all vessels operated by the port.
- Introduction of data relative to the supply chains in the port to feed the PAS model. The technical team in WP6 has developed a web tool (UI) allowing ports to introduce enough information to model their supply chains. In Figure 5.15, there is an example screenshots of this tool. The data that must be introduced by the port staff are: port areas, port equipment (machinery), resources and rules of the supply chains (prioritization of operations, work timetable of personnel and machinery, etc.).

A formation session is scheduled for the PIXEL ports to fulfil this data. This session will be recorded and will be included in the acquisition of PIXEL product by any external port.

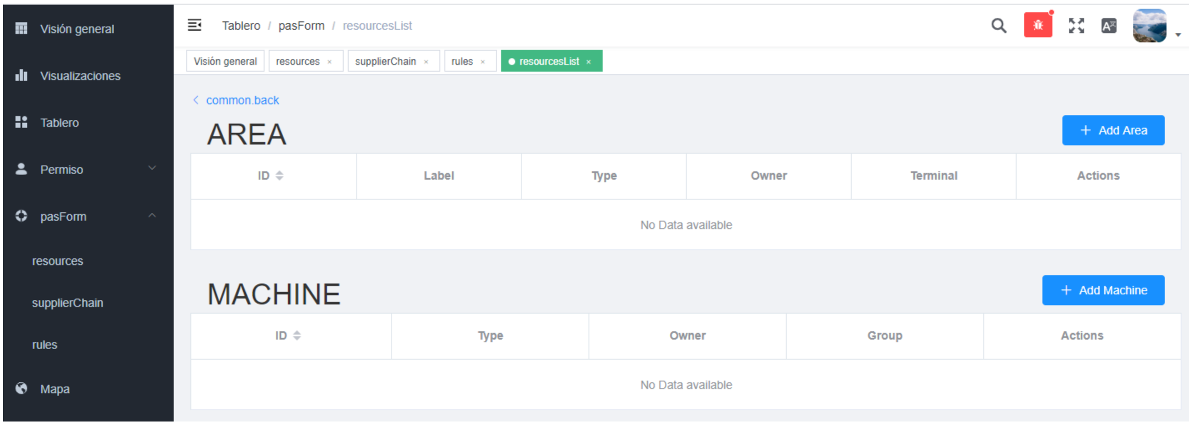


Figure 5.15 Screenshot of PAS configuration

Fourth action: *User*: Dynamic information to be introduced before running PEI (optional consequent times)

As commented in sections before, there is an important component of "auxiliary data" feeding the PEI backend calculation. This component has been referred as "configuration data" or just "tree". This information must be introduced (at least, once) by the user. Before the first execution of the PEI, all this data must be fulfilled. For consequent executions, if the user wishes to change the configurations, a proactive action is needed. If not changed, the scheduled execution will run with the original values. The parameters are the following:

- Weights and weighting method
- Normalization method (and normalization values if proceeds).
- Aggregation methods
- Updating strategy: This consists of some options that the user can select (mutually exclusive) for indicating the software how to proceed in case of not-updated value of eKPIs (e.g. the CO_2 value of the terminal was updated on 1st February and the system does not have a more recent register; however, the period of PEI calculation is from 15th February to 22nd February):
  - Ask every time: via a web form, so that the user can type the value desired to be used.
  - Replicate the last value available (this option would mean extrapolating the value of the eKPI for the proper extension of the current calculation period).
- Missing value strategy: whenever there are no values of a certain eKPI for that calculation period:
  - Use a valid average
  - Consider it zero
  - Drop that eKPI from PEI calculation

Despite being configurable, the first time the user enters in the UI for setting these parameters, they will be already completed with default values. The default values will be the ones resulting out of the work exposed in section 4, that will be refined during WP7 (T7.5).

Fourth action: Installation of the program and scheduling and

Whenever the previous is achieved, the technical team will install the PEI as a model (publish in the platform – see section 5.1.2), and it will be scheduled to be running each week.

Fifth action: Scheduled execution of the program: interaction and results

According to decisions made in WP5, the results will be updated and shown to the user on Monday morning with weekly and monthly periodicity.

Before every execution, the system will check if the web forms have been fulfilled for that period and, if not, will not run the PEI and will allow the user to type the data via those web forms or will also allow the user to select the completion of the information following the "update strategy" or the "missing value strategy"[11].

[11] This functionality has not yet been included in the software delivered, as it will be further analysed and deployed during the last months of tasks T5.4 and T5.5 and under the scope of task T7.5

After this is set, the PEI will run. Internally, all calculations detailed in 5.2 will be performed and the output will be stored in the Information Hub.

The visualization will be done through the specific tab that has been created in the menu (see left bar) of the PIXEL UI. Figure 5.16 shows a screenshot of the already-working tool.

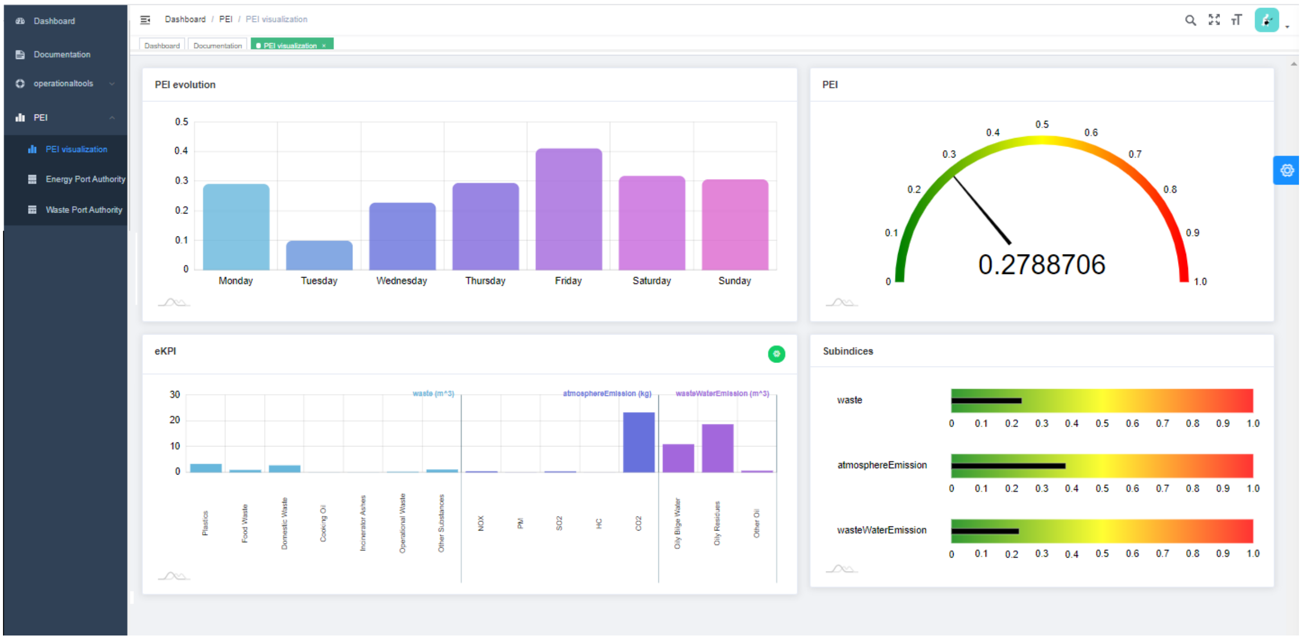


Figure 5.16 Generic visualization of PEI results

As it can be noted, the visualization implemented in the platform is completely aligned with the designs and specifications done at the beginning of task T5.3. Those designs can be consulted in section 9 of deliverable D5.2, which is publicly available in PIXEL website here: https://pixel-ports.eu/?page_id=30

Regarding the enhanced visualization interfaces mentioned at the end of that document, all have been analysed during the course of the task T5.3 and it has been decided that task T7.5 will deal with those implementations. The reasons behind this decision are:

a) Depending on which feature is more interesting for a port, one visualization or another will be deployed in each port.
b) Sensitivity and uncertainty propagation analysis have been postponed to task T7.5, altogether with further tests on the data, eKPIs and functionalities. It seemed wise to wait till those results will be available to deploy final visualizations, which will for sure be more fine-tuned.

Despite the previous, the remarkable aspect here is that the platform has been prepared to host and link all those visualization types (e.g. historical comparison of values, or what if scenario playground).

It is also remarkable that this slight deviation will not cause any major incidence to the project execution.

Sixth action (variant of the fifth): *The user* requests an execution of the PEI (on-demand)

This action will have the same results than the fifth. Alerts, management of missing/not updated values and visualization of the results will remain equal.

The only difference is that, in this case, the execution of the model is not triggered by an internal pre-planned scheduled but via a manual request by the user.

For the future – **Seventh and Eighth action**: Report of the execution and provision of recommendations

The final steps cannot be explained in detail at this moment. Both the report of the execution and the provision of the recommendations are planned to be ready (at a theoretical level) whenever T5.4 and T5.5 will end. However, it is expected that WP7 and WP8 will fine-tune those outcomes and the real final landscape of these features will not be closed till the end of the project.

Conclusion

The previous deliverable, 5.2 PEI and algorithms v1 laid out the baseline for building PEI as a composite indicator. This document, deliverable 5.3 PEI and algorithms v2, is a direct follow up and deals with the final procedures for the PEI data retrieval through IoT sources, eKPIs, statistical and technical toolboxes. In the first chapter the data acquisition methods, with the emphasis being on data availability and sources in the four PIXEL pilot ports were outlined. The following two chapters dealt with the final eKPIs and how they can be identified and quantified or calculated if proxy data is needed. Chapters 4 and 5 laid out the statistical methods and the technical toolbox which will be used for the PEI execution. The first real PEI trial with all the components will be executed in WP7, starting with Port of Thessaloniki as it was stated here because that port has suitable conditions for it.

References

African Development Fund (2008). Djibouti - Doraleh Container Terminal Port Project (Environmental and Social Impact Assessment Summary (Esias)). Private Sector Department Infrastructure and PPP Division (OPSM.3)

Bachvarova, E., Spasova, T. and Marinski, J. (2018), "Air Pollution and Specific Meteorological Conditions at the Adjacent Areas of Sea Ports", IFAC-PapersOnLine, Elsevier B.V., Vol. 51 No. 30, pp. 378–383.

Bailey, D. and Solomon, G. (2004), "Pollution prevention at ports: Clearing the air", Environmental Impact Assessment Review, Vol. 24 No. 7–8, pp. 749–774.

Bang, H.Q. and Khue, V.H.N.K. (2019), Air Emission Inventory, IntechOpen.

Bedrosian, T. A., & Nelson, R. J. (2017). Timing of light exposure affects mood and brain circuits. Translational psychiatry, 7(1), e1017. https://doi.org/10.1038/tp.2016.262

Cai, H., Wang, M., Elgowainy, A., & Han, J. (2012). Updated greenhouse gas and criteria air pollutant emission factors and their probability distribution functions for electricity generating units (No. ANL/ESD/12-2). Argonne National Lab.(ANL), Argonne, IL (United States).

Carruthers, D. and Kāla, A. (2012). Odour modelling using ADMS software. Aplinkos apsaugos agentūra. Lithuania

Chen, T.M., Gokhale, J., Shofer, S. and Kuschner, W.G. (2007), "Outdoor air pollution: Nitrogen dioxide, sulfur dioxide, and carbon monoxide health effects", American Journal of the Medical Sciences, Elsevier Masson SAS, Vol. 333 No. 4, pp. 249–256.

Chirmata, A., & Ichou, I. A. (2016). Odour Impact Assessment by Means of Dispersion Modeling, Dynamic Olfactometry and Mobile Electronic Nose around Agadir Fishing Port in Morocco. Journal of Environmental Protection, 7(12), 1745-1764.

Clear Seas. Air Pollution & Marine shipping. 2020 [Accessed: April 2020]. Available from: https://clearseas.org/en/air-pollution/

Corson, L. A., & Fisher, S. A. (2009). Manual of best management practices for port operations and model environmental management system.

Curtis, L., Rea, W., Smith-Willis, P., Fenyves, E. and Pan, Y. (2006), "Adverse health effects of outdoor air pollutants", Environment International, Vol. 32 No. 6, pp. 815–830.

Czachorski, M., & Leslie, N. (2009). Source energy and emission factors for building energy consumption. American Gas Association, prepared for Natural Gas Codes and Standards Research Consortium.

Darbra, R.M., Ronza, A., Stojanovic, T.A., Wooldridge, C. and Casal, J. (2005), "A procedure for identifying significant environmental aspects in sea ports", Marine Pollution Bulletin, Vol. 50 No. 8, pp. 866–874.

Deru, M., & Torcellini, P. (2007). Source Energy and Emission Factors for Energy Use in Buildings (Revised) (No. NREL/TP-550-38617). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Donateo, A., Gregoris, E., Gambaro, A., Merico, E., Giua, R., Nocioni, A. and Contini, D. (2014), "Contribution of harbour activities and ship traffic to PM2.5, particle number concentrations and PAHs in a port city of the Mediterranean Sea (Italy)", Environmental Science and Pollution Research, Vol. 21 No. 15, pp. 9415–9429.

Dravnieks, A., Masurat, T., & Lamm, R. A. (1984). Hedonics of odors and odor descriptors. Journal of the Air Pollution Control Association, 34(7), 752-755.

Ec.europa.eu. 2008. Directive 2008/98/EC On Waste (Waste Framework Directive) - Environment - European Commission. [online] Available at: <http://ec.europa.eu/environment/waste/framework/> [Accessed 2 April 2020].

Elsahragty M. andKim J.L. (2015). Assessment and strategies to reduce light pollution using geographic information systems. Procedia engineering. 2015 Jan 1;118:479-88.

Environment Agency (2011) Additional guidance for H4 Odour Management How to comply with your environmental permit. Environemntal Agency

ESPO. Environmental Report 2018. EcoPortsinSights 2018. European Sea Ports Organization (ESPO). 2018

ESPO (European Sea Ports Organisation), ESPO/EcoPorts Port Environmental Report 2019, EcoPortsinSights 2019. https://www.espo.be/media/Environmental%20Report-2019%20FINAL.pdf

Geerlings, H. and Van Duin, R. (2011), "A new method for assessing CO2-emissions from container terminals: A promising approach applied in Rotterdam", Journal of Cleaner Production, Elsevier Ltd, Vol. 19 No. 6–7, pp. 657–666.

GEF-UNDP-IMO GloMEEP (2018). Project and IAPH, 2018: Port Emissions Toolkit, Guide No.1, Assessment of port emissions.

Gómez, A.G., Ondiviela, B., Puente, A. and Juanes, J.A. (2015), "Environmental risk assessment of water quality in harbor areas: A new methodology applied to European ports", Journal of Environmental Management, Vol. 155, pp. 77–88.

Gothenburg Port Authority (2017). Sustainability Report 2017. Gothenburg Port Authority

Green Ship of the Future. Hydrocarbons. 2020 [Accessed: April 2020]. Available from: https://greenship.org/about/emission-wiki/hydrocarbons/

Gupta, A.K., Gupta, S.K. and Patil, R.S. (2005), "Environmental management plan for port and harbour projects", Clean Technologies and Environmental Policy, Vol. 7 No. 2, pp. 133–141.

de la Lanza Espino, G., Rodríguez, I.P. and Czitrom, S.P.R. (2010), "Water quality of a port in NW Mexico and its rehabilitation with swell energy", Marine Pollution Bulletin, Elsevier Ltd, Vol. 60 No. 1, pp. 123–130.

IMO International Maritime Organization. International Convention for the Prevention of Pollution from Ships (MARPOL). 2020 [Accessed: April 2020]. Available from: http://www.imo.org/en/Pages/Default.aspx

Jägerbrand, A. K., Brutemark, A., Svedén, J. B., & Gren, M. (2019). A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. Science of the Total Environment, 133637.

Joint Research Centre-European Commission. Handbook on constructing composite indicators: methodology and user guide. OECD publishing; 2008 Aug 22.

Kephalopoulos, S., Paviotti, M., & Anfosso-Lédée, F. (2012). Common noise assessment methods in Europe (CNOSSOS-EU).

Magutu, P. O., & Onsongo, C. O. (2011). Operationalising municipal solid waste management. Integrated Waste Management, 2, 3-10.

Martínez-Moya, J., Vazquez-Paja, B. and Gimenez Maldonado, J.A. (2019), "Energy efficiency and CO2 emissions of port container terminal equipment: Evidence from the Port of Valencia", Energy Policy, Elsevier Ltd, Vol. 131 No. March, pp. 312–319.

McCarthy M. (2003). Investigation into reducing odour emissions from partly loaded sheep vessels whilst in port. Project LIVE. 2003;213.

Mohee, R., Surroop, D., Mudhoo, A. and Rughooputh, B.K. (2012), "Inventory of waste streams in an industrial port and planning for a port waste management system as per ISO14001", Ocean and Coastal Management, Elsevier Ltd, Vol. 61, pp. 10–19.

Moldanová, J., Fridell, E., Winnes, H., Holmin-Fridell, S., Boman, J., Jedynska, A., ... & Ivleva, N. P. (2013). Physical and chemical characterisation of PM emissions from two ships operating in European Emission Control Areas. Atmospheric Measurement Techniques Discussions, 6(2).

Nicolay, X. (Ed.). (2006). Odors in the food industry (pp. 57-74). New York, NY, USA:: Springer.

Nielsen, M., Nielsen, O. K., & Plejdrup, M. (2018). Danish emission inventories for stationary combustion plants. Scientific Report from DCE – Danish Centre for Environment and Energy No. 279

Olson, P.H. (1994), "Handling of waste in ports", Marine Pollution Bulletin, Vol. 29 No. 6–12, pp. 284–295.

Paipai, E. (1999). Guidelines for Port Environmental Management, Report SR 554.

Pérez, I., González, M.M. and Jiménez, J.L. (2017), "Size matters? Evaluating the drivers of waste from ships at ports in Europe", Transportation Research Part D: Transport and Environment, Elsevier, Vol. 57, pp. 403–412.

Peris-Mora, E., Orejas, J.M.D., Subirats, A., Ibáñez, S. and Alvarez, P. (2005), "Development of a system of indicators for sustainable port management", Marine Pollution Bulletin, Vol. 50 No. 12, pp. 1649–1660.

Saharidis, G.K.D. and Konstantzos, G.E. (2018), "Critical overview of emission calculation models in order to evaluate their potential use in estimation of Greenhouse Gas emissions from in port truck operations", Journal of Cleaner Production, Elsevier Ltd, Vol. 185, pp. 1024–1031.

Schubert, E.F. (2006). Light-Emitting Diodes (2nd edition). Cambridge University Press. Cambridge

Sorte, S., Lopes, M., Rodrigues, V., Leitão, J., Monteiro, A., Ginja, J., Coutinho, M., et al. (2018), "Measures to reduce air pollution caused by fugitive dust emissions from harbour activities", International Journal of Environmental Impacts: Management, Mitigation and Recovery, Vol. 1 No. 2, pp. 115–126.

Spotlight. Where Maritime Regulation and Technology Meet. 2020 [Accessed: April 2020]. Available from: https://shipinsight.com/

Townsville Ocean Terminal (2007). Environment Impact Assessment (EIS). Townsville Ocean Terminal Project. 2007 Nov

Trozzi, C. and De Lauretis, R. (2019), EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016 - InternationalMaritime and Inland Navigation, National Navigation, National Fishing, Recreational Boats

Trozzi, C., Nielsen, O. K., Plejdrup, M., Rentz, O., Oertel, D., Woodfield, M., & Stewart, R. (2019), NFR: 1. A. 1 Energy industries SNAP: 01 Combustion in energy and transformation industries.

Van Breemen, T. (2008). Good Practice Guide on Port Area Noise Mapping and management, Noise Management in European Ports (NoMEPorts) project (pp. 44-50). LIFE05 ENV/NL/000018.

Viana, M., Hammingh, P., Colette, A., Querol, X., Degraeuwe, B., Vlieger, I. de and van Aardenne, J. (2014), "Impact of maritime transport emissions on coastal air quality in Europe", Atmospheric Environment, Elsevier Ltd, Vol. 90, pp. 96–105.

Villalba, G. and Gemechu, E.D. (2011), "Estimating GHG emissions of marine ports-the case of Barcelona", Energy Policy, Elsevier, Vol. 39 No. 3, pp. 1363–1368.

Weisser, D. (2007), "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies", Energy, Vol. 32 No. 9, pp. 1543–1559.

Whall C, Cooper D, Archer K, Twigger L, Thurston N, Ockwell D, McIntyre A, Ritchie A. (2002). Quantification of emissions from ships associated with ship movements between ports in the European Community. Report for the European Commission. Entec UK Limited, Northwich, Great Britain. 2002 Jul.

Wibowo, T. S., Purwanto, P., & Yulianto, B. (2017, March). Analysis of public perception about impaired odor in center fishery processing industry Tegalsari Tegal city. In AIP Conference Proceedings (Vol. 1818, No. 1, p. 020066). AIP Publishing LLC.

Zhang, Y., Peng, Y.Q., Wang, W., Gu, J., Wu, X.J. and Feng, X.J. (2017), “Air emission inventory of container ports’ cargo handling equipment with activity-based ‘bottom-up’ method”, Advances in Mechanical Engineering, Vol. 9 No. 7, pp. 1–9.

Appendix A – Sensors research

A.1. List of sensors in consideration

A.1.1. Noise

Expected outputs:

Table A.1 Expected outputs on noise sensors

Data required	Type of data	Unit
Date	Date	
Measure	Decimal value	dB
Location	Geographical coordinates	Decimal degrees (WGS84)
Method	Text	

Recommendable technical requirements:

- Measure sensor unit in decibels
- Fully solar-powered.
- 24h a day 7 day a week fully autonomous
- Access to its information via API
- WIFI, Ethernet or 3G (consider use of a gateway)
- Weatherproof and waterproof
- Microphone directive. Omnidirectional.

List of sensors available in the market:

Table A.2 Noise sensors studied (1): Urbiotica

Name	U-Sound noise sensor	***Manufacturer***	Urbiotica
Url	https://www.urbiotica.com/en/producto/u-sound-3/		
Description	U-Sound allows 24h a day 7 day a week fully autonomous noise monitoring. It enables the creation of a permanent monitoring network for controlling a city's trouble spots and configuring alerts for cases where the established noise levels are exceeded		
Technical details	- **Measurement quality**. Range is from 40dB to 110dB with an accuracy of ±2dB and a resolution of 0.1dB. Frequency range from 20Hz to 20kHz. - **Communication**: IEEE 802.15.4 at 2.4GHz and the maximum distance in relation to the communication elements is 100 meters. The communication between gateway and the platform is configurable: WIFI, Ethernet or 3G. - **Power**: It includes rechargeable batteries. It is powered by the lighting system or solar panels (U-Sun). - **Environment**: The operating temperature range is -33º to 65º and it has wind and rain protection. - **Dimensions**: Height is 34cm (microphone included), 7cm wide and 16cm long.		
Other details	- It is possible to receive alerts for exceeding the previously defined noise levels. - It is necessary the use of a gateway. - The access to the information is via **API**. - Discarded due to the complexity of the solution to be installed and price.		

Table A.3 Noise sensors studied (2): Sensor team

Name	IoT SoundSensor	***Manufacturer***	Sensor Team
Url	https://www.iotsoundsensor.com/en/		
Description	Noise monitoring using the Internet of Things. Live data dashboard and reporting. GPS positioning.		
Technical details	- **Solar powered**. Fully solar-powered. No power supply or internet connection is needed which allows our sensors to be installed anywhere. - **High-quality sound level monitoring**. Engineered using state-of-the-art technology, the IoT SoundSensor comes in a high-grade, damage resistant casing. - **Weatherproof and waterproof**. Our sensors come in a waterproof casing for year-round outdoor operability in all weather conditions. - **Nationwide coverage**. The system’s connection to the nationwide LoRa network makes that it works both indoors and outdoors. - 24/7 connectivity with LoRa wireless technology. Wireless LoRa connectivity. This network is ideally suited for long-distance data transmission. - **Dinamic range**. 33 to 121dB - **Microphone directive**. Omnidirectional. - **Operative temperature**. Range from -10º to 60º		
Other details	- It is possible to receive alerts for exceeding the previously defined noise levels. - It is necessary the use of a gateway. - The access to the information it’s via API. - Discarded due to difficulties on reaching the device provided.		
Price	- 1499€		

Table A.4 Noise sensors studied (3): enLight

Name	enLight Noise Sensor	***Manufacturer***	enLight
Url	http://enlight.network/noise-sensor/		
Description			
Technical details	- Programmable threshold. - Threshold exceeded event counter - RMS Sound level - Mountable at height away from interference - Takes power from enLight lantern or adapter - **Deployable** in a lantern or on a bracket attached to a column - **No batteries** to replace on recharge - **Environmental protection**: IP68 - **Temperature range**: 20º to 50º - **Connectivity**. enTalk ccompatible - **Weight** 80g - **Dimensions**: 35mm * 40 mm - **Sensitivity** / **range** ±1dB		
Other details	- 5-year guarantee - Color black		
Price	- Discarded due to difficulties on reaching the device provided.		

Table A.5 Noise sensors studied (4): IoT Sens

Name	IoTSens	***Manufacturer***	IoT Sens
Url	http://www.iotsens.com/sensors/sound-sensor/		
Description	The IoTsens sound sensor is able to record noise levels thanks to its integrated microphone. It is capable of analyzing surrounding ambient sound in the frequency spectrum audible to the human ear, displaying the collected data in dBA. This information is essential in certain spaces with high levels of noise pollution or with restrictions on noise levels.		
Technical details	- Wide temperature range - IP65 insulation level - Discarded due to lack of technical details - Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provided.		

Table A.6 Noise sensors studied (5): Intelkia

Name	In_noise	***Manufacturer***	Intelkia technology solutions
Url	http://www.intelkia.com/productos/in-noise-solucion-iot-monitorizacion-ruido/		
Description			
Technical details	- Parameter: LeqA. - Microphone sensitivity: 12.7 mV/Pa - Sensor range: 50dBA to 100dBA - Accuracy: ±0.5 dBA (1kHz) - Frequency range: 20Hz – 20kHz - Omnidirectional microphone - Unweighted sound pressure level measurement (dB) - Time integration modes: Fast (125ms) and Slow (1s) configurable by software - Communication technologies: GPRS, SIGFOX, LoRa and ZigBee		
Other details	- Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provider		

Table A.7 Noise sensors studied (6): Kunak

Name	KUNAK NOISE N10	***Manufacturer***	kunak
Url	https://www.kunak.es/en/products/ambient-monitoring/wireless-noise-monitor/		
Description	Low cost wireless system for the monitoring of urban and industrial noise. Type 2 sound level meter that captures data in real-time and sends it wirelessly to Kunak Cloud, a Noise Management Software for advanced analysis and remote configuration of sensors, which allows integration of information onto ERPs and Smart City platforms. **Applications:** Noise Monitoring, Industrial Noise, Smart Cities, Air quality and noise in EDUSI, Industrial emissions, Industrial perimeters and emissions, Research and Consultancy.		
Technical details	- Sampling and sending in real time 24/7. Easy to install. - IP65 External protection against dust and water - Kunak Cloud platform for advanced analysis - Power supply, solar panel + batteries - Communication through GPRS, Wi-Fi, RS232, Ethernet		
Price	- 3786.09€ - This sensor was seriously considered to be recommended, but it was finally discarded in favor of the one encompassing various sensors in the same price range (see A.2.1).		

A.1.2. Light

Expected outputs:

Table A.8 Expected outputs on light sensors

Data required	Type of data	Unit
Date	Date	
Measure	Decimal value	Lux
Location	Geographical coordinates	Decimal degrees (WGS84)
Method	Text	

Recommendable technical requirements:

- There are several light sensor units: The candela (luminous intensity), lumen (luminous flux), Lux.
- Weather resistance
- Network: supports WiFi, GPRS / 3G / 4G
- Supports APP push notifications or API.
- Battery life more than 2 months
- Easy to install

List of available sensors in the market:

Table A.9 Light sensors studied (1):TVILIGHT

Name	City Sense Plus	Manufacturer	TVILIGHT
Url	https://www.tvilight.com/citysense/		
Description	City Sense Plus is an award-winning street light sensor with an integrated wireless control. Designed for the harsh outdoor environments, it offers on-demand adaptive lighting, making the street lights adjust their brightness based on the presence of pedestrians, cyclists or cars. Using a real-time mesh network, CitySense Plus triggers neighboring lights and creates a safe circle of light around an occupant. The adjustment to human presence happens automatically. Interference factors such as small animals or moving trees are filtered out.		
Technical details	- Weather resistance - Failproof - Easy to install - Full remote management - Compatibility - Dimensions: 100mm * 125mm * 95mm		
Other details	- Up to 80% energy savings - Up to 50% maintenance cost reduction - Reduce light pollution and CO2 emissions - Light on demand - Discarded due to difficulties on reaching the device provider		

Table A.10 Light sensors studied (2): UBIBOT

Name	Wireless Smart Sensor WS1 Pro	**Manufacturer**	UBIBOT
Url	https://www.ubibot.io/ubibot-ws1/		
Description	The UbiBot WS1 Pro is a state-of-the-art environmental monitoring system that leverages the latest IoT technologies. Collect data in real-time anywhere in the world using the built in mobile data and WiFi. All data is automatically synced to the UbiBot ® IoT Platform. Device Access in real-time via our App or using a browser.		
Technical details	- Ambient Light Sensor - Precision: ±2% - Range 0.01 to 83K lux		
Other details	- Network: supports WiFi, GPRS / 3G / 4G - Ports: 2 Micro USB - External Probe: supports DS18B20 temperature probe (optional extra) - Sensing Range: Temperature -4°F to 140°F(-20°C to 60°C), Humidity 10% to 90% - Accuracy: temperature: ±0.3°C, humidity: ±3% RH, ambient light: ±2% - Battery Life: 4-6 months (WiFi only); 1-2 months (WiFi and SIM) - Device Setting: the minimum device sync interval (upload) is 1 minute, and minimum sensing interval is 1 minute (Temperature, Humidity, Light, External Probe and Battery Voltage). - Alert Types: supports APP push notifications, email, SMS text, phone call alerts and audible alerts. Alerts can be set on numeric- based sensor readings and network status (e.g. when connection is lost or batteries are low). All alerts are sent from the UbiBot Cloud. - Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provider		

Table A.11 Light sensors studied (3): NCD

Name	IoT Long Range Wireless Light Sensor	**Manufacturer**	NCD
Url	https://store.ncd.io/product/iot-long-range-wireless-light-sensor/		
Description	This device incorporates a precision Digital Ambient Light Sensor and wireless transmitter that wakes up, sends data and goes back to sleep at user defined intervals. This Long Range Wireless IoT Ligth Sensor has seconds (user configurable) and sending out samples if the change is greater than 10% (user configurable). To minimize power consumption, this sensor goes to sleep during the time it is not checking for changes in Ambient Light. Both of these features work together to support multiple application areas in one package. Powered by just 2AA batteries and an operational lifetime of 500.000 wireless transmissions, a 10 years battery life can be expected depending on environmental conditions and the data transmission interval. Optionally this IoT sensor may be externally powered for continuous operation.an additional feature of detecting changes in ambient light every 7 hours.		
Technical details	- Ambient Light Range 0 to 65k Lux with a Resolution of 1Lux - Ambient Light Sample Rate of 2.5 Samples per second - 10% Ambient Light Change Detection & Transmission - 2 Mile-Line-of-sight Range with On-Board Antenna		

Other details	- Industrial Grade Wireless Ambient Light Sensor with 16-bit resolution - Superior LOS Range of up to 28 Miles with High-Gain Antennas - Interface to Raspberry Pi, Microsoft Azure, Losant and More - Example Software for Visual Studio and LabView - Open Communication Protocol for Easy Software Integration - Includes Battery Level with Every Transmission - Validates and Retries Lost Communication Packets - This sensor was seriously considered to be recommended, but it was finally discarded in favor of the one encompassing various sensors in the same price range (see A.2.1).
Price	- 159.95$

A.1.3. Odour

Expected outputs:

Table A.12 Expected outputs on odour sensors

Data required	***Type of data***	***Unit***
Date	Date	
Measure	Decimal value	ouE/m^3
Location	Geographical coordinates	Decimal degrees (WGS84)

Recommendable technical requirements:

- Simple measurement of odor level. Selectable Gases
- Substance measured: Various odors, odor components
- Looking for sensors close to IoT solutions.

List of available sensors in the market:

Table A.13 Odour sensors studied (1): New Cosmos

Name	Odor Level Indicator (XP-329IIIR)	***Manufacturer***	New Cosmos
Url	https://www.newcosmos-global.com/product/2331/		
Technical details	- Detection principle. Indium oxide-based sensitivity hot wire semiconductor sensor - Response time. 20s or less (90% response) by calibrated odor - Operating temperature. 0 to 40ºC - Humidity. 10 to 80% RH (relative humidity) - Weight. Approx. 640kg (including batteries)		
Other details	- Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provider		

Table A.14 Odour sensors studied (2): New Cosmos

Name	Multi-point Type Odor monitor (V-819)	***Manufacturer***	New Cosmos
Url	https://www.newcosmos-global.com/product/2365/		
Description	Switchable indication between Odor strength level and Olfactory measured odor index.		

Technical details	- Sampling method. Diffusino type (Non-explosion-proof) - Operating temperature. -10º to 40º - Power Source. 110VAC ±10%, 200/220vac, 50/60Hz, 24VDC ±10% - Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provider

Table A.15 Odour sensors studied (3): MSS Forum

Name	MSS (Membrane-type surface stress sensor)	***Manufacturer***	MSS Forum
Url	https://mss-forum.com/en/about/		
Description	MSS is a versatile, ultra-compact / sensitive sensor element capable of measuring diverse molecules including various odorous gas molecules		
Technical details	- High sensitivity. Capable to measure gas molecules & biomolecules, depending on receptor materials. - Ultra Compact. Channels under 1sq.mm in size, i.e. 100 channels loadable in 1sq.cm - Versatile. Various organic & inorganic materials usable as receptor layer materials. - Temperature. Usable in both high and low temperatures depending on receptor materials - Low cost. Mass producible as is made of silicon - Low energy consumption. Each channel under 1mW - Quick response. Response under 1second is possible depending on gas flow rate - Stability. Stable thermally, electrically and mechanically - Coatings on both sides. Dip coating possible.		
Prize	- Discarded due to lack of information on prices - Discarded due to difficulties on reaching the device provider		

A.2. Sensor station selected

A.2.1. Description and justification

The final selection from the technical team has been the SmartSpot[12] of the company HOPU. As a matter of fact, what is interesting for PEI-PIXEL purposes is a variation of that sensor station.

This option (not listed before) has been selected for three main reasons: (1) it is customisable, (2) it can embed more than one interesting sensor in the same physical device, saving installation issues to the port and (3) the price ranges are quite competitive and within the margins of the equipment budgets of PIXEL ports.

A.2.2. Technical characteristics

Smart Sport Core System

- Enclosure IP65
- External antenna 3-1 (GPRS/GPS/WIFI)
- WIFI/GPRS connectivity support
- Geolocation support

Hardware expansion: Volatile Organic Compounds

- Alphasense metal oxide gas sensor for the detection of volatile organic compounds

Hardware expansion: Luminosity

- Ambient light sensor OPT3001 (Texas Instruments)

[12] https://smartcities.hopu.eu/smart-spot.html

- Accuracy: 0.01 Lux
- Range: 0.01 Lux to 83 kLux
- Precision optical filtering to suit the human eye
- Rejects > 99% (type) of infrared
- Deviation of measurement through temperature: 0.01 °C
- Operating temperature range: -40 ºC to +85 ºC

Hardware expansion: Noise

- Accuracy: 0.1 dB
- Range: 40 to 115 dB
- Maximum deviation
  - 40 to 50 dB: -1.7 dB to +3.5 dB
  - 50 to 115 dB: ±1.7 dB

Finally, price is estimated between 2.000 € and 4.500 €, depending on the hardware extensions selected.

A.2.3. Procedure followed by the team

The technical team thus recommended to PIXEL ports to purchase that smart sensor station in order to feed certain PEI inputs. In particular, what has been needed to proceed with the customization of the station is the following:

1 – Selection of an optimal spot for installation

The environmental expert team in PIXEL (partner MEDRI) reunited with all the ports to discuss the most optimal spot for installation. From the side of the environmental reasoning, a study of the influences on the noise values in the different zones of the port were made using the software Predictor Lima, running simulations with the ports' map and information of surrounding noise sources. From the side of the ports, a viability study of suitable locations was done. The merging of both procedures was discussed among the parties involved.

2 – Customisation of characteristics

In order to request a custom embedding of different sensors by HOPU and to have final offers, a set of questions were answered by the ports:

- Which kind of power is available in the area of installation? Would the sensor be able to have a direct connection to the network or should we request PV power?
- Which communication would be available? Is any AP WiFi covering the area? Any other possibility or should we request a 3G SIM?
- How would the installation be carried out? Your own technicians? External? Do you have any usual installator? Should we ask for help on that side?
- Apart from the noise, light and odour measurements... would you like to include air quality monitoring in the device? Which parameters would you want to have measured?
- Is odour relevant for your port?

Appendix B – OT interaction: files

B.1. GetInfo.json

The PEI uses this JSON to inform the Operational Tools about the information that the OTs will need to provide to the model at the moment of running it:

- Type of model
- Execution type (asynchronous,schedulable, not supporting subscription mode).
- The connector that will need (OT adaptor): in the case of the PEI, none adaptor is needed.
- Through the *GetInfo* designed for the PEI, the PEI "backend" (model implementation) is informing the OTs that the only information needed by the PEI are **connectors (in plural) with the IH API** are needed. It is detailed as well that those connection must be defined with a URL, an indexId, parameters to create the HTTP query and proper headers to get a 200 HTTP response.


```
{
  "name":"PEI",
  "version":"1.0",
  "description":"PEI model from SATRD-UPV",
  "supportSubscription":false,
  "supportExecSync":false,
  "supportExecAsync":true,
  "type":"model",
  "category":"pei",
  "system":{
     "connectors":[
        {
           "type":"ih-api",
           "description":"this connector provides info of the necessary parameters to be
           able to request the IH via HTTP",
           "options":[
              {
                 "name":"url",
                 "type":"string",
                 "description":"",
                 "required":true
              },
              {
                 "name":"indexId",
                 "type":"string",
                 "description":"id of the index in IHs Elasticsearch",
                 "required":true
              },
              {
                 "name":"reqParams",
                 "type":"string",
                 "description":"request parameters (if any)",
                 "required":false
              },
              {
                 "name":"headers",
                 "type":"headersObject",
                 "description":"necessary headers (if any)",
                 "required":false
              }
           ]
        },
```


Figure B.1 GetInfo.json for PEI (part example)

B.2. Instance.json

The information that Operational Tools introduces as "parameters" for running the PEI is the following:

- First input: how and from where to retrieve the Config (tree); indication of the different parameters needed: URL and indexId
- Second input: how and from where to retrieve the eKPIs; indication of the different parameters needed: URL, indexId, date of start of period, date of end of period.
- Third input: how and from where to retrieve the normalization values; indication of parameters: URL.
- Indication of the output: where to insert the results of the PEI calculation; parameters fulfilled: URL and indexId.
- Specification of logging: where to insert the different error/log messages generated during the execution; parameters fulfilled: URL and indexId.


```
"idRef":"5e99b5ad44fce835ce6a9f73",
"name":"pei-execution1",
"description":"PEI execution 1",
"mode":"ExecAsync",
"input":[
   {
      "name":"tree-PEI",
      "category":"ih-api",
      "type":"tree-PEI-format",
      "description":"Tree tructure for the PEI calculation",
      "metadata":{
      },
      "options":[
         {
            "name":"url",
            "type":"string",
            "description":"URL endpoint",
            "value":"http://otpixel.satrdlab.upv.es:9200"
         },
         {
            "name":"indexId",
            "type":"string",
            "description":"id of the index in IHs Elasticsearch",
            "value":"pei-config"
         }
      ]
   },
   {
      "name":"input-ekpis-PEI",
      "category":"ih-api",
      "type":"EnvironmentalKeyPerformanceIndicator",
      "description":"eKPIs calls with all info required for the PEI calculation (id,
      type, category, calculationPeriod, etc.)",
      "metadata":{
      },
      "options":[
         {
            "name":"url",
            "type":"string",
            "description":"URL endpoint",
            "value":"http://otpixel.satrdlab.upv.es:9200"
         },
         {
            "name":"indexId",
            "type":"string",
            "description":"id of the index in IHs Elasticsearch",
            "value":"ekpi-input"
         },
         {
            "name":"start",
            "type":"datetime (ISO 8601)",
            "description":"start of calculation period",
            "value":"2020-01-01T00:00:00.000Z"
         },
         {
            "name":"end",
            "type":"datetime (ISO 8601)",
            "description":"end of calculation period",
            "value":"2020-02-01T00:00:00.000Z"
         }
      ]
   },
   {
      "name":"norm-values-ekpis-PEI",
      "category":"pei-norm-api",
      "type":"norm-values-ekpis-PEI-format",
      "description":"eKPIs normalization values in order to normalize eKPIs for the PEI
      calculation",
      "metadata":{
      },
      "options":[
         {
            "name":"url",
            "type":"string",
            "description":"URL endpoint",
            "value":"http://otpixel.satrdlab.upv.es:4567"
         }
      ]
   }
],
"output":[
   {
      "name":"pei-output",
      "category":"ih-api",
      "type":"pei-output-format (it will include id_model, id_execution)",
      "description":"(estimated) PEI between the given timeframe. This is the format to
      be stored in the IH",
      "metadata":{
      },
      "options":[
         {
            "name":"url",
            "type":"string",
            "description":"URL endpoint",
            "value":"http://otpixel.satrdlab.upv.es:9200"
         },
         {
            "name":"indexId",
            "type":"string",
            "description":"id of the index in IHs Elasticsearch",
            "value":"ekpi-output"
         }
      ]
   }
],
"logging":[
   {
      "name":"pei-output-logging",
      "category":"ih-api",
      "type":"default-logging-format",
      "description":"activity logging for the PEI model",
      "metadata":{
      },
      "options":[
         {
            "name":"url",
            "type":"string",
            "description":"URL endpoint",
            "value":"http://otpixel.satrdlab.upv.es:9200"
         },
         {
            "name":"indexId",
            "type":"string",
            "description":"id of the index in IHs Elasticsearch",
            "value":"logging"
         }
      ]
   }
]
}
```


Figure B.2 Instance.json for PEI (complete example)

Appendix C – Class diagrams of the program for PEI calculation

C.1. Node

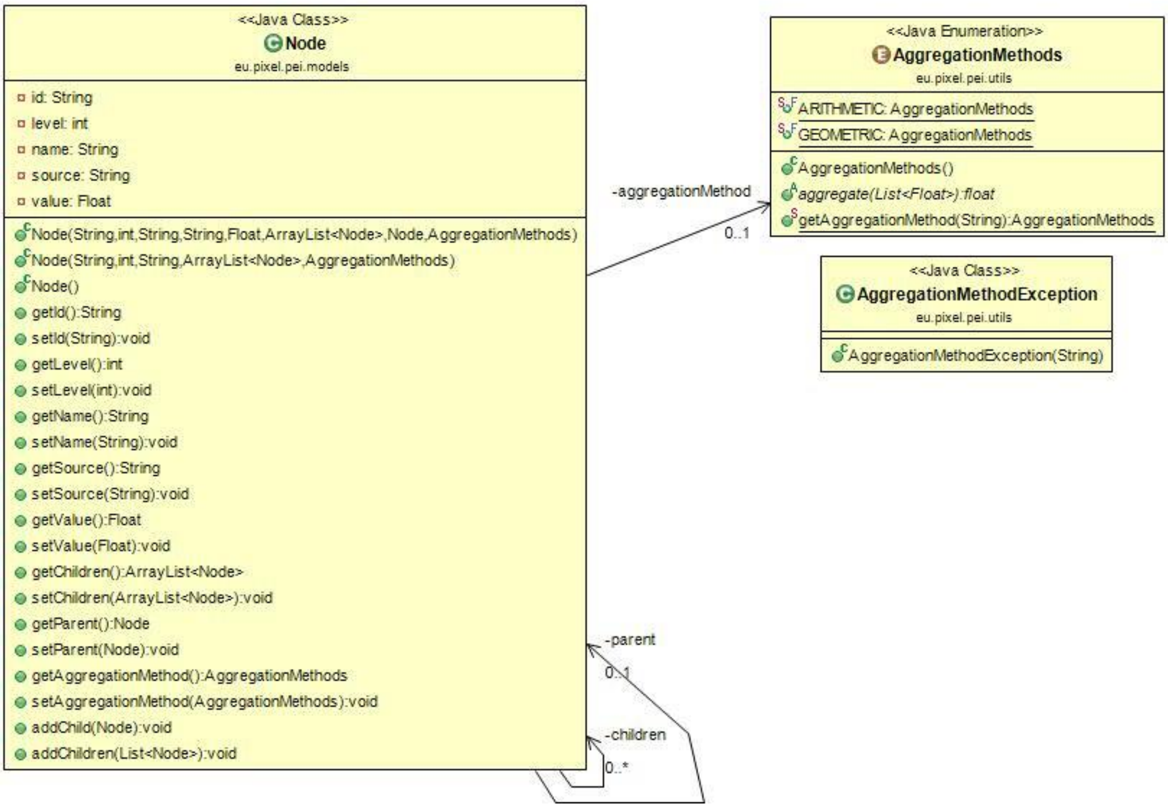


Figure C.1 Class diagrams (I): Node

C.2. Edge

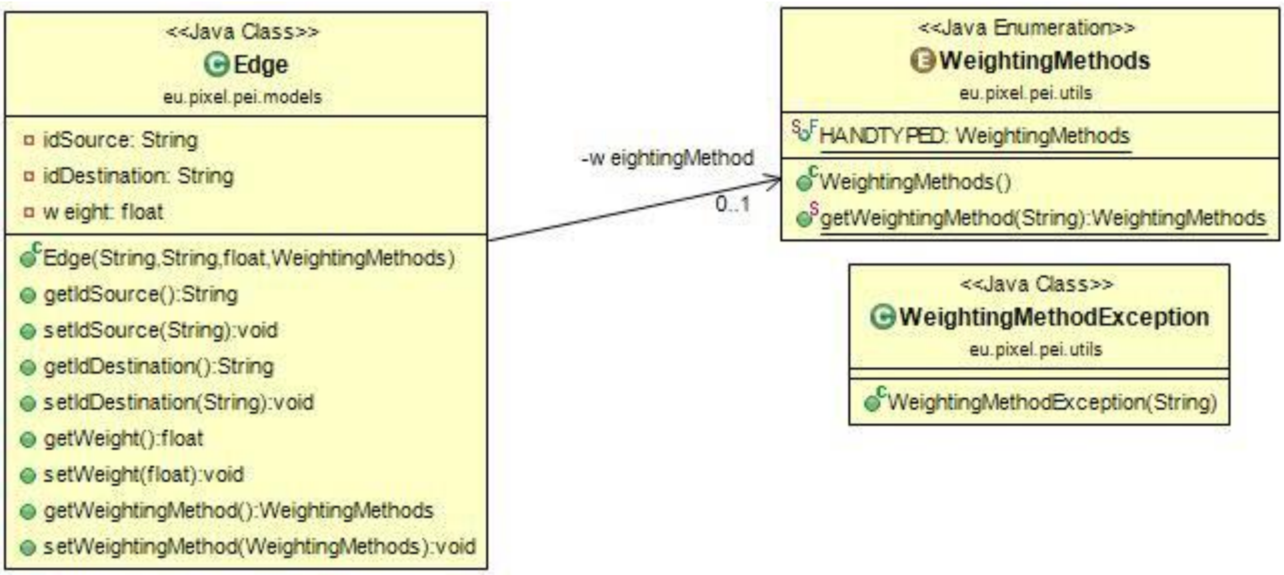


Figure C.2 Class diagrams (II): Edge

C.3. KPI

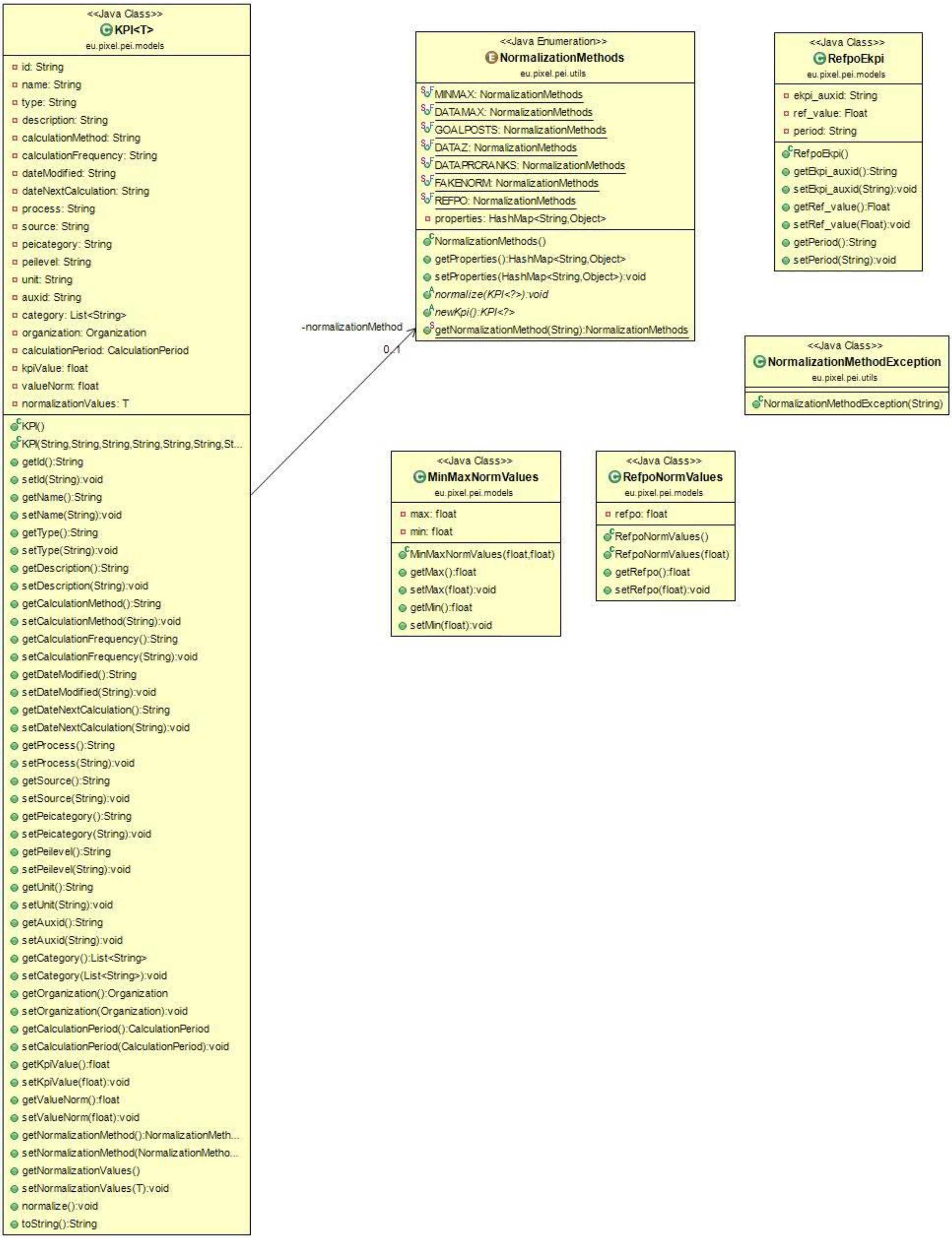


Figure C.3 Class diagrams (III): KPI

C.4. Tree as central element

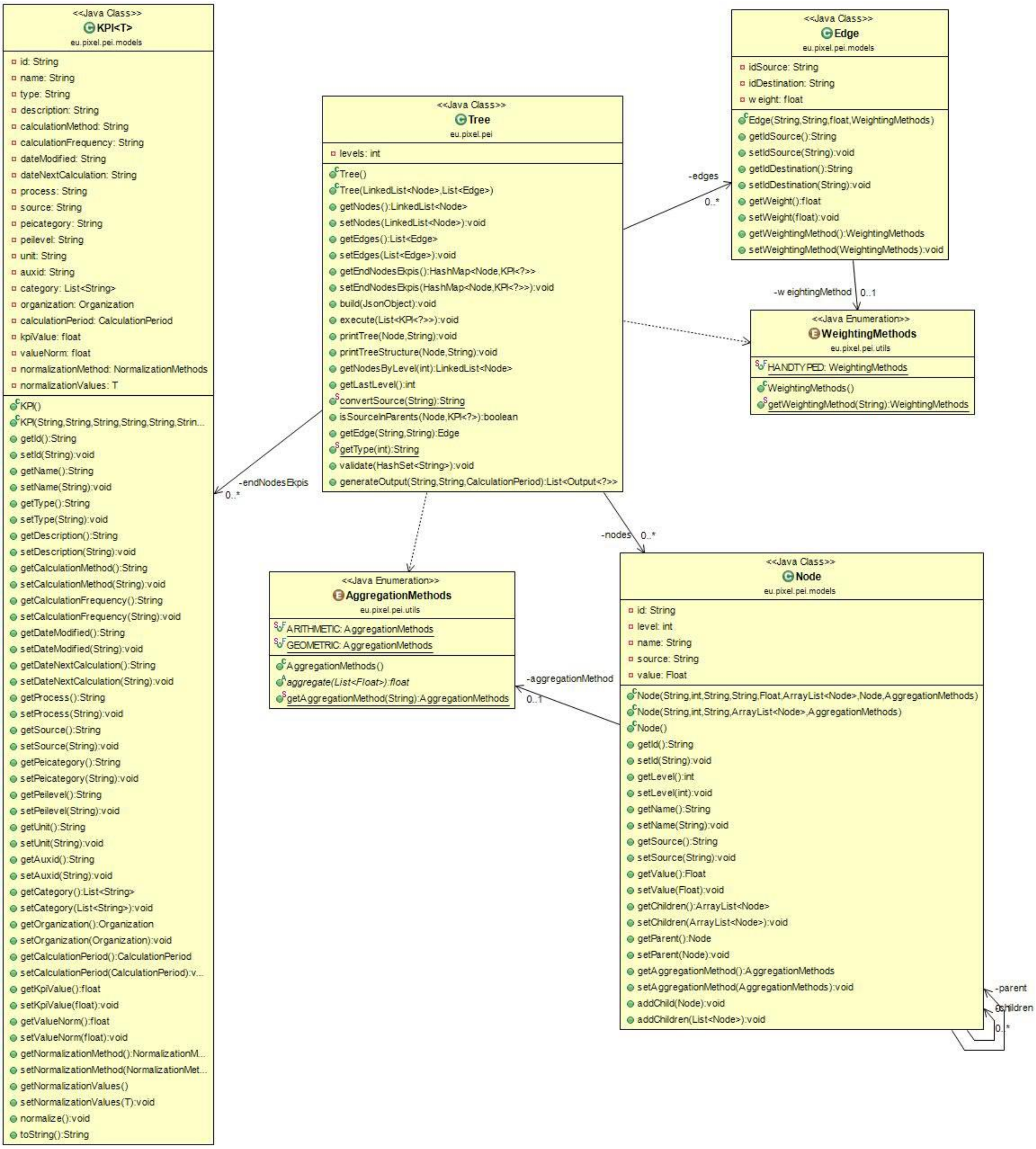


Figure C.4 Class diagrams (IV): Tree as central element

C.5. Whole program

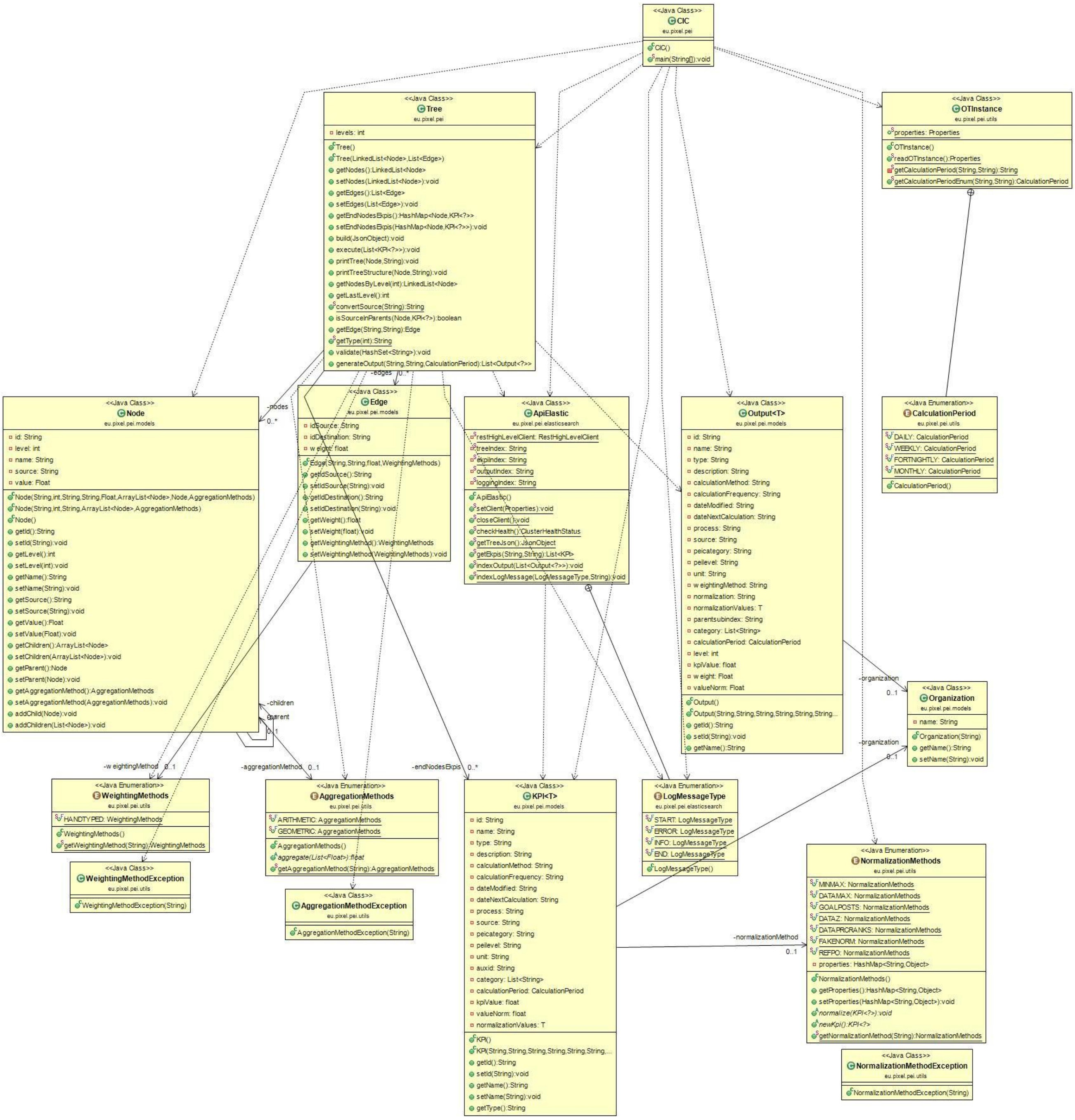


Figure C.5 Class diagrams (V): Whole program