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Sustainability and Decarbonisation Readiness of Indian Ports: Evidence from a Cross-Sectional Study

[1]Amit Kumar, [2]Dr. Anurag Kumar Srivastava, [3]Dr. Rupesh Kumar

[1]Ph.D Scholar, School of Liberal Studies, Pandit Deendayal Energy University, Gandhinagar

[2]Associate Professor, School of Liberal Studies, Pandit Deendayal Energy University, Gandhinagar

[3]Institute of Advanced Research, Gandhinagar

Abstract

Ports are extremely important in terms of sustainability and climate mitigation, but the decarbonisation process is not evenly distributed, particularly in the emerging economies. The research provides cross-sectional data on the preparedness of Indian ports to be sustainable and decarbonised, according to the perception of the stakeholders. The research identifies the enabling conditions as the presence of readiness and not the actual outcomes of the emissions through a readiness based framework. The main data was obtained as a structured survey of 138 maritime stakeholders such as the port authorities, terminal operators, logistics firms, policymakers, consultants, and academics in India. It looked at six dimensions of readiness, including policy and regulatory readiness; institutional capacity and coordination; technological and infrastructure readiness; environmental management practises; stakeholder awareness and engagement; and decarbonisation readiness. According to the descriptive analysis, port of India is seen to be comparatively better prepared in the environmental management practises and policy fit, yet less prepared in technological preparedness and decarbonisation-specific preparedness. The variation among the groups of stakeholders is not that much, which implies that the evaluation of the progress and limitations in the port ecosystem is shared widely. The results indicate that there is a distinct portrayal of disconnect between policy will and ability to execute, indicating the execution and capacity limitations, and not deficient in awareness or direction. Offering both a perception-based national-level assessment, the study can provide baseline empirical data on port sustainability and can provide policy-relevant information on how the Indian port industry can be better decarbonised to enhance decarbonisation preparedness.

Keywords: Port sustainability, Decarbonisation readiness, Indian ports, Green ports, Stakeholder perceptions

1. Introduction

Ports have taken a lead role in more recent debates of sustainability and climate policy, due to their aggregation of economic action, accompanied by the proportionate environmental externalities that they produce. Being key hubs in maritime and logistics systems, ports affect emissions related to vessel activities, cargo processing, auxiliary power consumption, and transport of hinterland. Therefore, the current agreement is that ports should actively engage in environmental mitigation, not just act as compliance locations. During the last few years, harbours in different regions have given sustainability commitments and initiated environmental programmes, which are indicative of a greater redefinition of the responsibilities of port authorities. Sustainability is no longer a pollution control but is seen as strategic governance choices, infrastructure planning, and consultation with shipping lines, logistics operators, and government bodies. However, as empirical studies show, the rate and intensity of the sustainability transition vary significantly among port systems, and depend on institutional strength, regulatory transparency, and level of investment (Hossain et al., 2021; Puig et al., 2022).

This broader sustainability agenda poses a specific issue with decarbonisation. The decrease in port emissions, unlike the actions of the internal environmental management, is severely reliant on the actions of the actors outside the port gate. All these emissions are associated with vessel hotelling, cargo-handling equipment, and hinterland transport, which are part of the systemic operational practises of energy, transport, and regulation (Han et al., 2011; Zhou et al., 2020). In this way, the decarbonisation process is usually based on cross-institutional

coordination, long-term investment in capital, and the correspondence of policy intentions and operational viability.

An emerging literature suggests that ports can have strong environmental management practises and still be behind in greater decarbonisation abilities. Environmental monitoring systems, certification programmes, and compliance systems are frequently more developed than infrastructural support of alternative fuels, electrification, or massive energy changes (Alexandropoulou et al., 2021; Kostidi & Lyridis, 2024) . This disequilibrium highlights the fact that it is necessary to separate symbolic sustainability measures and those that actually change the emissions pathways.

The complexity of governance and inequality in the development of institutions aggravates these problems in emerging economies. Knowing that multi-actor regulatory environments may create coordination gaps, especially in cases when the power to regulate the environment, energy policy, and infrastructure investment is divided among various agencies (Howes et al., 2017). Ports that act in these situations have structural constraints, and not motivational ones such that they have a limited ability to follow decarbonisation strategies despite supportive policy direction.

The Indian port sector has been an example of most of these dynamics. Ports are managed by a combination of central and state authorities, landlord port models and private terminal concessions that result in varied institutional frameworks throughout the national system. The past few years have been characterised by the increased focus of policies on sustainability, renewable energy, and green infrastructure in the maritime industry (Agarwala, 2022; Misra et al., 2017). However, the current body of empirical research is disjointed, with most investigations concentrating on ports, technologies, or the narrative of environmental efforts, thus providing little information on the preparedness at the system level.

Sustainability and decarbonisation as a means of readiness would be a useful analysis. Instead of direct measurement of the outcomes of emissions, readiness focuses on the degree to which the enabling conditions, such as policy clarity, institutional capacity, technological preparedness and stakeholder engagement are present in order to facilitate transition. It is the most relevant method mainly in industries where change is hindered by structural constraints and long-lived assets.

Although the use of readiness-based methods is increasing in the international arena, similar evidence at the national level of Indian ports is very scarce. Current literature does not question much on whether various facets of preparedness are progressing in an equal measure or the presence of critical bottlenecks. This gap is filled in the current paper, which provides a cross-sectional, stakeholder-based evaluation of sustainability and decarbonisation preparedness in Indian ports. Using the replies of 138 maritime professionals, the research provides a system-level overview of preparedness and constraints areas, thus providing the basis of empirical evidence underpinning current policy and academic discussions.

2. Literature Review

2.1 Port Sustainability

There has been a significant transformation in literature on port sustainability in the last twenty years. The initial research has defined sustainability mostly in the context of environmental conformity with the main focus on pollution control, waste management, and regulatory compliance. Environmental performance was often considered as an operational limitation instead of strategic goal entrenched in the port governance frameworks.

Recent scholarship redefines sustainability as an issue of strategic choice associated with decision-making power, institutional structure and long-term infrastructure planning (Fernández-Izquierdo et al., 2020; Pyykkö et al., 2021). Ports are also being examined as governance actors that can shape the environmental performance by pricing and incentive schemes and contractual agreements with the terminal operators and shipping lines (Lawer et al., 2019). Empirical data show that ports that have formal environmental policies and well-structured management systems are more likely to show more consistent sustainability performance, but this depends on the ability to enforce it and organisational resources (Vieira et al., 2014).

Comparative studies show that there is a high regional difference in sustainability adoption. In comparison to ports in North America or the Asia-Pacific region, European ports are more institutionalised in their environmental practises, which is characterised by the stronger regulatory pressure, stakeholder involvement, and support of public investments (Hossain et al., 2021). These results highlight the fact that sustainability outcomes are determined by the presence of technology, as well as coherence in governance and institutional maturity.

2.2 Decarbonisation Pathways

Decarbonisation is a particular aspect of port sustainability, which is more capital-intensive and more interdependent between players. Port-related emissions include marine vessels, cargo-handling equipment, and hinterland transport, vessels have always been found to be a major source of local air pollution in port areas (Carletti et al., 2012; Han et al., 2011). Emissions are further increased by road-based freight transport, which in most cases surpasses those caused by cargo-handling equipment (Zhou et al., 2020).

Although such technological solutions as electrification, alternative fuels, renewable energy systems, and digital optimisation are discussed and piloted more and more, their spread is uneven (Cunha et al., 2025; Hoang et al., 2022; Islam et al., 2022). High initial cost, lack of future fuel pathways, lock-in of infrastructure, and decentralised regulatory roles have remained in the literature as major obstacles to large-scale implementation (Alexandropoulou et al., 2021; Kostidi & Lyridis, 2024).

It is also noted in research that the maritime logistics processes are still especially hard to decarbonise because of business pressure, complicated supply-chain relationships, and a lack of incentives to early adoption (Issa-Zadeh & Garay-Rondero, 2025). As a result, ports can show improvements in environmental monitoring and reporting and still not be able to provide sustained emissions reductions.

2.3 Readiness as an Analytical Framework

The concept of readiness serves as an analytical tool to explain the uneven implementation outcomes, which scholars have been using more often. The readiness is often understood as the level of motivation, capability, and structural preparedness of organisations and systems to make a change (Holt & Vardaman, 2013). Follow-up research conceptualises the concept of readiness as a multidimensional variable that includes regulatory explicitness, institutional readiness, technological readiness, and participation of the stakeholders (Neofytou et al., 2020).

Implementation research highlights the fact that preparedness is created by institutional learning, communication, and a stable governance but not given in advance (Schilling et al., 2018). The available empirical data indicate that sustainability projects tend to face systematic obstacles associated with organisational inertia, poor coordination, and generic policy design (Ahmed et al., 2021; Misleh et al., 2024). Such difficulties are especially severe in sectors related to infrastructure, as adaptability is limited by the length of asset lifecycle and capital-intensity (Howes et al., 2017).

When applied to ports, readiness structures assist in separating the intent of policy and the ability to implement it. Research indicates that ports may express ambitious sustainability ambitions and fail to have the technological, financial, or institutional means to implement decarbonisation policies (Geerts et al., 2021; Meyer et al., 2021). This viewpoint can be used to analyse more fundamentally as compared to outcome-based indicators.

2.4 Governance, Institutions, and Port-Level Implementation

Governance systems are an important factor to determine the results of port sustainability by stipulating authority, incentive, and accountability. The studies on port governance reforms indicate that the allocation of roles between the state and the private players affects the investment behaviour and the environmental performance (Fernández-Izquierdo et al., 2020; Steen et al., 2024). Port authorities can often assume the role of mediators, converting policy goals into practise by way of concessions deals, performance benchmarks, and incentives plans (Lawer et al., 2019). Nonetheless, coordination failures may also be created by governance complexity. Disjointed regulatory frameworks and overlapping jurisdictions have been demonstrated to hamper sustainability and decarbonisation efforts especially where energy policy, environmental regulation, and infrastructure planning are

institutionally incompletely linked (Alamoush et al., 2022). The results highlight the need to study the institutional readiness and technological solutions.

2.5 Indian Port Context and Research Gap

Research reports indicate that in India, there is a growing focus on the environmental management and use of renewable energy in ports (Agarwala, 2022; Misra et al., 2017). Other studies also point to wider socio-economic effects of the development of maritime infrastructure, such as the creation of jobs and integration of hinterlands, especially after the expansion of inland waterways under the National Waterways Act, 2016 (Kumar & Kumar, 2022). Simultaneously, empirical literature singles out the long-standing issues of ageing equipment, disjointed performance measurements, and an ongoing focus on throughput rather than on environmental performance (Sengar et al., 2018; Sinha & Roy Chowdhury, 2022).

Even though cross-sectional and perception-based methods have been used in international studies to measure port sustainability and readiness (Geerts et al., 2021; Hossain et al., 2021), such national-level data on port sustainability and readiness is lacking in India. The available literature is either port-based or technology-based, which provides little information on system-wide preparedness on a multidimensional level. This gap is what drives the current research, which uses a readiness-based framework to determine the preparedness of sustainability and decarbonisation in the environment of Indian ports based on stakeholder perceptions.

3. Conceptual Framework

The current research employs a conceptual framework of readiness based on the study of the preparedness of sustainability and decarbonisation in the Indian ports. The concept of preparedness is considered to be multidimensional, describing the existence of enabling conditions needed to implement it, as opposed to realising quantifiable emissions or environmental results. This framing is especially suitable to the infrastructure sectors, including ports, where the lifespan of the assets, the capital intensity, and the complexity of the institutions tend to slow down the transformation of the policy intent into operational change (Holt & Vardaman, 2013; Neofytou et al., 2020).

The framework is based on the conceptualisations of readiness in six related dimensions based on the literature of sustainability, governance, and implementation reviewed above. Policy and regulatory preparedness is the transparency, consistency and plausibility of sustainability and decarbonisation policies that may inform port operations. Institutional capacity is evidence of organisational competence, coordination mechanisms, and administrative capability that are needed to institute such policies. Technology and infrastructure preparedness can be described as the accessibility and sufficiency of both physical and digital systems that can be used to facilitate cleaner operations and energy transition. Environmental management practises entrap laid down monitoring, compliance as well as mitigation of environmental impacts. The level of awareness and involvement of stakeholders indicates how much sustainability goals are learnt, embraced and internalised by actors in the port ecosystem. Lastly, decarbonisation preparedness is the preparedness to go further with emissions-reduction, such as electrification, alternative fuels, and integration with energy systems.

These dimensions are not believed to develop in a similar and consecutive manner. Rather, it is possible to have an uneven development in the dimensions in the framework, as ports that are strong in the areas of environmental management and policy orientation might not have the technological or institutional capacity to achieve deeper decarbonisation. The framework can help to assess the enabling conditions where it is most effective and structural constraints where it remains within the Indian port sector by concentrating on perceived readiness and results.

4. Research Methodology

The current study is designed as a cross-sectional, perception-based study that targets assessing the sustainability and decarbonisation preparedness at a single point in time. Such a methodological position is prudent in the sense that the task to be performed is to index readiness and map out relative strengths and weaknesses in a very complex, multi-actor system, and not to unwind causal relationships or trace longitudinal transformations. Similar cross-

sectional paradigms have been used in the antecedent research investigating the conditions of sustainability and readiness in port and infrastructural milieu (Geerts et al., 2021; Hossain et al., 2021).

Primary data collection was done through a structured online questionnaire that included a five-point Likert scale. The instrument was adjusted to operationalise the six readiness dimensions expressed within the conceptual framework, which are policy clarity, institutional coordination, technological availability, environmental management practises, stakeholder engagement, and decarbonisation capability. The distribution channels included the networks of professionals and the sectoral networks, and the targeted respondents were those directly engaged in the operations of the ports, regulation, planning, and the maritime logistics.

The obtained sample size was 138 valid answers that were obtained after sampling an eclectic pool of respondents, such as port authorities, private terminal operators, logistics enterprises, consultancy firms, and regulatory agencies. This heterogeneity enabled a system level look at preparedness, far beyond the gaze of any cohort of actors. The reliability test ensured a high level of internal consistency among the constructs and hence showed that the measurement items effectively captured the desired dimensions of readiness as envisaged.

The analysis of data focused on descriptive and comparative statistics to evaluate the relative preparedness on dimensions. Mean scores were used to determine where there is a relative strength and constraint and cross-dimensional comparison helped to shed light on imbalances between environmental management, policy orientation, and enhanced decarbonisation preparedness. Following the exploratory desire of this research, the analytical emphasis underpinned the identification of patterns and benchmarking at the expense of inferential or causal modelling.

5. Results

5.1 Respondent Profile

The data set consisted of 138 valid answers that had been selected after stringent screening in terms of completeness and internal consistency. The sample represents a wide cross-section of the Indian maritime ecosystem, which is in line with the pan-India orientation of the study. The biggest group was port authorities and port administration officials (28.3 percent), followed by terminal operators and port service providers (21.7 percent). Shipping and logistics professionals made 17.4% of the respondents with policymakers and regulatory officials making 11.6%. Professionals involved in consulting and industry experts made 11%, and academics and maritime researchers represented the rest 10%.

The distribution is done so that it is representative of the key categories of actors that contribute to port governance, operations, regulation and advisory services. The heterogeneity of the respondents supports a system-level evaluation of the sustainability and decarbonisation preparedness as opposed to views that are contained within a single institutional constituency.

5.2 Reliability Analysis

Cronbach alpha was used to measure internal consistency of the readiness constructs. Since the study is exploratory and descriptive and two indicators are used in each construct, alpha values above 0.60 were considered acceptable. The constructs all exceeded this value thus indicating good internal consistency and justifying their use in future analysis. The highest reliability was found in Environmental Management Practises (0.76), Technological and Infrastructure Readiness (0.74) and Decarbonisation Readiness (0.72). There was also good reliability in Policy and Regulatory Readiness, ($\alpha = 0.71$). Institutional Capacity and Coordination (0.68) and Stakeholder Awareness and Engagement (0.66) were a little bit lower but in a reasonable range to be explored. All in all, the reliability results indicate that the survey items were used in unison to measure the intended readiness dimensions.

5.3 Descriptive Readiness Scores

The mean scores of each dimension of readiness were calculated in order to assess the perceived levels of sustainability and decarbonisation preparedness. All construct measures have mean scores that exceed the

midpoint of the scale indicating that the perceptions are generally positive among the sample. However, there is significant difference among dimensions.

The highest mean score was 3.63 of Environmental Management Practises followed by 3.55 of Policy and Regulatory Readiness. Third (3.42) was Institutional Capacity and Coordination, and Stakeholder Awareness and Engagement was in the middle (3.34). The lowest mean score was noted in Technological and Infrastructure Readiness (3.22) and Decarbonisation Readiness (3.09) was the lowest of all the dimensions. The ranking pattern indicates a differentiated readiness pattern, which is relatively more focused on compliance-based and policy-related indicators, as well as relatively less focused on technology deployment and decarbonisation-related measures.

5.4 Limited Stakeholder-Wise Comparison

Mean comparisons were done on the broad categories of stakeholders to determine whether there were systematic differences in perceptions between groups of respondents. Port authority respondents indicated slightly higher average scores in the area of policy and institutional readiness, and shipping and logistics professionals gave rather lower ratings of decarbonisation readiness.

Nevertheless, the differences identified among the groups of stakeholders were small and could not represent statistically significant divergence in traditional levels. The comparisons between the stakeholders are seen as indicative, but not conclusive as the study is exploratory and lacks strong differentiation.

The findings demonstrate that Indian ports are viewed as having a higher level of preparedness in the environmental management practises and policy alignment, and a relatively lower level of preparedness in technological infrastructure and decarbonisation-related capabilities. These tendencies provide the empirical base on which to be interpreted in the next discussion section.

6. Discussion

This paper provides cross-sectional data on the sustainability and decarbonisation preparedness of Indian ports based on the views of a diverse group of maritime stakeholders. The results reveal a discriminated readiness pattern along the dimensions, in terms of comparatively high levels of environmental management and policy orientation, and comparatively low levels of technological and decarbonisation preparedness. The high score recorded on the environmental management practises could indicate that the Indian ports have indeed come out well on the implementation of formal practises in regards to monitoring, compliance and environmental reporting. These practises tend to form the most ancient dissemination of sustainability-related practises, as they are closely related to regulatory requirements and standardised management procedures. Current research on the topic of port sustainability argues that environmental management-based systems are generally more apt to develop faster than operational or technological innovation, especially in the context of a strong regulatory framework. The current results support this trend, and it means that sustainability activities in Indian ports are characterised by a strong procedural focus at the moment.

The policy and regulatory preparedness was also a fairly strong dimension. Stakeholders seem to be aware of the existence of strategic intent and policy direction as regards to green ports and decarbonisation. However, the identified gap between policy preparedness and the reduced scores of technological readiness and decarbonisation readiness highlights a well-known challenge in the implementation process. The implementation research has always stressed the point that the articulation of policy does not necessarily translate into operational capacity particularly in infrastructure-intensive industries that are typified by long-lasting asset life cycles and capital limitations.

The relatively low views on technological and decarbonisation preparedness are worth focusing on. The initiatives of decarbonisation usually require significant capital investment, the coordination of various actors, and the connexion to the external energy and transport systems. The deliberate evaluations of the stakeholders in these dimensions are probably related to practical limitations in terms of financing, availability of technology, institutional coordination, and implementation capability, and not a lack of awareness or strategic commitment.

The implications of the findings are therefore that the major obstacle to decarbonisation of ports in India is the ability to carry out the process, as opposed to the will of the policy.

The fact that the difference between the readiness perceptions of the stakeholder groups is minimal also supports the aggregate nature of the findings. Lack of intense separation implies a widely common perception of both advancements and limitations throughout the maritime ecosystem. Such a convergence strengthens the validity of the profile of readiness identified in the research and mitigates the possibility of results being largely influenced by the views of one group of actors.

Collectively, the findings suggest that sustainability preparedness at the Indian ports is further developed than decarbonisation preparedness. It seems that environmental management and policy alignment are already in place before technological and operational change. Although such sequencing is not exceptional in large infrastructure systems, it highlights the need to strengthen the implementation capacity in the event that the decarbonisation ambitions go beyond intent and early-stage adoption.

7. Policy Implications

The results of this research have a number of policy implications to the design and implementation of the policy in the port sector in India. To begin with, the disparity existing between comparatively robust policy and regulatory preparedness and less robust technological and decarbonisation preparedness indicates that future policy endeavours must focus on action. Strategic intent and regulatory signalling are clearly understood by the stakeholders; the challenge that is salient is to translate these signals into operational capability.

Second, the relatively high results of environmental management practises suggest that compliance-based sustainability practises have become widespread. Policymakers can leverage on this base by progressively increasing the transition in their policies between procedural compliance and decarbonisation efforts aimed at results. This shift would require that the emissions-reduction goals are explicitly incorporated into the planning of port, investment appraisal, and infrastructure development. Third, the reduced scores in technological preparedness highlight the necessity of systematic investment systems. Port decarbonisation projects are often reliant on associated energy supply, hinterland connectivity, and shipping performance. The use of policy instruments that can help in coordinating the actions of the port authorities, energy providers, and the private operators could be even more effective than the single interventions. The perceived risk could be reduced with blended financing structures, gradual investment plans, and joint infrastructure frameworks to increase implementation viability.

The fact that there has been a little difference in the perceptions of the stakeholders implies that there is plenty of room to act in concert. The common understanding of the constraints of readiness offers a foundation on which joint policy formulation, capacity-building efforts, and incremental implementation plans can be developed, which consider practical constraints but maintain long-term decarbonisation goals.

8. Conclusion

This research provides cross-sectional, country-level data on the sustainability and decarbonisation preparedness of Indian ports based on the perceptions of the stakeholders at the maritime sector. The findings show that, although the Indian ports are seen to have achieved significant progress in their environmental management practises and policy alignment, their preparedness to engage in decarbonisation is relatively low, especially in technological and operational aspects. The research is also a contribution to the literature in that it provides a system-level, perception-based measure of the preparedness, unlike other studies that focus on port case studies or outcome measures. The results provide a more detailed insight into port-sector transitions in an emerging-economy framework by discriminating between policy intent, procedural sustainability measures, and more profound decarbonisation preparedness.

There are a number of restrictions that deserve to be mentioned. The research is based on cross-sectional, perception-driven data and does not test objective performance indicators and emission results. To this end, the results are more akin to the current evaluations than empirically tested effects or longitudinal transformation. In addition, the analysis is exploratory in nature, which limits the ability to make causal inferences.

This work can be extended with future studies by case studies at the port level, longitudinal analysis, or the combination of quantitative emissions and investment data to identify how readiness is changing over time and how it can be converted into quantifiable decarbonisation results. Nevertheless, the study provides an opportune empirical evidence of the present-day situation of sustainability and decarbonisation preparedness in Indian ports, which gives a solid base on which the policy can be discussed and additional research conducted.

Declarations

"Author(s) declares no conflict of interest."

"Grammarly was utilized as an AI-assisted editing tool to refine the language and improve clarity during manuscript preparation. All suggestions were carefully reviewed, and the authors hold full responsibility for the final manuscript."

Appendix A

Survey Constructs and Measurement Items - all items were measured using a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree).

Construct Name	Item Code	Measurement Item
Policy and Regulatory Readiness (POL)	POL1	National maritime policies provide clear guidance on port sustainability objectives.
	POL2	Existing regulations adequately support decarbonisation initiatives at ports.
Institutional Capacity and Coordination (INST)	INST1	Port institutions have sufficient capacity to implement sustainability initiatives.
	INST2	Coordination among port authorities, regulators, and operators is effective.
Technological and Infrastructure Readiness (TECH)	TECH1	Ports have infrastructure that supports energy-efficient and low-emission operations.
	TECH2	Digital systems support environmental monitoring and reporting at ports.
Environmental Management Practices (ENV)	ENV1	Environmental management systems are actively implemented at ports.
	ENV2	Monitoring of emissions and environmental impacts is conducted on a regular basis.
Stakeholder Awareness and Engagement (AWARE)	AWARE1	Stakeholders are adequately informed about port sustainability and decarbonisation goals.
	AWARE2	Industry stakeholders actively engage with sustainability initiatives at ports.
Decarbonisation Readiness (DECARB)	DECARB1	Ports are prepared to implement emission-reduction measures.
	DECARB2	Decarbonisation objectives are integrated into port planning and operations.

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