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A review of port KPIs considering safety, environment, and productivity as the three dimensions of port sustainability

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Abstract. Together with economic growth, ports generate a series of externalities, both social and environmental. The need to minimize environmental externalities while promoting economic growth and addressing societal requirements defines the concept of port sustainability. Undertaking actions aimed at increasing port sustainability requires in parallel the availability of quantitative tools to evaluate and monitor the performance of a port in this sense. Using the critical literature review method, this paper proposes a framework which categorizes port sustainability key performance indicators (KPIs) according to the three lines of sustainability: social, economic, environmental. The ultimate scope is to identify a set of sustainable KPIs that port managers can use to monitor and assess the impact of actions aimed at improving their sustainability.

Keywords: Sustainable Port, KPIs, Port Safety, Port Performance, Port Efficiency.

1 Introduction

Ports are catalysts for economic development and are central to the growth of the global economy. Together with economic growth, however, ports also generate a series of externalities, both social and environmental [1]. The need to minimize environmental externalities while promoting economic growth and addressing societal requirements defines the concept of port sustainability (see, a.o., [2]).

The search for port sustainability has accelerated in the last two decades due to increased scrutiny of ports and environmental pressures [3]. Such growing attention towards port sustainability, and above all towards the measures that ports can implement internally to improve their performance in terms of sustainability, finds ample confirmation both in the practice of the port sector and in the relative rich scientific literature of the last decade [4].

Undertaking actions aimed at increasing port sustainability requires in parallel the availability of quantitative tools to evaluate and monitor the performance of a port in this sense. Performance assessment is indeed crucial to effectively supervise and manage logistics systems and is deemed essential for efficient planning and monitoring of activities within the decision-making process [5]. There are many reasons why a port or terminal should measure its performance, among the most relevant:

- it must know how effectively it is operating
- it must know what resources (manpower, equipment, areas, etc.) are needed in relation to its activities
- it must be able to monitor its performance and improvements over time, and compare them with those of its competitors
- it must be able to define a set of goals and compare its performance against those goals, and eventually adjust its goals for the future.

For these and other reasons, it is crucial that ports or terminals measure their performance, set performance targets and then regularly evaluate their performance against those targets.

The key role of performance measures in logistics systems has found large attention in the scientific literature [6-9], and several approaches have been applied to the purpose [10]. These approaches may vary depending on the perspective they adopt to investigate performance (product-oriented, process-oriented or planning level-oriented) or the method they use.

As for the latter, [11] provide an overview of the main methods used for the measurement of logistics performance, even in the port domain. Among the various methods available, the leading role of key performance indicators (KPIs) emerges for their simplicity of use and numerous advantages they offer: they are not predefined, they can be used to measure the performance of a specific process or segment of the system, to monitor its performance over time, to compare its performance with the others, etc.

This document proposes a review of the port sustainability KPIs, i.e. the indicators that can be used to evaluate the performance of a port from a sustainability-oriented perspective. The focus is on internal port sustainability and on the analysis of indicators that can be used to evaluate the sustainability performance of port actions which in turn strongly depend on the performance of the workers who carry them out. Port labor is in fact a key element in the performance of a port. Only in Europe, it is estimated that more than 110,000 regular dockworkers are engaged in loading and unloading ships and in other port-based services [12]. Despite the progressive shift towards the capital-intensive paradigm, the human factor still represents one of the most precious assets in ports [13]. Several scholars have investigated and proved the causal relation between port labor and competitiveness, concluding that port labor affects the final performance of a port [14], even in terms of sustainability.

The paradigm of port sustainability is here understood in its three-dimensional structure [15]. Breaking free from a concept of port sustainability which is still too often associated exclusively with the issue of environmental impact, the objective of the analysis is to investigate port performance indicators in relation to both environmental, economic, and social sustainability.

More specifically, the study involves the three spheres of port sustainability as follows:

- safety of operations, for the social dimension
- productivity of internal port operations, for the economic dimension

– energy consumptions and related emissions of internal port operations, for the environmental dimension.

As for the first sphere, sustainability and safety are two closely interrelated concepts that both concern the conservation of resources. Specifically, safety is about human resources and the safeguarding of human life and well-being. The basic principle is that a port system cannot be sustainable if it is not safe for humans. Port safety can thus be described as not only the measures taken to reduce the risk of port injuries and deaths but also the feeling of being safe in the port system and the reliability that port workers will not be injured or killed in that system. The focus of the analysis will be on active safety and the importance of monitoring operators' fatigue and stress for enhancing work performance while reducing the possibility of accidents.

As for the second sphere, broadly speaking, the term productivity refers to the measure of the efficiency of a production process, given by the ratio between output and input. A port can be considered efficient or highly productive if, for given inputs, it produces a maximum output, or if it uses minimal inputs to produce a given output. Because of the importance they hold for the assessment of the economic sustainability of port operations, productivity-related KPIs have long been a topic of interest to both port managers and academics.

As for the third sphere, international shipping is recognized as one of the largest GHG emitting sectors of the global economy. According to IMO estimates, the share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018, and emissions are projected to increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050 [16]. As for the port area, shipping emissions in ports are substantial, accounting for 18 million tons of CO_2 emissions, 0.4 million tons of NO_x, 0.2 million of SO_x and 0.03 million tons of PM_{10} in 2011. Most shipping emissions in ports (CH4, CO, CO_2 and NO_x) are estimated to grow fourfold up to 2050. This would bring CO_2-emissions from ships in ports to approximately 70 million tons in 2050 [17]. The focus of the analysis will be on environmental KPIs to monitor internal port emissions and energy consumption.

Using the method of critical literature review, this document proposes a framework that classifies port sustainability KPIs according to the three dimensions of sustainability. The ultimate goal is to identify a set of sustainable port KPIs that port managers can use to monitor and evaluate the impact of actions aimed at improving the sustainability of their operations.

The structure of the paper is the following. After this introductory section, Section 2 briefly presents the methodology used to perform this critical review, Section 3 discusses the proposed framework that classifies port sustainability KPIs according to its three dimensions, finally Section 4 concludes.

2 Methodology

This study uses the critical literature review method to answer the following research question: *what are the main quantitative KPIs that can be used to evaluate the sus-*

tainability of ports encompassing the triple bottom lines, i.e., the social, economic, and environmental dimensions?

The main goal of this overview is to categorize the available port sustainability KPIs into three categories:

- port KPIs related to safety of operations, stress and fatigue (social dimension)
- port KPIs related to productivity performance (economic dimension)
- port KPIs related to environmental and energy impact of internal port operations (environmental dimension).

The emphasis is on analyzing data from sufficient established research in the field, without covering all the studies contained in it, but still leading to a combination of different perspectives. Unlike a systematic literature review, which is commonly based only on peer-reviewed academic studies, this review is constructed following the triangulation search approach, which refers to the use of multiple and diverse data sources to develop a comprehensive understanding of the topic under study. To build an overall picture of the complex issue of port sustainability KPIs that considers the three dimensions of sustainability, this research therefore developed on two fronts:

- review of the relevant peer-reviewed academic production
- analysis of the relevant gray literature (chapters of books, proceedings, technical reports of trusted experts, etc.).

The selected studies were collected by searching the Scopus and Google Scholar databases between December 2022 and March 2023. Searching within titles and keywords iteratively used the following keywords: (port OR terminal) AND (Sustainab*) AND (measures OR indicators OR KPI OR performance OR evaluation).

The studies identified through the keyword search were preliminarily filtered by reading the abstracts to understand if they could fall within the scope of the analysis. Additional relevant studies that were not captured by keyword search were identified through the snowball technique and personal knowledge of the authors. In total, the review converges on approximately 40 studies whose contents are used to answer the proposed research question.

It should be noted that this research is not intended to be comprehensive or all-encompassing as there may be several studies that the research performed did not capture. However, it provides a general picture of the state of the art of the main KPIs so far available in the literature to measure port sustainability in its three dimensions.

3 Review of KPIs for port sustainability

This section presents the results of the performed review organized into three sub-paragraphs, each relating to a dimension of port sustainability:

- port KPIs related to safety of operations, stress and fatigue (social dimension)
- port KPIs related to productivity (economic dimension)
- port KPIs related to environmental and energy impact of internal port operations (environmental dimension).

3.1 Port KPIs related to safety of operations, stress and fatigue

According to the so-called "systemic approach", the port can be seen as a complex and dynamic system made up of three components: vehicles/equipment, infrastructures, and management system. Man is at the centre of this system and can be the recipient of the system design (man-user) or a component of the system itself (man-operator). In such a systemic vision of the port, each component interacts both with the other internal components and with the external environment. In the relationships between the components of the system, safety arises as a design area whose impact can fall - depending on the objectives - on the man-user or on the man-operator. In this regard, two different areas of study can be identified:

- passive safety, which deals with limiting the negative effects of the accident
- active safety, which deals instead with studying the measures useful for reducing the risk of an accident occurring.

Focusing on the performance of the operator, and therefore of the man-operator, the focus in this section will be on active safety and on the importance of monitoring operator fatigue and stress to improve work performance by reducing the possibility of accidents. Fatigue is multidimensional as it affects both the physical and psychological bodies. Operating while fatigued is associated with longer and more delayed reactions in response to changing demands, fewer steering corrections, reduced galvanic skin response, increased body movements, and increased irritability [18]. In addition to accidents, there are a number of work-related health problems associated with dock work (for example, musculoskeletal disorders, whole-body vibration effects, noise-induced hearing loss, accidental intoxication from chemical exposure and harmful biological substances, etc.). Furthermore, activities that require high levels of production and fast turnaround times, such as the loading and unloading of container ships, can lead to psychosocial health problems such as stress and fatigue which, in addition to making workers ill, also lead to which increase the risk of accidents. From the analysis of the state of the art it can be stated that there are not many studies on the safety and health conditions of port workers inside a port.

The literature seems to deal mainly with technical design and mathematical modelling problems with reference to the risk analysis techniques adopted for specific ports [19]. Analyzing the impacts that containerization has had on worker safety, [20] state that several factors can influence the frequency of occupational accidents, in particular economic factors, technologies used (e.g. low automation, discontinuous operation), work organization (e.g. execution of a specific task, availability of adequate equipment for this task), environmental conditions (e.g. weather conditions, time of day, day of the week, etc.) and human factors (e.g. age, work experience, education). In this regard, it has been shown that technological advances can lead to improvements in productivity and occupational health and safety, but not necessarily simultaneously.

The scientific literature on port worker stress and fatigue is not extensive. Among the analyzed studies related to stress and fatigue in the port environment, we can mention [21-23]. According to these authors, human error is one of the main factors influencing port safety. Indeed, in ports, 80-90% of accidents occurring on the docks are caused by human error. Therefore, despite the high degree of automation achieved in ports and container terminals, the operator continues to play a very important role. The growing level of specialization, especially required of crane operators, has also been accompanied by a growing level of stress and consequently by an increased risk of serious accidents. Studies on stress and fatigue fall within the scope of active safety. Active safety includes both the study of human factors and the areas of ergonomics and anthropometry. In general, the factors that cause work stress can be divided into:

- physical factors: environmental (heat, cold, noise, vibrations, etc.) and physiological (lack of sleep, dehydration, muscle fatigue, etc.)
- mental factors: cognitive (too much or too little information, judgment difficulties, etc.) and emotional (pressure, frustration, boredom/inactivity, etc.).

[24] propose a set of indicators to be applied in port areas related to health, safety and occupational safety starting from the indicators used by the ports and then implementing them on the basis of the proposals of the interested parties. The final list of selected occupational health indicators includes:

- the number of deaths from accidents at work in a period
- the number of full calendar days in which the operator is unable to work due to an accident at work
- the number of occupational accidents in a period.

Similarly, [20] propose two indices to analyze the incidence of port workers' injuries in the port of Genoa:

- the frequency index, given by the ratio between the total number of accidents and the number of hours worked
- the accident index, given by the ratio between the number of total accidents and the number of employees.

The study by [25] proposes to use the following port security indicators:

- damages per year or damages per 1000 TEU
- losses per year or losses per 1000 TEU
- damage to dangerous goods (in % of cases)
- total number of injuries per year.

To evaluate the effectiveness of simulator training, the study by [23] uses a series of indicators relating to operator safety, stress and fatigue. These include incorrect positioning of containers, the number of collisions and the stress level of the operators.

The paper by [21] highlights that there are no simple and immediate methods to measure stress and fatigue. The measures adopted so far in the literature concern:

- physiological parameters, used to evaluate tiredness and/or drowsiness (EEG electroencephalogram, ECG electrocardiogram, etc.)
- behavioral parameters, used to measure fatigue. They are mainly based on the frequency of body movements
- parameters of facial behavior, used to evaluate fatigue: changes in facial expression, eye and head movements are all indicators of fatigue. Other parameters such as pupil movement and saccades are indicative of the level of alertness.

- performance parameters: number of errors in carrying out the task, number of near misses, number of collisions, abrupt maneuvers, etc.

However, the data obtained from these measurements, mainly carried out with medical instruments, are not easy to interpret.

Table 1 lists the safety-related indicators analyzed. It should be noted that this analysis is not intended to be exhaustive as it mainly aims to provide a general picture of the state of the art of the main environmental/energy performance indicators used so far in the port sector.

Table 1. Summary of the analyzed safety-related KPIs used in ports.

Health, stress and fatigue indicators	Unit of measure	Reference
Frequency rate of fatal work accidents	Accidents/month or year	
Number of fatal work accidents	Fatal accidents/ year	[24]
Near miss	Near miss/month or year	
Frequency index	accidents/h worked	[20]
Injury index	accidents/employees	
Number of accidents in ports	accidents/year	[24, 25, 26]
Wrong container positioning	n. of events/employee	[23]
Collisions	n. of events/employee	
EEG, ECG		
Number of body movements recorded during task performance		
Changes of facial expression	*instrumental detection*	[21]
Eye movements		
Head movements		
Pupil movements and saccades		

Source: authors' own elaboration

3.2 Port KPIs related to productivity performance

Until the end of the 1990s, port efficiency studies mainly focused on partial productivity measures (e.g., vessel turnaround times, crane productivity, etc.), since then, academics have shown an increasing interest in the development of methods that analyze the overall efficiency of the port, especially for container terminals [27]. While looking at the overall productivity of the port seems to be the best solution, in practice it entails a number of problems. The port environment can be considered a dynamic system within which different actors interact (carriers, port operators, stevedores, dock workers, port authorities, shippers, railways, government, etc.). Each actor wants to achieve a certain objective (which often conflicts with the objective of other subjects), and, in pursuing it, it affects the overall productivity of the terminal (or even of the entire logistics system). The various subjects who relate to the terminal evaluate the quality and productivity of the port service with respect to various parameters. By way of example: the average hourly productivity of quay cranes represents an important indicator for the shipping company, while the presence of parking and maintenance areas for empty containers can be useful for the owning company [28].

Because of their importance, port performance indicators have long been a topic of interest to port managers and academics. As early as 1976, UNCTAD proposed a series of port performance indicators divided into two broad categories: financial and operational [29]. The former measured the financial performance of the port in terms of monetary units per ton of cargo, while the latter provided a measure of operational performance including late arrival (ship/day), waiting time (hours/ship), service (hours/vessel), delivery times (hours/vessel), tonnage per vessel (ton/vessel), number of groups per vessel per shift (groups/vessel shift), tons per vessel/hour in port (ton/h), tons per group-hour (tons/gang-h).

The paper by [25] proposes a set of quality and performance indicators for intermodal terminals using the point of view of the terminal customer and the terminal operator, respectively. The first group, called quality indicators, describes the service level of a terminal and provides customers with a correct view of the terminal's performance in terms of waiting times, reliability, accessibility, flexibility, security, services in general and frequencies. The second group, called performance indicators, describes the productivity of a terminal and its processes.

According to [30], the productivity of a container terminal depends on the efficient use of manpower, equipment and land, therefore productivity measurement serves to quantify the efficiency of these three resources. The authors list the elements of the terminal which - according to them - influence productivity and for each element they define productivity factors and productivity measures. The measure of gross crane productivity can be expressed in movements/gross group or crane hours, while the net productivity of the crane is measured in movements/gross group or crane hours - idle time. The measure of gross labor productivity is given by the number of movements/man/hour. It must be assumed that there are limits to the throughput of the terminal and such limits can be imposed by different factors (institutional, physical, economic, etc.) [31].

Table 2. Summary of the analyzed productivity KPIs used in ports.

Productivity KPIs	Unit of measure	Bibliographic reference
Vessel service time	hours/ship	
Tons per ship hour at berth	tons/hour-ship	[29]
Tons per gang-hour	tons/gang-hour	
Throughput	TEUs/day or week or year; TEUs/year-hectare; TEUs/year-employee	
Total number of transhipped TEU/loading units per hour	TEUs/hour	
Tranhipment capacity	TEUs/day or week or year	[a.o., 25, 21, 23]
Labour productivity	TEUs/year-employee	
Crane rate	TEUs/hour-crane	
Crane load	total annual through-put/n. of cranes	
Crane productivity	moves/hour-crane	
Gross labour productivity	moves/man hour	[30, 32, 21]
Equipment productivity	moves/hour-machine	
Single move time	time/move, average time/move, max time/move	
Wrong container positioning	n. of events/day or month or year	[23]
Extra container moves	n. of extra moves/ day or month or year	

Source: authors' own elaboration

Following a similar approach, [32] identifies among the various key productivity measures the following:

– crane productivity, calculated per crane and expressed in gross and net values

- productivity of the equipment, expressed as the number of container movements performed per hour of work
- labor productivity, calculated per man-hour in a given period.

Regarding labor productivity, the study by [21] analyzed the performance of dockside crane operators. In this study, the productivity and performance of dockside crane operators is measured in terms of containers moved per hour. The objective of the investigation was to construct experimentally performance curves for ship-to-shore gantry crane operators according to the Yerkes-Dodson model. The authors found that low workload translates into poor performance, because as the workload increases, the level of performance increases, until it reaches its peak. From there on, performance degrades as the workload increases. However, it has been observed that, if the operator is skilled, it is possible to maintain high levels of performance even under high workloads. This means that it is possible to intervene on the productivity of quayside cranes through the training and updating of quayside crane operators. In this regard, an interesting study on the use of the simulator as a training tool in container terminals can be found in [23]. To evaluate the effectiveness of simulator training, the authors quantify the performance of dockside crane operators using the following measures:

- number of moves per unit of time
- average and maximum travel time
- single movement time
- wrong container placement number
- number of extra container movements.

Table 2 summarizes the productivity indicators discussed in this section.

3.3 Port KPIs related to environmental and energy impact of port operations

There are estimates according to which berthing activities contribute to emissions of up to 69% of the total ship activities at the container port [33], but they are not the only emissions at hand. However, the percentage of CO_2 emissions to be specifically attributed to port activities has never been quantified, though it is widely recognized that since maritime trade will increase, in the absence of adequate measures, these emissions will also increase [34, 35]. In 2022, climate change has become, for the first time, the top environmental priority of European ports [36].

Analyzing the port system, GHG emissions are attributable to the following components:

- vessels
- port operations
- land transport.

Taking the Port of Los Angeles as an example, about 80% of total port emissions are generated by their customers (ships, trucks, and trains) while only 20% is attributable to port equipment [37]. In the literature, most of the studies have focused mainly on the emissions produced by ships at the quay and on those generated by land transport while very few articles have addressed the issue of CO_2 emissions from the point of view of port operations [38]. Among them, the study by [34] analyzes the policies that ports implement to reduce GHG emissions and, in particular, the technical and operational measures that the various "port polluters" (maritime operators, ports and land transport) should adopt. The measures identified for the reduction of GHG emissions in ports are the following:

- information measures, essential for monitoring emissions and energy consumption and establishing a baseline
- equipment, involving the physical change of emission sources in order to get newer, cleaner and more energy efficient engines
- energy measures, to provide cleaner energy, other than fossil fuels
- energy efficiency measures, to reduce the energy consumption of port equipment, buildings, vehicles, warehouses, and berthing vessels
- port operational measures such as digitalization, intelligent logistics, container terminal automation, green purchasing and procurement, circular economy, port city integration, etc.

Some authors have examined the environmental impact generated by the different equipment of a container terminal. Trucks (or tractor trailers or yard tractors), rubber gantry cranes and quay cranes are the main sources of CO_2 emissions. This has led researchers and terminal operators to focus on the study of appropriate energy efficiency measures in port terminals [39].

On the seaside, the main source of port pollution is the quay crane. To accommodate the phenomenon of naval gigantism and the growth of maritime trade, the market offers increasingly larger cranes with ever greater handling productivity, in order to minimize the permanence of ships in port. On the one hand, this has led to growing needs for electrical power (up to 4 MW for operating a crane) and, on the other hand, has increased the gap between technical productivity (crane cycles/h) and productivity achieved operationally, making this equipment unsustainable [40].

As regards the connection between the seaside area and the yard, CO_2 emissions generated by trucks have been shown to be one of the main sources of pollution in maritime transport [41]. Among the proposed solutions is the conversion of terminal tractors from diesel to more sustainable energy sources [42], or the replacement of traditional trucks with automated guided vehicles, which run smoother and more efficiently by being driven with controllable speeds and accelerations [40]. As with traditional trucks, optimization of consumption can be achieved through a driving style characterized by low accelerations and decelerations and a better synchronization of operations (see, among others, [43]). As regards the stacking of containers in the yard, some authors address the problem of choosing the most sustainable equipment [40] while others analyze to what extent the scheduling of yard cranes can optimize lifting operations thus reducing energy consumption [44].

What emerges in all cases is the need to monitor the phenomenon through the quantification of quantitative and measurable quantities. Environmental and energy efficiency indicators can thus be used to evaluate and monitor how a port is performing in this regard using scientific evidence and quantifiable measures.

However, despite the growing awareness of ports on the importance of using environmental and energy efficiency indicators, there is no common approach regarding which indicators can be adopted.

Table 3. Summary of the analyzed environmental and energy efficiency KPIs used in ports.

Environmental/Energy KPIs	Unit of measure	Bibliographic reference
Resources consumption	-	[45]
Diesel fuel consumption of yard tractors	TOEs (tonnes of oil equivalents)/year liters/TEU	[42]
Electrical consumption of STS cranes	KWh/year KWh/TEU	
GHG emissions	tons/week	[35]
CO_2 emissions of yard tractors and STS cranes	kg of CO_2/TEU	
Consumption of diesel-mechanically driven tractor trailers	liters/hour	[40]
Amount of energy per container visit (container passage through the terminal)	-	
Fuel consumption of the truck as acceleration varies	liters/second	[43]
Energy consumption per load unit	KJ / KW per load unit	[25]

Source: authors' own elaboration

The paper by [45] identifies a comprehensive set of environmental performance indicators used in the port sector distinguishing between management indicators (which provide information on management efforts affecting the environmental performance of the port), operational indicators (which provide information on the environmental performance of port operations) and environmental indicators (which provide information on environmental conditions). Martinez-Moya et al. [42] analyze the energy efficiency and CO_2 emissions of the Valencia terminal and propose an estimate of the diesel consumption of the terminal's engines expressed both in TOE (tonnes of oil equivalent) and in litres/TEU, and the corresponding emission in kgCO_2 /TEU. The authors also propose an estimate of the electricity consumption and CO_2 emissions of quay cranes expressed respectively in KWh or KWh/TEU, and in kgCO_2/TEU.

The study by [40] proposes to use the amount of energy per container visit to quantify the sustainability of a terminal. Following a similar aggregated approach, in which containers are viewed as energy consumers during handling, the paper by [25] defines a set of performance indicators for intermodal terminals which include energy consumption per load unit expressed in Kj/Kw. In [43], the energy consumption of diesel trucks used to transport containers within the terminal is analyzed using distance as the main factor.

Table 3 summarizes the environmental and energy efficiency indicators analyzed.

4 Discussion and conclusion

This document presented a framework that classifies port sustainability KPIs according to the three dimensions of sustainability: safety of operations (social dimension), productivity (economic dimension), environmental and energy impact of inland port operations (environmental dimension).

As far as the safety dimension is concerned, the indicators analyzed seem to be attributable to two main groups: KPIs that monitor the number, frequency, severity and cost of accidents and KPIs used to monitor the onset of stress and fatigue in port operators to reduce the likelihood of recurring accidents. If the first can be extremely useful for monitoring the port's performance over time in terms of safety and promptly identifying any critical issues that require timely intervention, the second can allow not only to establish for which workload values port workers can work in safety, but also to objectively verify the effects that safety-oriented measures and initiatives can have in terms of increasing safety or reducing risk. For example, to reduce the onset of stress and fatigue, port workers need to be sufficiently trained for the workload they will be subjected to. Indeed, port stakeholders typically advocate high standards of training to ensure safe and efficient operations in ports [46]. The analyzed indicators can then be used to evaluate the effectiveness of port training courses and the application of health and safety standards in a port or terminal. Since in the real world it can be difficult to measure the level of fatigue and stress of the operators, these analyzes are often carried out in a virtual environment using simulators assisted by electromedical devices for the detection of the physiological parameters linked to the onset of fatigue and stress.

As far as the productivity dimension is concerned, there is a wide range of KPIs that can be traced back to the evaluation of port performance, these indicators vary enormously according to the point of view adopted but have in common the fact that they can all be traced back to three fundamental elements: labour/workforce, port equipment and port infrastructure. Depending on the level of aggregation used in the estimation, these KPIs provide a measure of terminal productivity which can sometimes refer to a single piece of equipment, a single worker or team, a given unit of time (work hour, year, etc.) or infrastructural entity (linear meter of quay, square, etc.), sometimes to the entire port/terminal.

As for the port's environmental and energy sustainability KPIs, despite the growing awareness of ports on the importance of using these indicators, from the analysis carried out there does not seem to be a common approach on which indicators should be adopted. Most studies focus on emissions from port vessels and land transport, and very few articles address emissions from a port operations perspective. The analyzed energy/environmental KPIs can be classified into two large groups according to the approach on which they are based. The first group is based on an aggregated approach and provides a quantitative estimate of the amount of energy and/or pollutant emissions per container visit or per unit load. These aggregate KPIs consider containers, or more generally load units, as consumers of energy and producers of emissions during handling. The second group, on the other hand, adopts a disaggregated approach to provide an estimate of energy consumption and environmental impacts relating to the individual equipment used in carrying out port operations. These indicators mostly provide an estimate of energy consumption and related emissions as a function of the distance traveled or the reference time unit.

What emerges by observing the KPIs and the three dimensions of sustainability analyzed is that they are strongly correlated. Although a subdivision of the indicators analyzed within the three sustainability areas has been proposed, the same indicator can often be attributable to more than one area, and it is sometimes even difficult to understand which is the primary area of its impact. Some examples can help to understand the strong correlation that exists. Although the economic KPIs are mainly used to evaluate the profitability of the port, they also have implications in terms of both environmental and social sustainability. Similarly, improving the efficiency of port operations can reduce energy consumption and related CO_2 emissions. The productivity of the worker can depend on that of the equipment on which he works but also on the safety procedures adopted in the terminal and can in turn be both an indicator of safety, productivity, and cost-effectiveness. Consider, for example, the indicator related to the number of incorrect container placements or the number of extra container movements. This single indicator finds immediate space in all three dimensions analyzed as it can provide at the same time a measure of social sustainability (a high number of errors is usually related to high levels of fatigue and tiredness, low levels of training, a greater number of accidents), economic sustainability (unproductive maneuvers lead to a slowdown in the operating cycle and additional costs), environmental sustainability (extra movements mean higher energy consumption and extra emissions). These elements make it clear how much the evaluation of port sustainability must go through the evaluation of different elements, it must not be reduced to the use of single indicators but rather foresee their combined and integrated use.

Using the method of critical literature review, this paper has proposed a framework that classifies port sustainability KPIs according to the three dimensions of sustainability. The identified sets of sustainable port KPIs can help port policy makers and industry operators monitor and evaluate the impact of actions aimed at improving the sustainability of their operations and make reliable decisions for a wider implementation of sustainability. Looking in particular at the importance that advanced training practices are acquiring in the port environment for the improvement of sustainable performance, the quantification of the value assumed by the relevant indicators before and after the training period will allow port managers to evaluate the impact of the training on the three spheres considered. The ultimate goal is to make available to those who work in the port and logistics sector a series of tools that can help make operations safer, more efficient and more sustainable by acting directly on the advanced training of the human capital.

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