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Port Sustainability Index: Methodological Issues

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Abstract

Approaches to find impact of maritime transport on environmental performance of ports or port regions through models with different sets of assumptions suffer from limitations. The paper describes an integrated Port Sustainability Index (PSI) by combining relevant environmental aspects of port processes and operations by transforming each indicator to follow normal distribution and taking PSI as sum of such normally distributed indicator scores, avoiding skew and outliers. Thus, there is no bias for developed or under-developed ports. PSI is simple and satisfies desired properties including assessment of effectiveness of policy measures through responsiveness, statistical tests of equality of mean PSI across ports. Dimensions of PSI can be ranked by respective elasticity. The method also helps to find growth curve of PSI of a port over time. Proposed PSI may help port authorities to evaluate their performance from the sustainability angle along with performances in the relevant dimensions and may serve as a strategic tool for port environmental performance management.

Keywords: Port Sustainability Index; Composite Index; Normal Distribution; Convolution; Responsiveness; Test of Hypothesis

Abbreviations: LNG: Liquefied Natural Gas; OPS: Onshore Power Supply; SSE: Shore-side Electricity; IMO: International Maritime Organization; CI: Composite Index; PSI: Port Sustainability Index; TAT: Turn-around Time; GMEP: Green Marine Environmental Program; DWD: Dead Weight Tonnage; EEDI: Energy Efficiency Design Index; EEOI: Energy Efficiency Operation Index; PCA: Principal Component Analysis, FA: Factor Analysis; EEXI: Energy Efficiency Existing Ship Index. EU: European Union.

Introduction

Sustainability in ports is a growing concern for port authorities, port users, policy makers and also local communities [1]. Various activities in ports relating to handling of cargo and ships, logistics and distribution, etc. generate environmental degradation primarily through use of fuels and energy [2]. While chemical substances like PMx, Sulphur oxides, Nitrogen Oxides cause harmful effects on the environment (including human health), emissions of greenhouse gases CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (as per Kyoto Protocol in 1997) contribute to global warming and climate change. Harmful effects get extended to oceans and seas and affect marine ecosystems [3]. Shipping affects marine environment also by discharging Ballast water [4], containing a variety of non-native, nuisance, invasive, exotic species that can cause significant ecological and economic damage to aquatic ecosystems along with serious human health problems.

Sources of emission at ports could be due to stationary sources like warehouses, mechanical plants, offices, etc. and mobile sources such as ships (commercial and also port-owned), cranes, vehicles, etc. [5]. Even, aerial drones are being used for detecting emissions in ports [6]. However, emissions of pollutants depend on a large number of factors. For example, emission from a ship depends on phase of activities, time taken for each activity, engine type and engine category (main or auxiliary), fuel type, engine nominal power, engine load factors, emission factor for the type of vessel and the pollutant, etc. International shipping contributes around 15% of NOx and 5-8% of SOx emissions worldwide [7] causing serious harm to the environment and human health. As per Brandt, et al. [8] emissions from shipping caused about 50,000 premature deaths in Europe alone in 2000. In addition, oil spills and water pollution from ballast water carrying microorganisms causing significant devastation of local marine species adds to environmental degradation.

Green port covers broader topics of ecosystem protection through port sustainability plans and regulations on environmental planning [9]. Liquefied natural gas (LNG) is a promising alternative fuel for shipping as it produces no SOx or PM emissions and much lower NOx. But, the fossil fuel LNG reduces GHG emissions by 25% which is not adequate as per the recent international regulations. Besides alternative fuels, other strategies to reduce emissions include slow steaming, improved hull design, onshore power supply (OPS) or shore-side electricity (SSE). Reduction of speed by 20% helps to reduce fuel consumption by around 40% and CO_2 emission by about 7% [10]. Improved designs of hull have been driven by IMO directives like EEDI, SEEMP, etc. [11,12]. OPS/SSE helps ships not to run their auxiliary generators to provide power.

International Maritime Organization (IMO) has revised the target of GHG emission to be reduced by 70% or beyond and CO_2 emission should be close to zero (net) in 2050 from international shipping [13]. Similarly, upper limit of the sulphur content of ships' fuel oil was reduced to 0.5% (from 3.5% previously) to reduce significantly the amount of sulphur oxide emanating from ships. Assessment of port environmental externalities, and addressing societal needs, economic growth etc. are all included in multidimensional port sustainability index [14].

Roles played by ports are important to the transition of the maritime sector towards sustainability [15]. Sustainable ports focusing on the social, economic and environmental impacts, attempt to mitigate the above effects and also their carbon footprints by adopting policies to comply with national and international regulations [16]. Practices in making green ports involve several dimensions or sub-indices like environmental, technologies, monitoring and upgrading, process and quality improvement, active participation, communication and cooperation along with port management tools, monitoring, etc. [17].

Sustainability issues of port are multi-dimensional. Attempts have been made to construct Composite index (CI) by aggregating all relevant dimensions of sustainability and set of measurable indicators under each dimension to assess overall status facilitating monitoring various aspects of sustainability, comparing and ranking the entities across time and space based on longitudinal and also snap-shot data for better decision making [18].

Stages of Construction of CI

- Selection of dimensions and indicators under a dimension.
- Aggregation of indicators to obtain dimension scores (D_i) and aggregation of D_i s to get CI-scores.

However, there are no universally accepted set of indicators and dimensions for port sustainability index. Thus, the sustainability indices are not comparable across ports [19]. In addition to port operations including logistics functions (transport, terminal handling, warehousing and storage activities), industrial functions (goods and energy production, assembly, and recycling activities), shipping including nautical services to calling ships (through tug, pilotage, boats, etc.),other relevant areas like transportation through rail-road-inland water facilities, waste generated at sea due to maritime transport, oily water (mix of water and fuel during maintenance operations), effect on climate affecting marine flora and fauna are rather poorly addressed [20]. Clearly, ports environmental data originate from large number sources are heterogeneous with different units. Such data consisting of variables in ratio scales and also variables in ordinal scale need to be aggregated following methodological sound procedures to understand relationships of operational features and environmental measures so as to improve port environmental strategic decision-making processes. Illustrative desired properties of scoring a CI by combining all chosen indicators are:

- Meaningful arithmetic aggregation of indicator scores (item scores of ordinal scales) to get dimension scores and CI scores reflecting position of individuals by monotonically increasing continuous variables i.e. a small gain in a dimension/indicator score will increase the CI.
- Computation of moments like mean, variance and functions of other moments like skew, peak, outliers etc. of scale/dimension scores
- Same range of scores for each indicator/item
- Better comparisons and rankings
- Finding relative importance of the dimensions in terms of their contributions and/or elasticity's
- Quantification of progress or deterioration of a port or a group of ports by longitudinal data and undertake test of significance.

The paper proposes an integrated Port Sustainability Index (PSI) as a CI combining all relevant environmental aspects of port processes and operations, by transformation of item/indicator scores to continuous, monotonic and normally distributed scores in the range 1 to 100 satisfying above said desired properties and facilitating meaningful application of statistical analysis under parametric set up and may serve as a strategic tool for port environmental performance management.

Literature Survey

Stankovic, et al. [21] considered three pillars of sustainable developments of port regions viz. economic growth (10 indicators), social dimension (27 indicators) and environmental dimension (1 indicator viz. 2.5 emission). For Environmental issues and monitoring, Puig, et al. [22] investigated trends of environmental management in European ports and suggested large number of indicators relating to air quality, carbon footprint, energy consumption, marine ecosystems, noise, sediment quality, soil quality, terrestrial habitats, waste management, water quality, etc.

Different CIs and plans with different set of indicators have emerged like Green port program [1], Port Energy Environmental Plan [23], Plans for environmental protection, climate protection, climate initiative [9], clean air plans [24]. Most of large hub ports and many other ports are currently certified to environmental management standards such as ISO 14001.

Environmental standards are not uniform across ports and neither the relationships of environmental efficiency with operational practices of a port system. Port performance measures attempt to meet expectations of customers and stakeholders and consider indicators like cargo throughput, dwell time of vessels at port i.e. turn- around time (TAT), productivity, operating surplus, etc. Usual performance metrics of ports do not integrate sustainability measures like emission levels and effect of energy consumed.

Ports with draft constraints do not allow ships with full shipload of cargo which results in dead freighting, lower TAT, but higher emission per ton of cargo [25]. In addition, dead freighting gives rise to increased number of ship calls which also increases the emission levels. Similarly, old and inefficient cargo handling equipment increases consumption of energy. Port inefficiencies are reflected by longer dwell time of cargo and ships, interruptions in vessel traffic clearance, protracted documentation handling, lesser handling of container per crane-hour, higher emission of GHG gases per ton of cargo, etc. [26]. Volume of CO_2 emission per tonne-km tends to decrease as size of the ships increase [27].

Environmental Port Index (EPI), a shareholding company of ports and municipalities operating ports is located at Port of Bergen, Norway finds a ship's maximum tolerable environmental impact while at port, in terms of factors which can influence emission of CO_2, SO_2, NO_X and particle levels (baseline data). Actual data obtained from crew member of a ship on fuel consumption, emission levels, power usages, etc. during the ship's time at port are compared with the ship's EPI Baseline and EPI score between 0 and 100 is calculated and informed to the Port Operators, Ship Owners, against fees depending on the GRT. However, the methodology gets changed with every version of the EPI. Thus, EPI scores are not comparable and cannot be used as a time series.

In the context of sustainable development in ports, researchers have discussed impact of maritime transport on environmental performance either for selected performance indicators or through models. Carrera-Gómez, et al. [28] adopted ecological footprint of ports enabling authorities to prepare sustainable development plans by developing footprint-free products and absorption of wastages. European maritime companies used Green Marine Environmental Program (GMEP) to assess improvements of specific environmental performance indicators to maintain certification, where subjective self-evaluations are done to rank the performance indicators on a scale from 1 to 5 [29].

For energy management, studies mostly consider energy scheduling or saving methodologies with emphasis on the reefer clusters. Such optimization approaches are difficult to implement. Chen, et al. [30] described mathematical models to estimate relationship between direct and indirect emissions of GHG from shipping and development of global maritime fleets, in terms of deadweight tonnage (DWD) and found that slowdown of navigation speed, implementation of the Energy Efficiency Design Index (EEDI) and Energy Efficiency Operation Index (EEOI) are effective on the whole. EEDI developed by IMO with the objective of reducing CO_2 emissions as the first step towards shipping decarbonization. EEDI considers mechanical parameters in ratio scales which can influence CO_2 emissions. IRENA [31] suggested computation of EEDI as:

$$\text{EEDI}=\frac{\text{Engine power*Specific fuel consumption*Carbon factor}}{\text{DWD*Speed}} \quad (1)$$

To calculate CO_2 emissions from equipment and machines within the port terminal, Martinez Moya, et al. [32] suggested computing total CO_2 emissions (in tonnes) at a terminal as

$$CO_2 \text{ emission}=\sum_{i=1}^{4}\left(a_i * f_f\right)+\sum_{j=1}^{4}\left(b_j * f_e\right) \quad (2)$$

Where a_i: Yearly consumption of fuel in Tonnes of Oil Equivalents (TOEs) by the *i-th* equipment

f_f : Emission factor in tonnes of CO_2 emission per TOE
b_j : Yearly consumption of electricity in kWh with j-th equipment
f_e : Emission factor in tonnes of CO_2 emission per kWh
However, EEDI does not consider operational or commercial aspects. EEDI as not working tool for decarbonisation of shipping [33]. This led to the refinement of the index.

Osipova and Carraro [34] showed limitations of existing regulations in terms of CO_2 emissions and recommended for 100% reduction in CO_2 emissions by ships at-berth. The European Union (EU) has recently adopted two regulations: the FuelEU Maritime Regulation and the Alternative Fuels Infrastructure Regulation (AFIR). As per the FuelEU Maritime regulation, container and passenger ships, cruise ships) ≥5,000 gross tonnage (GT) must connect to shore power in main EU ports in the trans-European transport network (TEN-T)from 1st January, 2030. The AFIR aims to regulate shore power supply and incentivize infrastructure development in TEN-T ports.

Mallouppas and Yfantis [35] reviewed various pathways and possible technologies to achieve the IMO's deep decarbonization targets 2050 by the shipping sector and concluded that achievement of IMO's 2050 targets may be feasible via radical technology shift together with the aid of social pressure, financial incentives, regulatory and legislative reforms at the local, regional and international level given the maritime sector's 3% contribution to GHG emissions [36].

Besikci, et al. [37] considered Ship Energy Efficiency Management Plan (SEEMP) for existing ships and Energy Efficiency Design Index (EEDI) for new ships in the context of reduction of CO_2. For bulk carriers, Fan, et al. [38] built an energy efficiency model based on the Energy Efficiency Operational Indicator (EEOI). While SEEMP attempts to improve energy efficiency of a ship by providing an ongoing indication of CO_2 emissions, EEOI examines ship fuel consumption, ship main engine power, and ship drag characteristics. As per Fan, et al. [38], EEOI model provides more accuracy to simulate ship energy efficiency considering cargo load, ship speed, and random effects of natural environmental factors like wind, current, waves, and waterway depth, etc. and facilitates decision regarding optimization of ship energy efficiency. Energy Efficiency Existing Ship Index (EEXI) is another measure, based on the calculation formulas for EEDI establishing legally bindingCO_2 targets for newly built ships projected to be ratified in 2023, in-line with decarbonization targets in which IMO has planned a 70 % reduction in emissions level by 2050 using the same 2008 baseline. Formulation of EEXI and verification by sea trial tests specific to IMO Resolution MEPC. 203 (62), must address SEEMP or EEOI's shipping practice specific to real load control and management at the operational level. To formulate EEXI, the attained EEDI calculation, i.e., based on theoretical estimations and verified by sea trial tests specific to IMO Resolution MEPC.203 (62), must address SEEMP or EEOI's shipping practice specific to real load control and management at the operational level satisfying the equation [39]: attained

$$EEDI = 0.75 \times MCR \times fuel \times CF / DWT / S \ (g\ (CO_2)\ /tnm) \quad (3)$$

Where: 0.75 x MCR = 75% engine load; fuel = fuel consumption; CF = coefficient of CO_2 emission (kg/t of fuel); DWT = DWT by 70% payload; and S = ship speed.

However, no study confirms the best method for assessing hazard, risk, and energy assessment [40]. Multi-criteria decision-making (MCDM) methods decide weights by subjective, objective or mixed methods. Based on analytic hierarchy process (AHP), Kegalj, et al. [41] came up with a composite environmental index (I_E) considering environmental indicators like emission of air and noise, waste, energy consumption, water quality, etc. excluding impact of ships at berth and transport of containers from the terminal by rail-road modes. The selected indicators were ranked subjectively by experts on a 5-point scale (1 to 5). Relative weight for each individual indicator was taken in relation to other indicators.

To make the indicators unit-free, Min-Max transformation was used for normalization. I_E was obtained as a weighted sum. Methodological issues of I_E are:

- Problem to find weights of an indicator based on $\frac{n(n-1)}{2}$ pair-wise comparisons for n-number of alternatives in AHP get increased with increase in n. A number of methods proposed to avoid this disadvantage of AHP [42,43]. But these methods have been criticized as complex, ad-hoc in nature, may not provide efficient way for managerial decision-making in case of high number of alternatives [44].
- Determination of preference for the most important indicator (or the least important indicator), using a scale from 1 to 5 is subjective and is sensitive to the sample composition. Moreover, preferences or judgments of Government and Regularity Authorities may differ significantly from the shippers, port users, etc.
- Scale from 1 to 5 is not equidistant. Construct-distance between 1and 2 is ≠ construct-distance between 4 and 5 [45]. Hence, addition of preference (ordinal data) is not justified. Hand [46] opined that $\bar{X} > \bar{Y}$ or $\bar{X} < \bar{Y}$ is meaningless since the arithmetic mean is not defined for ordinal scales.
- I_E as weighted sum does not address variance of the weighted sum and correlation of I_E with the chosen

indicators. No weighting system is beyond criticism [47].

- Normalization by Min.-Max function as $Z=\frac{X-X_{Min}}{X_{Max}-X_{Min}}$ suffers from limitations. Such Z-score of a particular activity is relative to performance of others. Min-Max function changes distribution of the transformed scores and may affect I_E in unknown fashion. It depends on the extreme values which may be unreliable outliers. Gain in Z due to unit increase in X is different for different values of X.

Models based on Data Envelopment Analysis (DEA) were used to estimate environmental and operational performance of ports [25,48]. However, factors like selection of variables, methods used, associated assumptions, sample size, etc. may distort estimation of port efficiency by DEA [49]. Efficiency values were different for DEA-CCR and DEA-BCC models [50]. Cullinane, et al. [51] observed decreasing return of scale for British ports against increasing returns to scale for Spanish ports [52]. Moreover, the homogeneity condition of DEA may not always be fulfilled. Simple models to estimate CO_2 emissions as function of equipment type and transport modes at container terminals were developed [53]. Martinez-Moja, et al. [32] suggested model to evaluate energy efficiency and CO_2 emissions of container terminal equipment and found that major sources of CO_2 emissions are yard terminal tractors and rubber-tyred gantry cranes (RTGs). Sim [54] calculated total CO_2 emission (kg/TEU) at a container terminal as sum of carbon emissions from ship's movements inside the port, ship at berth, loading/unloading of TEUs, container transportation and container receiving and delivery. But, CO_2 emissions from different activities may not follow similar distributions and thus, addition may not be meaningful. X+Y = Z is most meaningful when X and Y follow similar distributions and enable finding distribution of Z i.e.

$$\text{Prob.}(Z \le z) = \text{Prob.}(X+Y \le z) = \int_{-\infty}^{\infty} \left(\int_{-\infty}^{z} f_{X,Y}(x, t-x)\, dt \right) \text{dx} \qquad (4)$$

Equation (4) ensures meaningful arithmetic aggregation for computation of mean, variance etc. and undertaking parametric statistical analysis like Principal Component analysis (PCA), Factor analysis (FA), Analysis of variance (ANOVA), statistical inferences like estimation and testing hypothesis of equality of mean across time and space, where basic assumption is normally distributed variables. Regression equation also requires normal distribution of residuals (error in prediction of dependent variable from the independent variable(s)). For normally distributed variable X, true CO_2 emissions from an activity with $X = x_0$ can be estimated by $x_0 \pm$ SEM where SEM=Sample S_E [55].

Proposed Method

Pre-Processing of Data

Ensure each variable is positively related to PSI i.e. take reciprocal of variables like TAT, volume of emission, etc. for which lower values imply improvement.

Method

Let X_1, X_2,..., X_n be the set of chosen indicators for assessment of Port Sustainability Index (PSI). The indicators could be physical parameters like cargo throughput, ship traffic, emission levels of pollutants, and stakeholders' perceptions of operational and environmental efficiencies, etc. Clearly, indicators are in different units. While physical and financial indicators are in ratio scale, stakeholders' perceptions/preferences generate ordinal data. Construction of PSI requires methodologically sound approach to aggregate the chosen indicators. The method of arithmetic aggregation of the indicators as given by Chakrabartty and Sinha [56] can be adopted where indicator scores are transformed to follow normal distribution which can be added to get scale scores also following normal. Here, ordinal data say in 5-point item are first converted to continuous equidistant scores (E-scores) using data-driven positive weightsW_{i1}, W_{i2}, W_{i3}, W_{i4}, W_{i5} based on frequency of response-categories of *i-th* item (f_{ij}) so that $5W_{i5}$-$4W_{i4}$= $4W_{i4}$-$3W_{i3}$= $3W_{i3}$-$2W_{i2}$=$2W_{i2}$-W_{i1} = Constant, value of which is different for different items. Zero value of E-scores is obtained when f_{ij}=0 for j-th response-category of the *i-th* item.

E-scores are standardized to $Z_i=\frac{E_i-\overline{E_i}}{SD(E_i)}\sim N(0,1)$ and further linear transformation to get to proposed score P_i by

$$P_i = (100-1)\left[\frac{Z_i - MinZ_i}{MaxZ_i - MinZ_i}\right] + 1 \qquad (5)$$

Where, $1 \le P_i \le 100$ ensures uniformity in score–range.

For variables in ratio scales, raw scores may be standardized to Z-scores followed by further transformation to P-scores. P-scores of variables in ratio scale following normal distribution and the same for variables in ordinal scales can be added with the benefit of knowing their convolution which also follows normal. Normally distributed P_i scores of the indicators belonging to a dimension or sub-index can be added to get dimension scores (D_i). Port Sustainability Index (PSI) is defined as the sum of the sub-index scores or equivalently sum of all indicator-wise P_i- scores (the scale scores). PSI and also D_i scores follow normal. For example, if $P_i \sim N(\mu_i, \sigma_i)$, PSI follows normal with mean $\sum_i \mu_i$ and variance

$(\sum\sigma_i^2+2\sum_{i\neq j}Cov(D_i,D_j))$. Thus, probability density function (pdf) of PSI as convolution of indicator-wise normally distributed P_i-scores can be found where parameters of the distribution of PSI can be estimated from the data.

Properties

PSI scores consider pattern of responses unlike raw scores (X) and give unique ranks to the individuals and satisfy desired properties like:

- Provides PSI score of an individual port by continuous and monotonically increasing scores where a marginal increase in an indicator will increase PSI
- Avoid skew and outliers (so that there is no bias for developed or under-developed ports)
- Facilitates comparisons of various ports with respect to average PSI values or a single port at different time periods using statistical test of equality of mean PSI and variance like $H_0: \mu_1=\mu_2$ by t-test or $H_0:\sigma_1^2=\sigma_1^2$ by F-test for longitudinal data or snap-shot data.
- Contribution of a dimension (or sub-index) to PSI may be quantified by $\frac{D_i}{PSI}\times 100$. Elasticity of an indicator or *i-th* dimension D_i can be found by

$$\frac{\frac{\Delta PSI}{PSI}}{\frac{\Delta D_i}{D_i}}$$

- The dimensions can be arranged by increasing order of elasticity (e_i). Policy makers can decide appropriate actions in terms of continuation of efforts towards the dimensions with high values of elasticity and corrective actions for the dimensions with lower elasticity that is, areas of concern.
- Progress/deterioration of the *i-th* port in *t*-th time-period over the previous year is assessed by $\frac{(PSI)_{it}-(PSI)_{i(t-1)}}{(PSI)_{i(t-1)}}\times 100$ which also quantifies responsiveness of PSI and effectiveness of adopted policy measures. $(PSI)_{it}>(PSI)_{i(t-1)}$ Implies progress in $t-th$ period over (t-1)-th period. Deterioration if any may be probed to identify the dimension(s) where deteriorations occurred and extent of deteriorations for possible corrective actions. Similarly, progress for a group of ports is reflected if

$$\overline{(PSI)_{it}}>\overline{(PSI)_{i(t-1)}}$$

- Plotting of progress/deterioration of a port across time helps to compare progress pattern that is, response to the policy measures adopted from the beginning of the longitudinal study. An increasing graph of PSI_{i_t} and time (t) indicates improvement of the *i-th* port over time and a decreasing graph will indicate the reverse.
- Statistical tests of significance of progress of PSI or *i-th* dimension can be tested $H_0:\frac{(PSI)_{it}-(PSI)_{i(t-1)}}{(PSI)_{i(t-1)}}$ or $H_0:\frac{D_{it}-D_{i(t-1)}}{D_{i(t-1)}}=0$ since ratio of two normally distributed variables follows χ^2distribution
- Facilitate estimation of mean PSI (μ_{PSI}) and σ_{PSI}^2 at population level of a country from a representative sample of ports in the country. For large sample (n), 95% confidence interval of μ_{PSI} is $\mu_{PSI}\pm 1.96\left(\frac{\sigma_{PSI}}{\sqrt{n}}\right)$
- Possible to find extent of association between PSI-scores and P-scores of dimensions of Port operations as Pearsonian correlation or by multiple correlation between PSI-scores and dimension scores or as canonical correlation between dimensions of PSI and dimension of port operations.
- Regression equation of PSI on port operations can be fitted using port performance scores. Equation of the form Overall Port performance =α+β.PSI can also be fitted to know effect of PSI on port performance. However, checking normality of error scores is suggested for fitting of regression equations.
- Normally distributed PSI facilitates testing of hypothesis of equality of mean two ports by usual t-test or for ports of several countries by ANOVA
- A group of ports can be classified into four mutually exclusive classes in terms of PSI-scores by quartile clustering with equal probability to each class i.e.

$$\int_0^{Q_1}f(x)dx=\int_{Q_1}^{Q_2}f(x)dx=\int_{Q_2}^{Q_3}f(x)dx=\int_{Q_3}^{Q_4}f(x)dx \quad (6)$$

Discussion

The proposed method of obtaining normally distributed PSI-scores is simple and easy to comprehend for meaningful evaluation of measurement properties for each indicator and dimension. The method can include all measurable sustainability related indicators (managerial, technological, organizational, and operational) either in ratio scale or in ordinal scale without any bias for developed or undeveloped ports.

Normally distributed PSI satisfies desired properties and basic assumption of statistical techniques and inferences and facilitates better ranking, comparisons across time and space.

Additional benefits include assessment of progress/ deterioration of one or a group of ports for monitoring of policies and strategies. Regression equation of PSI on port operations can be fitted using port performance scores. Regression equation of the form Overall Port performance

$\alpha + \beta.PSI$ can also be fitted to know effect of PSI on port performance. However, checking normality of error scores is suggested for fitting of regression equations.

It may be argued that the outliers may provide valuable information about port processes and should not be ignored. But outliers are different from mode of the distribution and may also result from measurement errors, data entry mistakes or natural data variation. Outliers can significantly influence values of mean and increase variance of data. In the context of CI, the term "robustness" refers to the handling of outliers and possible small variations in the input parameters [57]. Scatter plots of bivariate data can help in visualizing outliers and omission of them gives better fit of regression equation. An easy way to identify the outliers is through inter-quartile range (IQR) defined as $(Q_3 - Q_1)$ where High outlier $\leq Q_3 + (1.5 * IQR)$ and Low outlier $\leq Q_1 - (1.5 * IQR)$. Machine learning models and model techniques can be improved by eliminating the outliers [58].

Conclusion

The paper suggests a simple and methodologically sound method of obtaining PSI value for a port considering multi-criteria goals including environmental aspects of port's operations. The index PSI with continuous, monotonic scores follows normal distribution which solves the problems related to skew and outliers within environmental data sets in the port sector and satisfies many desired properties. The method helps the port planners to know overall performance of ports from the sustainability angle along with performances in the relevant dimensions and take necessary actions to balance emission reduction efforts without disturbing international trade and economic growth. Quantification of responsiveness of PSI using longitudinal data helps to assess effectiveness of adopted action plans.

The proposed method avoids disadvantages of existing methods which are either not methodologically sound or involve assumptions, verification of which are required before application of the methods. The method helps to find the growth curve of PSI of a port, which in turn provides another criterion for comparison among ports. The proposed method with wide application areas and benefits advances scholarly. However, the method requires careful selection of dimensions and measurable indicators within a dimension.

Future studies may emphasize on chemical pollution of water and air (from fuel spills, waste dumping, and exhaust), bio-fouling on hulls and invasive species (from discharge of ballast water) at local and global levels.

Statements and Declarations

Competing Interests

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Data Availability

No datasets were generated or analyzed in the study.

Code Availability

No application of software package or custom code

Ethics Approval

Not required for this methodological paper

Ethical Responsibilities of Authors

All authors have read, understood, and have complied as applicable with the statement on Ethical

Responsibilities of Authors

As found in the Instructions for Authors

Informed Consent

No data collected from individuals

Author's Contribution

The single author is involved in Conceptualization, Methodology, Writing- Original draft preparation, Writing- Reviewing and Editing.

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