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A low-cost business-oriented seaport energy effective management platform

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Article Info

ABSTRACT

Many seaports worldwide attempt to gain energy efficiency towards reducing their energy costs while mitigating climate change and environmental effects. In this pa- per, a low-cost business-oriented seaport energy effective management (PERFFECT) platform is introduced. PERFFECT intends to gain knowledge on fundamental port operational and business processes and evaluate them against energy efficiency and environmental footprint. Exploiting all the proposed PERFFECT applications like monitoring, evaluation, forecasting, and optimization, the energy efficiency of the op-erational infrastructure of the port's is achieved. Port's energy balance is estimated andused to decide the ports optimal energy usage. Moreover, the traffic volume producedby the gate check is simulated and utilized for further actions. These actions include energy savings and emission reduction recommendations. Finally, the proposed platform is evaluated against real-life data, while the experimental results present the out-come and efficiency of the system. The suggested system results in up to 82.82% lightenergy savings after a specific suggested action and up to 33% reduction of vehicle emissions, respectively.

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1. INTRODUCTION

The European Union (EU) imports almost 53.6% of the energy it consumes, spending almost one billion euros per day on it [1]. As a result, energy efficiency is one of the utmost priorities of the EU [2]. Within this context, ports are consuming a massive amount of energy for their operation processes and functions like central hubs in the transport. Accordingly, port authorities in Europe have developed energy efficiency tactics to comfort with the European legislation. Specifically, the main frameworks that the European port authorities adopt are i) the port environmental review system (PERS), ii) the international standards organization (ISO) 14001 standard, and iii) the eco-management and audit scheme (EMAS) [3].

While ISO 14001 and EMAS are more comprehensive, energy management systems (EMSs) may be applied to any process. The PERS focuses on ports incorporating the main general requirements of recognized environmental management standards (e.g., ISO 14001), but also takes into account the specificities

of ports. In general, EMAS is considered to have a stricter interpretation of how environmental processes should be planned and managed comparing to ISO 14001, including a comprehensive environmental review of the processes and a regularly published environmental statement. Apart from EMSs, the energy management system ISO 50001 may also serve as a useful tool for ports, however it focuses solely on the improvement of the energy performance of processes, contrary to EMSs that focus on the improvement of all environmental impacts of ports, including energy efficiency. Moreover, mediterranean countries like Greece, Italy, Slovenia, Montenegro and Albania developed port environmental management plans (PEMP) to manage their energy with an efficient way aiming to minimize their consumption and emissions [3].

Energy consumption ranked second among the environmental priorities of the European port sector from 2016 till 2019 [4]. As depicted in Figure 1, in the last year, European ports acknowledge energy efficiency, instead of energy consumption, as the third most important environmental priority, following air quality and climate change [4]. Energy efficiency influences the climate change so they are interlinked to a degree. The top priorities remain almost the same during the last years, indicating the key importance role of a port's collaborative action towards these factors. In addition, energy seaport management may facilitate these actions through optimization techniques, aiming in improving the energy efficiency while decreasing the environmental effects including air quality.

Figure 1. Top 7 environmental priorities for the port sector over the last years [4]

Furthermore, the international standards organization (ISO) addressed a useful tool to facilitate energy management while supporting the stakeholders to decrease their energy consumption [5]. The ISO 50001 'energy management' [6], presented in 2011, is based on data-driven processes to improve the energy performance exploiting the conventional plan-do-check-act (PDCA) improvement cycle [7]. The main environmental management systems (EMSs) frameworks that the European port authorities adopt are: i) The port environmental review system (PERS) ii) the ISO 14001 standard on EMS, and iii) the eco-management and audit scheme (EMAS) [5]. All these frameworks include energy management, carbon management and measurement, and environmental management [5].

All above legislation, frameworks and priorities indicate the fundamental importance of energy man- agement aiming at minimizing energy consumption and climatic effect. Port European authorities have to improve their operational processes exploiting technology-wise procedures, to gain an improved environmen- tal footprint while reducing energy consumption. Specifically, the latest energy-related technologies for ports to reduce track emissions include technologies like auxiliary power units and generator sets (APU/GS) [8], battery air-condition systems (BAC), electrified parking spaces (EPS) or truck stop electrification stations (TSES) [9], and manoeuvring eco-driving [10]. Another energy-efficient technology is cold ironing to reduce ship emissions during berth processes [11].

The aforementioned techniques and technologies are to a high degree proven energy and fuel efficient, but the initial cost is assessed extremely high. Indicatively, a typical installation cost for a TSES is between 15.000$ per space [12]. As a result, to effectively reduce truck emissions during idling using a TSES technology a capital of at least 75.000$ is needed (i.e., 5 spaces). Likewise, to design and construct a cold ironing terminal 1.5 million $ per berth for the shore-side infrastructure is required [11]. As a result, port authorities could be reluctant to adapt such high-cost solution.

To address the initial capital problem a comprehensive knowledge of the main port's operational and business processes that are energy related is necessitated. Port energy awareness can contribute to built a foundation that will facilitate the port authorities to use new low-cost technologies and practices to minimize the costs while reducing energy and emissions. Particularly, techniques that are data related can be exploited to manage energy in ports. Data analytics and data-driven machine learning models may be exploited to gain insight into the port's necessities.

Within this context, an adjustable low-cost, non-intrusive and feasible energy effective management platform is deployed. This platform introduces an innovative overall system to optimize energy management, reduce air-pollution based on port information and data, while providing a port overview to the stakeholders through a manifold knowledge of the main port business logic. The main objective of the seaport energy effective management platform (PERFFECT) is to help the port administrator to gain insight to all the ports fundamental processes at one glance while sending notifications for the current port traffic, climate mitigation and energy efficiency. Finally, PERFFECT engrosses all legislation and rules tailored to ports to its estimations and decisions. To this end, the rest of the paper is structured as follows: section 2. presents research related to energy management in seaports. Section 3. analyzes all the methodology used for PERFFECT platform and its individual components. Subsequently, the results are drawn in section 4.

2. RELATED WORK

An effective and technology-wised EMS of a seaport may have impor-tant advantages. The EMS consists of progressing techniques, methods, procedures, and tools for monitoring, controlling, and analyzing the energy requirements of a ports' facilities. The port's EMS manages the energy balance of the port while monitoring all other necessary conditions and parameters like environmental conditions, emissions, traffic, cargo management, and ships' arrivals/departures, towards energy efficiency. Energy management in ports is of crucial importance to mitigate energy and carbon emissions while helping the ports to improve their environmental footprint. As a result, some proposed port-tailored EMSs, and the most recent will be acknowledged in this section.

According to Martínez-López et al. [13], a ship's electricity cost could be minimized through an optimal power flow dispatch taking into consideration the energy produced from photovoltaics, battery, diesel and cold ironing [14]. The method suggested uses penalty functions that estimate certain system constraints like solar output, battery capacity, the solar energy produced, and specific port regulations. Consequently, a particle swarm algorithm is used to optimize the energy. The system was tested trough a simulation process and proved to be efficient for energy management. In general, cold ironing that exploits artificial intelligence techniques is a powerful tool for energy efficiency [15].

As stated in [16], various operational strategies that can improve the energy efficiency and environmental footprint exist. The authors suggest that there are research gaps related to energy efficiency that could be gained by studying and reducing time-consuming port operations (e.g. idling time, gate traffic) that could lead to less energy consumption and emissions. The exploitation of specific methodologies like peak shaving, cold-ironing and automated equipment may contribute to energy use optimization. Furthermore, other techniques for reducing emissions from idling at the port gate include traffic prediction as reported in [17].

As presented in the work of [18], green ports are studied emphasizing into sustainable techniques. The port authorities are mainly interested in reducing their impact on the environment by reducing their emissions as regulated by the local legislation. As the authors conclude, their is not sufficient research on how land-side transportation operations, like the movement from and to the port, may reduce the environmental effects. Furthermore, ports are rescheduling their facilities by transforming ports into smart grids and energy hubs. Some widely used techniques include: cold ironing (CI) [14], renewable energy sources (RES) [19], smart port lighting (SPL) [17], cargo handling cranes (CHC) [17], energy storage systems (ESS) [14] and reefer smart power supply (RSPS) [14].

In the work of [20], it is suggested that ports should focus on sustainability as transport systems have a tremendous effect on the the environment and climate. There are various techniques referred in the literature to mitigate port pollution and emissions focusing on different aspects like power and fuels, port plans and management, land activities, and sea activities. On the other hand, it is concluded that the literature should

focus more on decision making tools that would facilitate energy efficiency in ports. Finally, it is stated that EMSs that are based on port monitoring would benefit the energy and environmental management.

As addressed in the work of [21], it is mentioned that the exploitation of renewable energy sources is of key importance as ports are large scale energy users. As a result, port authorities must exploit EMS to reduce their energy consumption and emissions while considering renewable energy generation. The authors suggest a smart port microgrid to optimize the energy used by adapting a linear programming model. Their model aims to manage the ports grid to reduce energy cost and consumption. All, the above is summarized in Table 1.

Table 1. Comprehensive overview of energy management techniques in seaports

No	Objective	Target	Methodology	Reference
1	Electricity cost and	Ships	power flow dispatch AI for optimization	[13]
2	Emission minimization electricity cost and emission minimization	Ships	Cold ironing	[14], [15]
3	Reduce time consuming operations	Gate	Peak saving	[16]
4	Reduce time consuming operations	Gate	Traffic prediction	[17]
5	Green port	Port	Renewable Energy Sources (RES),Energy storage systems (ESS) and Reefer Smart Power Supply (RSPS)	[19], [21]
6	Energy management Port	Port	Smart PortLighting (SPL),	[17]
7	Sustainability at transport systems Port	Port	Cargo Handling Cranes (CHC),	[20]

3. PERFFECT METHODOLOGY

In this section, the methodology of PERFFECT is addressed. Initially, the basis of the main port operations and business logic is studied and analyzed to discover which are the processes and energy-related operations. All of these processes are sorted out to those that PERFFECT can intervene and monitor and those that are irrelevant and perplexing. Furthermore, as PERFFECT intends to follow a more widely-applicable, low-level and easy to manage operational analysis, specific high-level and complex activities like cargo storage were omitted at the initial analysis phase. However, cargo could be stated as one of the categories in the next updated analysis. Furthermore, the buildings of a port are not included as many building management systems (BMSs) exist, and building sector of a port could be considered as a typical public building. Nevertheless, such a category may be included if needed upon the stakeholders demand.

The legislation and specifications needed to estimate certain key performance indicators and environmental factors may be retrieved from the local legislation and by the port authorities itself as it is the main stakeholder. Based on the produced analysis outcome, the available data is retrieved and fed to artificial models to provide various information and recommendations. Finally, all results are evaluated based on selected energy or environmental key performance indicators.

3.1. Main port operations and business logic

A port has various roles like operating, economic, and administrative. Moreover, there are different port operational processes including but not limited to: ships' berthing, ships' anchoring and departure, vehicles gate control, cargo transportation, and building automation systems (BAS). Initially, the main energy-related operations are grouped to 4 main categories based on the fundamental port elements that could be monitored and/or controlled:

− Ships: Those operations include all ship procedures and sub-processes like ships' arrival rate, departure, anchoring, ships' emissions, and cargo/container/vehicles loading and unloading. All these operations are mentioned as *ships − No*, where *No* defines a distinct number for each different ship sub-process.

− Vehicles: Those operations include all vehicle procedures and sub-processes like vehicles' arrival rate, vehicles' traffic, vehicles gate control, vehicles idling, vehicles emission, vehicles on board. All these operations are mentioned as Vehicles − No, where No defines a distinct number for each different vehicle sub-process.

− Energy: Those operations include all energy consumption and generation procedures and sub-processes. All these operations are mentioned as Energy − No, where No defines a distinct number for each different energy sub-process.

− Lights: Those operations include all lights' processes and characteristics like number of lights, light's type, energy consumption, and lights' scheduling. All these operations are mentioned as Lights No, where No defines a distinct number for each different light sub-process.

Subsequently, based on the fundamental port's operations, specifications, and needs, the main PERFFECT processes are divided into 6 main categories that consist of various processes of the above 4 operations. Those processes where selected after processing the main operations that the PERFFECT methodology can intervene, manage, simulate, monitor, and evaluate. These are as depicted in Figure 2 and are described:
1) Port's operational processes. Those processes are the main port operations and businesses, and are:

(a) Ships-1: It refers to the number of ships arriving and deporting at the port.

(b) Ships-2: It refers to the number of ships that are anchored at the port.

(c) Vehicles-1: It refers to the vehicles' arrival rate to the port's gate. If the arrival rate is high it results in traffic congestion at the gate.

(d) Vehicles-2: It refers to the time the vehicles are idling at the port gate due to traffic congestion. Long idling time results in higher vehicle emissions.

(e) Light-1: It refers to the number and scheduling of the light that are situated in the pier's area-International ship and port facility security area (ISPS)

2) Port's energy: Those processes refer to the port's aggregate energy demand that may be controlled and the port's renewable resources energy power.

(a) Energy-1: It refers to the port's energy consumption that can be controlled.

(b) Energy-2: It refers to the port's energy generation from photovoltaics.

(c) Energy-3: It refers to the port's energy generation from wind-power.

3) Port specifications: Those specifications refer to specific legislation and specifications of the port administration and authorities.

(a) Vehicles-8: It refers to the maximum level of kilograms of carbon dioxide (CO_2), nitrogen oxide (NOx) and particulate matter (PM) conforming either to the existing legislation or port's environmental target.

(b) Energy-7: It refers to photovoltaics specifications conforming either to the existing legislation or port's specifications.

(c) Energy-8: It refers to wind-power specifications conforming either to the existing legislation or port's specifications.

(d) Lights-5: It refers to the maximum level of kilograms of Carbon dioxide (CO_2) conforming either to the existing legislation or port's environmental target.

(e) Lights-6: It refers to light scheduling based on seasonality and security.

4) Real time indicators: Those indicators are the real-time information that is monitored, estimated and simulated by the PERFFECT methodology.

(a) Vehicles-3: It refers to the volume of vehicles idling at the port gate.

(b) Vehicles-4: It refers to the kilograms of carbon dioxide (CO_2), nitrogen oxide (NOx) and particulate matter (PM) during vehicle's idling.

(c) Energy-4: It refers to the energy balance.

(d) Energy-5: It refers to total RES power generation.

(e) Lights-2: It refers to the lights energy consumption.

(f) Lights-3: It refers to the kilograms of carbon dioxide (CO_2) produced by lights.

5) Decisions/Notifications: They refer to real time decisions and notifications produced by the PERFFECT artificial intelligence (AI) algorithms. The notifications address to all the end-users (i.e, platform user, stakeholders, travellers and port administration).

(a) Vehicles-5: Notifications to the end-user to open an additional gate because of high arrival rate (based on the fact that all gates are not constantly open).

(b) Vehicles-6: Notifications to the trucks and buses company for high traffic and delays.

(c) Vehicles-7: Notifications to the travelers for high traffic and delays.

(d) Energy-6: Decision making through an optimization process to manage energy balance.

(e) Lights-4: Notifications to the end-user for light dimming to the international ship and port facility security code (ISPS) area.

6) Key performance indicators (KPIs)

(a) Vehicles-9: Percentage of vehicle emissions reduction.

(b) Energy-9: Percentage of produced green energy.

(c) Lights-7: Percentage of lights' consumption savings.

(d) Lights-8: Percentage of lights emissions reduction.

3.2. Perffect architecture

The main goal of the PERFFECT methodology is to collect, monitor and analyze all critical functional and non-functional port requirements and operations while turning them into a set of fundamental elements that are responsible for consuming energy and/or producing direct or indirect emissions. Specifically, the PERFFECT system consists of 5 basic sub-systems (Figure 3) that are i) PERFFECT safe cloud platform, ii) user interface (UI) System, iii) monitoring system, iv) berth allocation/planning system (BERTH), and v) application management and decision system. Each of the above systems runs smoothly and performs individual operations, which are presented through the PERFFECT platform (visual analytics).
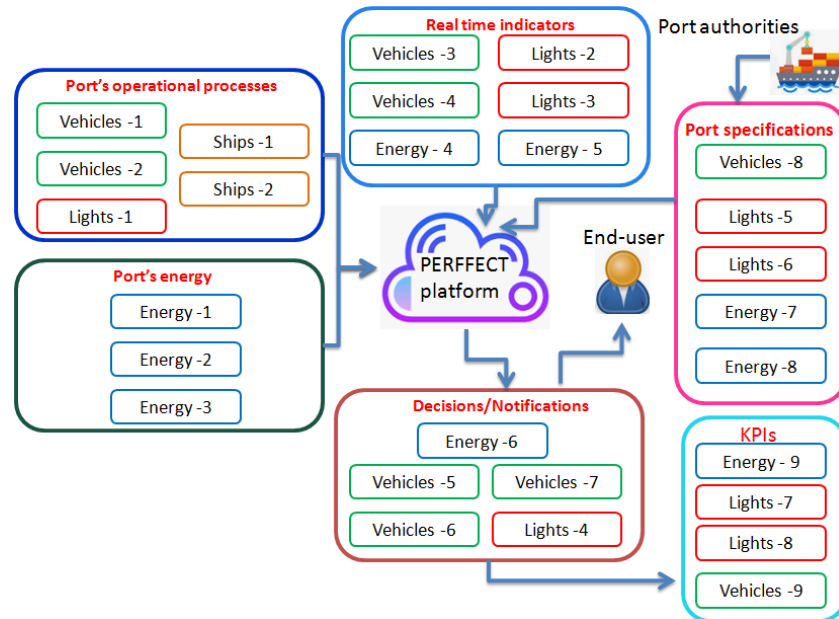
Figure 2. Port operational processes and business logic for energy related tasks
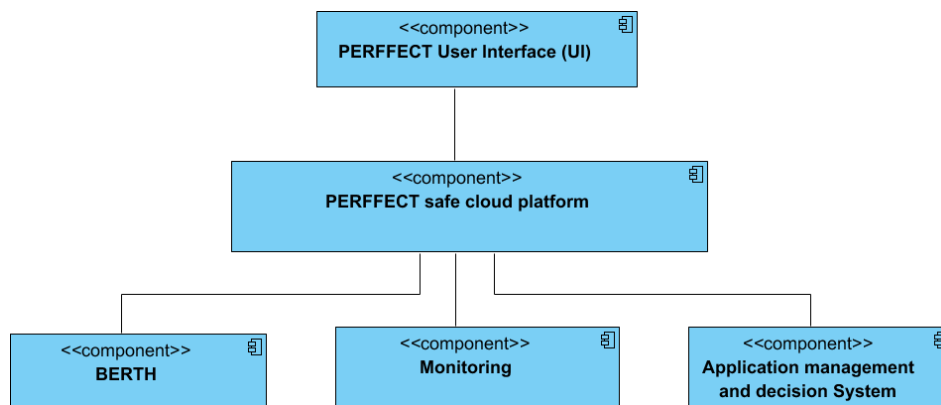

Figure 3. Perffect component diagram

Each of the aforementioned sub-systems have the ability to communicate, operate, and exchange information and data in an efficient way with the PERFFECT cloud platform, which also operates as an intermediate system (middleware). Moreover, each of the above sub-systems may include other sub-systems and applications. Some of these applications are performed autonomously (such as the traffic simulation), while other applications or sub-systems are performed at the "request" (on demand) of another applications or even sub-systems, such as the dynamic rule alert engine. Therefore, the sub-systems are combined into a single system based on certain characteristics like the communication protocols and operation mode. Devices, systems, and sub-systems interact with each other through various interfaces and communication protocols through the PERFFECT middleware. The subsystems and PERFFECT applications communicate with each other through the following protocols: message queuing telemetry transport (MQTT), RESTful API (REST API), simple objects access protocol (SOAP API), and file transfer protocol (FTP) [22].

Overall, the PERFFECT system retrieves all the necessary data from the monitoring system (e.g., weather data, consumption data, traffic data, BERTH data). Subsequently, it estimates the emissions based on the retrieved data. Moreover, notifications are sent to the end-user based on the key performance indicators. Furthermore, energy consumption is forecasted and decisions are produced to manage the energy in a more efficient way. All retrieved, estimated, simulated, and forecasted data are visualized in the UI PERFFECT conceptual architecture as depicted in Figure 4.
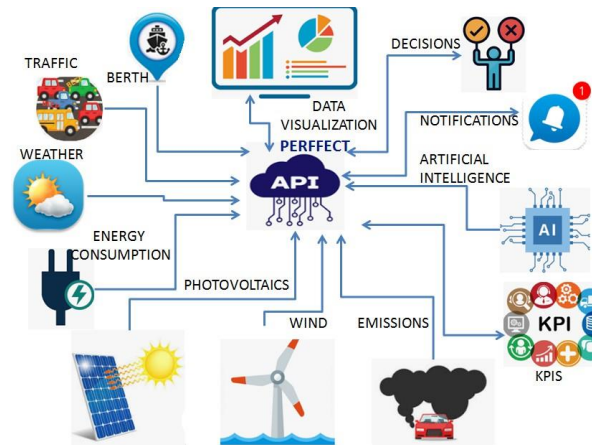
Figure 4. Conceptual perffect platform architecture

3.3. Port's operational processes

In this section, the main port's operations that are directly associated with other processes will be presented. The number of expected ships to depart influences the volume of vehicles and passengers that arrive to the port. The arrival rate of vehicles and passengers affects the traffic volume at the port gate. Finally, the traffic at the port gate influences the emissions produced by vehicles idling. PERFFECT platform processes both operation-related and energy-related data with environmental indicators to provide a detailed overview to port operators and guidance towards specified decisions. Ports have many Information and Communications technology (ICT) applications deployed to manage operational processes. The key objective of these systems is to enhance the efficiency of business processes through better management, security, and overall monitoring of the port situation.

One of the most fundamental operational processes for freight and passenger support operational systems is the berth allocation/ planning system in the case of roll on and roll off passenger (Ro-Ro/Ro-Pax) systems that manage berthing processes. Berth process is one of the most feasible to be exploited, but in other ports, more business processes could be taken into consideration if needed.

3.3.1. Berth management system

The Berth allocation system is an integrated information system that supports the entire process of berth assignment. The assignment of berthing positions is accomplished through a visual diagram that presents the total space (port pier) related to time. This allows temporal and spatial planning of the berths based on the characteristics of the ship and the specifications set by the port. Furthermore, the system provides the ability to represent the berthing places along with the plan for berth allocation. In this way, the end-user (planner) can have an overview of the allocated berth together with the period that the berth will be occupied by a certain vessel. The system used for berth allocation (BERTH), was selected in the PERFFECT overall architecture to provide operational information from the port. BERTH is called under request in real time to get the number of expected vessels to arrive at the port, the specific quay the ship will anchor, and the time the ship departs.

3.3.2. Traffic simulation

Traffic monitoring and management are of primary importance as congestion leads to departure delays and air pollution. Traffic management increases the port's operational efficiency, travellers' satisfaction while improving the ecological footprint. Consequently, the expected traffic at the port's gate is simulated to facilitate a better management of vehicle traffic during their arrival at the port. An insight in advance of the daily vehicle volume intends to lead the port administrator to take the necessary actions to manage traffic. Those actions could include operations like to open an additional gates.

To simulate the traffic at the port gate a gradient boost algorithm was utilized [17]. In the model that was developed, multiple inputs are taken into consideration to classify traffic into three categories that represent the traffic volume. The predictor variables are hour (clustering 0, 1, 2) referring to ship departures, month (clustering 0, 1, 2) referring to traffic vehicles generate, public holidays (Boolean), weekends (Boolean), number of ships departing abroad (0, 1, . . . , k1) and total number of ships departing (0, 1, . . . , k2, where k2 k1). The independent variable, traffic density, is categorized in three states that can be illustrated as:

$$y = \begin{cases} 0, \text{low traffic density} \\ 1, \text{medium traffic density} \\ \quad 2, \text{high traffic density} \end{cases} \qquad (1)$$

Low traffic ($y=0$) can be interpreted as almost no waiting time $W=0$ minutes for vehicles at the port gates. During medium volume traffic ($y=1$) the delay time is expected to surpass $W=20$ minutes. Finally, the waiting time during high traffic ($y=2$) exceeds $W=45$ minutes. The overall system of traffic simulation described above is as depicted in Figure 5.
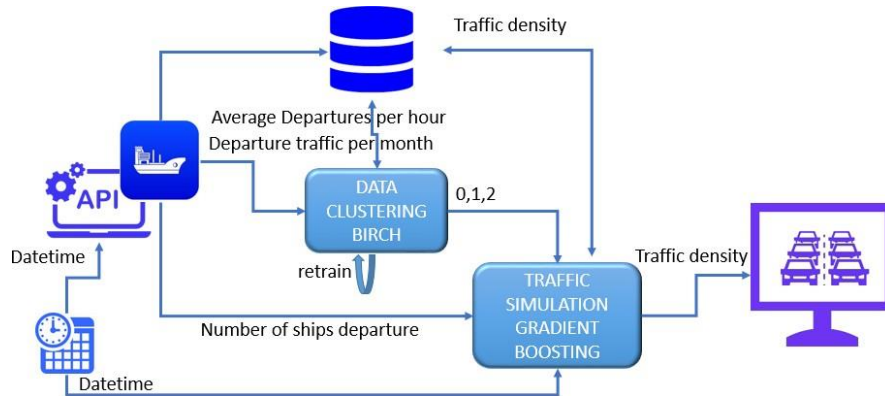
Figure 5. Traffic simulation conceptual architecture [18]

3.4. Ports' energy
3.4.1. Energy consumption
Energy consumption forecasting is crucial for other processes like the renewable energy sources (RES) and demand-response strategies. During load forecasting, patterns from historical load data are explored to predict future demand [23], where the time range of the data that is fed to a forecasting model is decided through a trial and error procedure. There are two main methods (single-step and multi-step) for load forecast- ing, where the selection depends on the frequency of the available data, the scope of application, and the time horizon [23]. Within PERFFECT a multi-step load forecasting model is applied [24].

3.4.2. Energy power generation and modelling
RES, and especially photovoltaics (PVs) and wind powers constitute the generated energy at a harbor. District optimization techniques rely upon decision making that depends on accurately generated energy sim- ulation. False underestimation or overestimation of the output energy could lead to operation costs, especially when pricing optimization is to be applied. With those mentioned, an accurate forecasting model has to be developed. However, the stochastic nature of the weather, that PV's and wind powers are heavily dependent, makes forecasting a thorny task. Various forecasting techniques have been proposed that can be classified into two main categories, Univariate–direct techniques [25] and multivariate- indirect [26].

For data-driven approaches, when there are sufficient historical data, an appropriate-machine learning model can be deployed/build to forecast future generation. If the historical data contain only past generation data, the forecasting technique is considered univariate, while when weather and temporal variables are in- cluded, the technique is considered multivariate. Data driven techniques are predominantly used lately, but they require adequate historical data that can be missing due to various reasons (e.g newly installed energy resource system).

For physical/analytical approaches, the entire renewable energy system is modelled with the configu- ration characteristics that is used during the installation process. Then by feeding the model with future weather variables retrieved by numerical weather prediction (NWP) models the future generation can be calculated as in [27]. PERFFECT exploits open-source libraries like PVlib and windpower lib that can simulate the installed energy systems and calculate power output while providing future weather data.

3.5. Real-time indicators
The main objective of real-time indicators is to inform the end-user about the current fundamental port conditions. These are depicted in the main PERFFECT port overview user interface (UI). In this section, processes that need further processing than described above are presented.

3.5.1. Vehicles emissions

Running vehicle engines and idling an engine produce several pollutants. Therefore, the total emissions of vehicles (ET) from idling time (EI) and running time (ER) are calculated by:

$$ET = EI + ER \tag{2}$$

For small distances the ER is negligible. As a result, a specific type of emission produced at the gate because of the waiting time is estimated by [28]:

$$ETi,j = EIi,j = \Delta t \times EFV\ Ii,j \tag{3}$$

Where EFV I is the emission factor kg/hr for Vehicles Idling and i refers to the vehicle type (like truck, car) and j refers to the type of the emission (like CO_2, PM, NOx) and Δt is the idling time in hours. For the nitrogen oxide (NOx) and particulate matter (PM) the emission factor was retrieved by [29]. The CO_2 emissions for idling time were estimated as mentioned in [30]. Vehicle emissions are mainly produced during the idling of the vehicles at the port gate. As a result, vehicle queuing is formed because of the waiting time needed to pass through the port's gates. Reducing this waiting time will result in the reduction of carbon dioxide (CO_2), nitrogen oxide (NOx) and particulate matter (PM). The queue or waiting line refers to the phenomenon created when the current system's demand for a service is greater than the current system's service rate. Specifically, for the traffic congestion problem the system's demand is the number of vehicles waiting in the queue to pass through the gates and the system's service rate is the number of vehicles that pass through the gates. To estimate the number of vehicles that are in a queue, based on Little's theory [31], the number of vehicles $V n$ that stands in the queue is:

$$Vn = \lambda W \tag{4}$$

Where W is the average time a vehicle stands in the queue and λ is the service rate. The vehicles in the queue may be served by a more than one gate, therefore it is a multi-service system as depicted in Figure 6. The number of vehicles waiting to be served will be:

$$Vn = \frac{Ng}{s}W \tag{5}$$

Where Ng is the number of the open gates that may serve the travelers and s is the average time it takes for each vehicle to be served.
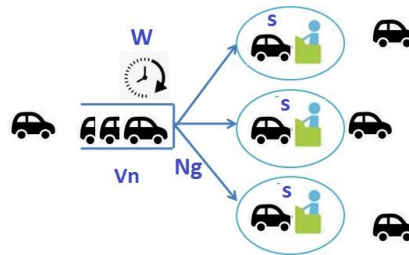
Figure 6. Port gate the multi-service system for emission estimation

The emissions of trucks are prominent due to the high emission factor they are characterized in contrast to the other types of vehicles. Omitting the emissions of the rest types of vehicles does not lead to a noticeable divergence between the real emissions. However, a considerable number of cars enter the port, thus car emissions should be included. According to the aforementioned approach, the number of vehicles can be defined as:

$$Vn = Vc + Vt + Vr \tag{6}$$

Where $V c$, $V t$ are the number of cars and trucks waiting to pass the port gate, respectively, while $V r$ represents the total vehicles of the rest vehicle types (e.g., motorcycle, bus, camber). To estimate cars and trucks as a percentage of the total vehicles ($V n$), a decision tree regression algorithm is used DTR. The percentage of vehicles are forecasted monthly for every category. In essence, given a specific month as input

to the decision tree model, a dual-output is retrieved (Pc, Pt), each output corresponding to a percentage of the total vehicles.

Decision tree regressor (DTR) is a tree architecture where each node refers to an attribute, each branch is a rule, and each leaf node decision tree regressor refers to the final decision. To divide the leaves, DTR uses node impurity to create the split points calculating the sum of square errors $Q_m(M)$:

$$Q_m(M) = \sum_{X_i \in R_m}(yi - c\hat{}m)^2 \tag{7}$$

Where, $Rm = m = 1, \ldots, M$, are the possible regions the data are divided, where M represents the number of months (total leaves), and $c\hat{}m$ is the average output for all the input data xi that belong to the region m. Finally, given a specific month and the total number of vehicles (Vn) waiting at the gate, the DTR estimates the percentage of cars (Pc) and the percentage of trucks Pt. As a result, the number of trucks and cars idling are estimated as:

$$Vc = Pc \times Vn \tag{8}$$

$$Vt = Pt \times Vn \tag{9}$$

To calculate the emissions for both vehicle categories and each type of emission in (3) is used. The exact time Δt for every vehicle cannot be estimated with accuracy as a result the average time W, a vehicle stands in the queue is used instead and (3) is modified as:

$$ETi,j = EIi,j = W \times EFV\ Ii,j \tag{10}$$

Considering that every vehicle is idling for W, in (1)0 is multiplied with $V\ i$ to compute the total emissions produced. The emissions for trucks (c) and cars (t) are estimated:

$$EIt,j = Vt \times W \times EFV\ It,j \tag{11}$$

$$EIc,j = Vc \times W \times EFV\ Ic,j \tag{12}$$

3.5.2. Lights emissions

As it is defined by the technical directive TOTEE 20701-1/2017, article 5 of 'KENAK' [32], CO_2 emissions are produced due to the consumable electricity that can be calculated according to in (13):

$$ECO_2 = PEC \times EFe, CO_2 \tag{13}$$

Where $EF_{e,CO2} = 0.989$ (kgCO_2) is the CO_2 emission factor of the primary energy consumption (PEC) in units of kWh of consumable electricity C in (kWh) :

$$PEC = C \times 2.9 \tag{14}$$

Because the lighting system is a main source of electricity consumption that can be easily controlled or dimmed it is examined separately. As a result, the above equation for lights L can be modified as:

$$EL, CO_2 = PECL \times EFe, CO_2 \tag{15}$$

Where $EF_{e,CO2} = 0.989$ (kg CO_2/kWh) [32].

3.6. Decisions and notifications
3.6.1. District optimization

Energy optimization is a fundamental procedure for building management systems, because when it is applied, it handles energy in an optimum manner to meet some optimization criteria [27]. Initially, an estimation of the energy balance is provided through the energy modelling process. A forecasting model is developed for each renewable source to simulate future generation as described above. Within this work, PV and wind energy sources are considered, but also others could be included. The forecasted generation such as the load demand are temporal dependent and are simulated for the same time period considering weather conditions which directly affect them. Moreover, the optimization criterion, the electricity price in the current work, is also feed-in-time series. Finally, decisions are made and the output y_i is generated, encoded as [27]:

$$y_i = \begin{cases} 0, & RES \\ 1, & DSO \\ 2, & SELL \\ 3, & ERROR \end{cases} \qquad\qquad (16)$$

In essence, the output consists of four possible options and/or notifications. After simulating the generated and load demand energy, decides if the produced energy is adequate to provide the district's energy load demand, if it is more profitable to sell the produced energy depending on the current electricity price and if there is an error with the RES production. In all cases in which energy load demand is not covered by the produced energy, distribution system operator (DSO) provides the required energy. Decisions provided by the multilayer perceptron (MLP) are configurable based on the stakeholders needs. Moreover, the optimization parameters may be specified by the user.

3.6.2. Suggested actions results

Notifications are sent to the end-user with suggested actions based on the real-time indicators. The end user is notified about an action that results in traffic reduction and light dimming. If the end-user decides to follow the suggested actions emissions will be reduced and energy will be saved. In this section, the process followed to estimate the results of the suggested actions are presented.

Reduction of vehicle emissions based on traffic simulation If the estimated emissions exceed a predefined configurable threshold, then PERFFECT notifies the port operator to open k new gates to reduce the emissions under the alert level. Opening new gates results in reducing the waiting time. The new waiting time $W' < W$ can be calculated exploiting (5):

$$\frac{Ng}{s}W = \frac{Ng+k}{s} \Longrightarrow w = \frac{Ng}{Ng+k} \times w \qquad\qquad (17)$$

As a result, the reduced emissions for a vehicle can be illustrated in (18) :

$$EIRi,j = W' \times EFV\ Ii,j \qquad\qquad (18)$$

Through the aforementioned approach, better traffic management is achieved while the benefits of implementing such a system are multiple such as:
- Environmental benefits, such as (reduction of pollutants, reduction of the greenhouse effect). Specifically, less CO_2, NOx and PM emissions ($ERCO_2,L$) are produced.
- Passengers' satisfaction because of better management of the traffic volume at the port gate.

Reduction of light emissions and energy consumption based on traffic simulation The lighting system is usually monitored and controlled by building management systems (BMS) or building operators. Lighting controlling is a multi-factorial procedure, where traffic should be considered a considerable factor when exam-ining ports because safety is a fundamental factor to be considered. Specifically, it serves no purpose to use lights during morning hours at ports. During no daylight (night) hours, low traffic is spotted through the traffic simulation algorithm that implies limited or no ships at the docks, and thus a light dimming is suggested to the port operator via a notification system.

A potential light dimming leads to the reduction of light consumption and reduction of light emission accordingly. The main concept of this use case is illustrated in Figure 7. Through the aforementioned approach, better energy management is achieved while the benefits of implementing such a system are multiple such as:
- Energy savings that are accomplished by light dimming. The reduced light consumption is notated as
- Environmental benefits, such as (reduction of pollutants, reduction of the greenhouse effect). Specifically, less CO_2 emissions ($ERCO_2,L$) are produced.
- Economic benefits, such as light dimming leads to reduced electricity bills.

3.7. Key performance indicators

Key performance indicators (KPIs) are the decisive factors towards an advance result. KPIs provide the basis for operations, strategy, and decision enhancement and improvement. Specifically, KPIs address the fundamental facts for evaluating selected actions towards development, recovery, revision, and growth. The main objective is to select indicators that can lead to achieve better outcome. An efficient port EMS includes KPIs that intend to optimize energy usage while mitigating emissions. The estimation of specific KPIs are presented in this section that either manage energy balance in a more efficient way or reduce emissions. The selected KPIs to present are those that were easy-to-deploy and low-cost.

3.7.1. Percentage of green energy

This performance indicator evaluates the percentage of renewable energy (GEP%) (sunlight and wind), often referred as green or clean energy. A percentage of 100% GEP% indicates that all energy consumed is by natural resources. The percentage of green energy is estimated by:

$$GEP\% = \frac{GE}{CF} \times 100 \tag{19}$$

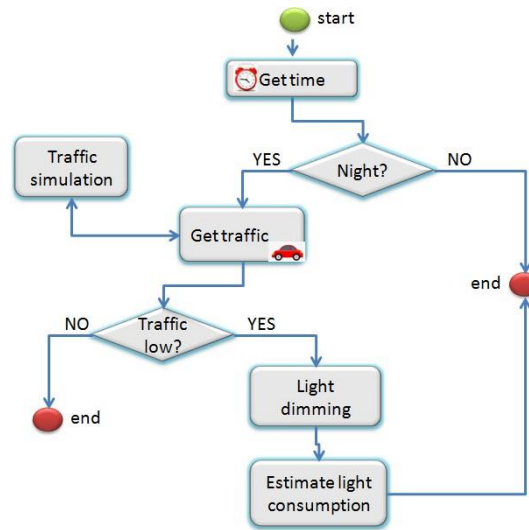Where GE is the total energy generated by renewable sources and EC is the total energy consumed by non-natural sources (e.g. electricity).

Figure 7. Light dimming and consumption estimation flow chart

3.7.2. Percentage of savings of lights consumption

This performance indicator evaluates the percentage of energy $EP_L\%$ that is saved from light consumption due to light dimming as presented in sub-section 3.6.2.

$$EP_L\% = \frac{E_L - ES_L}{E_L} \times 100 \tag{20}$$

Where E_L is the actual light consumption and the ES_L is the light consumption due to light dimming.

3.7.3. Percentage of reduction of lights emissions

This performance indicator evaluates the percentage of CO_2 emissions $EP_{CO2,L}\%$ that is saved from light consumption due to light dimming as presented in sub-section 3.6.2.

$$EP_{co2,L}\% = \frac{E_{CO2,L} - ER_{CO2,L}}{E_{CO2,L}} \times 100 \tag{21}$$

Where $EP_{co2,L}$ is the actual light CO_2 emissions and the $EP_{co2,L}$ is the light CO_2 emissions due to light dimming.

3.7.4. Percentage of reduction of vehicle emissions

To reduce the emissions that are produced due to the vehicle idling, the number of vehicles must be reduced and/or the waiting time, as a result opening an additional gate will result in reducing the service rate therefore the waiting time hence the number of vehicles idling. This performance indicator evaluates the percentage of emissions $EP_{i,j}\%$ that is reduced from opening additional gates as presented in sub-section 3.6.2.

$$EIP_{i,i}\% = \frac{El_{i,j} - EIR_{i,j}}{El_{i,j}} \times 100 \tag{22}$$

Where $EI_{i,j}$ is the actual vehicle emissions and the $EIR_{i,j}$ is the emissions from opening additional gates.

4.   EXPERIMENTAL RESULTS

Patra is a large city having one of the biggest ports of Greece. Patra's port is a paramount channel that connects Greece with Italy and Western Europe while providing a commercial and transport point to Ionian islands, Greece mainland and the Adriatic Sea (Figure 8). Indicatively, during the year 2020, 600,000 people, 340,000 vehicles and 8,400 containers travelled from and to the Patras Port [33]. Patra's South Port is mainly used for abroad itineraries and consists of 5 dock stations (i.e. A,B,C,D,E) available both for side-mooring and mooring by stern. The southern port includes a passenger terminal station, an administration building, a substation building, a fire department building, and a gate building.

The port of Patras has one permanent port facility also known as ISPS area that is situated in front of the quays. Patra is a roll-on/roll-off passenger (Ro/Pax) port. As a result, the entrance through the gate to the ISPS area is also a checkpoint for passengers and vehicles. Therefore, the gate checking process is a time-consuming procedure that directly affects the port's traffic.

Figure 8. Patras port location

4.1.   Port's operational processes
4.1.1. BERTH management system

As mentioned, BERTH is a vessel monitoring system that provides real-time data concerning ships that are about to moor, to sail, or even anchored at the port's quay. The data that are collected, are retrieved by relevant requests and then displayed and managed on the PERFFECT's platform user interface (UI). Specifically, the main information that are presented to the platform user regarding the ship schedules and monitoring contain details about the vessels arrival/departure/anchor time. In Figure 9, an overall view of the daily vessel scheduling can be depicted, while more information about each vessel can be displayed in a more detailed and extensive view for every quay in the port as illustrated in Figure 10.
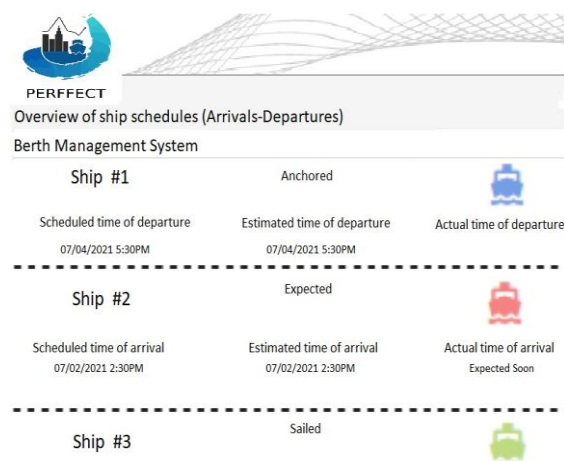
Figure 9. BERTH overview on PERFFECT UI   Figure 10. BERTH at a specific quay on PERFFECT UI
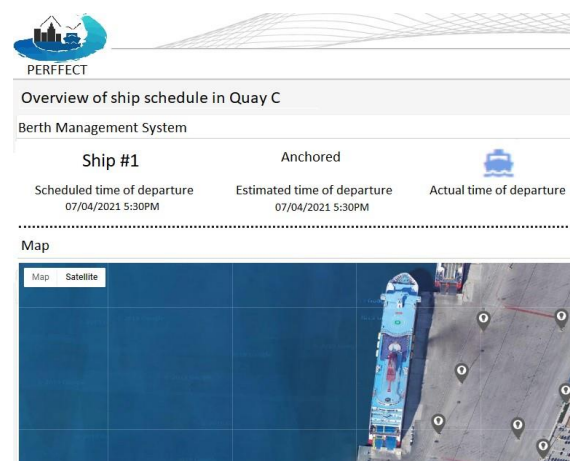
4.1.2. Lights scheduling

The exterior lighting of the ISPS area is controlled by an installed BMS system. The operating time of the luminaries depends on the sunset and sunrise time that alters during the year. For all the pillars located in

the ISPS area an economy (energy saving) program is implemented after midnight. In the ISPS area there are a total of 26 lighting pillars bearing HQI 1000W (1kW) lamps. Specifically, the ISPS lighting system consists of 3 groups:
− L1: 15 pillars × 8 luminaires with HQI 1000W lamps
− L2: 5 pillars × 5 luminaires with HQI 1000W lamps
− L3: 6 pillars × 5 luminaires with HQI 1000W lamps

Every luminaire at each pillar operates from sunset till 23:59. Then, an economy (energy saving) program is implemented as follows: In L2 and L3, every luminaire turns off from 00:00 till sunrise. In L1, 2 luminaires are kept open for safety reasons till sunrise. After sunrise, all luminaires are turned off.

4.2. Port's energy

The main electric consumption sources of port operations of the southern port of patras are buildings and external lighting system of the port (ISPS). Moreover, there is not any RES installation at the port that supplies energy to the system or to the grid.

4.2.1. Energy consumption

To estimate the energy consumed by the external lighting system of the port (ISPS area lights and street lights), the operational time schedule of the lights was considered. The street lights are not controlled and monitored by the port administrator and have a different time schedule from the ISPS lights. On the other hand, the ISPS lights can be controlled by the ports' building management system (BMS). Therefore, only the ISPS lights are taken into consideration in this paper. The annual energy consumption for the operation of the external lighting system is as depicted in Table 2.

According to the aforementioned time schedule of the ISPS lighting system, a power consumption diagram of ISPS lights through time can be depicted in Figure 11. The area of the diagram accounts for the total consumed energy derived from the ISPS lights at a specific day. The total energy consumed as well as the minimum and maximum power consumption can be observed in Figure 12. It should be mentioned that due to the lighting system steady demand behaviour, there is no need for a load forecasting algorithm for patras port.

Table 2. Annual Port's light consumption

Area	Annual primary energy consumption (kWh)
ISPS	1,130,620
Street lights	621,876
Total	1,752,496
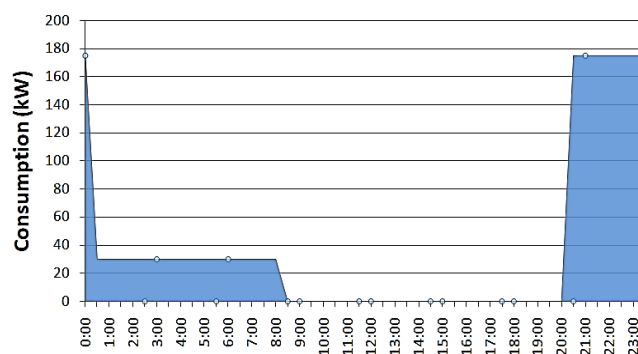
Figure 11. Energy consumption (ISPS lights)

Figure 12. Minimum and maximum values of power, and total daily energy consumption (ISPS lights)

4.2.2. Energy power generation

Research has been conducted at patras port to examine a potential transition towards energy sustainability and the installation of renewable energy sources. This action may have a beneficial influence on multiple factors such as considerable autonomy in terms of energy (save resources), potential energy contribution to the distribution system, and also improvement of the environmental footprint, RES are non-polluting and non-depletable. Within PERFFECT, a potential installation of PV and wind power has been analytically explored. PV power generation Solar power has become one of the most popular technologies for electricity gener- ation worldwide. Greece, as a European member, has established the necessary legislation for PV systems' installation. Indicatively, the most important Greek laws are:

− Definition of the new support scheme for renewable energy sources (RES), power plants and high effi-
   ciency combined heat power (CHP) plants, Law (L.4414/2016) [34].
− PV installation on buildings, which defines that no construction permission is required for PV installation
   on buildings up to 100 kW, Law (L.4759/2020, article 52) [34].
− Ministerial decision under the No 15084382,2019, which define issues for connection to the grid, energy
   communities and net metering installation, Law (L.4513/2018) [35].

Therefore to decide the theoretical and experimental installation of PV for clean energy production in the port of Patras, all the Greek laws and several scenarios were examined. The scenarios include the: port's location, meteorological data, port's orientation, buildings' construction, and port energy demand. As a result, it was decided that a typical PV installation of 2 50 kWp is more appropriate. Moreover, a type of poly crystalline solar module was selected with the electrical characteristics of 2550 Wp rated power and 16% efficiency. The installation of PVs as selected for the two buildings are as depicted in Table 3.

Table 3. PV's specification for a building at Patras port

Installation of poly-Si PV panels	Roof of the building 'Gate1'
Maximum power of PV panel	255Wp
Optimum operating voltage (Vmp)	30.8V Total rated Power installed
No of Panels	198
No of inverters	2
DC rated power	25.55kW
Ac nomimal power	230V/400V
No of strings	10, 5 to each inverter where they are connected 3 strings × 21 panels and 2 strings × 19 panels
Max efficieny	98.3

The results from the clean energy production of PVS as specified above are presented per hour, day, month and year on the perffect UI platform. A potential annual energy production was estimated to be 143,000 kWh [36] and would result to a reduction in energy consumption from the grid equal to 23.66% [37] and a relative reduction of CO_2 emissions. Solar power is directly connected to weather variables such as irradiance, cloud coverage, and tem- perature. Therefore, a diagram that relates irradiance and PV power generation is presented in Figure 13 while the total produced energy and power range is depicted in Figure 14. As it was expected lower solar irradiance values respond to reduced power generation from PV (Figure 15). The PV generation power does not exceed 28.4 kW in a less sunny day and the total produced energy have been reduced from 364 kWh to 240 kWh Figure 16.
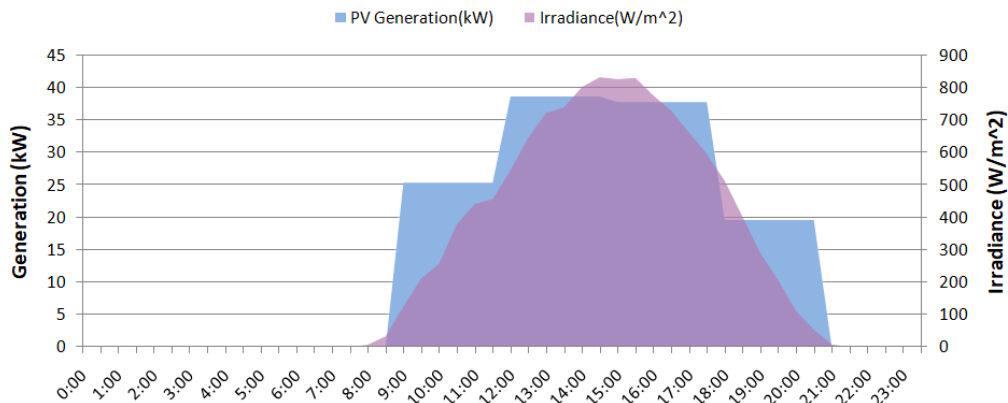
Figure 13. PV Power Generation estimation (19/04/2021)
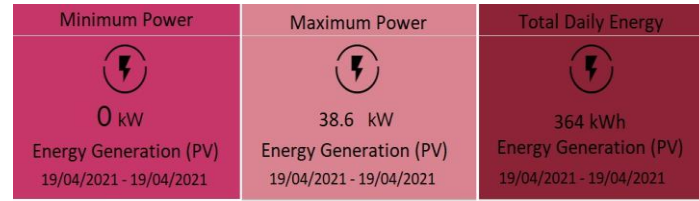
Figure 14. Minimum and maximum values of power, and total daily PV produced energy (19/04/2021)
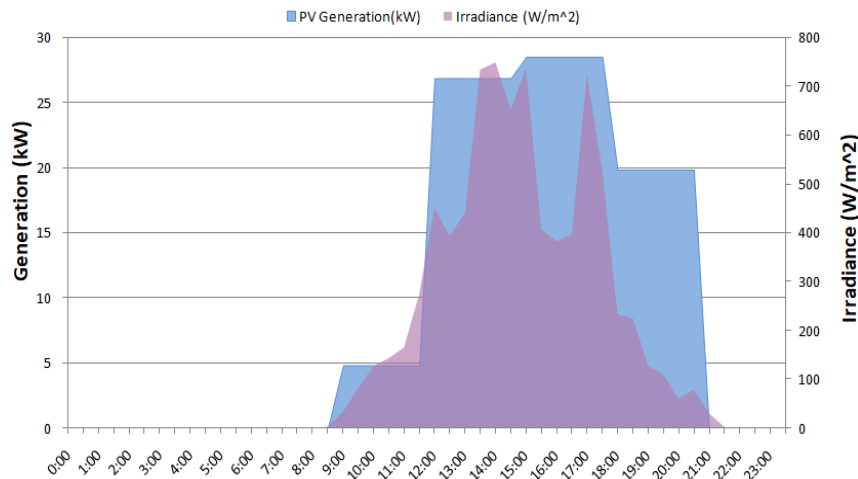
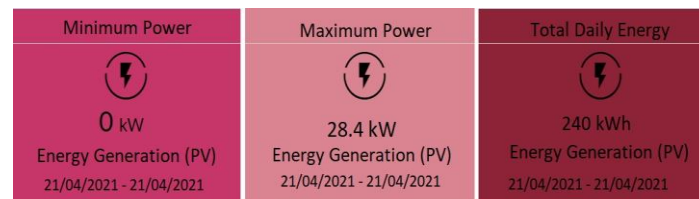Figure 15. PV Power generation estimation (21/04/2021)

Figure 16. Minimum and maximum values of power, and total daily PV produced energy (21/04/2021)

Wind power generation In Greece, wind farm is also one of the most important sectors for clean energy production. The wind energy Statistics and the Hellenic scientific association of wind energy stated that the installation of wind turbines exceeded 4,000 MW during 2020 [38]. Greece, as a European member, has established the necessary legislation for the installation/connection to the grid/of wind turbines. Indicatively,the most important Greek laws are:

− Laws (L3468/2006), published at the Official Government Gazette A' 129/27-6-2006 [39], (L3851/2010) published at the Official Government Gazette A' 85/4-6-2010 [40], (L3983/2011) published at the Official Government Gazette A' 144/17-6-2011 [41]in the beginning of RES installation.
− Law (L.4414/2016), as already mentioned above [34].
− Law (L4685/2020) that has been published at the Official Government Gazette A'92/7.5.2020. This Law defines the duration of the environmental licenses (EIA) for wind turbines' installation and other issues [29].
− The Ministerial decision under the no 74462/2976/ 2020 that has been published at the Official Government Gazette B' 3150/30-7-2020 and defines the licensing procedure for the installation and connection to the network of small wind turbines with an installed capacity of ≤ 60 kW [30].

Various types of wind turbines were examined to find the most efficient for theoretical and experimental installation for clean energy production in the port of Patras. According to the legislation for ports andthe maximum rated power of the wind turbine that is allowed to be installed, a typical 60 kW wind turbine was selected for the experimental operation of PERFFECT platform. The technical characteristics of the windturbine are illustrated in Table 4.

Table 4. Wind farm specifications

Installation of wind turbine	Port of Patras
Rated Power	60 kW
Start wind power	2.5 m/s
Type of axis	horizontal
Rated wind power	9 m/s
Rotor diameter	22.3 m
Swept area	390.4 m^2
Rated rotor speed	55 rpm
Safety	Mechanical pitch control Active yaw system
Tower height	24 m
Necessary area for the installation	30×30 m

The results from the clean energy production of wind power as specified above are presented per hour/ day/month/year on the PERFFECT UI platform. The wind power generation is simulated, as mentioned, through a physical model that takes as inputs future weather variables. Two different days have been selected to be presented in this paper. It should be noted that wind power is considered highly intermittent and its electrical output depends on many factors, such as wind speed, air density, and turbine characteristics.

Thus, a diagram of wind power's power related to the wind speed is depicted in Figure 17 in order to visualize the effect of wind speed to the produced power. As it can be noticed, the low wind speed values that are observed are insufficient to produce high power generation values, while the total daily energy produced hardly surpasses 10 kWh (Figure 18). In contrast, in a windier day where the wind speed varies between 7-8 m/s at some hours, the power generation reaches almost 50 kW (Figure 19) and the daily forecasted produced Energy 293 kWh (Figure 20). It can be easily noticed that for higher speed values that 8 m/s the power generation is 0 kW. That is due to the fact that wind turbines stop when the maximum wind speed is being exceeded and it is unsafe to continue. Therefore, automated braking systems are triggered to prevent undue stress on the motor and damage to the turbine.
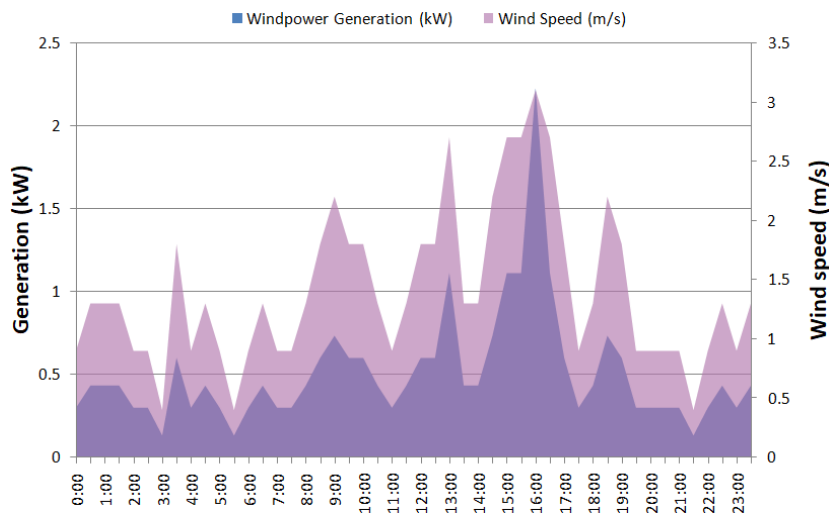
Figure 17. Wind power generation estimation (19/04/2021)
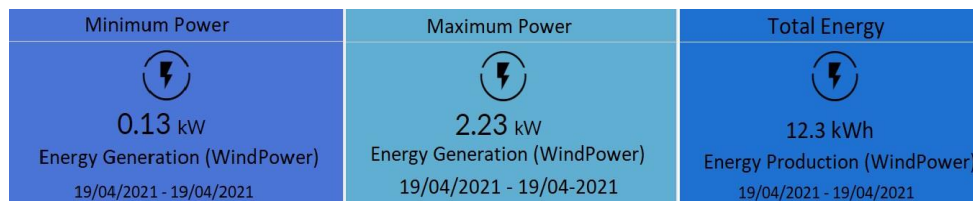
Figure 18. Windpower power range, and total daily produced energy from windpower (19/04/2021)

Figure 19. Wind power generation (21/04/2021)
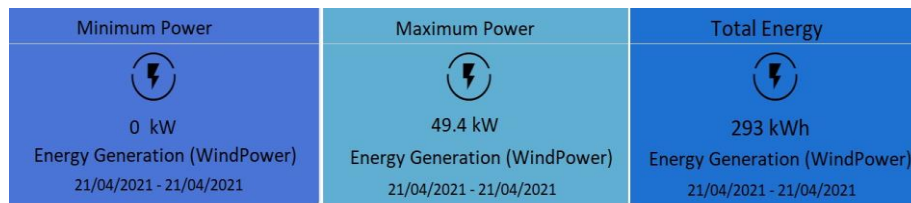
Figure 20. Wind power power range, and total daily produced energy from wind power (21/04/2021)

4.3. Real time indicators
4.3.1. Vehicles emissions

To improve the accuracy of emission estimation results, all vehicles were separated into categories according to their EURO emissions class [42]. Considering that the port is mostly used by vehicles from all over Europe, data for the EU fleet were used instead of national ones [42]. Within this paper only the trucks and the cars are taken into consideration since in Patras' port the number of vehicles of other categories are negligible. Finally, all emission factors used for a number of trucks (VT) and a number of cars (VC) are as depicted in Table 5. The number of vehicles is determined based on the procedure described in sub-section 3.5.1. in as depicted in Figure 21.

Table 5. Emission factors per vehicle type

Type	Emission Type	Emission factor (g/hr)	Equation
	Carbon dioxide	7200	$VT \times 7200 \times W$
Trucks	Nitrogen Oxide	101	$VT \times 101 \times W$
	Particulate matter	1.7	$VT \times 1.7 \times W$
	Carbon dioxide	1734.4	$VC \times 1743.3 \times W$
Cars	Nitrogen Oxide	0.2	$VC \times 0.2 \times W$
	Particulate matter	0	$VC \times 0 \times W$
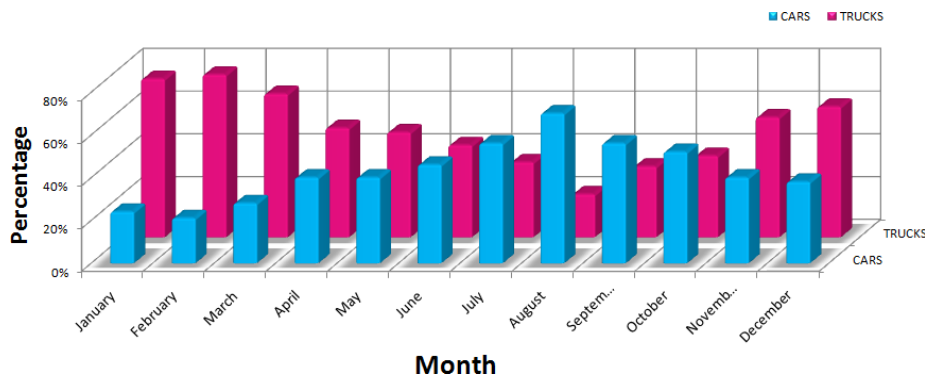
Figure 21. Cars and trucks percentage per month

To simulate the traffic at port gates in order to estimate the vehicle emissions the traffic simulation algorithm was used as explained in section 3.3.2. The implemented algorithm output y is the level of traffic density that appears at the gate, and is categorized to three states low $y=0$, medium $y=1$ and high $y=2$. When $y=0$, zero delay is detected at the gates and thus zero emissions derive from the vehicles. When $y=1$ or $y=2$ the average idling time for vehicles W is assumed 20 and 45 minutes respectively. Thus, the emissionsof cars and trucks can be calculated using in (11).

As it can be observed in Figures 22-24, a constant traffic density is detected at the traffic gates during lunch hours that result in C02, NOx and PM vehicle emissions. It can be easily noticed that cars' emissions and especially C02 and PM emissions are insignificant compared to the truck emissions based on Table 5 indicating very small emission factors to cars.
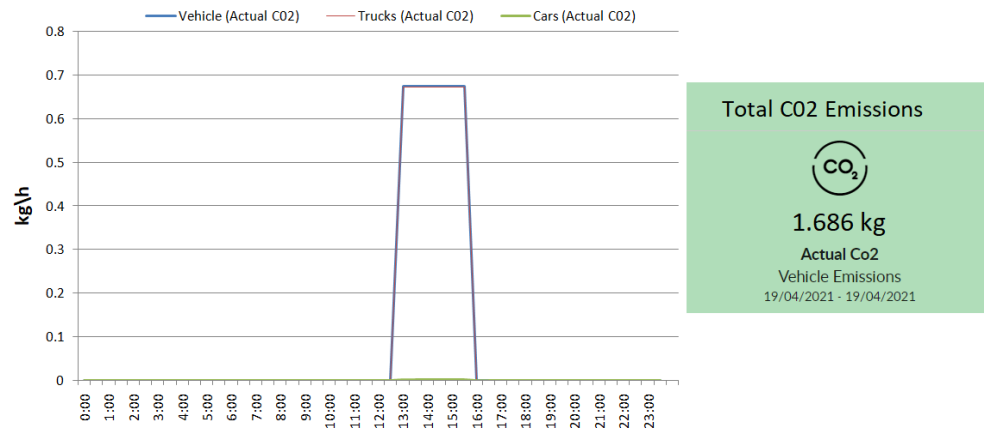
Figure 22. CO_2 emissions (19/04/2021)
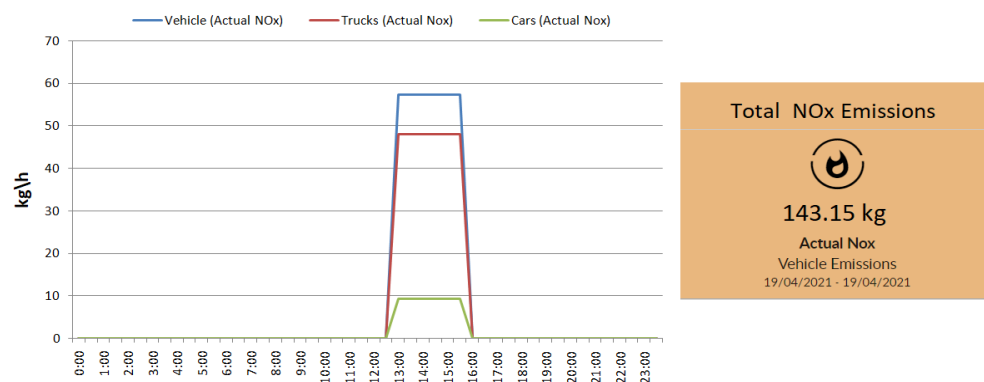
Figure 23. NOx emissions (19/04/2021)
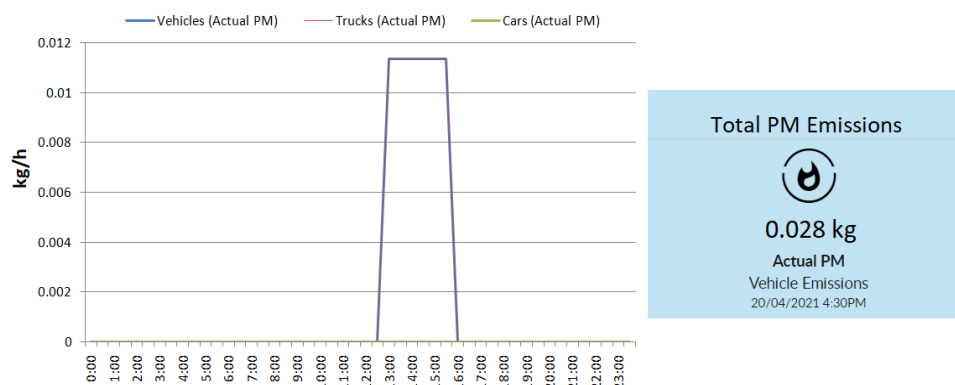
Figure 24. PM emissions (19/04/2021)

4.3.2. Lights emissions

The released CO_2 emissions to the atmosphere were estimated according to the Greek legislation, only from electricity consumption, as it is defined in the technical directive TOTEE 20701-1/ 2017, article 5 of 'KENAK' [32]. The annual CO_2 emissions due to the use of external lighting system, are estimated equal to 1.733 tn CO_2. Table 6 shows the emissions separately for ISPS area and the rest area of South port. It may be observed that ISPS lighting system is responsible for the 65% of total CO_2 emissions.

As mentioned, based on the estimation of the energy consumed for the ISPS lighting at port, the CO_2 emission corresponding to this consumption was calculated according to the in (15). In Figure 25 the rate of CO_2 emissions for a selected day can be observed, while the total CO_2 emissions were calculated approximately 2694 kg.

Table 6. Annual light CO_2 emissions

Place	Emissions of CO_2 (kg)
ISPS	1,118,183
Street lights	615,035
Total	1,733,219
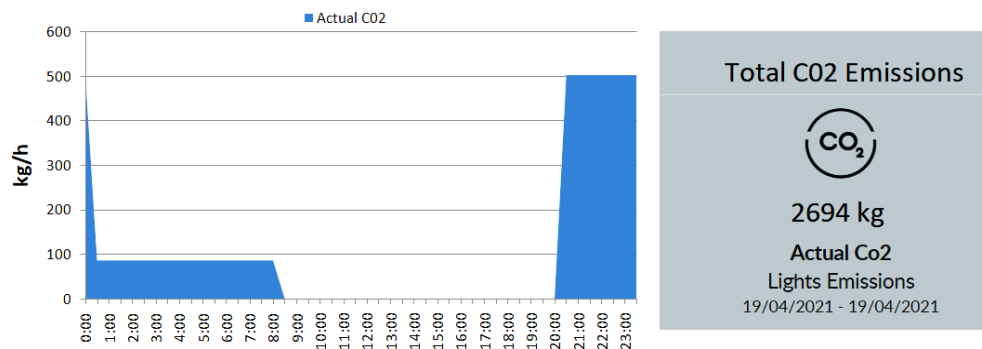
Figure 25. Light ISPS emissions

4.4. Decisions and notifications

This subsection elaborates decisions and notifications that came up from the conducted experiments at Patras Port. Specifically, decisions have been taken about how to manage the produced energy depending on an optimizing criterion. Push notifications were used to inform the user of PERFFECT'S platform about some critical issues such as potential traffic congestion at ports.

4.4.1. District optimization

Energy optimization is an essential procedure for high load demand systems and when it is applicable, it can handle energy in an optimum manner while corresponding an optimization criterion and electricity price was selected in this current work. Thus, exploiting an optimization algorithm the optimum utilization of the produced energy can be ensured at the port. Moreover, potential flaws or defects or damages to the RES systems could be identified if the forecasted power highly deviates from the ground truth values of power. Simulation and notifications to present an example of the simulation of the port's energy modelling and the decision made to optimize the energy balance, a typical day was selected. The consuming as well as the generation power of the RES is simulated and the energy for the next thirty minutes is calculated. According to the simulated results and the electricity price, the algorithm proposes the appropriate decision and informs the platform's users accordingly via notifications. As it may be noticed in Figure 26, during night and very early hours where there is an absence of PV production, RES power generation is insufficient to cover the ports' load demand (lights). Therefore, the algorithm's decision to cover the load requirements from the DSO was accurately produced.

During the morning and midday hours, where the lights are turned off according to the time schedule they conform to, the decision was also accurate and the produced energy was sold to the DSO. To optimize this decision based on the electricity price, a threshold was set equal to the average last ten days price of the electricity. Specifically, when the electricity price exceeds the pre-defined price threshold, the RES power is sold.
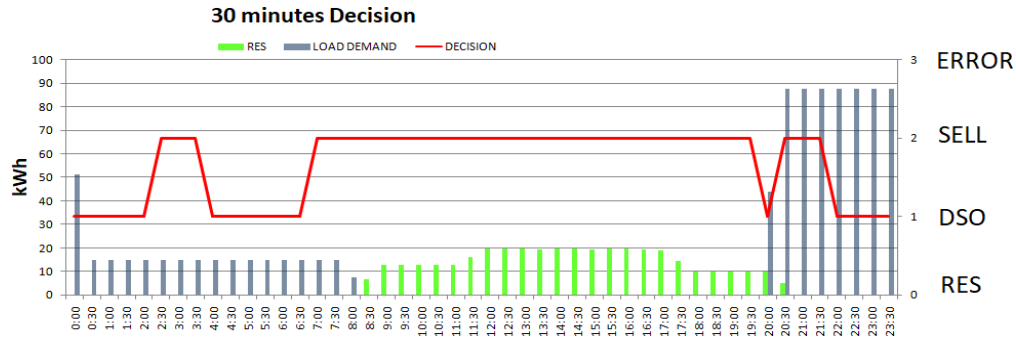
Figure 26. Simulation based decision support

4.4.2. Notifications

As mentioned above, PERFFECT's platform notifies the users via pop-up notifications and proposes potential actions based on real-time indicators that facilitate the proper functioning of ports' processes. End-user notifications the end-user accepts reports in the form of push notifications about actions in terms of traffic reduction and light dimming. The end-user taking into consideration the notifications can decide whether to follow the proposed actions. In case of approval of the suggested actions, emissions will be reduced and energy will be saved.

Particularly, if no or low traffic is detected at traffic gates through the simulation, traffic algorithm, that is interpreted as little traffic inside the port and a notification to dim the lights by enabling an economy light program, is suggested to the user (Figure 27). When, medium traffic congestion is occurred, the user is suggested to open a new gate to reduce the waiting time of the vehicles at the port and consequently the vehicle emissions. In case of extreme traffic congestion, notifications inform truck drivers that are about to arrive to the port about the traffic congestion. These proposed notifications can be illustrated in Figure 27.

Figure 27. Proposed actions to the platform's user

Reduction of vehicle emissions based on traffic simulation when medium or high traffic is detected or the estimated emissions exceed a predefined configurable threshold, then PERFFECT notifies the port operator to open k new gates to reduce the emissions the alert level. The potential reductions of performing this action and opening new gates for all emissions can be observed in Figures 28-30.

Reduction of energy consumption and light emissions based on traffic simulation If low traffic is spotted through the traffic simulation algorithm that implies limited or no ships at the docks, a light dimming is suggested to the platform's user via notifications. A potential light dimming leads to the reduction of light consumption and reduction of light emission accordingly because light CO_2 emissions are proportional to the light consumption. When the economy program is enabled then lights consume 30 kW instead of 175 kW and consequently the CO_2 emissions produced by lights are reduced from 175 0.989 2.9 = 501.9 kg/h to 30 0.989 2.9 = 86 kg/h. The reduction of CO_2 emissions at a specific day can be illustrated in Figure 31. The reduction in light consumption is omitted due to identical/proportional behavior.

4.5. Key performance indicators

Selected KPIs are presented in the platform to inform the end-user and the stakeholders of the current port's performance. In Figure 32, it may be observed that the percentage of green energy in 19/04/2021 at 22:00 is 0.2%. Moreover, the percentage of savings of light consumption and CO_2 emissions, due to the

absence of traffic, is approximately 82.82%. This reduction is the result of enabling the economy light program. Furthermore, in Figure 32, the reduction of vehicle emissions is up to 33.33% due to traffic volume reduction. This reduction is the result of in (17) by opening an additional gate. It should be noted that the presented KPIs may be enhanced upon current demand.
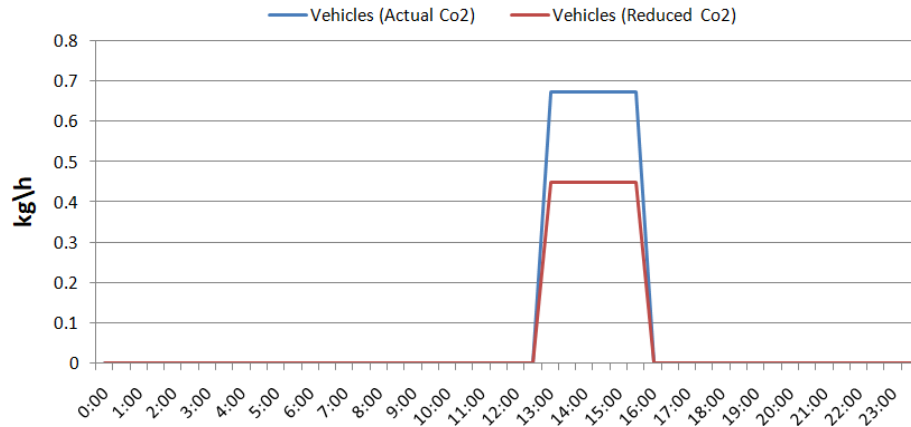
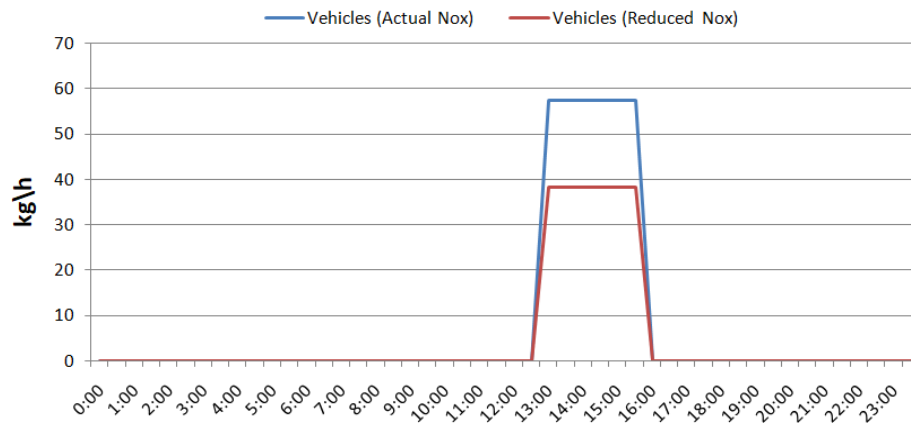Figure 28. Reduction of CO_2 emissions produced by vehicles
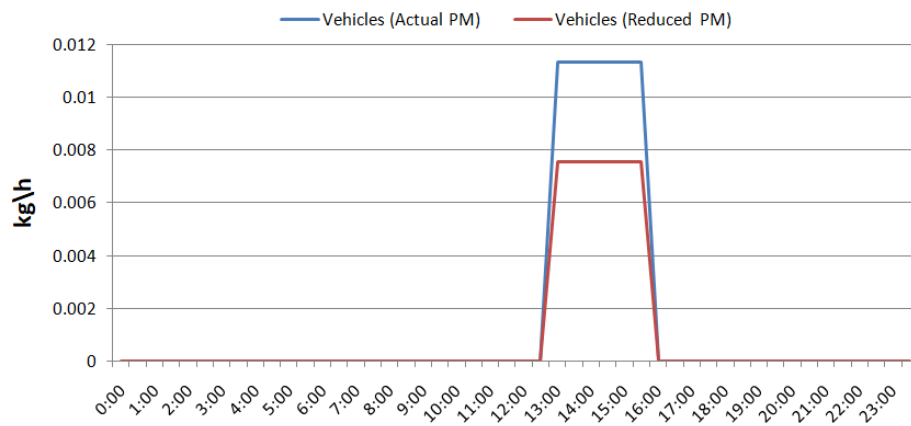

Figure 29. Reduction of NOx emissions produced by vehicles

Figure 30. Reduction of PM emissions produced by vehicles
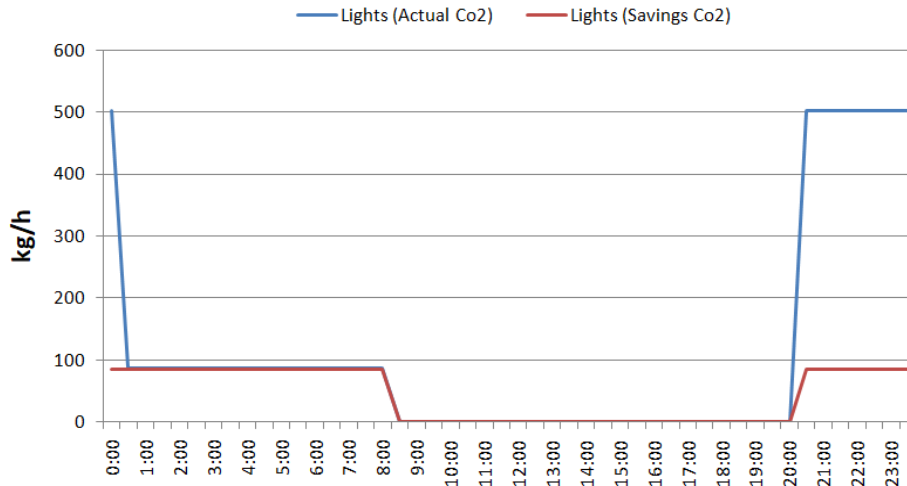
Figure 31. Reduction of CO_2 emissions produced by lights
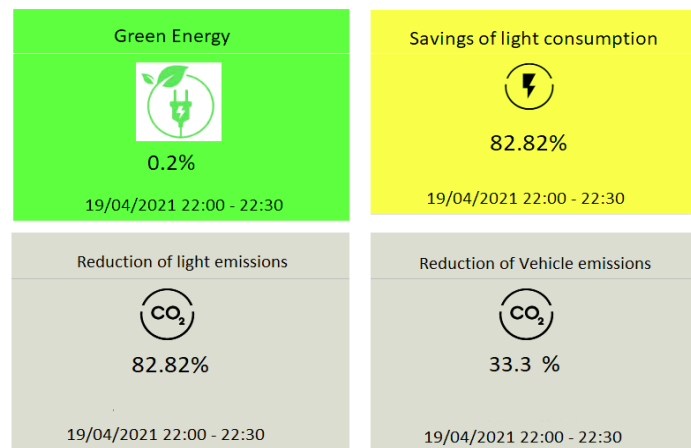
Figure 32. Selected KPIs night

4.6. Comparison of latest port energy management technologies to PERFFECT

To summarize, an assessment of the PERFFECT experimental results along with the aforementioned technologies in Introduction (section 1) is presented in Table 7. It may be observed that there exist technologies that result in substantial energy savings and emissions reduction like RES and TSES. Nevertheless, PERFFECT may provide efficient energy management and decarbonization with the minimum cost and the immediate future return on investment (ROI).

Table 7. Comparison of port energy management technologies

Method	Energy Savings	Reduction of emissions	Initial cost ($)	Return on investment (ROI)
PERFFECT	up to 82.82%	33%	1000 (server, database)	<1 year
RES	up to 100%	up to 40%	10.000 per square	>10 year
TSES	0%	100%	75000	>3 year
Cold Ironing	0%	100%	1.5 million	>10 year

5. DISCUSSION

European ports are connected to 848 ports in east and 629 in America, as a result a 74% of the European trade is accomplished through maritime transport. Energy port management and efficiency is of key importance not only because of the existing policies and regulations, but also for other factors. To begin with, energy management will increase the port's overall performance by regulating port processes. Moreover,

energy reduction will also lead to cost savings. Last, but not least, energy management results in the ports environmental impact.

PERFFECT research at the Port of Patras indicates that there is the potential to mitigate the energy and climate with a low-cost budget. PERFFECT can be deployed on almost any Greek port as the port legislation, and restrictions the platform was developed are the same in all Greek ports. Specifically, all information and legislation retrieved about the RES and PVS installation, emission estimation, emissions' threshold, and the main business process may be applied to all ports. Minor changes will have to be applied for traffic simulation as the vehicle and passengers' arrival rate at every port is different. On the other hand, the methodology and algorithms for traffic simulation can be applied without any severe modifications. Nevertheless, an investigation into the ports operational processes could result in new features if required or on stakeholders demand.

Moreover, PERFFECT could be deployed to any port worldwide following the same methodology. Initially, port legislation and restrictions will be gathered and analyzed to build a new port specification process applied to the respective port. Furthermore, an overview of the new port's business processes must be studied and evaluated to inspect all energy related processes. Afterwards, the emission factors based on the port's country must be estimated. Finally, the rate of the traffic must be retrieved and applied to the traffic simulation algorithm.

In addition, PERFFECT provides interoperability as it supports many communication protocols as stated in the previous section, as a result it is possible to access many other subsystems. Specifically, all data from heterogeneous sources can be pushed to the platform and be monitored, processed and visualized at the GUI. In particular, if there exists a real RES system the power generation will be measured by the appropriate meters and the data streams will be pushed to the platform instead of simulating the RES the system. Moreover, various other renewable sources apart from PVS and wind power may be added to the system like wave energy converters that will just increase the total generation power.

6. CONCLUSIONS

PERFFECT is a novel platform deployed to reduce port energy consumption and mitigate emissions through intelligent algorithms and a notification and visualization system. The system offers an overview of the current port situation, including but not limited to, ship arrivals and anchoring, traffic volume at the port's gate, vehicle emissions, and energy balance while facilitating the stakeholders and the platform-user to take specific actions. Moreover, detailed historical and daily port information is implemented through a dashboard navigation module providing further port awareness.

The first step towards port perception is the understanding of the main business and operational port processes and their association to procedures that may be monitored and/or controlled. Within this paper, 4 main factors have been studied to affect the overall port's functionality and are ships, vehicles, energy, and lights. All these parameters were thoroughly examined and directly related to 6 main port factors that are: port's operational processes, port's energy, port's specifications, real time indicators, decisions and notifications and key performance indicators. Each of them is identified with a specific application that is involved with energyand/or direct or indirect emissions production.

Furthermore, the main operational processes for freight and passenger support operational systems were evaluated and the most important amongst them was selected. A berth allocation and/or planning System in the case of Ro-Ro and Ro-Pax was selected to be deployed as a fundamental system. The volume of vehicles that arrive at a port gate depends on the BERTH system. Moreover, the more the number of vehicles, the more the vehicle emissions. As a result, the traffic simulation module is BERTH-depended. Moreover, the energy balance of the port is monitored and/or simulated. The energy is divided in energy consumed and energy produced by RES. Considering the produced energy and the current load demand, an intelligent decision tool is applied to determine the optimal energy exploitation. The decision is made based on a configurable optimization criterion. The suggested method was efficient during the experimental phase.

In addition, notifications are sent to the end-user to inform him/her of the current port's overview. Moreover, recommendations are produced to motivate the end-user to take actions in a more energy efficient and environmental way. Furthermore, pop-up messages are generated to alert the user to adhere circumstances like high volume traffic at the port gate. Finally, PERFFECT was evaluated against real-time BERTH data, environmental data, and energy data. All modules operated uninterruptedly and accurately. Furthermore, the results of the suggested actions were estimated. Enabling the economy light program leads to 82.82% energy reduction during the night, as a result it is beneficial both for the port's operational costs and environmental footprint. Moreover, the opening of an additional gate to regulate traffic levels results in 33.33% vehicle emissions.

To sum up PERFFECT is a data-driven platform that can handle all types of data. Various port processes may be appended to the system upon research on their energy consumption and emissions. Moreover,

based on the flexibility of the platform's interconnection the existing port BEMS, or EMS may be connected to the platform with many ways. The existing systems could be also visualized to the PERFFECT platform, and device controls could be pushed directly by the platform.

Future work will be focused on further tests to increase the total efficiency of the suggested PERFFECT platform. The proposed system could be enhanced with more port processes to increase the efficiency. More tests can be made for the suggested tools to ensure the interoperability and safety of the system. Finally,the proposed action to manage the traffic is based on opening an additional gate that is not the case for all ports.As a result, another parameter should also be examined.

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