A COMPARATIVE ANALYSIS OF ECONOMIC, SOCIAL AND ENVIRONMENTAL EFFICIENCY OF MAJOR SEAPORTS IN INDIA

Thesis

Submitted in partial fulfillment of the requirements for the degreeof

DOCTOR OF PHILOSOPHY

by

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DECLARATION

I declare that the research thesis entitled, **"A COMPARATIVE ANALYSIS OF ECONOMIC, SOCIAL AND ENVIRONMENTAL EFFICIENCY OF MAJOR SEAPORTS IN INDIA"** submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfilment of the requirements for the award ofthe Degree of **Doctor of Philosophy** in Management is a bonafide report of the research workcarried out by me. The material contained in this thesis has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

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DEDICATION

This thesis is dedicated to

my parents, Late Mr. Narasmiha Rao and

Late Mrs. Vishala N Rao,my wife, Mrs.

Akshatha B and my daughter Kum. Avani

Vishala Thumbe

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ABSTRACT

In performing the seaport operations, environmental, social, and economic-related issues are identified, which have resulted in the seaport operations primarily focusing on improving overall sustainability. To mitigate the negative environmental, social and, economic impacts around seaports, assessing sustainable key performance indicators initiatives is a fundamental principle for seaport functionality. This research study aims to achieve three objectives: First, to identify critical factors for sustainable seaports, seaport performance indicators and various key performance indicators relevant to major seaports in India. Second, to establish the relationships between different sustainability factors and various key performance indicators related to seaport sustainability performance measurement. Thirdly, to assess the efficiency of criteria-related to seaport sustainability efficiency and benchmark the seaports using sustainability indicators. The research study employs a mixed methods approach, integrating qualitative and quantitative research techniques.

Initially, this research identifies and categorizes aspects of seaport sustainability factors and key performance indicators through systematic literature analysis (SLA), examining the concept of seaport sustainability across global seaports. In the qualitative phase of the study, seaport dimensions, seaport performance indicators, and relevant seaport key performance indicators for assessing seaport sustainability performance were identified, specifically within the context of Indian seaports. This study involved conducting Importance-Performance analysis and semi-structured interviews with 37 maritime/seaport domain experts in India. This technique was applied to finalize the selection of seaport dimensions, seaport performance indicators, and seaport key performance indicators on seaport sustainability performance assessment. The assessment of port sustainability dimensions and their corresponding key performance indicators is based on mean importance and performance values. The port economic and social sustainability dimension was considered highly significant, with port environmental sustainability receiving the highest performance ranking.

The presence of a performance gap indicated areas necessitating improvement. The findings underscore the pivotal role of sustainable practices within India's maritime sector, underscoring the imperative to address all 37 assessment items for seaport sustainability. Expert evaluations, ranging from 4.11 to 4.42 on a five-point scale, highlighted the noteworthy sustainability performance across all criteria.

Quantitative data primarily consisted of responses collected through a questionnaire survey from 717 employees across the four major west coast seaports. This survey aimed to assess key performance indicators related to seaport sustainability initiatives. The collected data were then analyzed using the structural equation modeling method with AMOS 23.0. The research findings revealed that factors encompassing seaport environmental sustainability performance, seaport economic sustainability performance, seaport social sustainability performance, seaport internal sustainability performance, and seaport customer sustainability performance have significantly contributed to the overall holistic seaport sustainability performance.

The research study reveals significant and anticipated correlations among various dimensions of sustainability performance in seaports. The findings underscore interconnections between diverse sustainability dimensions, suggesting that enhancements in one dimension can positively influence other aspects within a seaport's sustainability framework. Additionally, the research indicates mediation effects within relationships among different sustainability dimensions. An analysis of variance compared mean scores of sustainability assessment dimensions across the four major seaports. The research emphasizes key areas to enhance seaport ecosystem sustainability and achieve benchmarks for environmentally sustainable development. Moreover, these results provided valuable insights for maritime policymakers to facilitate the effective implementation of comprehensive sustainability plans within major Indian seaports. These insights also emphasized the importance of considering the holistic seaport supply chains when devising sustainable developmental strategies.

Furthermore, benchmarking the sustainability performance of the four major west-coast seaports in India, responsible for handling a significant portion of liquid cargo, was conducted. This study involved the identification and analysis of longitudinal secondary data spanning the financial years 2016 to 2021. The research established a modeling framework to gauge efficiency and benchmark the sustainability-related performance of these seaports while identifying developmental targets. To achieve this, ten input and ten output parameters related to three pivotal dimensions of sustainability: social, economic, and environmental were examined. The data envelopment analysis (DEA) technique was used for the seaport performance evaluation considering sustainability dimensions. Both desirable and undesirable outputs were factored in under variable returns to scale (VRS), aiming to minimize undesirable attributes in seaport performance. The VRS (DEA-BCC) efficiency scale calculated values for the three sustainability dimensions and factors for

four major west coast seaports for six years. The research findings revealed that the efficiency of the four major west coast seaports, which primarily handle liquid cargo, varied within the value range of 72.37% to 96.13% for FY-2016-17 to FY-2021-22. The study's outcomes indicated a significant correlation between seaport sustainability input and its corresponding output variables. The study suggests that advancements in a few input seaport sustainability indicators can positively impact the output indicators. Consequently, seaport management and stakeholders should make strategic and tactical decisions to enhance seaport sustainability efforts, pinpointing the effects of sustainability aspects within the seaports.

Furthermore, the overall research findings illustrated variations in the values of seaport sustainability performance concerning environmental, economic, and social criteria. These discoveries aligned with established sustainability reports from significant global seaports. Moreover, the research outcomes gained further validation through correlation with real-world scenarios observed in Indian seaports. This research study offers comprehensive insights and can serve as a guiding framework for maritime researchers and port policymakers regarding seaport sustainability factors and their interconnected aspects. Future studies on this subject can leverage these findings to compare sustainability assessments of seaports in various regions and measure seaport sustainability performance (in environmental, economic, and social domains). Further study could involve benchmarking against major and minor seaports in India or globally, utilizing real-time data related to sustainability initiatives.

Keywords: Sustainable development, seaports, India, efficiency benchmarking, DEA analysis.

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LIST OF ABBREVIATIONS

AGFI: Adjusted Goodness of Fit

AHP: Analytical Hierarchy Process

AMOS: Analysis of a Moment Structure

ANOVA: Analysis of Variance

ANP: Analytical Network Process

AOPB: Average output per berth day

APA: American Association of Port Authorities

AQI: Air quality index data in port area

ARGU: Agility & Resource Utilization

ASV: Average Squared Shared Variance

ATRT: Average turn round time in days

AVE: Average Variance Extracted

CFA: Confirmatory Factor Analysis

CFI: Comparative Fit Index

Chi-Sq: Chi-Square

ChPA: Chennai Port Authority

CMV: Common-Method Variance

CO: Carbon Monoxide

CoPA: Cochin Port Authority, Cochin

CPCB: Central pollution control board

CR: Composite Reliability

CRS: Constant Return Scale

CRZ: Coastal Regulation Zone

CSR: Corporate Social Responsibility

CV: Convergent Validity

DEA: Data Envelopment Analysis

DEMATEL: Decision-making trial and evaluation laboratory

DF: Degree of Freedom

DG Shipping: Director General Shipping

DMU: Decision Making Units

DPA: Deendayal Port Authority, Kandla

DPR: Detailed Project Reports

DPSIR: Drivers, pressures, states, impacts, and responses

DV: Divergent Validity

EBS: E-Business Suite

EC: Environmental Compliance

ECI: Economic performance & impacts

ELP: Environmental level & Pollution

EFA: Exploratory Factor Analysis

EMS: Environmental Management System

ERC: Eliminate, Reduce, and Control

ESPO: European Sea Ports Organization

EU: European Union

EW: Effluents & waste

EXIM: Export -Import

FY: Financial Year

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GoF: Goodness of Fit

HDC: Haldia Dock Complex

ICS: International Chamber of Shipping

JNPA: Jawaharlal Nehru Port Authority

IEA: International Energy Agency

IMO: International Maritime Organization

IPA: Indian Ports Association

IPAA: Importance Performance Assessment Analysis

IPM: Importance-Performance matrix

ISM: International Safety Management Code

ISO: International Organization for Standardization

ISPS: International Shipping and Port Security

IT: Information Technology

KMO: Kaiser-Meyer-Olkin

KoPA: Kolkata Port Authority

KPI: Key Performance Indicators

KPL: Kamarajar Port Limited

Ldn: Average noise level in port area

LNG: Liquified Natural Gas

LPG: Liquefied Petroleum Gas

MARPOL: Marine Pollution

MbPA: Mumbai Port Authority, Mumbai

MDG: Millennium Development Goals

MGI: Management & Innovation

MgPA: Mormugao Port Authority

MOE: Margin of Error

MLC: Maritime Labour Convention

MoPSW: Ministry of Ports, Shipping and Waterways

MPA Act: Major Ports Authority Act

MRPL: Mangalore Refinery Petrochemical Ltd

MSV: Maximum Squared shared Variance

MTPS: Million Tonne per Annum

N: Number of Respondents

NCoEGPS: National Centre of Excellence for Green Port & Shipping

NFI: Normed Fit Index

NGO: Non- Governmental Organization

NITI Aayog: National Institution for Transforming India Aayog

NLP-M: National Logistics Portal Marine

NMPA: New Mangalore Port Authority, Mangalore

NO2: Nitrogen Dioxide

OECD: Organization for Economic Co-operation and Development

OHSS: Occupational, Health, Safety & Security

PCA: Principal components analysis

PCSP: Port Customer Sustainability Performance

PENSP: Port environmental sustainability performance

PECSP: Port economic sustainability performance

Ph: Power of Hydrogen level of drinking water/sewage effluent treated water

PIB: Press Information Bureau

PISP: Port Internal sustainability performance

PM2.5: Particulate matter -particles in the air with equal to 2.5 microns and below

PM10: Particulate matter - particles in the air with 10 microns and below

POL: Petroleum Oil and Lubricant

PORTOPIA: Ports Observatory for Performance Indicators Analysis

PPA: Paradip Port Authority

PPP: Public Private Partnership

PPRISM: Port Performance Indicators: Selection and Measurement

PRISMA: Preferred Reporting Items for Systematic Reviews Meta-Analysis

EPSI: Port Sustainability Indicators

PSSP: Port Social sustainability performance

PUC: Pollution under control

RFID: Radio Frequency Identification & Detection

RMR: Root Mean Square Residual

RMSEA: Root Mean Square Error of Approximation

RTI: Right to Information

SCM: Supply Chain ManagementSCA: Supply-Chain Activities

SDG: Sustainable Development Goals

SEM: Structural Equation Modelling

SEZ: Special Economic Zone

SLA: Systematic Literature Analysis

SMBSC: Sustainability Management Balanced Score Card

SOLAS: Safety of Life at Sea

SO2: Sulphur Dioxide

SPCB: State Pollution Control Board

SPM: Single Point Mooring

SPSS: Statistical Package for the Social Sciences

UN: United Nations

UNCTAD: United Nations Conference on Trade and Development

VIF: Variance Inflation Factor

VLCC: Very Large Crude oil carriers

VoCPA: V.O. Chidambaranar Port Authority

VPA: Vizag Port Authority

VRS: Variable Return Scale

WPSP: World Port Sustainability Program

CHAPTER 1
INTRODUCTION AND BACKGROUND OF THE STUDY

This introductory chapter of this thesis provides the background to the work of seaports and its related sustainability-related aspects; research problem; related problem statement; research questions and objectives; the significance of the research; scope of studies and also describes the structure of the document, by describing the sequence of chapters, and a brief description of the content of each section.

1.1. Overview

Seaports are categorized as hard infrastructures for driving economic growth. Maritime shipping is one of the important modes of transport carrying over 80% of world trade by volume and 70% of its value (UNCTAD, 2017; IPA,2018). A seaport is a region that encompasses both waterfront and inland areas, specifically designed to facilitate the exchange of goods through imports and exports (Cheon,2017). This location plays a well-developed connection to the surrounding hinterland by serving as a thriving hub for business and production related activities. Seaport plays very significant contribution towards international trade and logistics networks (Notteboom, 2001; Han,2018).

Seaports serve as central focus hub for a diverse range of commercial activities, acting as vital junctions where waterways seamlessly intersect with road and rail networks for the efficient collection and evacuation of cargo (Langen, 2003; Dooms,2015). Seaports play a crucial role in connecting both domestic and international markets through a comprehensive global transport network.

Seaports play a crucial role in coordinating the movement of goods and services between producers, consumers, and nations, serving as essential transport centers in the intermodal logistics chain that connects waterways, railways, roadways and airways (Munim,2021; Ha,2017). Many of the world's major cities have experienced concentrated development near natural seaports. Efficient seaport management is of utmost importance to seaport users and related stakeholders, as it ensures the smooth flow of cargo and vessels through seaport terminals determining prosperity and enhancement of the seaports (Oconnor,2019; Kim,2017).

1.2. Background of the Study

Seaports have recognized the importance of sustainability management aspects in response to the growing interest in sustainability among governments, corporations, and NGOs. It is anticipated that seaports will increasingly prioritize sustainability related issues in the future (Wang, 2017). In the past, seaport entities primarily focused on cost reduction and profit maximization while attempting to minimize their negative environmental and social impacts (Port of Gothenburg, 2012). However, sustainability management has now become their most urgent goal, as seaports strive to achieve a balance between economic -social development with environmental preservation mechanism.

The concept of "green activity" emerged in the 1960's which was influenced by the rise of environmental related movements that aimed to mitigate the environmental impact of rapidly growing sectors like manufacturing and transportation. The maritime industry responded positively to this trend (Silveira, 2004). The idea of "sustainability" gained prominence in the 1980's when it became apparent that economic growth not only affected environmental issues but also had social related implications (Giovannoni and Fabietti, 2013). However, in around 2010, sustainability issues in the shipping and maritime industry domain started receiving significant attention. In recent years, sustainability has gained increasing focus due to stricter environmental regulations and calls to action from governments and NGOs, such as the UN's 2030 Sustainable Goals (Sustainable Development Knowledge Platform, 2015; WPSP,2015).

The intensification of seaport activities on land and the increase in vessel related traffic have resulted in adverse impacts on the environment and ecology. Consequently, seaports are compelled to think and shift their traditional focus on economic growth and instead strive towards balanced economic progress, social advancement, and environmental friendliness. These functionalities associate seaports with defined dimensions of environment, society, and economy (Roh, 2016; Lu, 2016; Siu Lee Lam, 2018; Wang, 2018; Muangpan, 2019; Senegar,2017; Narasimha,2021; Eswari,2021; Peris-Mora,2016). With increasing socio-economic and environmental pressures, seaport authorities are implementing various measures to achieve sustainability related initiatives in seaport activities. Seaport engaged in sustainable management must integrate external customers, supply chain partners (suppliers, terminal operators, truck companies, and stevedoring companies), government agencies, and related internal seaport sustainable process management to enhance the sustainability performance of seaport organizations (Roh,2021; Eswai,2021; Asgari,2015).

If seaport partners collaborate with seaport authorities to improve sustainability performance, they can benefit from factors such as an enhanced business reputation, cost savings (fines, lawsuits, cleanup expenses, claims, increased premiums), efficient utilization of raw materials (fuel oil consumption. engine efficiency), reduced inspections, and faster turnaround times in seaports (Lir,2013; Oh,2018; Peris-Mora,2015). Hence, this research study contributes towards these issues by assessing the practices and initiatives on sustainability factors along the seaport supply chain performance indicators and key performance indicators for four west coast major seaports of India handling liquid cargo profile.

1.3. Research Problem Statement

Indian major seaports play a significant role, accounting for 70% of the nation's trade by value (IPA, 2018). However, the progress of sustainable development in Indian seaports is still relatively slow compared to developed nations seaports, primarily due to the lack of a comprehensive framework for achieving sustainability across all dimensions and considering sustainability performance in the seaport supply chain (Senegar, 2018; Narasimha PT,2022). This research aims to identify the seaport sustainability factors, seaport performance indicators, and seaport key port performance indicators that can contribute to enhancing seaport sustainability within the context of Indian major seaports. Additionally, there is a need to analyze the relationship between various dimensions of seaport sustainability and key its performance indicators pertaining to seaport sustainability practices and initiatives. Also, it is required to determine the seaport sustainability performance-related criteria efficiency of sustainability factors using three sustainable related seaport sustainability input and output parameters towards benchmarking of seaports.

1.4 Research Questions

RQ1: What are the primary dimensions, performance indicators, and key performance indicators involved in evaluating the sustainability practices of seaports?

RQ2: How do the different dimensions and key performance indicators for seaports relate to the measurement of sustainability performance?

RQ3: What methodologies and evaluation criteria are employed to determine the sustainability performance of seaports?

1.5 Research Objectives

RO1: To identify and analyze the crucial dimensions, port performance indicators, and key performance indicators for assessing sustainability practices in seaports.

RO2: To analyze the relationship between various dimensions and port key performance indicators that are relevant to seaport sustainability performance.

RO3: To determine the methodology for measuring port sustainability performance, including the evaluation criteria, and propose improvement or optimal strategies.

1.6. Scope of Study

This research study primarily focuses primarily on four major west coast ports in India, namely New Mangalore, Cochin, Mumbai, and Kandla. These ports have been selected due to their significant handling of liquid cargo, which accounts for 89.66% of the total liquid cargo handled by major seaports in India from 2010 to 2022. This study adopts a mixed methods approach, combining qualitative and quantitative research techniques. The initial phase of the research involves a systematic literature analysis to identify and categorize the aspects of seaport sustainability factors and key performance indicators based on global seaports' sustainability concepts.

In the qualitative stage of research, seaport dimensions, performance indicators, and key performance indicators related to seaport sustainability assessment are identified, specifically within the context of Indian seaports. This process involves conducting importance-performance analysis and semi-structured interviews with maritime domain experts in India. These activities contribute to the final selection of seaport dimensions, performance indicators, and key performance indicators for assessing seaport sustainability performance.

For the quantitative phase, primary data is collected through a questionnaire survey administered to employees of the four major west coast seaports. The survey focuses on key performance indicators related to seaport sustainability initiatives. The collected data is then analyzed to derive research results pertaining to the factors and key performance indicators for assessing overall seaport sustainability performance.

The study also aims to benchmark the sustainability performance of these four major seaports by analyzing key performance indicators related to social, economic, and environmental aspects. This analysis will be conducted using longitudinal secondary data from the years 2016 to 2022. The application of Data Envelopment Analysis (DEA) methodology will provide insights into the ports' performance and their evolution over time.

The overall findings of this research study will contribute to the assessment framework of sustainability initiatives for major Indian seaports with a focus on liquid cargo. It will provide valuable insights for seaport managers and policymakers in the Indian maritime industry, enabling them to validate and improve their sustainability practices and strategies.

1.7 Organization of Thesis

This section provides an overview of the thesis structure, outlining the research's aims, objectives, and results. The thesis comprises seven chapters, which are organized as follows:

Chapter-1 offers a comprehensive description of the research, introducing the research background, aim, research objectives, research question, scope, and the contribution the research will make to the field.

Chapter-2 discusses the research context and provides a description of sustainability aspects in the global maritime scenario and specifically in the context of Indian seaports. It also outlines the context of major seaports in India, with a focus on the west coast major seaports and their liquid cargo profile. The chapter highlights the major seaport profiles included in the research study for analysis, as well as key characteristics related to seaport sustainability.

Chapter-3 investigates existing research trends through a systematic literature review related to seaport sustainability. It aims to provide a basic understanding of the knowledge in the field and identify any gaps in the literature. Additionally, this chapter outlines the reasons why no research has been conducted on seaport holistic sustainability. It also reviews various frameworks on seaport sustainability assessment, seaport sustainability performance, and benchmarking seaport sustainability performance indicators related to efficiency.

Chapter-4 focuses on the identification and assessment of sustainability practices for seaports. It presents the qualitative stage of the research, including the pre-selection of port sustainability dimensions and performance indicators through the formation of a theoretical framework based on literature studies. This chapter describes the selection and assessment of seaport sustainability dimensions and performance indicators, employing thematic analysis and semi-structured interviews with maritime domain experts in India for validation. The chapter also presents the results for research objective:1, ranking the impacts of sustainability factors and indicators based on their mean importance and performance in the Indian maritime context. This chapter establishes the foundation for the research and provides a sustainability framework for Indian major liquid cargo-based seaports.

Chapter-5 focuses on the relationship between various dimensions and indicators related to seaport sustainability, which is the second research objective of the study. It explores the connections and power dynamics between each aspect of seaport sustainability by conducting primary quantitative research with four major west coast liquid cargo seaports in India. The chapter discusses the conceptual framework, hypotheses development framework, measurement scales for factors, content validity, pilot study, reliability analysis, exploratory factor analysis (EFA), questionnaire, data collection technique, descriptive related statistics, reliability analysis, and structural equation modeling (SEM). The results, including reliability, descriptive and demographic analysis, address research questions and demonstrate the findings for research objective:2. This chapter suggests a holistic sustainability framework for Indian major liquid cargo-based seaports.

Chapter-6 focuses on determining seaport sustainability performance measurement by benchmarking the efficiency of four major liquid cargo seaports in India. It utilizes secondary data from the respective seaports and outlines a framework for seaport sustainability benchmarking, identifying input and output indicators to attain research objective:3. The chapter develops an appropriate DEA (Data Envelopment Analysis) model to determine scale efficiency from 2016 to 2021 for the four major liquid cargo seaports. The results are validated, and improvement strategies and recommendations for seaports in India are provided.

Chapter-7 concludes the entire research study and presents concluding remarks and policy implications. It identifies the limitations of the study and offers suggestions for potential future research in the area of seaport sustainability management.

1.8 Summary

This chapter has offered an overview of the research work, encompassing the aim, objectives, and research question. It has also discussed the significance of seaport sustainability, emphasizing the importance of researching this topic and the potential benefits it can bring. Additionally, the chapter has provided a rationale for developing a seaport sustainability framework specifically for liquid cargo seaports. It has highlighted the research findings related to the environmental, economic, and social efficiency of seaports in this study, enriching the knowledge in the field of seaport management through the utilization of various research methods. Finally, the chapter has outlined the structure of the entire thesis.

CHAPTER 2
RESEARCH CONTEXT

2.1 Overview

This chapter serves as an introduction to the research by providing background information and presenting the research context related to the sustainability aspects of seaports. It begins by discussing the sustainability aspects of seaports in the global scenario, highlighting their significance. It then focuses on the sustainability aspects of environmental, social and economic performance indicators of seaports in the Indian maritime context, providing insights into the specific challenges and opportunities faced by Indian major seaports.

2.2 Sustainability and Seaports in Global Scenario

At the Millennium Summit in 2000, the United Nations adopted the Millennium Development Goals (MDGs), consisting of eight goals and 18 targets aimed at addressing various development issues. These goals included eradicating extreme poverty and hunger, achieving universal primary education, promoting gender equality, reducing child mortality, improving maternal health, malaria, and other diseases, ensuring environmental sustainability, and developing a global partnership for development. However, these goals focused primarily on social and economic aspects of development.

In 2012, the UN Conference on Sustainable Development in Rio de Janeiro initiated discussions for the post-2015 development agenda. As a result, the seventeen Sustainable Development Goals (SDGs) were adopted by the UN General Assembly in its 70th Session. These goals, along with 169 associated targets, came into effect on January 1, 2016. Although not legally binding, the SDGs have become internationally recognized commitments, potentially reshaping countries' spending priorities over the next fifteen years. Nations are expected to take ownership of the SDGs and establish national frameworks to achieve these goals. The implementation and success of the SDGs depend on each country's sustainable development policies, plans, and programs. Regular reviews at the national level will monitor progress toward the goals and targets.

Seaports are vital in enhancing the sustainability of the global supply chain and have gained increasing importance due to the growth in maritime trade. Sustainability has become a focal point for seaports, with policymakers, reports, and researchers recognizing its significance. Seaports play a leading role in achieving international targets outlined in the

2030 Agenda and the Paris Agreement. To broaden the scope of their efforts and redefine climate change objectives, the Port Environment Committee has established the World Port Sustainability Program (WPSP,2018) as a successor to the World Port Climate Initiative. The WPSP aligns with the seventeen UN Sustainable Development Goals to guide the sustainable development of seaports which is illustrated in Figure 2.1.

Figure 2.1: UN Sustainable Development Goals; Source: WPSP

The World Ports Sustainability Program (WPSP) is designed to align with the UN Sustainable Development Goals (SDGs) and focuses on five key themes, each encompassing various topics. The first theme is Climate and Energy, where seaports commit to the Paris Climate Goal of limiting global warming to below 2°C. Building on the World Ports Climate Initiative, seaport community actors collaborate to develop tools for reducing CO2 emissions from shipping, seaport operations, and landside activities. energy transition, improving air quality, and promoting circular economy practices are also encouraged. Under community Outreach and port-city dialogue, port community stakeholders collaborate to address collective challenges both within and outside the seaport area. This includes tackling issues such as hinterland bottlenecks, training and education, IT, marketing and promotion, innovation, and internationalization. Establishing a dialogue with urban stakeholders contributes to the attractiveness and resilience of seaport cities.

Governance and Ethics focus on promoting good corporate governance principles among port authorities, regardless of their ownership. High standards of ethics and transparency are encouraged for all seaport community stakeholders. This includes initiatives such as transparency, integrity, equal rights and opportunities, fair trade, anti-corruption measures, and responsible supply chains. Resilient Infrastructure aims to develop seaport and seaport-related infrastructure that can anticipate the demands of maritime transport and adapt to climate and weather changes. The goal is to harmonize development with local communities, nature, and heritage. Initiatives encompass seaport planning and design, public-private partnerships, financing, digitization, automation, climate resilience, and ecosystem management.

Finally, Safety and Security aspects encompass the regulatory duties and responsibilities related to ensuring the safety and security of ships and cargo operations within the seaport. With the rise of global terrorism and digitalization, security concerns have taken on new dimensions. Topics in this area include cyber-security, protection of critical infrastructure, seaport security, nautical safety, labour safety, and responsible care. The WPSP's implementation of the SDGs across these themes demonstrates the commitment of seaports to sustainable practices and their contribution to global development objectives. The five key themes highlight on aspects of sustainability which includes indicators and efficiency determination related to social, environmental and economic factors of seaports. Figure 2.2 illustrates five key themes of the World Ports Sustainability Program (WPSP) aligned with the UN Sustainable Development Goals (SDGs).

Figure 2.2: Five key themes of WPSP aligned with UN SDGs; Source: WPSP

2.3 Sustainability and Seaports in Indian Scenario

India is a signatory to the resolution adopted on 'Transforming our World: the 2030 Agenda for Sustainable Development' at the 70th Session of the United Nations General Assembly in 2015. To monitor the SDGs and their associated targets, a National Indicator Framework comprising 306 national indicators has been developed by the Ministry of Statistics and Program Implementation in consultation with NITI Aayog, Central Ministries, State Governments, and other stakeholders such as UN Agencies, and Civil Society. The five Pillars are people, planet, prosperity, peace, and partnership which capture the broad scope of this agenda with three aspects of social, economic, and environmental factors which is illustrated in Figure 2.3.

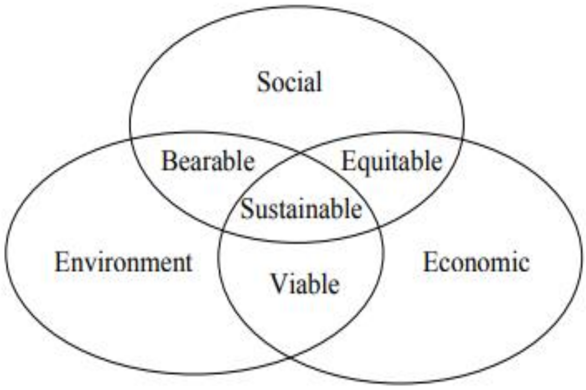

Figure 2.3: Sustainability related factors; Source: IPA,2018

In the Indian economy, the seaports play a special role by handling around 90% of EXIM Cargo by volume and 70% by value (IPA, 2018). There are 12 major ports and 200 non-major ports (minor ports) in the country. While the Major Ports are under the administrative control of the Ministry of Shipping, the non-major ports are under the jurisdiction of respective State Maritime Boards/ State Governments. All 12 Major ports are functional. Out of the 200 non-major ports, around 65 ports are handling cargo and the others are seaport Limits where no cargo is handled and these are used by fishing vessels and by small ferries to carry passengers across the creeks.

India has a total of 12 major ports, with six located on the east coast and six on the west coast, spanning a coastline of 7,516 kilometers from Gujarat to West Bengal. Currently, 11 of these major ports operate as autonomous port authorities, while Kamarajar Port Limited functions as a corporation. The government has implemented several measures to enhance capacity and operational efficiency in these major ports. However, due to the constraints imposed by the Major Port Trusts (MPT) Act, these ports face challenges in operating in a highly competitive environment and adapting to market demands. The decision-making process within the Board of Trustees, which consists of representatives from various stakeholders such as port users, labor, and trade associations, can be cumbersome. This sometimes leads to decisions that do not fully align with commercial and economic interests. Despite efforts to delegate more powers and make amendments to the MPT Act over time, the primary objective of providing efficient services to port users has not been fully achieved.

To address these issues and provide greater autonomy and flexibility to major ports, a comprehensive amendment to the Major Port Trusts Act of 1963 was proposed in 2016. This resulted in the enactment of the Major Port Authority Bill, 2020, which came into effect on November 2, 2021(PIB,2021). The focus of this bill is to significantly enhance port capacity, develop infrastructure, and increase cargo handling capabilities in all major ports. The figure 2.4 shows the location of major Ports along the Indian coastline.

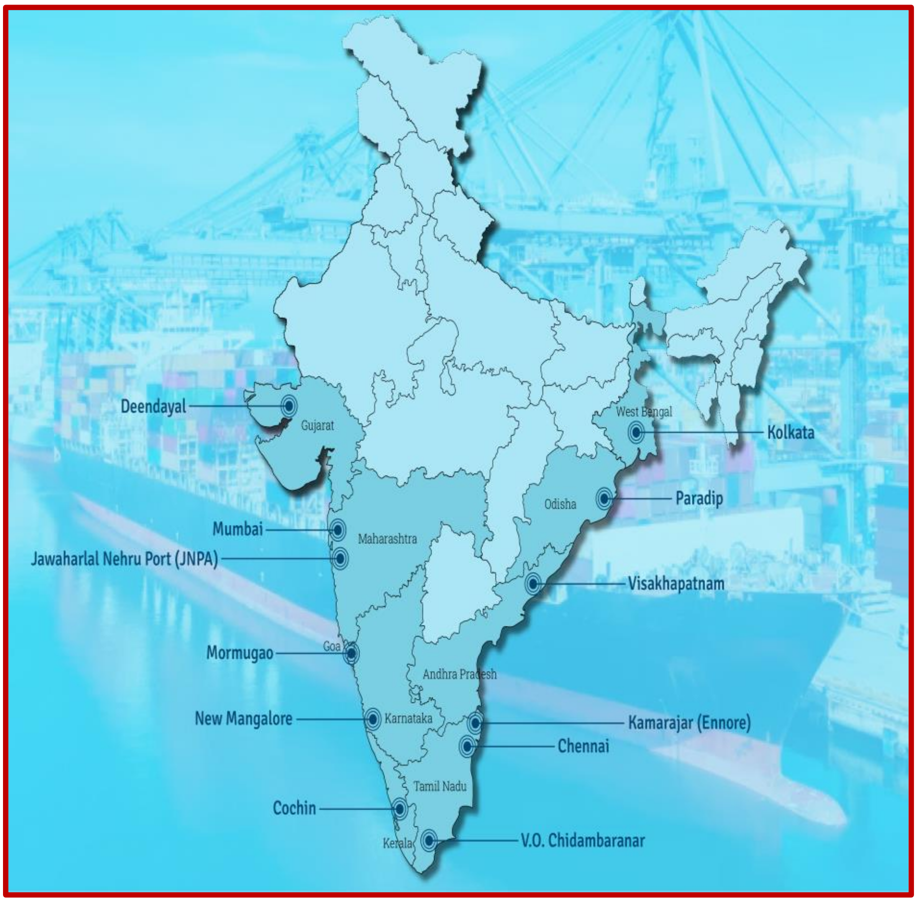

Figure 2.4: Map showing the location of Indian Major Ports;

Source: www.mapsofindia.com

The major ports in India have varying characteristics, with some being natural ports, others semi-natural, and some fully artificial. The development and functioning of these ports face various constraints, leading to variations in their performance levels. Overall, the objective of the recent legislations and reforms is to professionalize the governance of major ports, allowing for greater efficiency and development in the Indian maritime sector (Dayananda Shetty, 2018). The details of 12 major seaports in India are detailed as follows:

1. Shyama Prasad Mukherjee Port, Kolkata & Haldia Dock Complex, Haldia

Kolkata Port, established in 1870, holds the distinction of being the earliest major port in India where the government took administrative control through the appointment of a Port Commission. It remains the premier port in the country, serving as the gateway to Eastern India and playing a vital role in facilitating trade and commerce for the vast hinterland. To address the congestion at Kolkata Port, the Haldia Dock Complex was constructed. Located on the west bank of the River Hooghly, Haldia was chosen as the site for the new dock complex after a thorough investigation.

The Haldia Dock Complex commenced operations in 1968 and gained momentum with the commissioning of Haldia Port in February 1977, marking the beginning of international operations. Strategically positioned near major steel plants, power plants, ore mines, and coal mines in India, the Haldia Dock Complex holds significant growth potential due to the promising prospects of the industries within its hinterland. Haldia Dock Complex facilitates planned land allotment for various facilities, including plants, storage facilities, pipelines, tank farms, container freight stations, warehouses, offices, and commercial complexes. The primary commodities handled at Kolkata and Haldia seaports include iron ore, mica, metallurgical coke, ferrochrome, and coal. These seaports' diverse cargo handling capabilities, along with their growth prospects, position them as crucial contributors to the maritime industry, driving economic development in the region.

2. Paradip Port

Paradip Port is recognized as one of the major ports in India, and its establishment is credited to the Late Biju Patnaik, the former Chief Minister of Odisha. On April 18, 1966, the Government of India declared Paradip Port as the Eighth Major Port, making it the first major port on the East Coast to be commissioned after India gained independence. Situated on the eastern coast along the Bay of Bengal, Paradip Port is the sole major port in the state of Odisha.

The strategic positioning of Paradip Port allows it to cater to a vast hinterland spanning multiple states, including Odisha, Jharkhand, Chhattisgarh, Madhya Pradesh, Uttar Pradesh, Bihar, and West Bengal. With its favorable location, Paradip Port serves as a crucial gateway, facilitating trade and connectivity for the surrounding regions. It plays a significant role in supporting the economic development and industrial growth of the states within its hinterland. The port handles a diverse range of cargo including crude oil, petroleum and oil products, iron ore, thermal coal, chrome ore, coking coal, manganese ore, charge chrome, ferro chrome, ferro manganese, limestone, hard coke, ingots and molds, billets, finished steel, scrap, fertilizer, fertilizer raw materials, clinker, gypsum, project cargo, and containers.

3. Visakhapatnam Port

Visakhapatnam Port, located in Andhra Pradesh, is one of the major ports in India and the sole major port in the state. It holds the distinction of being India's third-largest state-owned port in terms of cargo volume and the largest on the Eastern Coast. Positioned between Chennai and Kolkata Ports along the Bay of Bengal, Visakhapatnam Port comprises three harbors: the outer harbor, inner harbor, and fishing harbor. The outer harbor consists of six berths with the capacity to handle vessels with a draft of up to 17 meters. On the other hand, the smaller inner harbor features 18 berths. The port primarily handles a wide range of commodities, including coal, iron ore, petroleum, oil and lubricants (POL), crude oil, chrome ore, manganese ore, timber, and various other industrial products.

4. Kamarajar (Ennore) Port Limited

The port commenced operations in 2001 with the establishment of a modern cargo terminal through a Public-Private Partnership or Captive model. Located about 20 km north of Chennai Port on the East Coast of India in Tamil Nadu, it is known as Kamarajar Port Limited (formerly Ennore Port Limited), the 12th Major Port in the country. It stands as the first and currently the only Corporatized Major Port under the management control of Kamarajar Port Limited (KPL).

In March 1999, the port was designated as a Major Port under the Indian Ports Act, 1908, and subsequently incorporated as Ennore Port Limited under the Companies Act, 1956 in October 1999. Ennore Port Limited specializes in handling diverse commodities including coal, coke, iron ore, manganese, bauxite, and other metals.

5. Chennai Port

Chennai Port, one of India's twelve major ports and the third oldest, is rapidly establishing itself as a prominent hub port along the East Coast. With an impressive history spanning 142 years, it has played a pivotal role in the country's maritime trade. Chennai Port boasts state-of-the-art multipurpose berths that cater to a diverse range of cargo and accommodate vessels of varying sizes. Its cargo handling operations encompass a wide spectrum of goods, including petroleum, oil, and lubricants (POL), containers, automobiles, cruise ships, edible oil, over-dimensional project cargo, fertilizers, as well as various bulk commodities such as coal, coke, iron ore and pellets, manganese ore, and bauxite. Chennai Port is recognized for its cost-effective operations, robust infrastructure facilities, efficient pipeline connectivity, and exceptional rail, road, and sea links.

6. V.O. Chidambaranar (Tuticorin) Port

V.O. Chidambaranar Port Authority is a prominent natural port and one of India's major ports. It was officially designated as a major port on July 11, 1974. As the second-largest port in Tamil Nadu and the third-largest container terminal in the country, V.O. Chidambaranar Port plays a crucial role in the region's maritime activities. It is an artificial port, serving as the third international port in Tamil Nadu and the second all-weather port. V.O. Chidambaranar Port Trust has recently been rebranded as the V.O. Chidambaranar Port Authority. This port is primarily engaged in handling a diverse range of commodities, including thermal coal, timber, petroleum products, various dry bulk, and break-bulk cargo, as well as containerized cargo. It serves as a crucial hub for the efficient transportation and trade of these goods.

7. Cochin Port

Cochin Port, also known as Kochi Port, has a historical origin from year 1341 when it was formed due to severe floods in the Periyar River. Situated in the city of Kochi, it serves as a prominent major port along the Arabian Sea, Laccadive Sea, and the Indian Ocean Sea route. Cochin Port holds a significant position among India's largest ports. On 26th May 1928, the first ship entered the Cochin harbour, marking a pivotal moment in its maritime history. Since then, the port has played a vital role in trade and commerce, aided by the introduction of road and rail networks that connect important trading points inland. Cochin Port stands as a crucial trading hub on the vibrant Kerala coast. Cochin Port handles a diverse range of commodities, including iron ore, LPG, crude oil, POL (petroleum, oil, and lubricants), granite stones, sand, salt, coal, zinc, clay, gypsum, and sulphur. Its versatile capabilities contribute significantly to the region's maritime trade and economic growth.

8. New Mangalore Port (NMP)

The inception of the Mangalore Harbour Project dates back to 1962, with maritime construction commencing in 1968. Subsequently, the New Mangalore Port, the sole Major Port in Karnataka, was officially designated as the 9th Major Port on May 4th, 1974. Its formal inauguration took place on January 11th, 1975. The regulations outlined in the Major Port Trust Act of 1963 were applied to the New Mangalore Port Trust (NMPT) starting from April 1st, 1980. New Mangalore Port, which serves as a thriving hub for importers and exporters in the region. Notable commodities imported through the port encompass POL crude for MRPL, cement, coal, fertilizer, edible oil, liquid chemicals, and containerized cargo, among others. The New Mangalore Port continues to serve as a crucial gateway for trade in the region, fostering economic development and facilitating international connections.

9. Mormugao Port

The declaration of Mormugao as a Major Port in 1964 marked a significant milestone in its history, elevating it to the ranks of the country's ten major ports. This designation paved the way for systematic development of Mormugao Port, with a focus on deep waters and high-capacity loading, particularly for iron ore exports. The objective was to enhance competitiveness in the global market by reducing transportation costs. Through strategic development and modernization initiatives, Mormugao Port has established itself as a crucial hub for trade and commerce, particularly in the iron ore sector. Mormugao Port handles a diverse range of cargo, including key commodities such as iron ore, POL (Petroleum, Oil, and Lubricants) products, fish exports, iron ore castings, metal scrap, liquor, and pharmaceutical products.

10. Jawaharlal Nehru Port (JNP)

The layout of Jawaharlal Nehru Port Authority (JNPA) in Navi Mumbai, highlights the port's infrastructure and arrangement. JNPA is recognized as the leading container handling port in India, accounting for approximately 50% of the country's total containerized cargo volume across major ports. Since its commissioning on 26th May 1989, JNPA has undergone a remarkable transformation from a bulk-cargo terminal to emerge as the premier container port in the nation ranking 26th among the top 100 Container Ports internationally. The port plays a pivotal role in facilitating the movement of various commodities, including containers, POL (Petroleum, Oil, and Lubricants) products, polymers, medicines, frozen meat and animal products, insecticides, copper, copper alloys, cars, motorcycles, fabrics, non-alloy steel, and parts and accessories of motor vehicles.

11. Mumbai Port

Mumbai Port has been the primary entrance to India, playing a crucial role in the growth of the national economy, trade, commerce, and the prosperity of Mumbai city. The port's esteemed position has been achieved through consistent efforts to meet the evolving requirements of maritime trade. While originally designed for handling general cargo, the port has successfully adapted to changing shipping practices, including the transition from break bulk to unitization, palletization, and containerization. Mumbai Port's ability to adapt to new shipping trends and technologies has strengthened its position as a dynamic hub for international trade. Port of Mumbai is strategically located on the West coast of India, benefiting from a natural deep-water Harbor spanning approximately 400 square kilometers. Its deep waters ensure year-round accessibility for shipping vessels.

12. Deendayaal (Kandla) Port

Kandla, officially known as Deendayal Port Authority, is a prominent seaport and town situated in the Kutch district of Gujarat state in Western India, close to the city of Gandhidham. Positioned along the Gulf of Kutch, it holds a significant position as one of India's major ports on the west coast. Located approximately 256 nautical miles southeast of the Port of Karachi in Pakistan and around 430 nautical miles north-northwest of the Port of Mumbai, Kandla Port serves as the primary seaport for western India. Notable imports at the Port of Kandla include petroleum, chemicals, iron and steel, and machinery, while it also facilitates the handling of salt, textiles, and grain

2.4 Liquid Cargo Profile

The cargo profiles of major seaports in India encompass solid, liquid, and container cargo. The prevailing global economic downturn has presented challenges and opportunities for the shipping industry. The slower pace of national development has led to reduced shipping prices while creating import opportunities for specific products, notably oil. Developing countries, in particular, witness a high demand for imports of bulk and petroleum products to support continuous national development. This dynamic scenario places both pressure and development prospects on liquid bulk cargo seaports. The country's robust GDP growth has resulted in increased energy demand, with around 75 percent of India's crude oil demand being met through imports (MoS, 2018). In the financial year 2018, India's imports of crude oil and petroleum products reached 256.33 million metric tonnes, indicating a 7.6 percent increase compared to the financial year 2008.

The details of major seaport with various cargo details, liquid cargo, other cargo (container, solid cargo) from year 2010-20 is considered and percentage and average for liquid cargo to total cargo is taken, so as to identify liquid cargo oriented major ports of India. The major seaports in India with volume handling of 50 percentage and above is selected for this research study (Simeon ,2019; L Wang, 2018; Beatriz,2020). As per observations of data values from Table 2.1 this research mainly concentrates on four major seaports in west coast of India which includes (New Mangalore Port, Cochin Port, Mumbai Port, Deendayal Port-Kandla).

Table 2.1: Liquid cargo to total cargo Percentage (2010-20) for major seaports in India

Major Port	Liquid cargo to total cargo %age (2010-20)
Cochin	67.47
New Mangalore	64.71
Mumbai	59.64
Kandla	58.37
Paradip	27.17
Vizag	26.67
Chennai	24.08
Haldia	23.03
Tuticorin	21.92
Ennore	8.54
JNPA	7.10
Kolkata	5.22
Goa	2.83

Source: IPA Report Data & Authors Calculation

The liquid cargo profile includes a diverse range of commodities such as reformate pol products, fish oil, butyl acrylate, motor spirit, super kerosene oil, diesel oil, high-speed diesel oil, naphtha, low aromatic naphtha, furnace oil, fuel oil, grease, asphalt, coal tar, bitumen, ammonia, ammonia gas, phosphoric acid, sulphuric acid, ortho-xylene, styrene monomer, ethylene dichloride, cyclohexanone, cumene, methanol, phenol, caustic soda dye, acids, chemicals of all kinds crystals, automatic transmission fluid, other liquids, palm oil, vegetable oil, oil seeds, molasses, lube oil, liquefied natural gas, liquefied petroleum gas, soybean oil, sunflower oil, aviation fuel, gasoline, motor spirit, petrol, furnace oil, liquefied petroleum gas, vacuum gas oil, liquefied natural gas, alcohol, benzene, glycerine, methanol, mixed xylene, palm oil, and crude oil.

Liquid cargo in India is categorized into three segments: petroleum products and crude oil, LNG, and chemicals and edible oil. The International Energy Agency (IEA) predicts that by 2040, India's economy will be five times its current size, making it the most populous nation globally and resulting in the highest energy demand. India is projected to contribute to a 25percent increase in global energy consumption, with a significant portion relying on coal and oil. India is the second-largest importer of oil in the world after China, fulfilling over 4 percent of the world's consumption. The nation also relies on imports for edible oil and industrial chemicals. With a significant dependency on crude, natural gas, and cooking gas, demand for handling, storing, and distributing liquid cargo in ports and hinterland areas is expected to grow steadily (IEA, 2020).

Oil seaports are associated with a higher risk of negative environmental impacts and safety concerns compared to other types of ports. In addition, the capacity for handling cargo may not adequately match the increasing volume of trade, resulting in frequent incidents and inefficiencies. These impacts can arise from various sources, such as wastewater generated from pipeline operations, tank cleaning, and floor washes in the LPG area. To mitigate these impacts, the wastewater is treated in a sewage treatment plant, and the treated water is utilized for gardening purposes.

There is also the discharge of water used for fire-fighting tests into the sea. Furthermore, the presence of hazardous substances like LPG, propane, butane, POL, and HSD at the site poses risks to human health and the environment, including flora, fauna, and water supplies. It is crucial to address these concerns and implement appropriate measures to safeguard both the environment and public health. Table 2.2 specifies cargo percentage share between liquid bulk cargo, container cargo and bulk break cargos for major seaports in India during the period FY.2016, FY 2019 and FY.2020.

Table 2.2: Percentage of Liquid Cargo to Other Cargo for Major Seaports in India (FY 2016, 2019, and 2020)

FY.2016		FY.2019		FY.2020	
Cargo	**Percentage Share**	**Cargo**	**Percentage Share**	**Cargo**	**Percentage Share**
Iron Ore	2.1	Iron Ore	5.8	Iron Ore	7.8%
Coal	22.7	Coal	23.1	Coal	21.1
Fertilizer	2.6	Fertilizer	2.2	Fertilizer	2.1
Other Cargo	18.9	Other Cargo	10.6	Other Cargo	10.06
Container Cargo	20.3	Container Cargo	20.8	Container Cargo	20.84
Liquid Cargo	**33.3**	**Liquid Cargo**	**37.5**	**Liquid Cargo**	**37.8**

Source: IPA Report Data & Authors Calculation

2.5 West Coast Major Seaports

The initial focus of seaport development in India was on the west coast, particularly in Mumbai and Surat, due to their convenient import and export facilities. The opening of the Suez Canal in the 1870s further accelerated the development of the western coast. India primarily imports liquid cargo from the Middle East, Latin America, and Africa, and Indian oil majors have also invested in overseas oil and natural gas fields in various regions. The west coast seaports have dominated cargo traffic due to their proximity to major consumption centers, industrial belts, well-developed pipeline networks, oil refineries, storage capacities, and multi-modal transport networks. Petrochemical companies are establishing captive liquid chemical terminals to reduce freight and transportation costs, with several entities promoting the construction of port and storage terminal facilities for liquid chemical cargo handling. West coast ports also have deep drafts of over 12.5 meters and channels to accommodate larger vessels.

In contrast, the east coast is known as an emergent coast, as it has been exposed by a relative fall in sea levels. The sea depth is shallower in the Bay of Bengal compared to the Arabian Sea, which results in less variation in water height during tides. The west coast is located in a moderately active seismic region (Zone III) and carries a moderate risk of potential earthquake damage. Oil spills pose a severe and ongoing threat to the marine ecosystem and invertebrates, with millions of metric tons of oil transported by sea each day and significant petroleum entering the ocean annually. Accidents and leaks from oil vessels can cause pollution and damage to the marine environment and economy, often due to human error or mechanical faults. Detection and tracking of oil spills are crucial for implementing mitigation measures, considering the quantity, location, and prevailing environmental conditions. Recent incidents on the west coast have highlighted the need for extensive studies on oil spills under various conditions.

Due to the sensitive nature of oil seaports, their higher environmental impact and safety concerns, and the inadequate capacity to handle increasing trade volumes, incidents and inefficiencies occur frequently. Liquid cargo in oil seaports includes sensitive products, chemicals, derivatives, oil drums, barrels, and hazardous cargo, requiring a range of logistics services, quality control, supply management, transportation distribution, expertise, reliable handling, well-trained workers, and efficient modal access to the hinterland. The aim is to assess the changes that have occurred at major Indian seaports specializing in oil import and refining in terms of sustainable development.

Initial development focus was of seaports in India was on west coast due to convenience of import and export facilities from Indian west coast. (Eg: Developing city of Mumbai and Surat). Opening of Suez Canal in 1870's gave an impetus to the development of Western Coast. India imports majority of liquid cargo from the Middle East, Latin America, and Africa and Indian oil majors also have acquired equity stakes in overseas oil and natural gas fields in South America, Africa, Gulf nations, and the Caspian Sea region. The seaports along the west coast have dominated cargo traffic due to their proximity to India's major consumption centres and the industrial belt and has well developed network of pipeline, Industries and oil refineries, storage area capacity and multi modal transport networks petrochemical companies are developing a captive liquid chemical terminal to achieve savings in freight and transportation costs., several entities promoting the Project Companies to set up port and storage terminal facilities for handling liquid chemical cargo at the port.

The other features of west coast ports are draft above 12.5 meters, channel in Port to bring in larger vessels. Also, Indian west coast has more seaports because depth of sea is more. The east coast is called emergent coast because the coast has been exposed by the sea by a relative fall in sea levels. East Coast Sea is not very deep when compared to west coast. Bay of Bengal is much wider than Arabian Sea. So, when the tides occur and pull up the sea water, the force is spread over the vast Bay of Bengal and the equivalent rise in water is less. But in case of Arabian Sea, which is comparatively small than Bay of Bengal, the water that can be pulled up is more because the same force is exerted on the water and as there is less water, the same force of high tides pull up more water and hence more variation in height for low and high tide in Arabian Sea in comparison to Bay of Bengal.

The west coast area is moderately active seismic region in the seismic Zone III (having moderate seismic intensity) of the Seismic Map of India (as per IS:1893, Part I, 2002) and therefore has a moderate risk of potential damage due to earthquake. As per central water & power research station report (2018) oil spill poses a severe and ongoing threat to marine ecosystem and the invertebrate. Over 100 million Metric Tons of oil is transported by sea per day and more than 1.3 million metric tons of petroleum enters the ocean each year. When an oil spill occurs, the damage depends upon its location and prevailing weather condition. The major cause of sea pollution is oil spill due to the oil vessel collision and leakages resulting in heavy loss to living and non-living things in the sea.

The accidents may occur due to human error and leakage could be due to mechanical faults in the pipes or containers. Detection and tracking of oil are essential to determine the required mitigation measures. The oil spread does not only depend on the quantity of spill but also on the location and prevailing environmental conditions. Thus, an extensive study is required to simulate oil spill under various environmental conditions at different locations. In recent times, many accidents have been reported from west coast of India causing huge loss to environment and economy.

Due to oil seaport’s higher sensitivity to negative environmental impact and safety issues in comparison to other port types, as well as the incompletely fitted cargo handling capacity to the increasing trading quantity, many incidents and inefficiencies do happen in the oil seaport on a relatively frequent basis (Wang,2018).The liquid cargo characteristics includes; sensitive products (biggest number of stainless steel tanks worldwide),chemicals and derivatives, oil drums, barrels and hazardous cargo which must possess a range of logistics services, such as quality control, supply management, transportation distribution; expertise and very reliable handling; well trained workers and modal access and rapid transport to the hinterland. The aim is therefore to verify the changes that have taken place at Indian major sea ports specializing in the import and refining of oil over the period mentioned and from the perspective of sustainable development.

2.6 Major Seaport Profiles in Research Study Area

This research focuses on four major seaports on the Indian west coast, namely Deendayal Port (DPA, Kandla Port), Mumbai Port (MbPA), New Mangalore Port (NMPA), and Cochin Port (CoPA). These ports collectively handle 89.66% of the overall liquid cargo in India, and for the west coast, they handle 95.76% of the liquid cargo. Detailed profiles of these major seaports, including seaport map layouts, are highlighted in this study.

1. **Deendayal Port Authority, Kandla**

   Kandla Port, situated at Latitude 23º 01' N and Longitude 70º 13' E, is located on the west bank of Kandla Creek in the district of Kutch. The creek runs into the Gulf of Kutch, about 90 nautical miles from the Arabian Sea. The channel width varies from 200 meters to 1,000 meters, and the contour depth along the shipping channel is approximately 10 meters. The Kandla Port Approach Channel spans a total length of around 23 kilometres. Navigation is allowed both during the day and night, depending on the ship's draft.

   Pilots board the ships at Outer Tuna Buoy two hours before high tide. Dredging operations are carried out throughout the year, enabling ships with a draft of up to 13 meters to enter within the tidal window. Kandla Port is an all-weather port, operational throughout the year, benefiting from its sheltered location in a creek, which eliminates adverse wave effects. The map layout of Kandla port is depicted in Figure 2.5.

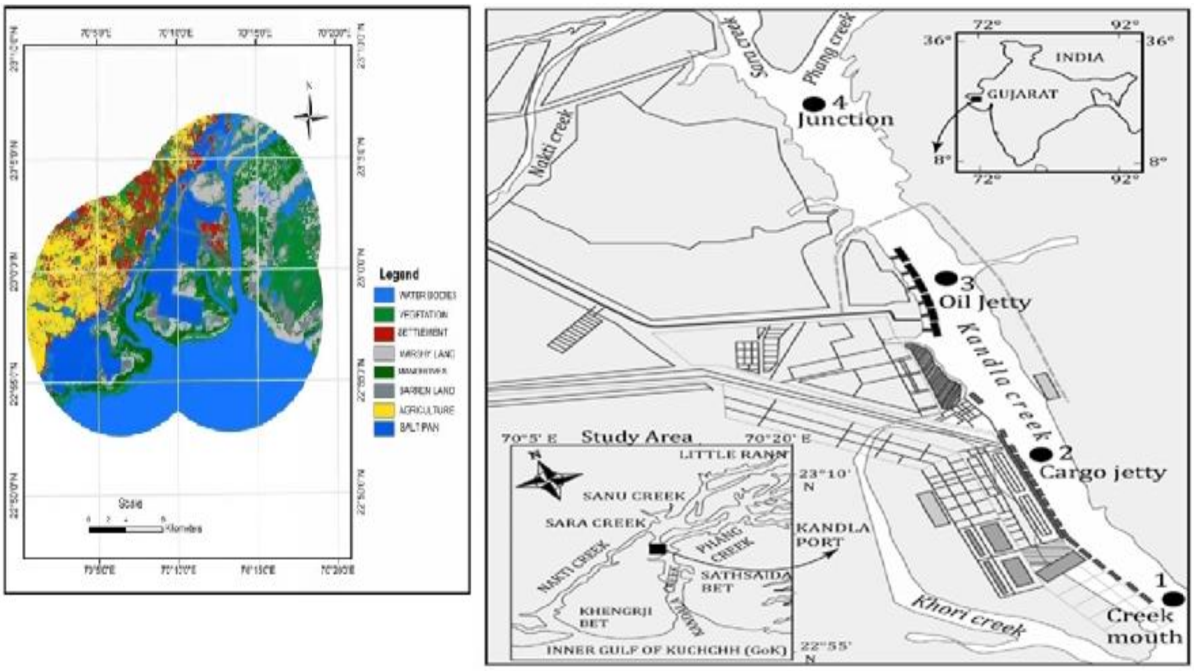

Figure 2.5: Deendayal Port, Kandla Map layout; Source: DPA, Kandla website

The region experiences low rainfall, making it suitable for handling food grains. The port is well-connected to the hinterland through a broad-gauge railway system and National Highway. It has the capability to handle various types of cargo, including dry bulk, break bulk, liquid bulk, and containers. Kandla Port serves as the closest major port to the Middle East and Europe and also acts as an enroute port for ships calling at Karachi, the only major port in Pakistan.

2. **Mumbai Port Authority, Mumbai**

Mumbai Port, located at Latitude 18°54' N and Longitude 72°49' E, is situated almost midway on the west coast of India. It boasts a natural deep-water harbor covering an area of approximately 400 square kilometers, protected by the Konkan mainland on its east and the Mumbai island on its west. The harbor's deep waters offer ample shelter for shipping year-round. The entrances to the harbor are well illuminated, with the Prongs lighthouse to the north visible from a distance of 27 kilometers, and the Kennery lighthouse to the south visible from 29 kilometers away. The harbor entrance, which has approaches from the southwest, lies between Prongs Reef and Thull Reef, located about 9 kilometers off the mainland to the southeast.

The map layout of Mumbai Port is depicted in Figure 2.6. The primary navigational channel in the harbor is largely a natural deep-water fairway, which has been deepened to a depth of 15 meters. With a mean high water neap tide of 3.3 meters, the channel adequately accommodates a wide range of cargo vessels, passenger ships, and deep-draft tankers. The port has well-established lighting arrangements, allowing for round-the-clock navigation.

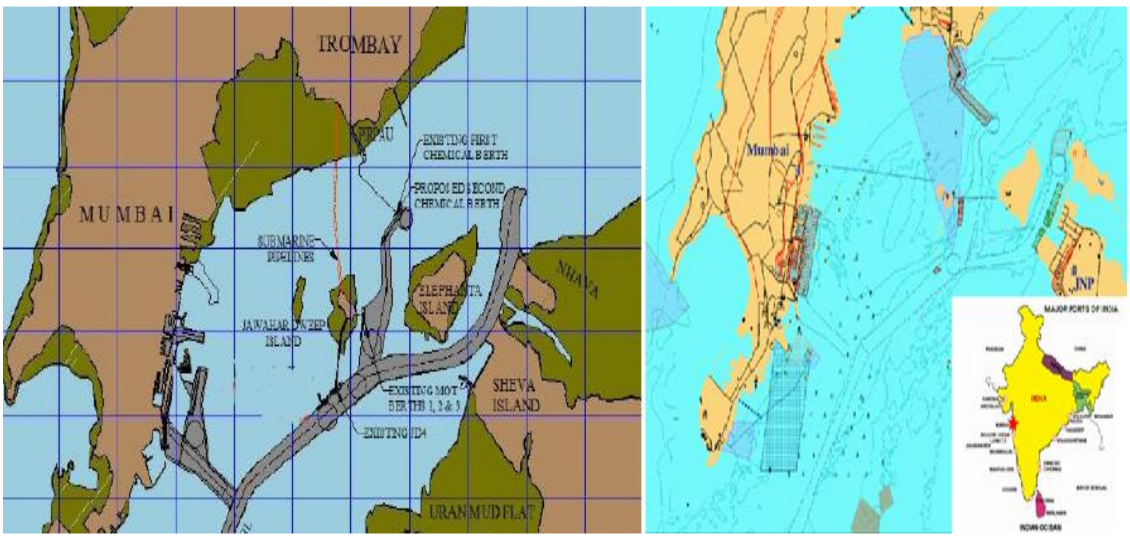

Figure 2.6: Mumbai Port Authority Map layout; Source: MbPA website

3. **New Mangalore Port Authority, Mangalore**

New Mangalore Port was designated as the 9th Major Port in India. It is situated on the West Coast of India and is the sole major port in the state of Karnataka out of the 12 major ports in the country. The port's coordinates are Latitude 12° 55' North and Longitude 74° 48' East. New Mangalore Port is a lagoon-type harbor with a long approach channel that has been artificially created through dredging.

Located at Panambur, Mangalore in the state of Karnataka, on the west coast of India, it is a modern all-weather port positioned 170 nautical miles south of Mormugao and 191 nautical miles north of Cochin Port. The port consists of three dock systems, namely the Eastern Dock arm, Oil Dock arm, and the western dock arm, with a total of 16 berths. Some of these berths can accommodate vessels with a maximum draft of 14.0 meters. Access to the port is facilitated through a 7.5-kilometer-long channel, with outer channel water depths measuring 15.4 meters and inner channel water depths measuring 15.1 meters. The map layout of New Mangalore Port can be observed in Figure 2.7.

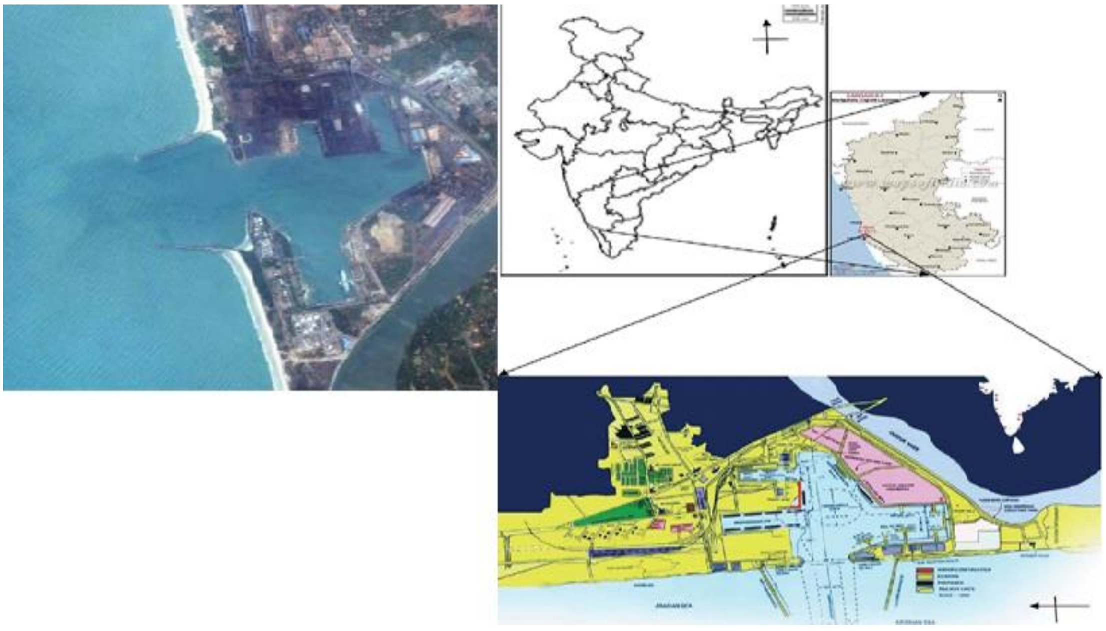

Figure 2.7: New Mangalore Port Authority Map layout; Source: NMPA website

With a land area of approximately 822 hectares and a water spread area of 120 hectares, the Port is well-connected to three National Highways, primarily utilized for southbound cargo transportation. One of these highways, NH 66, is a four-lane road, while certain sections are currently being widened from two lanes to four lanes, with provision for future expansion to six lanes to accommodate anticipated growth. New Mangalore Port is seamlessly linked to the Indian Railway Network through Southern Railway, South Western Railway, and Konkan Railway. The Railway Marshalling Yard located at Panambur, within the premises of New Mangalore Port, operates under the Southern Railway.

4. Cochin Port Authority, Cochin

Cochin Port, one of India's thirteen Major Ports, is a thriving all-weather natural port and the rapidly growing maritime gateway to the southern region of the country. Governed by the Cochin Port Authority (CoPA), it enjoys a strategic location close to the busiest international sea routes connecting Europe to Australia and the Far East. The diversion distance from the main trunk route to Cochin is merely 76 nautical miles, and there is a mere 11 nautical miles diversion from the Singapore-Gulf Sea route to reach Cochin. This unparalleled proximity to maritime highways sets Cochin Port apart from other major ports in India.

As India's first e-Port, Cochin Port holds ISO 9001-2008 certification and complies with the ISPS (International Shipping and Port Security) and MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978) codes and regulations, enabling round-the-clock navigation throughout the year. The map layout of Cochin Port is depicted in Figure 2.21. The entrance to the port is through the Cochin Gut, located between Vypeen and Fort Kochi. The port's jurisdiction extends to encompass the entire backwaters, along with the connecting creeks and channels.

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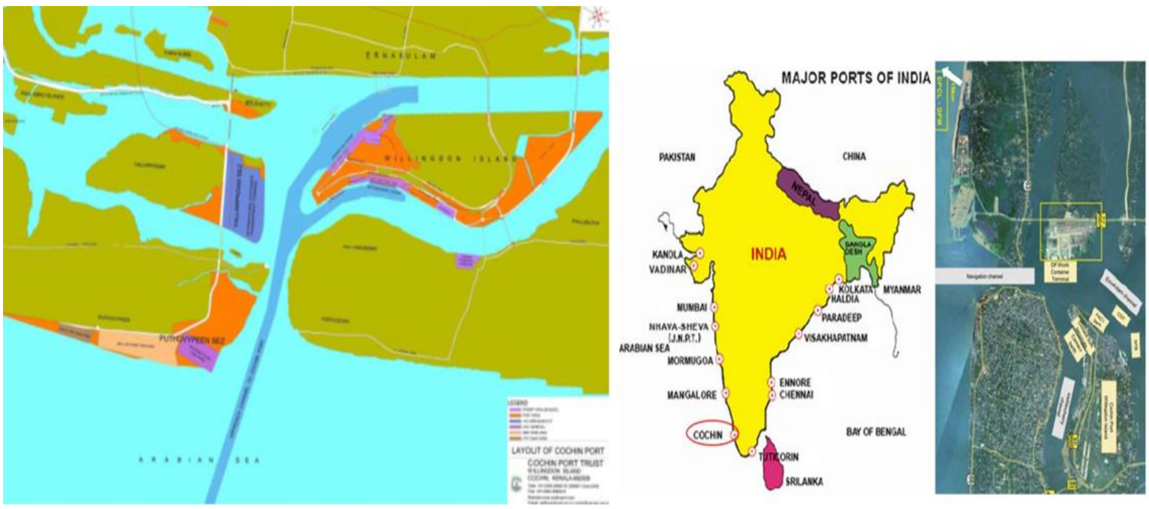

Figure 2.8: Cochin Port Authority Map layout; Source: CoPA website

The approach channel to the Cochin Gut spans approximately 1000 meters in length and 200 meters in width, consistently maintained at a depth of 13.8 meters. The port has excellent connectivity with the railway and national highway network, providing convenient access to other regions of the country. Additionally, the Cochin International Airport is located approximately 40 km away from the Port, ensuring efficient air transportation. The current Port infrastructure primarily occupies Willingdon Island, covering an area of approximately 385 hectares (ha). According to the seismic zone classification defined by IS 1893 (Part-I): 2002, Cochin Port falls within Seismic Zone III, which is categorized as a Moderate Risk Zone.

This chapter highlights the necessity of considering influences among various seaport sustainability factors and evaluating the efficiency. The research study objectives focus on the liquid cargo profile of four west coast major seaports of India by evaluating the environmental, economic, and social efficiency through a mixed-method research approach.

2.7 Summary

From these discussions, Chapter-2 of the thesis provides background information and a research context for sustainability-related aspects by including the general dimensions and key performance indicators in determining seaport sustainability in a global and Indian maritime context. This chapter also discusses the basis behind incorporating sustainability-related aspects. It underscores the necessity of considering connections among various sustainability factors and evaluating the efficiency of the dimensions. The research study objectives focus on the liquid cargo profile of four west coast major seaports of India by assessing the sustainability efficiency through a mixed-method research approach.

CHAPTER 3
LITERATURE REVIEW

3.1 Overview

This chapter reviews seaport sustainability literature to explore mission drivers and motives of research objectives. It examines the evolution of sustainability in seaports and identifies key characteristics. Understanding seaport sustainability is essential for the research's objectives and recognizing its evolution in the industry. Finding the need to develop overall sustainability development in seaport organisations is gained from a literature review, which provides the answers to achieve research objective 1, research objective 2 and research objective 3 of the thesis.

Literature review studies of two research objectives in this study which includes seaports across the globe for identification and assessment of sustainability practices in seaports (RO1) and analyzing the relationship between dimensions and indicators related to seaport sustainability performance (RO2). Literature reviews on seaport sustainability assessment analyze performance, dimensions, and indicators while considering planning, requirements, and stakeholder influences and aid in identifying sustainability dimensions and performance indicators for sustainable planning in seaports. Benchmarking seaport sustainability performance indicators provides insight into input and output parameters that affect real-time data values. This information guides the specification of additional requirements and implementation for seaport sustainability. The chapter concludes with a summary of the reviewed topics.

3.2 Assessment and Relationship Identification of Seaport Sustainability Performance Dimensions and Indicators: A Review

The expansion of international seaborne trade and port operations has had significant negative impacts on the environment, including increased noise, air pollution, loss of biodiversity, water pollution, and risks to public health and safety (UNCTAD, 1993; Endersen et al., 2003; Corbett and Winebrake, 2007). To address these concerns, global regulations such as MARPOL and the Kyoto Protocol have been developed and implemented, placing greater pressure on ports to meet regulatory and societal demands for operational sustainability (Zhang, 2016; Bodansky, 2016). Ports must take proactive measures in this area as it has become a crucial factor for shipping companies when selecting ports of call. Ports operating at a high level of sustainability are more likely to receive support from the government, communities, the public, and potential investors in the maritime industry (Thai, 2016; Parola et al., 2017; Ding et al., 2019). Consequently, ports are increasingly making substantial investments to ensure regulatory compliance and enhance their social responsibility image (UNCTAD, 2015; Acciaro, 2015).

Although seaport sustainability development and its related aspects have gained attention from maritime practitioners and researchers, the literature on seaport functions in this domain remains limited (Lu, 2016; Muangpan, 2019; Oh, 2018; Peris-Mora, 2005; Sislian., 2016; Roh, 2021; Hossain, 2021; Kim, 2017). Existing studies on sustainable seaport development have only addressed a few comprehensive aspects of seaport sustainable development, focusing on related sustainability dimensions (Geerts, 2020; Alamoush, 2021; Ashrafi,2019). In recent years, there has been a growing emphasis on seaport sustainability development and its various dimensions. However, the existing literature in this field remains limited and insufficient (Senegar,2018; Lam,2014). Most research studies have primarily focused on examining the environmental factors and indicators related to seaports, with some considering the triple-bottom-line dimensions (Koberg, 2019; Kang, 2017; Lima, 2019; Cheon, 2017; Acciaro, 2020; O'Connor,2019).

Environmental aspects such as air quality, greenhouse gas emissions, water conditions, energy consumption, noise pollution, carbon footprint, and waste management have received considerable attention (Ha, 2021; Cheon, 2017; DiVaio, 2018; Shiau, 2015; Wang, 2020; Lam, 2012; Hiranandani, 2014).Moreover, studies have also explored economic aspects such as stakeholder involvement, competition, resource utilization, financial state, relationships, logistics, and traffic forecast methods in the context of seaport sustainability. Additionally, social factors including employment generation, security and safety, corporate social responsibility, community relationships, and transparency have been acknowledged (Ha,2018; Lu,2016). The global seaborne business and seaport development have had significant adverse impacts on the environment, such as increased noise levels, reduced air quality, biodiversity loss, water pollution, and threats to public health and safety (Chen,2018; Adams,2009; Bordils,2020). With the implementation of international conventions addressing environmental issues in maritime transportation, seaports face growing pressures to adhere to regulatory and community requirements for sustainable practices.

Seaports now need to prioritize sustainability to attract support from authorities, society, and potential investors in the maritime industry. The importance of sustainable development in the maritime supply chain has gained recognition in recent years, particularly in the seaport sector (Peris-Mora et al., 2005; Eswari ,2022). Seaport development involves various stakeholders, and it requires a multifaceted approach considering economic, administrative, social, and environmental dimensions to ensure business performance aligns with sustainable development goals (Peris-Mora et al., 2005; Le et al., 2014; Darbra et al., 2009). To address the growing importance of seaport sustainability, the International Association of Ports and Harbors has established the World Port Sustainability Program to integrate sustainability mechanisms and enhance sustainability efforts in seaports (WPSP,2018). This initiative recognizes and rewards seaports that demonstrate sustainable development practices, aligning global seaports with international sustainability standards and the United Nations Sustainable Development Goals.

While the topic of seaport sustainability has gained attention from practitioners and researchers, the available literature in this domain remains limited (Peris-Mora et al., 2005; Le et al., 2014; Roos and Neto, 2017; Darbra et al., 2009). The maritime trade and seaport industry have experienced significant growth in recent decades, highlighting the crucial role of seaports in global trade and the economy (Lam and Van de Voorde, 2012). However, this rapid economic expansion has come at the expense of the environment, with seaport operations causing adverse effects on the ocean, soil, and air, leading to ecological degradation (Lu et al., 2012; Darbra et al., 2009). Consequently, there has been a surge in research on environmental issues and sustainability impacts related to seaports (Denktas-Sakar and Karatas-Cetin, 2012).

In addition to environmental concerns, there has been a growing recognition of the social dimension of sustainability, including stakeholder management and corporate social responsibility, which has received limited attention in previous literature (Shiau, 2015; Lu et al. 2012) highlighted the valuable insights that seaport organizations can provide on port sustainability, emphasizing the need for comprehensive criteria to assess sustainability in the industry, covering economic, environmental, and social aspects. To address this gap, Lu et al. (2012) developed a set of criteria to evaluate the sustainability of international seaports, focusing on these dimensions.

While their study focused on three seaports in Taiwan, their approach can be applied to other regions as well. Previous studies have also explored seaport sustainability in various locations, such as the UK, Spain, Taiwan, Vietnam and Cambodia, Brazil, the EU, and more (Kuznetsov et al., 2015; Peris-Mora et al., 2005; Le et al., 2014; Roos and Neto, 2017;

Darbra et al., 2009; Puig et al., 2015). Despite India's significant role in global trade and shipping, there is a lack of research examining the sustainability of its seaports. Recognizing the importance of studying sustainable development in Indian seaports, this study aims to fill this gap. Given the increasing significance of sustainability for these seaports, there is a need to investigate the assessment criteria for port sustainability (Senegar,2018; Narasimha PT,2022). The significance of seaport sustainability has grown as organizations in the port industry aim to align their operational activities with their supply chains and adapt to the changing business landscape (Roy, et al., 2012; Sahu, 2018). Seaport sustainability has been recognized as a standard business practice, emphasizing the need for seaports to implement strategies and engage in activities that meet the present and future requirements of the port and its stakeholders, while also preserving human and natural resources.

Although seaport activities contribute to economic growth, they often have negative environmental impacts, such as air and water pollution and noise pollution (Ault et al., 2009; Roh et al., 2016). Regardless of seaport size, geography, or activity profile, seaport authorities increasingly acknowledge the importance of sustainability and are aligning their management objectives with sustainable development goals, considering economic demands, cost reduction, risk mitigation, and responsible port practices (Puig et al., 2015). In addition, this section provides a comprehensive review of studies focusing on seaports, categorized according to regional classification. It examines the sustainability assessment of seaports within each region, highlighting the assessment methods employed and presenting the research findings.

The following subsections present a detailed account of the sustainability assessment for seaports in each region of the globe.

a. European Region Seaports

Peris-Mora et al. (2005) conducted a study to develop a system of indicators for sustainable seaport management using a combination of multi-criteria decision-making and case study methods. The seaport of Valencia was selected as a case study, while other Spanish and European ports were included in the multi-criteria analysis. The aim of the study was to propose a system of sustainable environmental management indicators that could be utilized by any seaport authority.

The European Sea Ports Organization (ESPO, PPRISM, 2010) undertook a project to identify relevant port performance indicators (PPIs) and categorized them into five groups: environmental performance (Management, Monitoring, Priorities, Green action), connectivity and supply chain performance (connectivity Inter-modal ,seaport, Logistics services, Throughput/quay meter, Area usage, Spatial productivity), market structure & throughput (Waterside ,Rail, Container ,Liquid bulk ,Dry bulk, General cargo),Container dependency, Measurement transhipments, comm. activities), social-economic impacts (Employment-Direct & Indirect) and governance features (Ownership, Authority, Background aspects). The study aimed to create a dashboard and standard toolkit of these indicators for all European seaports.

PPRISM (2012) established indicators accepted by stakeholders to promote seaport sustainability and laid the foundation for the future European Port Observatory, facilitating the measurement of seaport performance in areas such as value added, employment, carbon footprint, waste management, maritime connectivity, and customs procedures quality.

Bergmans et al. (2014) conducted a case study on the Port of Antwerp, examining its sustainability reporting initiatives and the performance of the harbour community in sustainability reporting. The study revealed that these initiatives fostered the development of new discursive spaces, practices, and reporting standards while contributing to the formation of a community identity. Hence, it was found that discussing and negotiating sustainability related indicators is the way of reaching desired futures of an ideal harbour community.

Acciaro (2014) explored different methods for successful innovations to enhance environmental sustainability in seaports, proposing a framework and technique to measure the success of innovations in achieving specific goals. The study utilized several case studies, including on-shore power supply and substitute fuels, highlighting the dynamic fit of innovations based on the demands of seaport actors and the port environment.

Darbra et al. (2015) employed a bottom-up and top-down approach, utilizing stakeholder feedback, to identify various seaport-related indicators for occupational health, safety, security, and environmental factors. The study emphasized the importance of these indicators in considering seaport sustainability and employed a self-diagnosis questionnaire within a qualitative method based on sustainability development.

PORTOPIA (2016) continued the work initiated by PPRISM, focusing on four categories: environmental management indicators, environmental monitoring indicators, top environmental priorities, and services to shipping. These categories included aspects such as the existence of environmental training programs, inventory of relevant environmental legislation, air and water quality monitoring, and on-shore power supply availability.

Laxe et al. (2016) investigated factors related to 28 Spanish seaports, employing a seaport sustainability synthetic index based on economic and environmental dimensions. The study found that not all Port Authorities fulfilled the requirements specified in the port law, with only four seaports providing comprehensive sustainability reports. It also highlighted the importance of global and integrated management for sea ports with higher synthetic indexes, which effectively addressed user demands and continuously adapted to changing conditions of international competition.

Carbone, Grosso, and Comi (2021) titled "Assessing sustainability performance in European ports: The case of Italy" examined the sustainability performance of ports in Italy within the broader context of European seaports. This study employed a comprehensive approach to assess the sustainability practices and outcomes of Italian ports, considering economic, environmental, and social dimensions. Through a combination of quantitative and qualitative analysis, the authors evaluate key indicators and identify strengths and weaknesses in sustainability performance. The findings contribute to a better understanding of the current state of sustainability in European ports and provide insights for enhancing sustainability practices in the Italian seaport industry.

Fei, Wang, Zhang, and Li (2021) through research work titled "Towards sustainable port development in Europe: A bibliometric review" provided a comprehensive review of the existing literature on sustainable port development in Europe. Using bibliometric analysis, the authors identified key research trends, influential authors, and thematic clusters in the field of sustainable port development. This review highlights the importance of sustainability considerations in the planning and management of European ports, including environmental impact assessment, green technologies, and stakeholder engagement. The findings contribute to a deeper understanding of the current state of research in this area and provide a foundation for future studies and policy development to promote sustainable port development in Europe.

Gonzalez-Prieto and Coto-Millan (2021) through research work examined the relationship between sustainability and the competitiveness of European ports. The research investigated the impact of sustainability practices, such as environmental management and social responsibility, on the overall competitiveness of ports. The findings highlighted that seaport that prioritize sustainability measures tend to enhance their competitiveness by attracting more customers, fostering collaboration with stakeholders, and achieving better financial performance. The study emphasized the importance of integrating sustainability into the strategic planning and operations of European ports to enhance their competitiveness in the global market while promoting environmental and social well-being.

b. Asia/Pacific Region Seaports

Lirn et al. (2012) conducted a research study on three of the largest seaports in Asia to identify vital indicators and provide recommendations to improve seaport sustainability. The study categorized seventeen green indicators into five dimensions and developed a framework to prioritize these key indicators. The dimensions included air pollution management, aesthetic and noise pollution management, solid waste pollution management, liquid pollution management, and marine biology preservation. The study recommended potential solutions to enhance seaport sustainability.

In a study conducted by Kim and Chang (2014) in Busan Port, interviews were conducted to guide seaports in implementing sustainability practices into their operations. The study identified four important work processes that, if improved, would enhance the sustainability performance of seaports. These processes included container traffic growth, low environmental impacts and corporate responsible image making, operational efficiency, and efficient use of the seaport area. The study proposed that simultaneous implementation of these processes would improve the overall sustainability of the seaport.

Hiranandani (2014) conducted a study that included four case studies in Asian seaports, demonstrating the increasing momentum of sustainability development in the functioning of seaports. The study highlighted the progress made toward sustainable development and examined these practices from the perspectives of diverse seaport stakeholders. The findings emphasized the need for a holistic and comprehensive analysis of seaport operations and environmental practices in response to the demands of globalization for overall seaport sustainability.

Roh et al. (2016) identified necessary criteria for sustainable seaport development from the perspective of seaport authorities. The study conducted in-depth interviews with Asian seaport authorities and considered both internal and external management aspects. The identified criteria included establishing a clear environmental policy, reducing environmental risks and damages, collaborating with business partners to manage environmental risks and develop a green supply chain, saving costs through the use of cleaner technology, improving welfare and working conditions for employees, providing training and education for employees, and supporting community social and economic activities. The study highlighted the importance of overall environmental management, optimized operation planning, cost savings, internal social programs, environmental collaboration with shipping companies and suppliers, external social programs, and evaluation collaboration for sustainable seaport development.

Lu et al. (2016) examined the effects of a sustainable supply chain on the sustainability performance of seaports in Taiwan. The study collected survey data and conducted a confirmatory factor analysis to assess the psychometric properties and relationships among the variables. The study concluded that internal sustainable management plays a mediating role in the effects of external sustainable relationships on the sustainability performance of seaports. It emphasized the need for enhancing internal collaboration for seaport operators to develop sustainable performance through cooperation with external customers and suppliers.

Di et al. (2017) constructed an assessment model for the quantitative dimension of green seaport development based on the drivers, pressures, states, impacts, and responses (DPSIR) structure. The study utilized the Analytical Hierarchy Process (AHP) method and conducted a comparative analysis of five seaports in China. This study served as a benchmark for future studies on green seaport development in both developed and developing countries.

Ha et al. (2017) developed a hybrid seaport performance measurement model that considered perspectives from various seaport stakeholders. The study conducted a case study on four major container seaports in South Korea and utilized a combination of decision-making trial and evaluation laboratory (DEMATEL) and analytical network process (ANP) techniques to capture the interdependency among performance indicators. The study incorporated multiple objectives of key stakeholders and employed a multi-criteria decision-making model to evaluate the performance of the seaports.

Xiao and Lam (2017) conducted a case study on Singapore seaport to measure its sustainability using a systems framework. This research study aimed to narrow the gap between adopting systems theory and sustainable development. The analysis demonstrated a positive relationship between the port and the city, suggesting that the Singapore port could continue developing by reducing negative environmental relationships while increasing positive economic and social relationships.

Wang et al. (2017) developed a conceptual model for Chinese oil-based seaports in the context of seaport sustainability. The study conducted a systematic literature review and semi-structured interviews to identify sustainability indicators and formulate a sustainability framework to guide seaport managers in improving their seaport's sustainability performance. The study contributed to the existing literature by developing specific measures to assess oil -based seaport sustainability and proposing a holistic sustainability framework for Chinese oil-based ports.

In their study, Sengar et al. (2018) focused on identifying key sustainability factors and appraisal criteria within the framework of significant features for sustainability initiatives in Indian seaports. Using the Analytical Hierarchy Process framework, the study identified three main sustainable factors and fourteen sub-factors to evaluate port sustainability. The study concluded that economic and social features play a significant role in seaport sustainability, but the protection of the seaport environment is at the core of sustainable practices. The findings emphasized the importance for seaport authorities and policymakers to implement a structured approach that prioritizes the protection of the seaport environment and promotes green practices. This approach should be integrated with the economic and social characteristics of seaports to ensure the holistic and sustainable development of Indian seaports.

Singh and Vashistha (2017) presented a comprehensive review of sustainable development initiatives adopted by Indian seaports. The study evaluated the environmental performance of Indian seaports and identified the key sustainability challenges faced by the seaports. The authors highlighted the need for sustainable seaport development and identify the key sustainable seaport development initiatives adopted by Indian seaports, including the use of renewable energy, eco-friendly dredging practices, and waste management practices.

Sahu and Jain (2018) presented an assessment of sustainability-related practices adopted by Indian seaports using a sustainability performance index. The study evaluated the environmental, social, and economic sustainability performance of Indian seaports and identified the key sustainability challenges faced by seaports. The researchers highlighted the need for adopting a holistic approach to sustainable seaport development and identify the key sustainability practices adopted by Indian seaports, including the use of renewable energy, water conservation practices, and environmental management practices.

Aditi and Singh (2018) presented an analysis of sustainability reporting practices and disclosures by Indian seaports. The study evaluated the extent and quality of sustainability reporting by Indian seaports and identified the key sustainability issues reported by the seaports. The authors highlighted the need for improving sustainability reporting practices and disclosures by Indian seaports and identify the key sustainability-related issues that need to be addressed, including environmental management, social responsibility, and economic viability.

Bhatia et al. (2020) examined the challenges and issues associated with sustainable seaport development in India. The study analyzed the policy and regulatory framework, stakeholder engagement initiatives, and technological innovations aimed at promoting sustainable seaport operations in the Indian seaport context. The authors identified the key barriers to implementation and emphasize the importance of effective governance, technological innovations, and stakeholder engagement in achieving sustainable port development in India.

Jha et al. (2019) assessed the sustainable development practices in Indian seaports. The study evaluated the performance of seaports in terms of environmental, economic, and social sustainability indicators and identified the challenges and opportunities for sustainable development. The researchers highlighted the significance of effective seaport policy implementation, stakeholder-related engagement, and technological innovation in promoting sustainable seaport operations in India.

Gupta and Yadav (2018) analyzed the green seaport initiatives in India, focusing on policies and practices. The study evaluated the policy and regulatory framework, technological innovations, and stakeholder engagement initiatives aimed at promoting green seaports in India. The authors identified the key challenges and opportunities facing the maritime industry and stress the importance of effective policy implementation, stakeholder engagement, and technological innovation in advancing sustainable seaport operations. They also emphasize the need for collaboration among stakeholders to address industry challenges.

Kumar et al. (2017) provided a comprehensive review of policies and practices for sustainable seaport development in India. The study evaluated the policy and regulatory framework, stakeholder engagement initiatives, and technological innovations in promoting sustainable seaport operations. The authors identified the key barriers to implementation and underscored the significance of effective governance, technological innovation, and stakeholder engagement in fostering sustainable seaport development. They also emphasized on the need for stakeholder collaboration to overcome seaport and maritime industry challenges.

Muangpan (2019) conducted a study on Thailand's ports in the Eastern Economic Corridor to identify key performance indicators (KPIs) for sustainable port development. The study analyzed the environmental, economic, social, and organizational dimensions to determine the KPIs. Two main groups of sustainable port KPIs were identified: critical and preferable groups. A survey was conducted among port employees to gather data, which was then subjected to exploratory factor analysis to identify the factor loading of sustainable port KPIs. Analysis of variance was used to compare the means of important KPI levels among three types of ports: container, non-container, and multi-purpose ports. The study revealed significant differences in sustainable port KPIs among the different types of ports, particularly in the preferable group. These findings provide valuable recommendations for the development of sustainable practices in seaports.

Roh (2021), conducted the research study with a focus on examining the key practices that contribute to sustainable seaport development in Korean ports. The study aimed to establish a typology of a seaport stakeholder decision framework for sustainable seaport development. To achieve this, a comprehensive literature review was conducted to identify the main practices associated with sustainable seaport development. The study also utilized a holistic conceptual framework based on sustainable development and stakeholder management theories. Semi-structured interviews were conducted with port managers in Kov.rea to gather insights and perspectives on sustainable seaport development.

The collected data were then analyzed using the Fuzzy Analytic Hierarchy Process (FAHP) method, which involved input from the seaport managers. This analysis helped determine the priorities of the sustainable port development practices. Based on the findings, this research study concluded that all the proposed sustainability practices should be utilized for evaluating sustainable port development. The typology of the seaport stakeholder decision framework provides a valuable guide for port managers and stakeholders involved in sustainable seaport development in Korea and can serve as a reference for similar initiatives in other regions.

c. Middle East Region Seaports

Alzahrani, S. M. (2021) conducted a research study titled "Implementing green port strategies in Saudi ports to achieve environmental sustainability." The study focused on developing and implementing strategies to promote environmental sustainability in Saudi ports. The research aimed to identify the challenges and opportunities in adopting green practices, assess the effectiveness of existing strategies, and propose recommendations for enhancing sustainability in Saudi ports. The findings of this study contribute to the knowledge and understanding of green port initiatives in the Saudi Arabian context.

Sislian (2018) conducted a study on integrating port sustainability indicators into a Sustainability Management Balanced Score Card (SMBSC) and implemented it as a decision-making tool for maritime ports in the Egyptian Port of Alexandria. The study incorporated a triple bottom-line framework for port sustainability and utilized four perspectives of the SMBSC: financial, social and environmental, internal processes, and innovation and worker learning. The findings of the study guided port managers and operators, enabling them to enhance productivity, profitability, and long-term social and environmental sustainability by reducing gas emissions in port operations.

AlSalem and Zavadskas (2019) conducted a systematic literature review to assess the sustainability of port projects. Their study explored various dimensions of sustainability, including economic, environmental, and social aspects, and identified key indicators for measuring sustainability performance in port projects. The research provides valuable insights into the current state of knowledge in this field and highlights the need for further research to address gaps and improve assessment methodologies. The findings of this study contribute to the development of sustainable practices in port projects and provide a foundation for future research and decision-making in the context of sustainable port development.

Elnabawi (2019) conducted a comprehensive review of achieving sustainability in ports. The study examined various aspects of sustainability, including environmental, social, and economic dimensions, and analyzed the initiatives and practices implemented in ports worldwide. The research identified key challenges and barriers to sustainability in ports, such as pollution, climate change, and stakeholder engagement. It also highlighted the importance of integrating sustainable practices into port operations and decision-making processes. The findings of this review contribute to a better understanding of sustainable port development and provide insights for policymakers, port authorities, and stakeholders in their efforts to achieve sustainability goals in the maritime industry.

Ameli and Khaksar-Haghani (2020) conducted a systematic review and bibliometric analysis of sustainability in ports. The study examined the existing literature on port sustainability and analyzed the trends, patterns, and themes within the field. It identified key research topics, methodologies, and influential authors in the domain of port sustainability. The review highlighted the significance of environmental, social, and economic dimensions of sustainability in port operations and emphasized the need for holistic approaches. The findings of this study provide a comprehensive overview of the current state of knowledge on sustainability in ports and serve as a valuable resource for researchers, practitioners, and policymakers in the maritime industry.

d. African Region Seaports

Adenso-Diaz and Triantis (2019) through research study conducted an extensive analysis of the state of port sustainability in Africa. The authors critically reviewed existing literature to identify key challenges, opportunities, and strategies for promoting sustainable development in African seaports. They examined various aspects such as environmental impact, social responsibility, economic development, and governance. This study emphasized the importance of adopting sustainable practices in port operations and highlighted the potential benefits of sustainable port development for local communities, the environment, and the overall economy. It provided valuable insights and recommendations for policymakers, port authorities, and stakeholders involved in African seaport sustainability initiatives.

e. North America Region Seaports

Adegoke (2018) conducted a study on 13 North American seaports with the aim was to benchmark the sustainability performance of these seaports. The study utilized three Data Envelopment Analysis (DEA) methods to identify and analyze indicators for comparing the performance of seaports. Through a detailed review of prior literature, indicators were categorized into economic, environmental, and social dimensions. These key performance indicators were refined with the input of relevant stakeholders and resulted in ten sub-indicators, including container throughput, GHG emissions, sewage emissions, congestion, accidents, berth length, terminal area, number of gantry cranes, technology investment fund, and existence of environmental policy. The study used DEA methods to measure seaport sustainability performance, with a focus on minimizing undesirable attributes of port productivity. The research findings highlighted variations in seaport performance evaluations based on economic and social criteria, and suggested future research extensions to analyze seaport evolution over time.

Hossain (2018), studies initiatives of thirty-six global ports, with twelve seaports in each of the three regions of Canada, were evaluated. The study examined port sustainability initiatives (PSIs) through a desktop study using port websites. It employed a comprehensive scale-based assessment of twenty-five predefined sustainability indicators for various sea ports and stakeholders. The findings indicated that most seaports have implemented measures for impact identification, mitigation, and monitoring, as well as improved energy management and stakeholder engagement. The study revealed progress in areas such as environmental monitoring (air, water, noise), wildlife protection, environmental performance disclosure on port websites, research and development, stakeholder participation, and support for enhancing environmental performance in port operations.

Anas S. Alamoush (2021) conducted research on seaport sustainability studies are expanding rapidly, but their findings are often scattered and lack a cohesive framework for assessment. This study was aimed to address this gap by developing a comprehensive framework that categorizes port actions, measures, and implementation schemes, using a critical literature review approach. The study emphasizes the connection between port sustainability and the United Nations' Sustainable Development Goals (UN SDGs). It identified sixteen interconnected sustainability categories and provides a non-exhaustive list of operational measures that cover the environmental, economic, and social dimensions of sustainability. The implementation schemes were classified into four groups. The study's practical implications offered guidance to port policymakers and industry professionals for effective decision-making and broader sustainability implementation.

3.3 A Review of Seaport Sustainability Performance Indicators with a Focus on Efficiency Benchmarking

This section illustrates literature review for research objective:3 which highlights on review on benchmarking seaport sustainability efficiency determination for seaports across the globe. Research studies on seaport sustainability have become progressively common in recent years, as the maritime industry has come under larger scrutiny for its environmental impact. One approach to assessing seaport sustainability is through the use of data envelopment analysis (DEA), a non-parametric technique used to measure efficiency and productivity.

Bichou, Gray, and Johnson (2007) employed Data Envelopment Analysis (DEA) to assess the sustainability of six UK seaports. This study utilized a set of environmental, economic, and social indicators to evaluate each seaport's sustainability and revealed variations in sustainability levels among the seaports.

Wanke, Barros, and Chen (2017) conducted a research study using a combination of DEA, entropy, and TOPSIS to evaluate the sustainability of 25 Latin American and Caribbean seaports. Findings indicated that the ports with higher sustainability levels were those that had implemented environmental management systems, had lower pollution levels, and fostered strong community relationships.

Lijesen and Woxenius (2019) provided a comprehensive review of recent research on seaport sustainability, including studies that utilized DEA. This study highlighted the usefulness of DEA as a tool for assessing seaport sustainability but emphasized the importance of carefully selecting indicators for analysis.

Ferrari et al. (2018) analyzed the sustainability of fifteen Italian seaports using DEA and a set of environmental, economic, and social indicators. This research study revealed that ports with higher sustainability levels had implemented environmental management systems, maintained strong community relationships, and exhibited lower pollution levels.

Gargiulo and Senatore (2021) employed DEA and principal component analysis (PCA) to assess the environmental sustainability of ten seaports in Italy. Findings indicated that ports with higher sustainability levels had implemented environmental management systems, demonstrated lower pollution levels, and achieved higher eco-efficiency.

Ruan et al. (2019) proposed an integrated approach combining DEA and fuzzy analytic hierarchy process (FAHP) to evaluate the sustainability of forteen seaports in China. This study considered environmental, economic, and social indicators and identified ports with higher sustainability levels based on environmental management systems, lower pollution levels, and stronger economic and social performance.

Kehagia et al. (2021) utilized DEA methodology to evaluate the sustainability of eighty-six seaports in Europe. This study incorporated environmental, economic, and social indicators and found that ports with higher sustainability levels had implemented environmental management systems, showcased lower pollution levels, and exhibited stronger economic and social performance.

Chen et al. (2018) employed DEA to evaluate the sustainability of twenty-five container ports in the Asia-Pacific region. This study utilized environmental, economic, and social indicators and revealed that ports with higher sustainability levels had implemented environmental management systems, exhibited lower pollution levels, and demonstrated stronger economic and social performance.

Wang et al. (2019) proposed an integrated approach combining DEA and additive ratio assessment to evaluate the sustainability of seventeen seaports in China. This research study considered environmental, economic, and social indicators and identified ports with higher sustainability levels based on the implementation of environmental management systems, lower pollution levels, and stronger economic and social performance.

Adegoke's (2018) through the research case study conducted regarding benchmarking of the sustainability performance of 13 North American seaports. The aim was to identify and analyze indicators using three DEA methods to compare the seaports' sustainability performance based on cross-sectional data. Initially, a comprehensive literature review was conducted to review prior research and identify indicators related to seaport sustainability. These indicators were categorized into three macro dimensions: economic, environmental, and social. Further refinement of these indicators was carried out with the input of relevant seaport stakeholders, resulting in the identification of ten sub-indicators. These sub-indicators included container throughput, GHG emissions, sewage emissions, congestion, accidents, berth length, terminal area, number of gantry cranes, technology investment fund, and existence of environmental policy.

To measure seaport sustainability performance while considering the dimensions of sustainable development, the research applied two data envelopment analysis (DEA) methods: Variable Returns to Scale (VRS) and Constant Returns to Scale (CRS). Research findings indicated that seaport performance evaluations varied depending on the economic and social criteria used. It was suggested that future research should consider analyzing seaport performance across dynamic and longitudinal time frames to gain insights into the evolutionary nature of seaports' sustainability practices over time. This study provides valuable insights into seaport sustainability assessment using DEA methods. The research highlighted the importance of considering economic, environmental, and social dimensions and suggests further analysis to gain a deeper understanding of seaports' sustainability performance over time.

Xie, Xu, Yang, and Li (2021) conducted a research study focusing on seaport sustainability assessment using a slack-based measure of efficiency with dynamic network Data Envelopment Analysis (DEA). This study aimed to develop a comprehensive approach to evaluate the sustainability performance of seaports. The authors proposed a dynamic network DEA model that considers both the static and dynamic efficiencies of seaports. The dynamic efficiency captures the intertemporal changes in seaport sustainability performance, while the slack-based measure of efficiency accounts for the desirable and undesirable outputs and inputs. This research used panel data from multiple seaports over a certain period and incorporates various sustainability indicators, including economic, environmental, and social dimensions. The authors analyzed the sustainability performance of seaports and identify the determinants of inefficiency. Findings of the study provided a valuable insight into seaport sustainability and offered practical implications for improving sustainability practices. The dynamic network DEA approach allowed seaport managers and policymakers to assess and compare the sustainability performance of different seaports over time. It also helped in identifying areas of improvement and formulating strategies to enhance overall sustainability in seaport operations.

3.4 Research Gaps Identification

1. Previous research on seaport sustainability has predominantly focused on environmental indicators, neglecting the social and financial dimensions of sustainability (Darbra et al., 2005; Seuring & Muller, 2008; Cheon & Deakin, 2010; Yap & Lam, 2013; Shiau & Chuang, 2015; Asgari, 2015; Roh, 2016; Wang, 2017; Senegar, 2018; Chen & Siu Lee Lam, 2018; Munagpan, 2019). However, understanding the social and economic aspects is equally important for assessing seaport sustainability (Schipper, 2017). Therefore, empirical research is necessary to explore seaport sustainability among seaport chain stakeholders, incorporating environmental, social, and economic factors along with key performance indicators.
2. Previous studies on seaport sustainability have emphasized environmental dimensions such as air quality, greenhouse gas emissions, water condition, energy consumption, noise, carbon footprint, and waste management (Benktas & Cetin, 2012; Yap & Lam, 2013; Lu et al., 2016; Wang, 2017). Economic dimensions have mainly covered stakeholder involvement, port competition, resource utilization, port financial state, and port relationships (Benktas & Cetin, 2012; Yap & Lam, 2013; Wang, 2017). Social issues like employment, security and safety, and port relationships have also been addressed, particularly in terms of security indicators and oil spill response mechanisms (Cheon & Deakin, 2010; Yap & Lam, 2013; Wang, 2017). Therefore, assessing holistic seaport sustainability initiatives is challenging but crucial for port authorities worldwide. However, there is a lack of historical quantitative data on port sustainability key performance indicators (KPIs), highlighting the need for primary research on seaport sustainability practices assessment.
3. Existing studies on seaport sustainability frameworks have primarily focused on specific geographical regions such as China, South Korea, Singapore, Vietnam, Taiwan, Egypt, the UK, and the EU, with a focus on container handling (Lu, 2016; Wang, 2017; Roh, 2016; PPRISM, 2012; Ha, 2018). Some studies have validated sustainable development factors based on a limited population of one or two seaports within a specific geographic scope (Lam, 2013; Asgari, 2015; Laxe, 2016; Wang,

2017). Therefore, the assessment of seaport sustainability initiatives should also consider major handling cargoes such as liquid or solid cargo profiles.

4. Indian seaports handle 70% of the nation's trade by value (IPA, 2018), yet sustainable development in Indian ports is still in its early stages due to the lack of a universal framework for sustainability management across all dimensions (Senegar, 2018; Narasimha PT,2021). To the best of our knowledge, no academic study exists that strengthens the sustainable development framework with a supply chain perspective specifically tailored to the Indian seaport context with a focus on liquid cargo.
5. While the importance of measuring sustainable management across the port supply chain is recognized, empirical studies examining the impact of sustainable maritime supply chains on sustainability performance are limited (Lu, 2016; Puig et al., 2017; Hossain, 2017). Therefore, there is a need for an effective implementation of sustainability in ports that considers sustainable management in both internal port processes and external customer perspectives.
6. Seaports are complex organizations, and consistent and viable performance benchmarking analysis requires the use of standardized variables (Panayides et al., 2009; Peris-Mora et al., 2005). However, there is a lack of research validating a standard set of sustainable indicators, with most studies focusing on productivity and efficiency. Thus, there is a need to identify sustainability-related dimensions and practices within seaports, considering both internal and external sustainable management aspects, and to determine the efficiency performance of these dimensions in real-time scenarios for major Indian seaports with a liquid cargo profile.

3.5 Summary

This theoretical literature review provides an overview of existing research studies that shed light on the diverse influences, drivers, and requirements associated with seaport sustainability. These factors significantly impact the sustainability goals of seaport organizations. By examining and synthesizing relevant research, this chapter has established a solid foundation for the current study. Furthermore, the identified research gap aligns with the three research objectives, thus setting a clear direction for this investigation.

CHAPTER 4
ANALYSIS AND EVALUATION OF SUSTAINABILITY DIMENSIONS AND PRACTICES IN SEAPORTS

4.1 Overview

This chapter provides an overview of identifying and assessing sustainability dimensions, indicators, and practices for major seaports in India. The pre-selection of dimensions and indicators is done in Chapter-3 of this thesis where detailed literature review on seaport sustainability is carried out and different sustainability related works across the global seaport is identified. In this section of the thesis a sustainability framework, thematic analysis, and systematic literature review was carried out. Indian seaport sustainability is then evaluated through with semi structured interview with maritime domain experts and seaport professionals to find the appropriateness of sustainability dimensions and performance indicators in Indian major seaports context. Maritime domain experts were consulted regarding the adoption of proposed sustainable development practices for major seaports in India. Their responses were categorized as no, yes, or not-applicable (NA).

The importance and performance of seaport sustainability factors and key performance indicators were assessed through Importance-Performance Analysis (IPA), using the mean performance and mean importance values derived from the experts' responses. The study analyzed the impact of various sustainability factors and key performance indicators, highlighting the assessment of seaport sustainability in the Indian context. Finally, the findings and implications of the research study is discussed.

4.2 Pre-Selection of Port sustainability dimensions and performance Indictors

To address the challenge of numerous key performance indicators (KPIs) under seaport sustainability, this study adopts a rigorous selection process to identify a set of indicators that are most relevant and useful. The initial selection of indicators is based on a theoretical assessment using specific criteria to filter out seaport sustainability-related indicators. Adopting an upstream approach, journal articles are thoroughly reviewed, and categories are identified based on seaport sustainability performance indicators and sustainability key performance indicators and found in the literature. The indicators are then further refined through consultation with port policy makers and stakeholders, ensuring alignment with the research topic. This approach, as outlined by Khadka (2012), allows for a focused and refined selection of indicators that best suit the research objectives.

In previous research, many seaport researchers have suggested a sequence of sustainability indicator selection criterions, such as robustness; relevance; frequency; policy responsive; policy relevance; measurability (UNCATD et al., 2013; UN, 2007; Puig et al., 2014, Wang,2018). A theoretical holistic sustainability seaport framework for liquid cargo seaport organization and its related practices with associated sustainability dimensions, performance indicators and key performance indicators were identified and categorized first via Systematic Literature Analysis (SLA) through concept of seaport sustainability across the global seaports were considered.

The search for insights into seaport sustainability/port sustainability involved querying the literary database. Among databases, Elsevier's Scopus stands out as a user-friendly option, surpassing Web of Science due to its comprehensive coverage and dependable results. Scopus, resembling Web of Science, was developed by Elsevier and offers 20% more quality coverage while outperforming Google Scholar in accuracy (Boyle and Sherman, 2006). Google Scholar, though widely used, lacks quality indicators and may include duplicates and non-scholarly content (Matthew,2008). Employing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) approach, the Scopus database was utilized to extract and analyze articles on seaport sustainability/port sustainability.

The systematic approach employed for conducting the literature search and subsequent review process is outlined below in a comprehensive manner:

Step 1: Defining Keywords and Criteria: The initial step involved formulating a keyword protocol for the literature search. The primary keywords used were "Seaport sustainability" and "Sustainable seaports." These keywords were restricted to articles within the document type and source type of journals. Certain exclusions were also established, encompassing conference articles, book chapters, dissertations, theses, and grey literature, which includes reports, working papers, government documents, and white papers from port organizations (Petticrew and Roberts, 2008). The protocol usage was as follows: "TITLE-ABS-KEY ("Seaport Sustainab*" OR "Port Sustainab*") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j")) AND (EXCLUDE (SUBJAREA,"EART")) AND (EXCLUDE (SUBJAREA, "BIOC")). The time frame considered for this study spanned from 1987 to June 2021, with a focus on research articles available in full text and written in English. This keyword search conducted on July 18, 2021, yielded a comprehensive list of 107 journal articles centred on seaport sustainability.

Step 2: Usage of Reputable Search Engines: The subsequent step involved utilizing prominent journal publisher websites such as Science Direct, Taylor and Francis, Springer, SAGE, Emerald, Wiley, and Inderscience to access relevant seaport sustainability research documents. The keywords employed here were "Seaport Sustainability" OR "Port Sustainability." This manual search, executed on February 17, 2021, resulted in the identification of 378 article listings as highlighted in Table 4.1.

Table 4.1: Articles extracted through key journal publisher's website search engine

Journal Publisher	No. of Articles on Seaport sustainability OR Sustainable seaports	Source
Elsevier	98	https://www.sciencedirect.com
Emerald	67	https://www.emerald.com/insight
Inderscience	29	https://www.inderscienceonline.com
Sage	13	https://journals.sagepub.com
Springer	91	https://link.springer.com
Taylor and Francis	46	https://www.tandfonline.com
Wiley	34	https://onlinelibrary.wiley.com
Total: 378		

Source: Research Literature Review

Step 3: Consolidation of Article Lists: All the articles obtained from Step 1 and Step 2 were consolidated to eliminate duplicate article titles and this process led to the final article list comprising of 421 journal articles.

Step 4: Selection of Relevant Documents: From the 421 articles, only relevant documents of focus area on seaport sustainability research, with an emphasis on perspectives from seaport stakeholders and sustainability dimensions. This process produced a list of 273 relevant articles.

Step 5: Focusing on Impact and Ranking: The subsequent stage involved narrowing down the selection to articles within the 'top 50%' of the impact factor distribution, corresponding to the first two quartiles in Scopus classification/ranking. This criterion aimed to identify articles with greater influence and relevance in the field of seaport sustainability. Additionally, articles from journals with high Scopus metric rankings were incorporated to address research gaps. This careful selection resulted in a list of 69 articles for in-depth review and gap identification.

Step 6: In-depth Exploration and Gap Identification: To enhance the understanding of seaport sustainability, the review process extended to additional articles. These articles were scrutinized for insights into specific sustainability theories, stakeholder perspectives, and seaport sustainability dimensions. The study also reviewed additional documents to identify any significant contributions in the field or to know any critical gap that needs attention.

Step 7: Ongoing Literature Update: The review process was further refined by updating the literature search through the Scopus database on November 18, 2022, using the same keyword protocol. This subsequent search revealed an additional 184 articles related to seaport sustainability, underscoring the dynamic nature of the field. By methodically implementing these steps, a comprehensive review of the literature on seaport sustainability was conducted, ensuring the inclusion of relevant articles and insights into the evolving landscape of this vital research area and is highlighted in Table C.1 of Appendix C.

4.3 Seaport sustainability performance factors identification

4.3.1 Port Environmental sustainability performance dimension

The environmental dimension of sustainable development has garnered significant attention from authors in the literature. Various perspectives contribute to this field. Wooldridge et al. (1999) discuss the relationship between environmental sustainability and ports/port construction. Some authors, such as Darbra et al. (2005) and Gupta et al. (2005), specifically focus on the environmental management systems (EMS) of ports. Chiu et al. (2014) and Le et al. (2014) have conducted studies that consider factors for environmental management and highlight the importance of implementing an EMS to manage air, water, and land pollution within and around port premises. Another group of authors, including Park and Yeo (2012), Autry et al. (2013), Chiu et al. (2014), and Elzarka and Elgazzar (2014) evaluate the greenness of seaports from different perspectives.

These research studies consider a variety of factors to assess the environmental sustainability of ports and emphasize the significance of implementing an EMS with clear performance indicators. Additionally, authors such as Peris-Mora et al. (2005), Chiu et al. (2014), and Asgari et al. (2015) argue that providing environmental education to port employees contributes to achieving environmental sustainability. The environmental performance dimension focuses on reducing the environmental impact within ports. Key performance variables include environmental levels and pollution, effluents and waste management, energy consumption, and compliance with environmental regulations. These aspects are evaluated from a supply chain perspective in ports.

4.3.2 Port Social sustainability performance dimension

The social dimension of sustainability in seaports has received limited attention in the existing literature, as highlighted by studies conducted by Ashby et al. (2012), Ahi and Searcy (2015), and Mani et al. (2016). Only a few studies have attempted to enhance our understanding of social sustainability specifically for seaports, such as the works by Parola and Maugeri (2013) and Shiau and Chuang (2013). However, a subset of authors recognizes the importance of considering social factors in conjunction with the other two dimensions for achieving overall sustainability. Yap and Lam (2013) have considered all three dimensions when addressing sustainability issues in port and coastal development.

When studying seaport efficiency, Wu and Goh (2010) underscore the significance of welfare programs for employees and education as crucial aspects of social sustainability. Mani et al. (2015) also identify education and training as significant factors that impact social sustainability. Furthermore, the importance of a safe working environment has been emphasized by authors in supply chains (Mani et al., 2016) as well as in ports (Marshall et al., 2005; Gimenez et al., 2012). The social port performance sustainability dimension focuses on the management of social factors related to operational practices in ports, aiming to promote social sustainability. The performance variables in achieving seaport social sustainability performance variables are health and safety, training & education, employee engagement and local communities.

4.3.3 Port Economic sustainability performance dimension

The economic dimension of sustainable development in seaports has received limited attention in the existing literature, as highlighted by studies conducted by Yap and Lam (2013) and Sislian et al. (2016). These studies emphasize the importance of considering all three dimensions (economic, environmental, and social) when examining the relationship between a port's spatial expansion development and sustainability. Additionally, Dekker et al. (2008) have focused on the seaport's capacity utilization as a key aspect of port business.

While few authors have touched upon economic factors alongside environmental and social dimensions, there is still a need for more comprehensive exploration of economic development in seaport sustainability. Asgari et al. (2015) consider cost efficiency and high-quality services as economic factors in ranking sustainability in UK ports. Roh et al. (2016) categorize factors for study into operational efficiency and cost-saving factors, with their research suggesting that berth planning plays a significant role in the sustainable management of seaports.

The economic performance dimension in seaport sustainability aims to achieve cost efficiency. This is accomplished through the assessment of economic performance and impacts, as well as the consideration of various supply chain activities within the ports. Economic-Performance dimension refers achieving of cost efficiency in seaports. This is achieved by performance economic performance & impacts and supply-chain activities aspects and considering various chain activities of the ports.

4.3.4 Port Internal Sustainability Performance dimension

To ensure the effective delivery of maritime services and meet the needs of seaport customers responsibly, it is crucial for seaport organizations to focus on key internal operational methods and polices related to various operations. Policy makers must prioritize efficient internal business operations to foster innovation, problem-solving, and the provision of high-quality consumer management services. By addressing internal processes and striving for more efficient maritime transport operations, organizations can improve delivery performance and customer satisfaction. Seaport administrators should conduct thorough internal evaluations that not only measure the inner processes of the port but also review innovation in maritime services offered by the seaport. This dimension, known as port internal sustainable performance management, integrates with the main dimensions of sustainability performance in the maritime supply chain.

Within the seaport internal sustainability performance (PISP) dimension, two main variables are considered: agility & resource utilization and management & innovation. These variables contribute to the determination of internal port sustainability and can be integrated with external port supply customers or with three key performance dimensions of environmental, economic and social dimensions pertaining to sustainability performance. This integration aims to achieve performance sustainability in three major aspects: environmental, economic, and social (Zhu, Sarkis, and Lai 2007; Seuring and Müller 2008; Lu, Marlow, and Lai 2010; Shang, Lu, and Li 2010; Gul and Cimen 2012).

4.3.5 Port Customer Sustainability Performance dimension

Recognizing the importance of measuring sustainability in the maritime supply chain, several researchers have emphasized the development of sustainable supply chains to enhance management performance (Lu, Marlow, and Lai 2010; Gul and Cimen 2012). Furthermore, few maritime research studies have examined sustainability in seaports from a supply chain perspective, considering factors such as collaboration among seaport partners and achieving collective goals (Acciaro et al. 2014; Lam and Notteboom 2014; Lam 2015; Leone and Iris, 2015; Shiau and Chung 2015).

The dimension of seaport customer sustainability performance (supplier cand carrier collaboration) focuses on the effective implementation of a sustainable maritime supply chain. It emphasizes the willingness of seaport partners to work together, understand different perspectives, share information and resources, and collectively pursue sustainability goals (Stank, Keller, and Daugherty 2001). This dimension integrates with the internal sustainability performance dimension and three basic sustainability performance dimensions within the comprehensive seaport supply chain.

Within this dimension, seaport external members such as service/material suppliers, shipping companies, and port carriers/customers collaborate with the port's internal sustainable management. The aim is to achieve overall seaport performance sustainability across environmental, economic, and social aspects (Zhu, Sarkis, and Lai 2007; Seuring and Müller 2008; Lu, Marlow, and Lai 2010; Shang, Lu, and Li 2010; Gul and Cimen 2012). Within the seaport customer sustainability performance (PCSP) dimension, only one main variable of Customer is considered in this research study.

4.4. Selection and Evaluation of Seaport Sustainability Dimensions and Performance Indicators

4.4.1 Thematic Analysis of Qualitative Study

In the qualitative stage, various seaport sustainability dimensions, port performance indicators and port key performance indicators for seaport sustainability performance assessment were covered using thematical analysis framework with sub-groups involving port performance indicators and key performance indicators for dimensions of port environment performance, port economic performance, port social performance, seaport customer and internal sustainability performance related aspects. The details of various seaport sustainability performance related dimensions, port performance indicators and key performance indicators and its related literature is illustrated from Table 4.2.

Seaport sustainability performance dimensions are categorised into five main categories, thirteen sub dimensions and thirty-seven key performance indicators respectively which includes:- environmental sustainability performance dimension (four seaport performance indicators with thirteen key performance indicators); port social sustainability performance dimension (four seaport performance indicators with nine key performance indicators); port economical sustainability performance dimension (two seaport performance indicators with seven key performance indicators); port internal sustainability performance dimension (two seaport performance indicators with five key performance indicators) and port customer sustainability performance dimension (one sea port performance indicators three key performance indicators).

Table 4.2: Seaport sustainability performance dimensions, principal performance indicators, key performance indicators, and related Literature

Port environmental sustainability performance (PENSP) Criterion	Key performance indicators	Related Literature
Environmental level & Pollution (ELP)	Greenhouse gas emissions & exhaust of gases/particles (ELP1)	Asgari(2015);Chen(2017); Chiu(2014); ESPO (2012); Roh(2015); Oha(2018); Hiranandani(2014); IMO (2019); Kim(2017);Laxe(2016); Lu(2016); Parola(2017); Acciaro (2015);Ha(2017); Peris (2015);Oconnor (2019); OECD(2009); Lee(2018); PORTOPIA (2016); Puig(2014); Roh (2016); Senegar(2018);Lim(2019); Shiau (2015); Munagpan (2019); Hosian (2018); UNCATD(2015);World Bank Report (2017); PPRISM(2012);Dabra (2005); Muller (2008); Sisilan (2016);Mora(2005);Gupta(2005);
	Air quality level assessment & emission inventory track (ELP2)	
	Water quality level assessment &water consumption (ELP3)	
	Smoke& dust pollution level (ELP4)	
	Smell/odour pollution level (ELP5)	
	Noise level (ELP6)	
Effluents & waste (EW)	Innovative waste-management strategies for disposing effluents (EW1)	
	Safe and environmentally sound disposal procedures (EW2)	

Energy (EN)	Installation of renewable energy sources & its Utilization (EN1)	Wooldridge (1999);Park (2012); Di (2017); Bergmans(2015); WPSP (2019); ISO14001 (2015); Sagarmala (2018);Narasimha(2022)
	Eco-friendly environmental initiatives for energy reduction (EN2)	
Environmental Compliance (EC)	Preparedness level/adaptation towards mitigating rapid climate change & its impacts (EC1)	
	Support & compliance towards improvement in port Sustainable aspects (EC2)	
	Conservation level of port environment, coastal habitats & related ecosystem (EC3)	
Port Social sustainability performance (PSSP)/Criterion	**Key performance indicators**	**Related Literature**
Health and safety (HS)	Establishing Health and Safety Committees and Evaluating the Status of OHSS Programs (HS1)	Asgari(2015);Cheon(2017); Dooms (2015); ESPO(2012); Roh(2015) ; Oha (2018);IMO(2019);Lee(2018);Vonck(2015); Laxe(2016); Lu(2016); Parola (2017); Acciaro(2014); Ha(2017); Peris(2015);
	Occurrences of Non-Compliance Regarding Health, Safety, and Security Implications (HS2)	

Training and education (TE)	Internal & external training courses towards improving employee skill & education (TE1)	Oconor(2019); PORTOPIA (2016); Roh (2016); Senegar(2018); Lim(2019); Shiau (2015); Munagpan(2019);Hossian (2018); UNCATD (2015); World Bank Report (2017); Benktas(2013); Sisilan (2016);Wu(2010); Mani(2016);Lam(2013); Mansouri(2015); WPSP (2019); Sagarmala (2018); IMO (2003); Narasimha(2022)
	Conducting performance and career development evaluations for port employees (TE2)	
Employee Engagement (EE)	Salary& remuneration to promote diversity, job security & social equality (EE1)	
	Employee engagement & welfare initiatives (EE2)	
Local communities (LC)	Sustainable livelihood, engagement in CSR & with local communities (LC1)	
	Representation from all stakeholders, government support & stakeholder engagement activities (LC2)	
	Managing impacts of port expansion activities on local communities (LC3)	
Port economic sustainability performance (PECSP)	**Key performance indicators**	**Related Literature**
Economic performance & impacts (ECI)	Total operational costs/ expenditure with port changes in productivity, performance & efficiency	Asgari(2015); Bichou (2004); Brooks (2004); Cheon(2017); Dooms

	parameters, operational costs with utilization of infrastructure, land & space (ECI1)	(2015);Dayananda (2018); Deepankar (2017); Lee (2018); De Langen (2017); ESPO(2012); Oha (2018); IMO (2019); Laxe (2016); Lu(2016); Parola (2017); Mandal(2016); Ha (2017); Peris (2015); Notteboom (2002); Oconnor (2019);PORTOPIA (2016); Senegar (2018); Lim (2019);Munagpan (2019); UNCATD (2015); PPRISM(2012); Lam (2013); Sisilan (2016); Bergmans (2015); WPSP(2019); Sagarmala (2018); Narasimha(2022)
	Commitment towards employment generation & trade facilitation activities (ECI2).	
	Port infrastructure, facilities investments& cruise tourism services (ECI3)	
	Impacts of deteriorating social or environmental conditions by usage of ICT & optimized routing for vehicles (ECI4)	
Supply-Chain Activities (SCA)	Intermodal connectivity services with proximity to SEZ & for seamless logistics & supply chain operations (SCA1)	
	Capacity level to handle diverse cargo with improved service quality level (SCA2)	
	Cargo damage & delay incidence with preference to vessel calls (SCA3)	

Port Internal sustainability performance (PISP) /Criterion	Key performance indicators	Related Literature
Agility & Resource utilization (AGRU)	Agile service responsiveness in port services (AGRU1)	Han(2018);Cullinane (2009); Kim(2018);Oha(2018); IMO(2019); Jinag(2015);Laxe (2016); Lee(2018); Laxe(2017); Ha(2017); Lim(2017);Peris (2015);Lu(2016); Munim(2018); Kurtz (2001); Parola (2014); Gul(2012);Bala Subramaniam(2018); Narasimha(2022)
	Utilization percentage of equipment's functioning, infrastructure capacity & services towards decision making (AGRU2)	
	ISO certification for port services (AGRU3)	
Management & Innovation (MGI)	Frequency of developing new port related services in port activities (MGIN1)	
	Port sustainability management policies, processes, procedures & training w.r.t legal & regulatory systems considering risk assessment aspects (MGIN2)	

Port External Sustainability Performance (PESP) /Criterion	Key performance indicators	Related Literature
Customer communication & satisfaction degree (CS)	Overall charges at port & related services along with port workers attitude towards stakeholders (CS1).	Han(2018);Cullinane (2009); Kim(2018); Oha(2018);IMO(2019); Jinag(2015);Laxe (2016); Lee(2018); Laxe(2017); Ha(2017); Lim(2017);Peris (2015);Lu(2016); Munim(2018); Kurtz (2001); Parola (2014); Gul(2012);Bala Subramaniam (2018); Narasimha(2022)
	Customs clearance procedures & solving port incident related issues for valued addition & quality services (CS2)	
	Handling customer issues for port customer satisfaction level & information sharing with port stakeholders (CS3)	

Source: Research Study-Literature Review

4.4.2 Validation of Sustainability Dimensions and Key Performance Indicators through Semi-Structured Interviews with Experts

This research study aimed to address the limited research on dimensions related to sustainable seaport development. To achieve this, a comprehensive set of thirty-seven sustainable key performance indicators for seaport development was adopted. These indicators were derived from a wide range of seaport sustainability literature and were validated through in-depth semi-structured interviews with maritime domain experts and seaport professionals from major Indian seaports. The chosen indicators were assessed for their suitability in the Indian seaport context. To ensure both theoretical and practical knowledge in the maritime sustainability aspects specific to Indian seaports, a group of experts from the port industry was identified. These experts had significant experience in port/shipping and had published works in reputable journals in the field. Their expertise contributed to the content and construct validity of the chosen indicators.

A semi-structured validation interview protocol was designed based on an extensive literature review. This protocol, in the form of an MS Excel file, was distributed to seaport experts and maritime professionals in India. Thirty-seven maritime professionals participated in the interviews, which were conducted through direct meetings, telephone conversations, or online platforms like Google Meet. The purpose was to examine the theoretical framework and develop a practical and holistic sustainability framework specifically tailored to Indian seaports, with a focus on oil ports. The details of

the During the interviews, Importance-Performance Analysis (IPA) was conducted to determine the sustainability assessment criteria for major Indian seaports. The interviewees were also asked to provide their perspectives on whether the proposed seaport sustainable development practices should be incorporated into Indian seaports. Their responses were coded as 0 for "No," 1 for "Yes," and NA for "Not sure." Additionally, open-ended questions were included to gain further insights into the sustainable development of Indian seaports.

Through this research study, the aim was to fill the gap in understanding sustainable seaport development by providing a practical framework that considers the unique context of Indian seaports. The input and feedback from seaport managers and maritime professionals played a crucial role in refining the framework and identifying the key performance indicators necessary for promoting sustainability in Indian seaports.

4.4.3 Importance-performance analysis

Importance-Performance Analysis (IPA), introduced by Martilla and James (1977), was employed as a valuable technique to assess the sustainability criteria of seaports. This method is commonly used to prioritize service improvements by examining stakeholder-perceived importance and performance. The assessment criteria's perceived importance and performance measures were categorized as high or low and plotted on a two-dimensional graph with axes representing mean importance and performance. The resulting importance-performance matrix (IPM) allows for interpretation, as the attributes are sorted based on their values and plotted as points. This approach provides a comprehensive understanding of the seaport sustainability assessment criteria. The attributes are sorted and plotted on the importance-performance matrix (IPM) for interpretation, as depicted in Figure 4.1. The IPM is divided into four quadrants for analysis, with the vertical axis representing attribute importance and the horizontal axis indicating perceived performance (references: Lai and Cheng, 2003; Feng, 2010; Matzler et al., 2004).

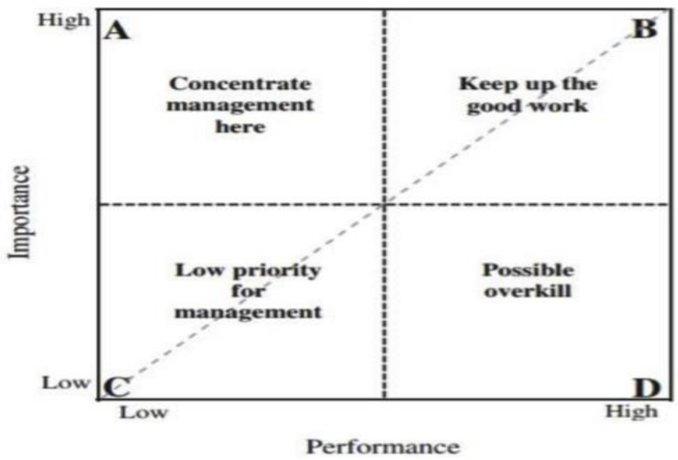

Figure 4.1: Importance-performance grid including the diagonal line for gap analysis (Source: Chen, 2014)

The Importance-Performance Analysis (IPA) technique allows for the interpretation of the four quadrants in the Importance-Performance Matrix (IPM). Quadrant A represents attributes that are important but underperforming, suggesting areas that require attention. Quadrant B indicates attributes that are both important and performing well, signifying areas of strength. Quadrant C represents attributes that are neither important nor performing well, indicating low priority. Quadrant D consists of attributes with relatively low importance but high performance, suggesting potential overemphasis ((Martilla and James, 1977).

Gap analysis is conducted by drawing a diagonal line from the lower left to the upper right of the matrix, separating the IPM into two triangular areas. Attributes positioned to the right of diagonal line have positive gaps, indicating that their performance exceeds their importance. Attributes located to left of the line have negative gaps, indicating performance below importance (Taplin, 2012; Chen, 2014; Taplin, 2012).

In this research study, IPA is utilized to assess the sustainability criteria of major seaports in India. The perceived importance and performance measures of seaport sustainability criteria are classified as high or low, and a two-dimensional graph is created using mean importance and performance as the axes. The IPA method has previously been applied in the seaport sector to evaluate port effectiveness and logistics capabilities Brooks et al. (2010; Feng 2010).

The survey questionnaire designed for this research incorporates the IPA technique for data analysis. Respondents are asked to rank each sustainability assessment items for environmental, economic, and social, port internal and port external sustainability aspects based on its importance and performance using a five-point Likert scale (from 1: very unimportant to 5: very important and from 1: performing really badly to 5: performing really well). The questionnaire specifically targets maritime domain experts and seaport professionals to gather diverse perspectives on the research area. Follow-up communication is conducted to encourage participation. A total of 37 questionnaires were distributed for data collection.

This research contributes to filling the gap in assessing port sustainability in India using the IPA approach. The findings from the IPA analysis provide valuable insights into the importance and performance of sustainability criteria for seaports. Negative gap scores indicate areas where performance falls short despite high importance, emphasizing the need for management attention. The IPA technique offers a comprehensive understanding of the seaport sustainability landscape, enabling targeted improvements and resource allocation.

Overall, this research employs IPA to assess the sustainability criteria of major seaports in India, revealing areas of strength and weakness. The methodology facilitates a thorough analysis of the importance-performance relationship, providing guidance for port management in prioritizing sustainability efforts and enhancing long-term sustainability. The questionnaires were sent to experts of seaports/maritime domain professionals to obtain various perspectives around the research area. After sending out the questionnaires, follow-up phone calls/emails/videocall were made to encourage participation. A total of 37 questionnaires responses from maritime experts/seaport professionals were received, containing usable data for further analysis.

4.5 Analysis and Results

Maritime domain experts' information for this research was sourced from the Indian Ports Association's CENTRE OF EXCELLENCE (CoE) consultant list. Focusing on seaports like Mumbai, Cochin, Kandla, and Mangalore, expertise areas spanned projects, environment, finance, legal, disaster management, and more (IPA, 2020-2021). Table D.1 in Annexure D represents comprehensive details on 37 marine experts involved in the research study, including age, gender, education, designation, department, and location. Mean importance and mean performance values are provided for five seaport sustainability dimensions.

A total of 37 responses were collected through semi-structured interviews with maritime experts. The participants had diverse working experience, with 31.34% having 5 to 10 years, 14.93% having 10 to 15 years, and 53.73% having 16 to 20 years of experience. The majority of respondents approved the inclusion of all proposed sustainable practices in the sustainable seaport development framework, encompassing all five dimensions of sustainable development and their corresponding 37 key performance indicators. The data collected from the interviews were analyzed to validate the prospective sustainable seaport development practices in terms of seaport sustainability. Additionally, since the majority of experts responded positively (above 85%), all the key performance indicators were selected based on expert opinion. The selection criteria followed a benchmark of 50% and above, as recommended by Wang (2018), Lu (2020), and Muangpan (2019). The validated dimensions, principal performance indicators, and seaport practices for sustainable seaport development are presented in Table 4.3, based on the semi-structured interviews conducted for all five aspects of sustainable development and the 37 seaport practices

Table 4.3: Assessment of attitudes towards sustainable seaport development practices in context of major seaports in India (mean importance and performance ratings, and percentage of responses from semi-structured interviews with participants)

Sustainability Seaport Practices Code	1-Yes	0-No	NA-Not sure	Summary of Means of Importance	Summary of Means of Performance	Performance minus importance
ELP1	97	3	0	4.786	4.33	-0.456
ELP2	98	2	0	4.812	4.29	-0.522
ELP3	96	2	2	4.651	4.34	-0.311
ELP4	91	4	5	4.79	4.19	-0.6
ELP5	93	1	6	4.87	4.11	-0.76
ELP6	99	0	1	4.85	4.18	-0.67
EW1	91	4	5	4.89	4.18	-0.71
EW2	98	0	2	4.82	4.29	-0.53
EN1	94	0	6	4.85	4.48	-0.37
EN2	97	0	3	4.81	4.41	-0.4
EC1	98	2	0	4.93	4.19	-0.74
EC2	91	3	6	4.84	4.43	-0.41
EC3	98	0	2	4.87	4.42	-0.45
HS1	99	0	1	4.92	4.17	-0.75
HS2	98	0	2	4.86	4.21	-0.65
TE1	99	0	1	4.812	4.18	-0.632
TE2	99	0	1	4.812	4.13	-0.682
EE1	98	0	2	4.79	4.19	-0.6

EE2	97	0	3	4.78	4.18	-0.6
LC1	95	0	5	4.96	4.36	-0.6
LC2	97	1	2	4.92	4.45	-0.47
LC3	99	0	1	4.93	4.68	-0.25
ECI1	90	0	10	4.88	4.11	-0.77
ECI2	98	0	2	4.92	4.26	-0.66
ECI3	99	0	1	4.914	4.34	-0.574
ECI4	99	0	1	4.72	4.19	-0.53
SCA1	98	0	2	4.88	4.33	-0.55
SCA2	99	0	1	4.87	4.29	-0.58
SCA3	97	1	2	4.84	4.19	-0.65
ARGU1	99	0	1	4.814	4.12	-0.694
ARGU2	98	0	2	4.88	4.15	-0.73
ARGU3	90	4	6	4.87	4.17	-0.7
MGIN1	98	0	2	4.81	4.12	-0.69
MGIN2	97	1	2	4.89	4.21	-0.68
CS1	94	0	6	4.82	4.09	-0.73
CS2	93	2	5	4.85	4.19	-0.66
CS3	99	0	1	4.88	4.258	-0.622

Source: Research Qualitative Study approach (IPA analysis)

The final sustainable seaport development framework covering seaport sustainability dimensions, performance indicators and key performance indicators for major seaports in India based on Expert assessment study is illustrated in Table 4.4.

Table 4.4: Seaport Sustainability dimensions, performance indicators and key performance indicators for major seaports in India based on Expert assessment study

Port environmental sustainability performance (PENSP) Criterion	Key performance indicators
Environmental level & Pollution (ELP)	Greenhouse gas emissions & exhaust of gases/particles (ELP1)
	Air quality level assessment & emission inventory track (ELP2)
	Water quality level assessment &water consumption (ELP3)
	Smoke& dust pollution level (ELP4)
	Smell/odour pollution level (ELP5)
	Noise level (ELP6)
Effluents & waste (EW)	Innovative waste-management strategies for disposing effluents (EW1)
	Safe and environmentally sound disposal procedures (EW2)
Energy (EN)	Installation of renewable energy sources & its Utilization (EN1)
	Eco-friendly environmental initiatives for energy reduction (EN2)
Environmental Compliance (EC)	Preparedness level/adaptation towards mitigating rapid climate change & its impacts (EC1)
	Support & compliance towards improvement in port Sustainable aspects (EC2)
	Conservation level of port environment, coastal habitats & related ecosystem (EC3)
Port Social sustainability performance (PSSP)/Criterion	**Key performance indicators**
Health and safety (HS)	Establishing Health and Safety Committees and Evaluating the Status of OHSS Programs (HS1)
	Occurrences of Non-Compliance Regarding Health, Safety, and Security Implications (HS2)
Training and education (TE)	Internal & external training courses towards improving employee skill & education (TE1)
	Conducting performance and career development evaluations for port employees (TE2)
Employee Engagement (EE)	Salary& remuneration to promote diversity, job security & social equality (EE1)
	Employee engagement & welfare initiatives (EE2)
Local communities (LC)	Sustainable livelihood, engagement in CSR & with local communities (LC1)
	Representation from all stakeholders, government support & stakeholder engagement activities (LC2)

	Managing impacts of port expansion activities on local communities(LC3)
Port economic sustainability performance (PECSP)	**Key performance indicators**
Economic performance & impacts (ECI)	Total operational costs/ expenditure with port changes in productivity, performance & efficiency parameters, operational costs with utilization of infrastructure, land & space (ECI1)
	Commitment towards employment generation & trade facilitation activities (ECI2).
	Port infrastructure, facilities investments& cruise tourism services (ECI3)
	Impacts of deteriorating social or environmental conditions by usage of ICT & optimized routing for vehicles (ECI4)
Supply-Chain Activities (SCA)	Intermodal connectivity services with proximity to SEZ & for seamless logistics & supply chain operations (SCA1)
	Capacity level to handle diverse cargo with improved service quality level (SCA2)
	Cargo damage & delay incidence with preference to vessel calls (SCA3)
Port Internal sustainability performance (PISP) /Criterion	**Key performance indicators**
Agility & Resource utilization (AGRU)	Agile service responsiveness in port services (AGRU1)
	Utilization percentage of equipment's functioning, infrastructure capacity & services towards decision making (AGRU2)
	ISO certification for port services (AGRU3)
Management & Innovation (MGI)	Frequency of developing new port related services in port activities (MGIN1)
	Port sustainability management policies, processes, procedures & training w.r.t legal & regulatory systems considering risk assessment aspects (MGIN2)
Port External Sustainability Performance (PESP) /Criterion	**Key performance indicators**
Customer communication & satisfaction degree (CS)	Overall charges at port & related services along with port workers attitude towards stakeholders (CS1).
	Customs clearance procedures & solving port incident related issues for valued addition & quality services (CS2)
	Handling customer issues for port customer satisfaction level & information sharing with port stakeholders (CS3)

Source: Research Data Study

The analysis of research reveals the rankings of different sustainability performance criteria based on their mean importance and mean performance levels. Table 4.5 indicates port Sustainability dimension Mean Importance and Mean Performance values with respective ranks.

Table 4.5: Seaport sustainability dimension mean importance and mean performance values with respective ranks

Port Sustainability Dimension	Mean Importance	Mean Performance	Importance Rank	Performance Rank
PENSP	4.84	4.35	3	1
PSOSP	4.86	4.28	2	3
PECSP	4.87	4.29	1	2
PISP	4.80	4.15	4	5
PCSP	4.77	4.18	5	4

Source: Research Data Study

Based on maritime domain experts' assessment on seaport sustainability dimensions for importance and performance of average scores for different aspects at four seaports locations of Cochin, Kandla, Mangalore, and Mumbai are analyzed location-wise and based on importance and performance basis of expert judgement which is illustrated in Graphical format in figure 4.2 and figure 4.3.

The aspects include PENSP-Performance, PSOSP-Performance, PECSP-Performance, PINSP-Performance, and PCSP-Performance Cochin, Mumbai, and Mangalore have higher average importance scores compared to Kandla. This suggests that maritime experts generally perceive that these three ports as having a higher level of importance for the mentioned aspects compared to Kandla location. Locations of Cochin, Mumbai, and Mangalore have consistent high scores in various aspects, which might indicate their strong commitment to these areas. While PECSP and PENSP have similar trends across all ports, other aspects such as PSOSP and PINSP vary slightly.

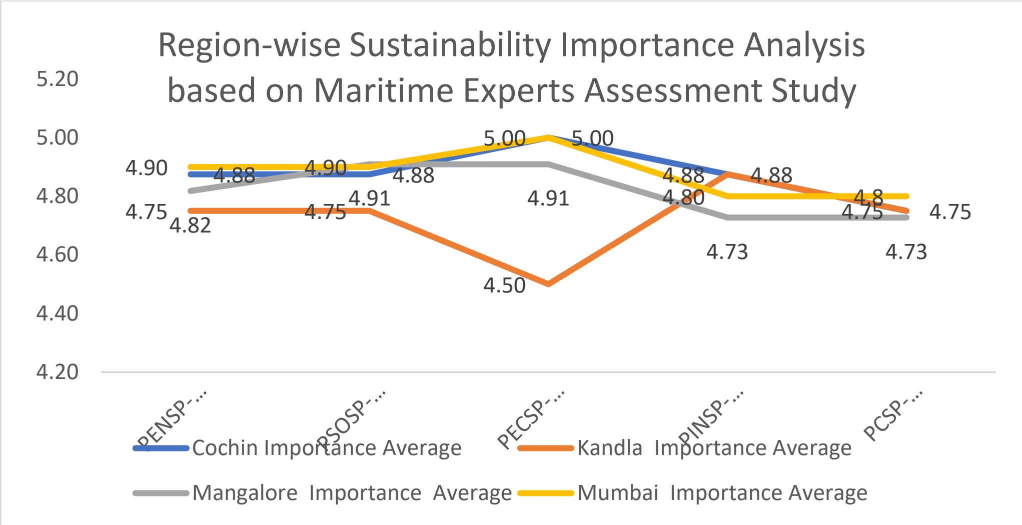

Fig 4.2: Region-wise Sustainability Importance Analysis based on Maritime Experts Assessment Study

W.r.t the sustainability performance average scores vary across the different aspects and seaports. Different aspects have varying performance average scores for each seaport. For example, Mangalore has the highest performance average in PENSP, whereas Kandla has the highest performance average in PSOSP. Mangalore generally has higher performance average scores compared to the other ports, suggesting that it is perceived as performing well across the mentioned aspects.

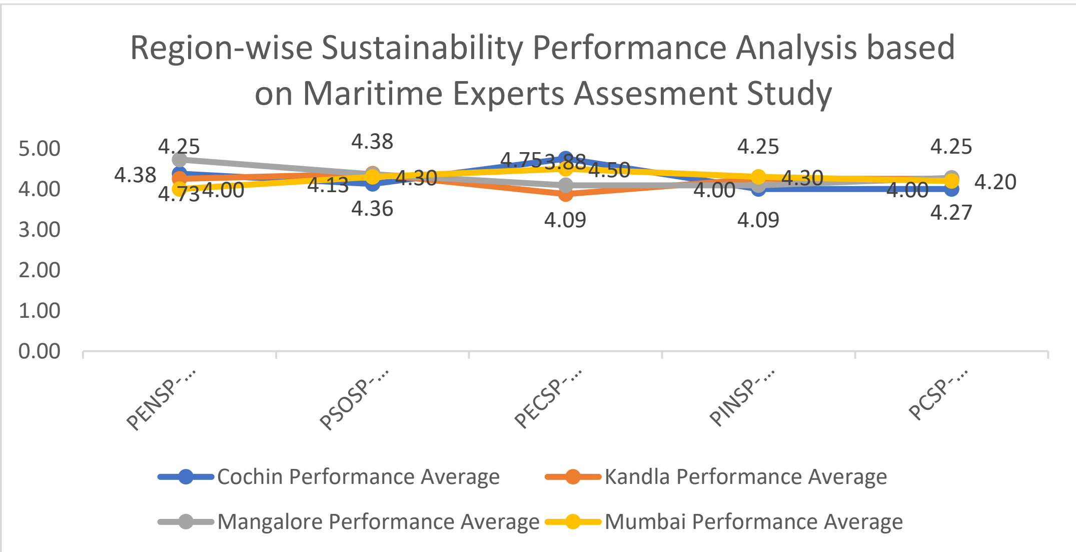

Fig 4.3: Region-wise Sustainability Performance Analysis based on Maritime Experts Assessment Study

In terms of mean importance level criteria, the highest-ranking criterion is port economic sustainability performance with a score of 4.87. This indicates that the experts and professionals involved in the study consider economic sustainability to be of utmost importance in seaport development. Following closely behind are port social sustainability (4.86), port environmental sustainability (4.84), port internal sustainability (4.80), and port customer sustainability (4.77). These findings suggest that all five dimensions of sustainability are considered highly important in the context of seaport development.

When evaluating mean performance level criteria, port environmental sustainability performance takes the lead with a score of 4.35. This indicates that the seaports involved in the study are performing relatively well in terms of environmental sustainability. Port economic sustainability (4.29), port social sustainability (4.28), port customer sustainability (4.18), and port internal sustainability (4.15) follow in descending order. These results suggest that while there is overall good performance across various sustainability dimensions, there is room for improvement in areas such as economic through Diversification of Revenue Streams; Investment in Innovation; Supply Chain Optimization; Cost-Effective Infrastructure Maintenance and Customer Relationship Management and social sustainability through Employee Well-being by supporting OHSS initiatives**;** Community/Stakeholder Engagement**;** Diversity and Inclusion of port employees; Social Impact Assessment**;** Education/ Skill Development & related collaboration and Local Sourcing and Procurement**.**

Addressing these areas of improvement in seaport economic and social sustainability will not only enhance the overall performance of the seaport but also contribute to a more inclusive, resilient, and responsible port operation that benefits both the port organization’s operational and the port surrounding communities. The analysis highlights the importance of considering both the perceived importance and performance levels of sustainability criteria in seaport development. It underscores the need to focus on improving areas where performance falls short of perceived importance, as indicated by the negative gaps identified in the previous analysis. This information can guide port management in allocating resources and prioritizing efforts to enhance the overall sustainability of seaports.

Table 4.6 presents the mean performance scores and rankings for various sustainability indicators in five dimensions: PENSP (port environmental sustainability performance), PSOSP (port social sustainability performance), PECSP (port economic sustainability performance), PISP (port internal sustainability performance), and PCSP (port customer sustainability performance). Looking at the rankings within each dimension, the following observations can be made:

For, port environmental sustainability performance (PENSP): Indicator EN1: installation of renewable energy sources & its utilization holds the highest mean performance score of 4.48 and is ranked first in this dimension. Indicator EN2: eco-friendly environmental initiatives for energy reduction follows closely with a mean performance score of 4.41, ranking fourth. Indicators ELP3: water quality level assessment &water consumption, ELP2: air quality level assessment & emission inventory track, and ELP1: greenhouse gas emissions & exhaust of gases/particles are also noteworthy;

For, port social sustainability performance (PSOSP): indicator LC3: managing impacts of port expansion activities on local communities achieves the highest mean performance score of 4.68, securing the top rank in this dimension. Indicator LC2: representation from all stakeholders, government support & stakeholder engagement activities follow with a mean performance score of 4.45, ranking second. Indicator HS1: establishing health and safety committees and evaluating the status of OHSS programs obtains a mean performance score of 4.17, placing eighth;

For, port economic sustainability performance (PECSP): indicator ECI3: port infrastructure, facilities investments& cruise tourism services demonstrate the highest mean performance score of 4.34, ranking first in this dimension followed by indicator SCA2 intermodal connectivity services with proximity to SEZ & for seamless logistics & supply chain operations which is followed by ECI2: commitment towards employment generation & trade facilitation activities follows closely with a mean performance score of 4.26, securing the fourth rank. Indicator ECI1: total operational costs/ expenditure with port changes in productivity, performance & efficiency parameters, operational costs with utilization of infrastructure, land & space achieves a mean performance score of 4.11;

For, port internal sustainability performance (PISP): indicator ARGU1: agile service responsiveness in port services attains a mean performance score of 4.12 and secures the fourth rank. Indicator ARGU2: utilization percentage of equipment's functioning, infrastructure capacity & services towards decision making obtains a mean performance score of 4.15, ranking third. indicator ARGU3: ISO certification for port services achieves a mean performance score of 4.17; For, port customer sustainability performance (PCSP): indicator CS3: handling customer issues for port customer satisfaction level & information sharing with port stakeholders demonstrates the highest mean performance score of 4.258, securing the first rank in this dimension. Indicator CS2: customs clearance procedures & solving port incident related issues for valued addition & quality services follows closely with a mean performance score of 4.19, ranking second. Indicator CS1: overall charges at port & related services along with port workers attitude towards stakeholders attains a mean performance score of 4.09 and ranks third.

The expert group covered both males and females, representing various designations from seaport departments of Civil, Traffic, Finance, Medical, Marine, Mechanical, and Administration. Their experience ranged from 10 to 31 years, reflecting a varied seniority level. Out of 37 maritime domain experts, 23 are male, and 14 are female, with both genders distributed across designations and departments. This diversity underscores a commitment to gender inclusivity within the seaport organization. The experts had educational backgrounds, from bachelor's to master's degrees, and are having almost equally experienced in their respective roles.

Gender comparisons reveal comparable mean importance and mean performance ratings across seaport aspects and performance indicators, indicating that there is no significant gender-related differences. High importance ratings of nearly five (PENSP, PSOSP, PECSP, PINSP, PCSP) are consistently assigned, particularly for roles in planning, execution, supervision, and control within seaport sustainability. Performance ratings in certain aspects (e.g., PCSP) tend to be slightly lower compared to importance ratings.

Mean importance ratings average around 4.8, indicating the experts' perceived significance in their seaport roles. Mean performance ratings, at approximately 4.3 to 4.4, suggest room for improvement in specific seaport indicators. The higher importance than performance ratings suggest potential to enhance seaport sustainability efficiency and overall performance in certain dimensions.

Overall, the analysis provides insights into the performance and rankings of various sustainability indicators within each dimension. This information can help stakeholders identify areas of strength and areas that require improvement to enhance the overall sustainability performance of the seaport.

Table:4.6: Seaport KPI's Mean Performance values with respective ranks for seaport sustainability dimensions

PENSP indicators				PSOSP indicators				PECSP indicators				PISP indicators				PCSP indicators			
Sl No	**Code**	**Mean Performance**	**Rank**	**Sl No**	**Code**	**Mean Performance**	**Rank**	**Sl No**	**Code**	**Mean Performance**	**Rank**	**Sl No**	**Code**	**Mean Performance**	**Rank**	**Sl No**	**Code**	**Mean Performance**	**Rank**
1	EC1	4.19	9	1	HS1	4.17	8	1	ECI1	4.11	6	1	ARGU1	4.12	4	1	CS1	4.09	3
2	EC2	4.43	2	2	HS2	4.21	4	2	ECI2	4.26	4	2	ARGU2	4.15	3	2	CS2	4.19	2
3	EC3	4.42	3	3	TE1	4.18	6	3	ECI3	4.34	1	3	ARGU3	4.17	2	3	CS3	4.258	1
4	ELP 1	4.33	6	4	TE2	4.13	9	4	ECI4	4.19	5	4	MGIN1	4.12	4				
5	ELP 2	4.29	7	5	EE1	4.19	5	5	SCA1	4.33	2	5	MGIN2	4.21	1				
6	ELP 3	4.34	5	6	EE2	4.18	6	6	SCA2	4.29	3								
7	ELP 4	4.19	9	7	LC1	4.36	3	7	SCA3	4.19	5								
8	ELP 5	4.11	13	8	LC2	4.45	2												
9	ELP 6	4.18	11	9	LC3	4.68	1												
10	EN1	4.48	1																
11	EN2	4.41	4																
12	EW1	4.18	12																
13	EW3	4.29	7																

Source: Research Data Study

The purpose of this research was to assess the sustainability of major seaports in India and identify key criteria using the Importance-Performance Analysis (IPA) technique. The results revealed that the maritime domain experts and seaport professionals attached significant importance to all proposed sustainability practices across the five dimensions of seaport sustainability (all sustainability dimensions values with above four on the five-point Likert scale). The importance ratings of the assessment items were high, indicating the experts' recognition of their significance. A sustainable seaport aims to progress the equilibrium of economic dimension along with environmental dimension, social dimension, internal sustainability dimension and external sustainability dimension and its related sustainable practices in the seaport. Similarly, the attribute performance ratings were also relatively high (results are recorded between 4.1 to 4.5 and on the five-point scale), suggesting that the seaports were performing well on all the thirty-seven sustainability assessment criteria.

Also, since the value of yes responses (above 85%) by the maritime experts and seaport professionals for all the seaport sustainability key performance indicators reflected that seaport in India should incorporate all the proposed seaport sustainable development practices for all five seaport sustainability dimensions. This research results indicates towards assessing sustainability practices in Indian major seaports were selected based on expert opinion and previous literature studies regarding seaport sustainability indicators selection (with benchmark of 50% & above can be selected on basis of Wang,2018; Lu, 2020; Muangpan (2019)). The seaport sustainability factors and key performance indicators were ranked based on mean performance and mean importance values. The rankings showed that port economic sustainability and port social sustainability were perceived as the most important aspects. In terms of performance, port environmental sustainability was ranked highest. However, there was a performance gap, indicating areas where improvements were needed to enhance sustainability.

The findings highlight the importance of pursuing sustainability in the Indian maritime context and emphasize the need to address all 37 assessment items for assessing seaport sustainability (with value above four i.e., value 4.2 and above on the five-point Likert scale and results were recorded between 4.11 and 4.42 on the five-point scale, suggesting that maritime domain expert's and seaport professionals considered that the seaport sustainability performance level on all the thirty-seven sustainability assessment criteria were high).

The negative performance gaps identify areas of weakness and call for attention and resource allocation to improve sustainability in these aspects. Notably, the attribute with the largest performance gap score requires immediate attention to enhance port performance by calling for increased top management focus and allocation of resources to address the corresponding factors and enhance the seaports' sustainability. The research contributes to understanding seaport sustainability in India by identifying crucial assessment criteria and highlighting the gaps between perceived importance and performance. It provides valuable insights for port management and policymakers to prioritize resources and develop policies for assessing and improving port sustainability. By addressing the research gap and adopting a balanced approach, this study enhances both policy and theoretical knowledge in seaport sustainability.

4.6 Theoretical Discussions & Policy Contributions

This study aimed to comprehensively evaluate the sustainability of major Indian seaports from a maritime perspective. The main objective was to identify and assess critical criteria for seaport sustainability, specifically tailored to the Indian context. The study covered all dimensions of sustainability to achieve a balanced assessment. A total of thirty-seven sustainability assessment measures were identified through an extensive review and interviews, and the importance-performance analysis (IPA) technique was employed to evaluate seaport sustainability.

This research is the first to apply the importance-performance analysis technique in examining seaport sustainability in major Indian seaports, contributing to the existing knowledge in this field. Empirical studies in seaport sustainability have been limited, despite its significant interest in academia and management, as pointed out by previous researchers. This study fills this gap by providing concrete evidence and empirical verification of seaport sustainability.

The overall findings indicate that the performance of assessed criteria falls short of their importance ratings. This suggests the need for improvement in seaport performance to achieve sustainability objectives. The results highlight specific areas requiring attention and emphasize the importance of enhancing performance to enhance seaport sustainability in major Indian seaports. The findings reveal that economic factors, particularly employment opportunities, are considered the most important for assessing the sustainability of major Indian seaports. This aligns with the argument put forth by Seo et al. (2018) that seaports should contribute to regional economic growth and employment. It is noteworthy that the emphasis on economic factors in India, being a developing country with a focus on processing trade, may stem from the perception that economic development is more crucial than environmental concerns.

The importance of environmental issues in seaport sustainability may vary in developed countries with higher incomes and different perspectives. Nevertheless, the study findings emphasize the significance of environmental factors in major Indian seaports, aligning with previous research (Peris-Mora et al., 2005; Laxe et al., 2016; Oh et al., 2018). Experts in the maritime domain also highlighted the importance of social aspects, such as job security and port safety management, in achieving sustainability. The results underscore the interplay of environmental, economic, port internal, port external, and social dimensions in attaining port sustainability, reflecting the views of sustainability scholars. Overall, the high mean importance scores for all 37 attributes indicate their significance in sustainability assessment.

However, the importance assigned to mitigating light influence on other sustainability aspects was relatively lower in terms of environmental issues. Generally, economic aspects were considered the most important, followed by environmental concerns and social issues. This research fills a research gap by examining the importance and performance of sustainability factors in seaports and contributes to policy and theoretical knowledge. The study identifies critical criteria for assessing port sustainability and ranks them based on their perceived importance. These findings provide valuable insights for government bodies, port authorities, policymakers, and managers to effectively allocate resources and develop policies for assessing port sustainability. In the context of this research study, seaport sustainability goes beyond financial and environmental perspectives. The study explores how seaports can achieve sustainability by considering social aspects and the involvement of stakeholders throughout the maritime supply chain. With the impact of the COVID-19 pandemic, maritime policy-making organizations and seaports emphasize the transition towards an eco-friendly and inclusive economy (Prathvi et al., 2021) This shift takes into account not only financial and environmental considerations but also social aspects and the holistic well-being of the maritime supply chain stakeholders.

This research study's framework serves as a valuable tool for seaport managers and maritime policymakers in navigating the paradigm shift toward sustainable seaport development. To ensure the successful implementation of seaport sustainability assessments, it is crucial to transform and enhance the stakeholders' understanding and perspectives on sustainable seaport development. The proposed sustainable seaport development framework in this study validates the literature in the context of major Indian seaports. It establishes a comprehensive system for seaports to transition into holistic and sustainable entities through an improvement structure. This framework serves as a focal point for formulating and implementing specific sustainable seaport development practices, taking into account the perspectives of various seaport stakeholders. From a policy standpoint, the findings and recommendation decision framework of this research study provide valuable guidance to maritime researchers on broader sustainability aspects in the Indian seaport context. By adopting this research framework, seaport authorities can establish an inclusive and organized decision-support system for sustainable seaport development. Given the significance placed on seaport sustainability dimensions by seaport managers, this research study contributes to maritime research by highlighting areas that are crucial for sustainable seaport development. It bridges the gap between existing literature and practical implementation in various seaport organizations, involving diverse stakeholders.

Based on the primary findings of this study, the development of a sustainable seaport requires the formulation and execution of sustainable activities involving both internal and external stakeholders. Seaport managers need to strike a balance among various sustainability practices and activities, considering the complex network of seaport-related stakeholders and their perspectives on sustainability. Investments in social dimension-related aspects and infrastructure are currently prioritized in the seaport sector to ensure sustainability. Constant assessment of sustainable seaport development dimensions and indicators is essential for the efficient and effective development of seaport infrastructure.

The results of this research study can inform the formulation of sustainable strategies for each seaport organization, contributing to the seaport environment and the local society. Additionally, seaport authorities can make informed macro-level decisions by leveraging the positive effects of social, environmental, and economic aspects of maritime supply chain collaboration in global seaport development plans. Seaports need to establish sustainability frameworks and guidelines for stakeholders, including business continuity plans, logistics policies, institutional frameworks for consolidated seaport stakeholders, and disaster management plans for emergencies. The research assessment structure presented in this study serves as a basis for a balanced vision of seaports' responsibilities towards the local society and stakeholders.

Ranking seaport sustainability dimensions mean importance and performance levels by maritime domain experts offers insights into areas requiring immediate attention and where the seaport is excelling. Rankings should be context-specific, involving seaport stakeholders.

In mean importance ranking, Environmental sustainability is considered as top priority due to global concerns and regulatory pressures, followed by Economic Sustainability for operational stability, operational/logistic efficiency, and revenue to support investments. Customer and internal sustainability follow, with social sustainability last, focusing on seaport employee well-being, port-community relations, and port- local impact as these issues are increasingly gaining importance for maintaining the seaport organizations positive reputation and social license to operate.

In mean performance ranking, Economic Sustainability leads, signifying strong logistics/ operations and revenue. Environmental sustainability follows for responsible practices that reduce the seaport's ecological footprint, then followed by customer sustainability and internal sustainability. Social sustainability ranks last, indicating positive relationships with employees, port stakeholders and port area local communities needs to get increased support and reduction in operational disruptions.

Comparing these rankings identify gaps or misalignments between sustainability dimensions importance and performance. High importance but low performance in seaport environmental sustainability implies a need to improve environmental practices and reduce its negative impact. If social sustainability has high importance but lower performance, increased community engagement, port employee well-being, and diversity efforts may be required. Conversely, lower importance but high-performance in seaport economic sustainability suggests port is performing well in areas of operations and finance, but might be neglecting other crucial seaport sustainability dimensions that could impact seaports long-term success.

By understanding these importance and performance rankings of seaport sustainability dimensions, seaport authorities can allocate resources, set priorities, and develop strategies that align with the areas needing improvement while capitalizing on existing strengths of the seaport. In conclusion, this empirical study makes a valuable contribution to understanding seaport sustainability in the context of major Indian seaports. The findings highlight the need for improved performance in various dimensions and provide insights for policymakers and stakeholders to enhance seaport sustainability in India.

4.7 Summary

This research study focuses on conceptualizing a sustainable development framework for Indian major seaports, drawing insights from existing literature on seaport sustainability indicators across global seaports. The framework is empirically validated using data from Indian major seaports using qualitative based research approach, highlighting the priority rankings of sustainable development dimensions. The study also incorporates the perspectives of key stakeholders in the seaport industry to ensure comprehensive and sustainable seaport development. Semi-structured interviews with seaport managers and maritime experts confirm the relevance of the identified indicators and practices for sustainable seaport development.

Additionally, the study utilizes Important-Performance Analysis (IPA) to assess the significance and performance of seaport sustainability dimensions and key performance indicators as perceived by Indian seaport managers and maritime experts. This research lays the foundation for future studies on systematic and comprehensive sustainability assessments in seaports, informing strategies for sustainable improvements in future seaport expansion and development.

CHAPTER 5
ANALYZING THE RELATIONSHIP BETWEEN DIMENSIONS AND INDICATORS RELATED TO SEAPORT SUSTAINABILITY PERFORMANCE

5.1 Overview

In this chapter, the primary research conceptual framework, hypothesis development, research design, sampling design, sampling frame, sampling size, data collection methods, tools used for primary data collection, and data analysis techniques used are elaborated. The measurement scale employed in the study to assess the proposed constructs is also discussed, along with details about the pilot study and the final study. Furthermore, this section provides an in-depth analysis and interpretation of the research results derived from the primary data. These results are examined through the implementation of a measuring model and a structural model, which are then linked to the research questions, objectives, and hypotheses, leading to a comprehensive discussion of their implications.

5.2 Research Conceptual Model

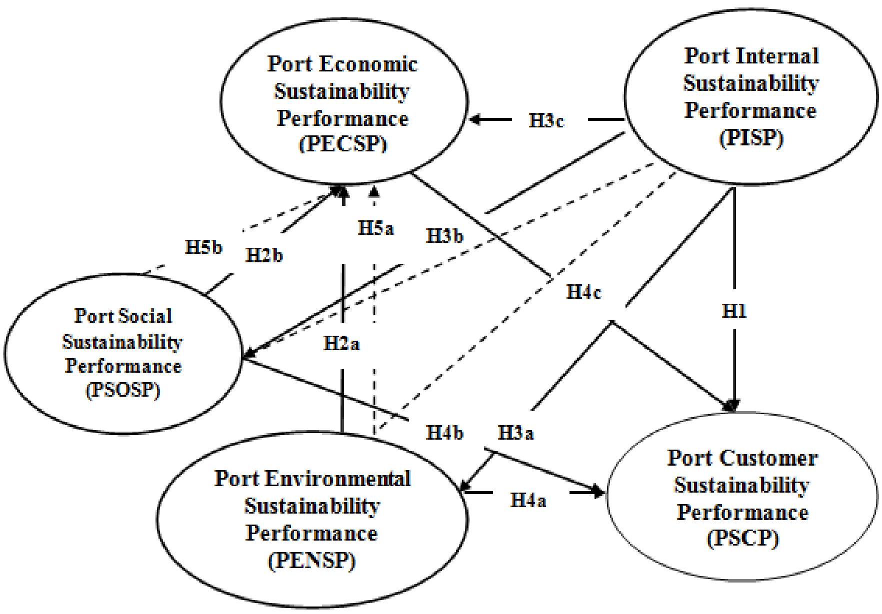

Figure 5.1: Conceptual Research Model-Port Sustainability Initiatives Assessment, Source: Authors

5.3 Research Hypothesis

In this research, there are 11 hypotheses that drive the indicators to indicate relationship among the five dimensions of the seaport sustainability aspects are as follows:

H1: Port Internal sustainability performance (PISP) will positively affect the Port Customer sustainability performance (PCSP).

H2a: Port environmental sustainability performance (PENSP) will positively affect the Port economic sustainability performance (PECSP).

H2b: Port Social sustainability performance (PSOSP) will positively affect the Port economic sustainability performance (PECSP).

H3a: Port Internal sustainability performance (PISP) will positively affect the Port environmental sustainability performance (PENSP).

H3b: Port Internal sustainability performance (PISP) will positively affect the Port Social sustainability performance (PSOSP).

H3c: Port Internal sustainability performance (PISP)will positively affect the Port economic sustainability performance (PECSP).

H4a: Port Customer sustainability performance (PCSP) will positively affect the Port environmental sustainability performance (PENSP).

H4b: Port Customer sustainability performance (PSCP) will positively affect the Port Social sustainability performance (PSOSP).

H4c: Port Customer sustainability performance (PCSP) will positively affect the Port Economical sustainability performance (PECSP)

H5a: Port environmental sustainability performance (PENSP) mediates the positive relationship between Port Internal sustainability performance (PISP) and Port economic sustainability performance (PECSP).

H5b: Port Social sustainability performance (PSOSP) mediates the positive relationship between Port Internal sustainability performance (PISP) and Port economic sustainability performance (PECSP).

5.4 Development of Measurement Scale for Factors

A complete literature evaluation was undertaken to incorporate and examine all the factors proposed in this research study. Factors refer to those aspects that cannot be directly measured but are represented through a set of indicators. Seaport organizations strive to identify sustainability performance dimensions and the corresponding key performance indicators to gain a competitive edge and assess their efficiency. It has been a challenge for maritime/seaport experts and practitioners to measure overall seaport sustainability performance and its related efficiency as each seaport employee and employee work location differs in their behavior and perceptions towards seaport sustainability performance factors and key performance indicators.

Hence there is a needto understand the construct of seaport sustainability performance dimensions. A comprehensive literature review is conductedfor this study is mentioned in chapter three; literature review. As a result, this research involves five factors in the research model suggesting the study. Table 5.1 provides more information on the development of measurement scales for factors. All factors are rated on a five-point Likert scale, with one indicating strongly disagree, two indicating disagree, three indicating neutrality, four indicating agree, and five indicating strongly agree. Table 5.1 also elaborates research study's proposed indicators projected for the final research study based on the pilot study's findings.

Table 5.1: Development of measurement scale for factors

Port environmental sustainability performance (PENSP) Criterion	**Key performance indicators**	**Scale of Measurement**
Environmental level & Pollution (ELP)	Greenhouse gas emissions & exhaust of gases/particles (ELP1)	For this study, a thirteen-item scales representing four broad areas of the seaport environmental sustainability performance was developed and all thirteen items were included in
	Air quality level assessment & emission inventory track (ELP2)	
	Water quality level assessment &water consumption (ELP3)	
	Smoke& dust pollution level (ELP4)	
	Smell/odour pollution level (ELP5)	
	Noise level (ELP6)	
Effluents & waste (EW)	Innovative waste-management strategies for disposing effluents (EW1)	
	Safe and environmentally sound disposal	

	procedures (EW2)	pilot study.
Energy (EN)	Installation of renewable energy sources & its Utilization (EN1)	
	Eco-friendly environmental initiatives for energy reduction (EN2)	
Environmental Compliance (EC)	Preparedness level/adaptation towards mitigating rapid climate change & its impacts (EC1)	
	Support & compliance towards improvement in port Sustainable aspects (EC2)	
	Conservation level of port environment, coastal habitats & related ecosystem (EC3)	
Port Social sustainability performance (PSSP)/Criterion	**Key performance indicators**	**Scale of Measurement**
Health and safety (HS)	Establishing Health and Safety Committees and Evaluating the Status of OHSS Programs (HS1)	For this study, a nine-item scales representing four area of the seaport social sustainability performance was developed and all nine items were included in pilot study
	Occurrences of Non-Compliance Regarding Health, Safety, and Security Implications (HS2)	
Training and education (TE)	Internal & external training courses towards improving employee skill & education (TE1)	
	Conducting performance and career development evaluations for port employees (TE2)	
Employee Engagement (EE)	Salary& remuneration to promote diversity, job security & social equality (EE1)	

	Employee engagement & welfare initiatives (EE2)	
Local communities (LC)	Sustainable livelihood, engagement in CSR & with local communities (LC1)	
	Representation from all stakeholders, government support & stakeholder engagement activities (LC2)	
	Managing impacts of port expansion activities on local communities (LC3)	
Port economic sustainability performance (PECSP)	**Key performance indicators**	**Scale of Measurement**
Economic performance & impacts (ECI)	Total operational costs/ expenditure with port changes in productivity, performance & efficiency parameters, operational costs with utilization of infrastructure, land & space (ECI1)	For this study, a seven-item scales representing two area of the seaport economic sustainability performance was developed and all seven items were included in pilot study
	Commitment towards employment generation & trade facilitation activities (ECI2).	
	Port infrastructure, facilities investments& cruise tourism services (ECI3)	
	Impacts of deteriorating social or environmental conditions by usage of ICT & optimized routing for vehicles (ECI4)	
Supply-Chain Activities (SCA)	Intermodal connectivity services with proximity to SEZ & for seamless logistics & supply chain operations (SCA1)	
	Capacity level to handle diverse cargo with improved service quality level (SCA2)	
	Cargo damage & delay incidence with preference to vessel calls (SCA3)	

Port Internal sustainability performance (PISP) /Criterion	Key performance indicators	Scale of Measurement
Agility & Resource utilization (AGRU)	Agile service responsiveness in port services (AGRU1)	For this study, a five-item scales representing two area of the seaport internal sustainability performance was developed and all five items were included in pilot study
	Utilization percentage of equipment's functioning, infrastructure capacity & services towards decision making (AGRU2)	
	ISO certification (AGRU3)	
Management & Innovation (MGI)	Frequency of developing new port related services in port activities (MGIN1)	
	Port sustainability management policies, processes, procedures & training w.r.t legal & regulatory systems considering risk assessment aspects (MGIN2)	
Port External Sustainability Performance (PESP) /Criterion	**Key performance indicators**	**Scale of Measurement**
Customer communication & satisfaction degree (CS)	Overall charges at port & related services along with port workers attitude towards stakeholders (CS1).	For this study, a three-item scales representing one area of the seaport external sustainability performance was developed and all three items were included in pilot study.
	Customs clearance procedures & solving port incident related issues for valued addition & quality services (CS2)	
	Handling customer issues for port customer satisfaction level & information sharing with port stakeholders (CS3)	

Source: Literature review

5.5 The Scales' Content Validity

Content validity refers to the process of assessing the suitability and relevance of the scale and its items in measuring the intended construct. In this study, the proposed items underwent review by maritime experts and seaport managers/practitioners from the industry. Once the content validity of the scales was established, both pilot and actual studies were conducted.

5.6 Pilot Study

The online/offline pilot study was carried out to ensure the validity of the questionnaire. Pilot study analysis indicates the questionnaire's face validity and reliability. It also supports in understanding the measuring factors strengths and relationship to other factors. EFA Exploratory Factor Analysis is used to check the constructs' multidimensionality. In pilot study section of this research study the results of thepilot study are provided. Data was collected from 139 respondents for the pilot study, with 123 respondents and data being comprehensive and is considered for pilot study. Three components to the questionnaire: Demographic details of the respondents (eight items); questions on the factors of seaport related sustainability aspects (thirty-seven items) and descriptive question on opinion on seaport sustainability and related suggestions (one question) questionnaire.

The demographics of respondents for the pilot project were collected using a questionnaire that included multiple-choice questions and constructs questions using a five- point Likert scale and descriptive question on opinion on seaport sustainability and related suggestions.

5.6.1 Pilot Study Reliability Analysis

To assess internal consistency of a scale, the reliability measure is employed, which determines the degree of consistency among the items or indicators that measure the same construct (Hair et al., 2010). A commonly used reliability test is Cronbach's alpha, where a value greater than 0.70 is generally considered acceptable. In the pilot stage of this study, the reliability test for the five components was conducted with 123 responses. SPSS 22 was utilized to calculate Cronbach's alpha. The results of this analysis can be found in the data analysis and interpretation section of this chapter.

5.6.2 Exploratory Factor Analysis (EFA)

Factor analysis is a statistical method used to identify underlying patterns and relationships among multiple variables, aiming to condense the data into a smaller number of factors. In the pilot study, exploratory factor analysis (EFA) was conducted using average extraction and rotation techniques to uncover latent components. According to Hair et al. (2015), factor loading represents the correlation between a variable and the observed factor, with the squared loading indicating the proportion of total variance explained. For instance, a factor loading of 0.30 suggests approximately 10% of the variance, while 0.50 indicates 25%.

To ensure that a factor explains over 50% of the variance, a factor loading of at least 0.70 is required. Loadings above 0.70 indicate a well-defined structure, desirable in factor analysis. In this study, a cutoff value of 0.71 was set for significant factor loadings. Hence, factors with a loading of 0.71 or higher were considered meaningful. The software tool SPSS 22 was utilized for the EFA analysis conducted in the pilot study.

a. Kaiser Meyer – Olkin (KMO): Prior to conducting factor analysis, it is crucial to evaluate the appropriateness of the data. The measure is used to assess the sample adequacy for exploratory factor analysis (EFA). According to Hair Jr (2017), the KMO value ranges between 0 and 1. A low KMO score indicates that the variables do not sufficiently explain the correlations between pairs of variables, suggesting that factor analysis may not be suitable. Generally, a KMO value above 0.6 is considered acceptable, indicating that further analysis can proceed.

b. Extraction method: This is employed in factor analysis determines the structure of the observed variables, indicators, or objects. In this study, the objective is to extract a minimal number of factors that account for the maximum variance in the data. Principal components analysis (PCA) is used for this purpose. It identifies the smallest set of variables that explains the most variance in the data while disregarding factors with limited unique variance and incorrect variance after considering the overall variance. During the analysis of principal components, the total variance in the data is examined. Eigenvalues, greater than one are considered significant, while eigenvalues below one is considered negligible and disregarded (Ghasedi, 2021). In this study, principal components analysis with the varimax rotation method is employed.

5.7 Research Approach

Seaports encounter significant challenges in identifying, selecting, and evaluating aspects of seaport sustainability performance dimensions and key performance indicators, as highlighted in maritime domain studies. Simultaneously, the assessment of seaport sustainability performance dimensions and key performance indicators, along with determining their efficiency, is increasingly valuable for seaports and their stakeholders.

Research and empirical evidence suggest that establishing efficient seaport sustainability aspects can yield positive outcomes for seaports and their stakeholders in terms of port business activities. This includes fulfilling the roles of seaport stakeholders and addressing both external and internal issues related to seaports. Consequently, a systematic research approach is necessary to investigate this study, employing a deductive technique.

The study utilizes both exploratory and descriptive research methods. The exploratory research method is employed to explore the relationship between five seaport sustainability performance dimensions and key performance indicators. This is complemented by a descriptive research approach based on existing literature. The research adopts a deductive reasoning approach. Further details regarding the data collection technique, sampling design, sample size estimation, response rate, and the research tool employed in the study will be further elaborated.

5.8 Procedure for Gathering Final Study Data

The data for the research analysis was gathered from primary sources. Primary data was collected through hard copy questionnaire and soft copy in form of Google forms from respondents of four major west coast major seaports and secondary data sources such as journal related- articles, published books, reports, and global seaport websites would be used to compile the study's literature.

5.8.1 Research Tool

The survey method is used to obtain data from four seaport employees who are respondents in this research study. The primary data was collected using a self-administered, structured questionnaire. The survey was split into three parts, the first of which focused on the demographics of the seaport employees of four major west coast seaports in India as respondents. The indicators for components were discussed in the second section, which included five factors of port environmental sustainability performance (PENSP); port social sustainability performance (PENSP); port economical sustainability performance (PENSP); port Internal sustainability performance (PISP) and port Customer Sustainability performance (PCSP). The second portion provides 37 items about the five factors measurement. Third section included the descriptive question on opinion on seaport sustainability related suggestions

5.8.2 Sampling

The sampling procedure in the study is determined by the type of study being conducted and the target population. It is important for the study sample to accurately represent the entire population, so that the findings can be applicable to the total population. In this particular study, the focus is on major seaports in India located on the west coast that handle liquid cargo as bulk cargo. Therefore, the population for the study comprises the total number of employees in these four seaports. Further, the sample size from each stratum is proportionate to the population of each of these major seaports. This method is popular and widely used by many researchers and refers to the proportional stratified sampling approach. Further, because it is challenging to locate a particular employee in a seaport, which is also an unfeasible choice, a non-probability sampling method is adopted.

Since the study is limited to the major seaports in India at west coast handling liquid cargo as bulk cargo, the total employees in these four seaports form the population for the study. Details of the employees (population) of these four seaports are provided in Table 5.2. The study intends to collect data from the four major seaports employees serving in the seaport with liquid cargo as a major cargo for the seaport in aspects of seaport sustainability considering internal and external factors. The perceptions and insights from these employees are valuable in framing the adoption strategies for seaport sustainability. The sample will be decided based on the appropriate sample design procedure and sample size estimation formula.

The results of the sampling process are, therefore, a reference to the number and the way in which the data needs to be collected from these four major seaports. Here, the study mainly adopts a convenience sampling and snowball sampling methods to identify the respondents from these four major seaports. Under the conditions of large population size and uncertainty in finding a particular respondent, these, techniques are believed to be an appropriate and acceptable methods which are commonly adopted by the past researchers (Chen et al., 2016; Kumar, Adlakaha, & Mukherjee, 2018; Chauhan, Gupta, & Jaiswal, 2018; Ochara & Mawela, 2015; Sharma, 2015). Since the population is very large, it is essential to use an adequate sample size estimation method to calculate the sample size. Here, the two formulas of Cochran and Solvin are primarily used to estimate the size of the sample under these conditions. Both of these formulas were used in the analysis to assess the sample size and, based on the findings, the most suitable one was chosen.

Cochran's formula (Cochran, 2007)	Slovin's formula (Ryan, 2013)
Sample size (n)=(Z^2*P(1-P))/e^2	Sample size (n)= N/((1+ne^2))

Where,

Z is the standard normal ordinate which is 1.96 for 95% confidence level

P is the (estimated) proportion of the population which has the attribute in question where 0.5 is the maximum variability that can be considered under no information condition.

e is the margin of error

N is the total population size

Here, a 95% confidence interval with five per cent margin of error (MOE) is considered as an acceptable limit and is used in most of the previous literature (Sharma et al., 2018; Al-Hubaishi et al., 2018). However, based on the most popular thumb rule for the estimation of sample size, which specifies a minimum sample of 10 times the number of items, is required to obtain reliable results (Hair, Black, Babin, & Anderson, 2010). Sample size of 386 is required to obtain reliable results (Solvins, 2013).

The sample size of 650 is therefore required based on 65 items, including demographic data, of the questionnaire. Hence, the current study considers the sample size needed as 650. Here, using the proportional stratified sampling approach the requirement for each major seaport is estimated and is provided in Table 5.2. However, the sample size in the range of 372 -650 is acceptable in the context of time and resource constraints.

Table 5.2: Population details and Sample Size Estimations

Port Name	Population Employee Total Count (As per April 2021)	Solvin's Formula 5% MOE & 95% CL	Cochran's Sample Size 5% MOE & 95% CL	Hair et al. 2011 (10 Times Rule Method) 10*No. of Items
Deendayal Port, Kandla	2,247	77	74	130
Mumbai Port, Mumbai	7,068	243	234	410
New Mangalore Port, Mangalore	512	18	17	29
Cochin Port, Cochin	1,394	48	46	81
Total Samples Required	**11,221**	**386**	**372**	**650**

Source: Research Methodology

The study intends to collect data from the four major seaports employees serving in the seaport with liquid cargo as a major cargo for the seaport in aspects of seaport sustainability considering internal and external factors. The perceptions and insights from these employees are valuable in framing the adoption strategies for seaport sustainability. The sample will be decided based on the appropriate sample design procedure and sample size estimation formula. The data collection for the survey was conducted pre-covid, covid and post-covid scenarios, and the aim was to collect the sample from employees working in four west coast liquid cargo profile major Indian seaports.

5.8.3 Sample Size Estimation and Response Rate

The researcher used Structural Equation Modelling (SEM) to test the proposed research model. According to Bentler (1987), the bottom-line ratio for using structural equation modeling is 5:1 in the case of a standard and elliptical theory. In which 5 is the sample size and 1 is the independent limit. In the case of random distributions, this ratio is between 8:1 or 10:1 (Taherdoost, 2017). The currentstudy comprises five constructs measured with 37 items, bringing the sample approximately 370 as per the thumb rule; however, research has data of 717, which is greater than 370, and therefore SEM, considered for final study analysis (Nunnally,1967). .

5.9 Final Study

Offline data was collected with 139 responses, and 123 valid responses were considered for the pilot study. A researcher had viewed 37 items with five factors for the pilot study. After receiving the pilot study-based results, a researcher had considered all 37 items considering methodological research steps (Smith, 2000) with five factors with the target population from the four major west coast liquid cargo seaports employees, with 717 responses were assessed.

5.9.1 Descriptive Statistics

Descriptive statistics provide information on the essential properties of a set of data. This workused descriptive statistics to calculate each latent variable's mean, standard deviation, skewness, and kurtosis value is less than 2.20, thevariable is devoid of outliers.

5.9.2 Reliability Analysis for Final Study

With 717 responses, a reliability analysis of all five components was conducted for the final research study.

5.9.3 Structural Equation Modeling (SEM)

Multiple regression and factor analysis are combined in SEM, a multivariate approach. It enables the researcher to look at a collection of interconnected dependent relationships between observed variables and latent components. SEM allows researchers to examine all dependent variables at once and researcher can create a path diagram using the SEM's structural model based on theory and depict all the variables' interactions as paths. SEM is employed to assess the correlations between latent and observable variables in this research study.

5.9.3.1 Measurement Model Validity

The measurement model validity is process-based, and it has to fulfill the following conditions to perform SEM. The measurement model discusses the items of each factor proposed in the research study and enables researchers to measure factor validity. Following thresholds are followed to perform confirmatory factor analysis (CFA). The first condition of measurement validity is fulfilling the following indices with threshold values.

Acceptance Level of Goodness of Fit: The acceptance level of goodness of fit is measured based on the indices such as GOF, adjustedAGFI, CFI, RMSEA, and normed Chi-square. The measurement model indices are shown in Table 5.3 with values (Hair et al., 2015). After the first conditions of the measurement model are satisfied, the second process is to run the construct validity, which can be achieved by running convergent and discriminant validity.

Table 5.3: Measurement model indices

Indices	**Threshold Value**
Normed chi-square	>1 and <3
GFI	>0.90
AGFI	>0.90
CFI	>0.95
RMSEA	<0.08

Source: Research Methodology

Construct Validity Performed with Convergent Validity: Convergent validity ensures that items from different constructs share a large proportion of their variance. The three indices (1. Factor loadings, 2. AVE, 3. Composite reliability) are used to determine convergent validity. Each of retained items had factor loadings greater than 0.5 per latent factor. Hair et al. (2015) state that all of latent factors had an average variance extracted (AVE) of greater than 0.5 and construct reliability (CR) of greaterthan 0.7, indicating that results were satisfactory.

Construct Validity Performed with Discriminant Validity: Discriminant validity determines if the constructs are distinct from one another (Hair et al., 2015). The square roots of the latent constructions' AVEs were higher thanall the inter construct correlations in the final study (Hair et al., 2015.

Common Method Bias: The spurious variance is attributable to the measurement method rather than the factors the measures are meant to represent is known as common-method variance (CMV) (Podsakoff et al. (2003)).

Multicollinearity: The presence of multicollinearity concerns is measured with the VIF (Variance Inflation Factor) calculated for each independent variable (O'Brien 2007). VIF values were less than 3.3, showing no multicollinearity issues in this study. In regression analysis, the variance inflation factor (VIF) reveals multicollinearity. When there is a correlation between predictors (independent variables) in a research model, it is identified as multicollinearity, and its existence might harm your regression findings.

5.9.3.2 Structural Model

Once validity of the measurement model has been established, it is necessary to examine the structural model which evaluates the significance of the relationships between variables and focuses on the connections between the latent factors. This model consists of one or more dependency relationships that link the constructs within the proposed model. By proving the interrelationships among variables, the structural model provides insights into the underlying connections within the system. Following are the two-step process to perform the structural model.

a. Acceptance level of goodness of fit (GOF)- GOF, adjusted AGFI, CFI, RMSEA,Normed Chi-square.
b. Path diagram & its analysis: 1. beta value or path coefficient 2. critical ratio or t value 3.Significance level (P) value.

Three factors are taken into account when performing path analysis; these are (i) the beta value (β), also known as the path-coefficient value, (ii) the critical ratio (CR), also known as the t value, and (iii) the significancelevel (p) value.

5.10 Mediation Analysis

In the current study, port environmental sustainability performance (PENSP) mediates the positive relationship between port Internal sustainability performance (PINSP) and port economic sustainability performance (PECSP) and port social sustainability performance (PSOSP) mediates the positive relationship between port internal sustainability performance (PINSP) and port economic sustainability performance (PEECSP). The mediation model assumes that mediating variable, M1, is intermediate in the link between an independent variable, X1, and an outcome, Y1 and explains how or why two variables are related (Baron and Kenny,1986) for evaluating the mediation hypothesis. The steps in the technique are as follows: independent and dependent variables must be significantly related; independent and mediating variables must be significantly related; mediator and dependent variable must be significantly related and when the mediator is held constant (full mediation), independent variable must have no effect or become significantly smaller on dependent variable (partial mediation).

5.11 Differences in perceptions of assessment dimensions

To examine the perceived differences of sustainability assessment dimensions between four major west coast liquid cargo major seaports in India, ANOVA was performed based on a post hoc test of Scheffe which is used in Analysis of Variance. Once, ANOVA process is completed a significant F-statistic (rejected the null hypothesis that the means are the same), then run Sheffe’s test to find out which pairs of means are significant. The Scheffe test corrects alpha for simple and complex mean comparisons. Complex mean comparisons involve comparing more than one pair of means simultaneously.

5.12 Content Validity

This study research framework contains a total of five factors and all factors are measured using a five Likert scale. Seven hundred seventeen responses were analyzed for final research study, comprising 37 questions that predicted five study's proposed factors. The questionnaire was thoroughly discussed with the supervisor and maritime practitioners and seaport consultants to determine whether questions accurately measure the most critical issues to undertake the final research and is highlighted in Appendix B section.

5.13 Pilot Study

Pilot study was carried out to ensure the validity of the questionnaire. Data were obtainedfrom 139 respondents for the pilot analysis, with 123 respondents' data being complete and considered for pilot study analysis. The questionnaire had three parts: demographic information for respondents, factor-by-factor questionnaire and one descriptive question on suggestion on seaport sustainability aspects. A questionnaire with multiple-choicequestions and constructed questions using a five-point Likert scale was used to collect data from respondents.

5.13.1 Reliability Analysis for Pilot Study

All of the factors have Cronbach's Alpha values higher than the acceptable level of 0.7 (Dennis Howitt, 2008), suggesting that all items are internally consistent and shown in Table 5.4. As a result, the study's instrument is rated dependable and internally consistent. Results indicated the reliability of all the factors considered in the research model. The results of pilot study indicated an acceptable Kaiser-Meyer-Olkin (KMO) & Bartlett's test value is of 0.839, which is higher than the threshold (0.5) indicating the sampling adequacy as fair and can perform factor analysis per Malhotra (2004).

Table 5.4: Result of reliability analysis (Pilot Study)

Constructs	Cronbach's Alpha
Port environmental sustainability performance (PENSP)	0.839
Port Social sustainability performance (PSSP)	0.862
Port economic sustainability performance (PECSP)	0.759
Port Internal sustainability performance (PISP)	0.841
Port Customer Sustainability Performance (PCSP)	0.739

Source: Primary data

5.13.2 Exploratory Factor Analysis (EFA)

As per Ian Jolliffe (2005) all factors scored higher than 0.5, indicating that the data is suitable for factor analysis. Principal Component Analysis (PCA) was used with Varimax rotation. Under the same design, most of the factor loadings were over the allowed level and exhibited good loadings. Average Variation Extracted is analyzed for all factors. Every factor was above the permissible level of 0.5 (Fornell & Larcker, 1981), and construct reliability was similarly above the acceptable level for all constructs. For the final study, the five factors are evaluated in the final questionnaire, with high-loading factors in each construct taken into account and Smith's (2000) research methodology steps, whichtake features from each component into account.

Exploratory Factor Analysis (EFA) was performed for testing the validity of the scale items used in measuring the constructs. A Principal Component Analysis (PCA) was conducted on the 37 scale items of seaport sustainability for five constructs using the varimax rotation method for indicating the factor loading for each item. Total variance accounted by all the five factors in this research study was 83.251%, which was greater than 50%, showing good sampling adequacy (Fuller et al., 2016). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy value of 0.919 is above the acceptable level of 0.5 and the Bartlett's test of spherecity is significant (p <0.05). According to Malhotra (2004), high KMO value between 0.5 and 1.0 shows that the factor analysis is appropriate. Three items (ELP5, ELP6 and ARGU3) were deleted due to low factor loading and they have cross loaded significantly across factors 1 to 5.

5.14 Final Study

Results of the pilot study have to lead to the construction of the final questionnaire and thefinal study conducted. Seven hundred seventeen responses are considered for the final study.

5.14.1 Descriptive Statistics of Final Study

The descriptive statistics on the questionnaire used for the final analysis are presented in Table 5.5. The final 717 responses received in questionnaire were tested for normality using the skewness and kurtosis values which were within the threshold of 3.3 (Hair et al., 2017).

Table 5.5: Normality Testing- Descriptive statistics of the final study

Variable	Skewness	Std. Error of Skewness	Kurtosis	Std. Error of Kurtosis
ELP1	-0.38	0.09	-0.47	0.18
ELP2	-0.34	0.09	-0.89	0.18
ELP3	-0.27	0.09	-0.49	0.18
ELP4	-0.20	0.09	-0.91	0.18
ELP5	0.03	0.09	-1.07	0.18
ELP6	-0.10	0.09	-1.00	0.18
EW1	0.03	0.09	-0.65	0.18
EW2	-0.68	0.09	0.90	0.18
EN1	-0.52	0.09	0.73	0.18
EN2	-0.69	0.09	0.73	0.18
EC1	-0.63	0.09	1.12	0.18
EC2	-0.63	0.09	1.11	0.18
EC3	-0.60	0.09	1.02	0.18
HS1	-0.61	0.09	1.11	0.18
HS2	-0.35	0.09	1.78	0.18
TE1	-0.71	0.09	1.72	0.18
TE2	-0.84	0.09	1.34	0.18
EE1	-0.87	0.09	2.31	0.18

EE2	-0.66	0.09	1.23	0.18
LC1	-0.53	0.09	0.62	0.18
LC2	-0.61	0.09	0.41	0.18
LC3	-0.70	0.09	0.65	0.18
ECI1	-0.34	0.09	0.42	0.18
ECI2	-0.05	0.09	-0.36	0.18
ECI3	0.03	0.09	-0.65	0.18
ECI4	-0.68	0.09	0.90	0.18
SCA1	-0.52	0.09	0.73	0.18
SCA2	-0.69	0.09	0.73	0.18
SCA3	-0.63	0.09	1.12	0.18
ARGU1	-0.63	0.09	1.11	0.18
ARGU2	-0.60	0.09	1.02	0.18
MGIN1	-0.61	0.09	1.11	0.18
MGIN2	-0.35	0.09	1.78	0.18
CS1	-0.71	0.09	1.72	0.18
CS2	-0.84	0.09	1.34	0.18
CS3	-0.87	0.09	2.31	0.18

Source: Primary data

5.14.2 Reliability Analysis

Cronbach's Alphas were determined for all five factors: port environmental sustainability performance (PENSP); port social sustainability performance (PENSP); port economical sustainability performance (PENSP); port Internal sustainability performance (PISP) and port Customer Sustainability performance (PCSP). As presented in Table 5.6, reliability Alpha values were in the range of 0.8641 to 0.7417.

A Principal Component Analysis (PCA) was conducted on the 37 scale items of seaport sustainability for five constructs using the varimax rotation method for indicating the factor loading for each item.

Table 5.6: Reliability analysis (Final Study)

Constructs	Cronbach's Alpha
Port environmental sustainability performance (PENSP)	0.8629
Port Social sustainability performance (PSSP)	0.8601
Port economic sustainability performance (PECSP)	0.7522
Port Internal sustainability performance (PISP)	0.8641
Port Customer Sustainability Performance (PCSP)	0.7417

Source: Primary data

5.14.3 Demographics of the Respondents

The demographics of the seaport employees who are respondents are stated in Table 5.7 which were considered to understand the demographic background of the 717 population responses of four major west coast liquid cargo seaports in India. Table 5.7 helped the researcher to understand thebackground information about demographics and how data is spread among various demographical factors.

Table 5.7: Demographics of the Respondents in the Final Study

Variable		Frequency	Percentage
Gender	Male	488	68.06
	Female	229	31.94
Age	20 – 29 years	32	4.46
	30 – 39 years	173	24.13
	40 – 49 years	239	33.33
	50 – 59 years	273	38.08
Education	Diploma Degree	77	10.74
	Bachelor's Degree	358	49.93
	Master's Degree	242	33.75
	Doctorate Degree	40	5.58
Ports	Deendayal Port Trust, Kandla	82	11.44
	Mumbai Port Trust, Mumbai	86	11.99
	New Mangalore Port Trust, Mangalore	412	57.46
	Cochin Port Trust, Cochin	137	19.11
Designation	Port -Top Level Manager	344	47.98
	Port-Middle Level Manager	253	35.29
	Port- Operation Level Employee	120	16.74
Department	Administration	125	17.43

	Marine Operations	37	5.16
	Traffic Operations	158	22.04
	Engineering (Civil/Mechanical)	126	17.57
	Finance	189	26.36
	Medical	32	4.46
	Maritime/Port Supply chain	47	6.56
	Sustainable Development	3	0.42
Experience	1 to 10 Years	89	12.41
	11 to 20 Years	245	34.17
	21 to 30 Years	334	46.58
	31 to 40 Years	49	6.83
Income	Rs.20,000 – Rs.39,999	29	4.04
	Rs.40,000 – Rs.59,999	86	11.99
	Rs.60,000 – Rs.79,999	126	17.57
	Rs.80,000 – Rs.99,999	253	35.29
	Above Rs.1,00,000	223	31.10

Source: Primary Data

To bring out socio-demographic details, SPSS 23.0 software has been used and descriptive statistics and inferential statistics were done for the socio-demographic variables. Socio-demographic results depict that the majority of respondents are from Mumbai Port, Mumbai with about 57.46 percent (412 respondents) followed by Deendayal Port, Kandla with 19.1% (137 respondents) followed by New Mangalore Port, Mangalore with 11.99% (86 respondents) and Cochin Port, Cochin with 11.43% (82 respondents). In terms of demographics, approximately 68.06 percent (488 respondents) of respondents are male and 31.93 percent are female (229 respondents). This reflected that in major seaports of India, males are more involved in the port and maritime and shipping business compared to female employees.

According to the age distribution data, most of the respondents were in the age (50–59 years old constituting about 38.08% of the sample followed by 40–49 years old constituting about 33.33% of the sample). These are the people who are economically oriented and having sufficient knowledge about operations concerning to Indian seaports and maritime sector in terms of social, economic, environmental and seaport internal and external sustainability knowledge. Most of respondents had university degrees, among them, 49.93% had bachelor degrees as a higher level of education and 33.75% had postgraduate degrees; and 5.58% had doctorate degree. On the other hand, respondents who had been working in the seaport and shipping business with 21 to 30 years presented with 46.58%;34.17% had experience of range 11 to 20 years followed by 12.41% with experience of 1 to 10 years. Also, 47.98% of respondents of this research were from top management followed by 35.29% from middle level port management and 16.74% were employees from port- operation level.

The research study respondents were working in various departments of seaport which included: Administration (17.43%); Marine operations (5.16%); Traffic operations (22.04%); Engineering-Civil/Mechanical (17.57%); Finance (26.36%) Medical (4.46%); Maritime/Port Supply chain (6.56%) and Sustainable Development (0.42%).On Income related aspects 35.29% of employees were earning income in range Rs.80,000 to Rs.99,999 followed by above Rs.1,00,000 (31.10%); Rs.60,000 to Rs.79,999 (17.57%); Rs.40,000 to Rs.59,999 (11.99%) followed by Rs.20,000 to Rs.39,999 (4.04%).

5.14.4 Confirmatory Factor Analysis

In CFA, five factors were identified and total variance accounted by all the five factors in this research study was 83.251%, which was greater than 50%, showing good sampling adequacy (Fuller et al., 2016). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy value of 0.919 is above the acceptable level of 0.5 and the Bartlett's test of spherecity is significant (p <0.05). According to Malhotra (2004), high KMO value between 0.5 and 1.0 shows that the factor analysis is appropriate (Hair, 2006). Three items (ELP5, ELP6 and ARGU3) were deleted due to low factor loading and have cross loaded significantly across factors 1 to 5. In the final questionnaire, items with higher factor loadings were considered for each construct. The constructs and their factor loadings are mentioned in Table 5.8.

Table 5.8: Constructs and their factor loadings

Construct	Measurement Instruments	Factor Loadings of indicators
Port environmental sustainability performance (PENSP)	ELP1	0.691
	ELP2	0.685
	ELP3	0.757
	ELP4	0.579
	EW1	0.735
	EW2	0.669
	EN1	0.626

	EN2	0.682
	EC1	0.663
	EC2	0.752
	EC3	0.744
Port Social sustainability performance (PSSP)	HS1	0.654
	HS2	0.711
	TE1	0.736
	TE2	0.761
	EE1	0.696
	EE2	0.708
	LC1	0.696
	LC2	0.752
	LC3	0.744
Port economic sustainability performance (PECSP)	ECI1	0.654
	ECI2	0.699
	ECI3	0.835
	ECI4	0.733
	SCA1	0.721
	SCA2	0.717
	SCA3	0.746
Port Internal sustainability performance (PISP)	AGRU1	0.73
	AGRU2	0.725
	MGIN1	0.644
	MGIN2	0.722
Port Customer Sustainability Performance (PESP)	CS1	0.717
	CS2	0.706
	CS3	0.774

Source: Primary Data

Based on the factor loading, further analysis is performed.

5.15 Measurement Model

The structural model evaluates all hypothetical dependencies based on the path analysis, whereas the measurement model measures latent or composite variables. If the data meets the requirements of the measurement model for indices, further research is possible; however, if the indices are not within the range, further analysis is problematic, and model fit will be complicated. Table 5.9 shows the measurement modelwith indices.

Table 5.9: Measurement model indices

Indices	**Threshold Value (Hair et al. 2015)**	**Present study results**
Normed chi-square	>1 and <3	2.257
GFI	>0.90	0.941
AGFI	>0.90	0.919
CFI	>0.95	.969
RMSEA	<0.08	.047

Source: Primary data

5.16 **Convergent Validity**

Convergent validity assures that items from different constructs share a large fraction of their variance. Following conditions are used to perform convergent validity: a. “factor loadingof constructs should be greater than 0.5; AVE of all constructs should be greater than 0.5; CR of all constructs should be greater than 0.7 indicating an acceptable degree of criteria and allowing further analysis for the SEM procedure (Hair et al., 2015). Table 5.10 shows the convergent validity of the items.

Table 5.10: Convergent validity for the items

Construct	MeasurementInstruments	Factor Loadings of indicators	Factor Loading of dimensions	Construct reliability (CR) (>0.6)	Average Variance Extracted (AVE) (> 0.5)	Average Square Variance (ASV) R^2
PENSP	ELP1	0.691	0.752	0.8629	0.5584	0.565
	ELP2	0.685				
	ELP3	0.757				
	ELP4	0.579				
	EW1	0.735				
	EW2	0.669				
	EN1	0.626				
	EN2	0.682				
	EC1	0.663				
	EC2	0.752				
	EC3	0.744				
PSSP	HS1	0.654	0.717	0.8601	0.5067	0.514
	HS2	0.711				
	TE1	0.736				
	TE2	0.761				
	EE1	0.696				
	EE2	0.708				
	LC1	0.696				
	LC2	0.752				
	LC3	0.744				
PECSP	ECI1	0.654	0.765	0.7322	0.5776	0.585
	ECI2	0.699				
	ECI3	0.835				

	ECI4	0.733				
	SCA1	0.721				
	SCA2	0.717				
	SCA3	0.746				
PISP	AGRU1	0.73	0.756	0.8641	0.5156	0.571
	AGRU2	0.725				
	MGIN1	0.644				
	MGIN2	0.722				
PESP	CS1	0.717	0.684	0.7071	0.5483	0.467
	CS2	0.706				
	CS3	0.774				

Source: Primary data

Discriminant validity determines whether or not the constructs are distinct. The discriminant validity is performed with the following conditions that must be met and within the threshold range: the constructs' AVE should be greater than MSV and ASV (Fornell &Larcker, 1981). It symbolizes the acceptance level and that all constructs are distinct (Hair et al., 2015). Table 5.11 displays the results of the analysisdone.

Table 5.11: Results for discriminant validity

Construct	PENSP	PSSP	PECSP	PISP	PCSP
PENSP	**0.747**				
PSSP	0.704	**0.712**			
PECSP	0.686	0.635	**0.76**		
PISP	0.706	0.698	0.66	**0.718**	
PCSP	0.612	0.608	0.723	0.528	**0.741**

Source: Primary data

5.17 Divergent Validity

There is much evidence that common method bias impacts items validities, item reliabilities, and latent construct covariation (Scott B. MacKenzie, 2012). These are necessary for the measuring model. Then, the researcher can run the SEM model to check the model's goodnessof fit. Path analysis can be performed if the data is free of common method bias. If the percentage of variance is less than 50 percent for 1st factor, there is no common method bias (MacKenzie S. P., 2012). Total variance accounted by all the five factors in this research study was 83.251%, which was greater than 50%, showing good sampling adequacy (Fuller et al., 2016).

5.18 Multicollinearity

Multicollinearity analysis is used when a proposed model comprises multiple independent constructs to see no correlation between the independent variables presented in the study. It could cause issues with model fit. Theresult for variance inflation factor is shown in Table 5.12.

Table 5.12: Multicollinearity table showing VIF

Dependent Constructs	Independent Constructs	Collinearity Statistics VIF
PENSP	PSOSP	1.053
	PECSP	1.025
	PINSP	1.017
PSOSP	PENSP	1.124
	PECSP	1.107
	PINSP	1.095
PECSP	PSOSP	1.011
	PENSP	1.128
	PINSP	1.093
PINSP	PSOSP	1.042
	PECSP	1.048
	PENSP	1.104

Source: Primary data

The structural model is built on conditions and processes. All of the above modification indices and data validity must be completed for measurement model fit. SEM is performed once the acceptability level of all tests is within the range.

5.19 Structural Model

The path for performing a structural model is straightforward; it is quantified using model fit indices and predicted in Table 5.13. Goodness of Fit Index as defined (GFI). A statistic for how well the hypothesized model and the observed covariance matrix fit together. The Adjusted Goodness of Fit Index (AGFI) corrects the GFI as a function of the number of latent variable indicators. Path analysis can analyze the direct and indirect relationships of theconstructs given in the study based on the theoretical model when a satisfactory model fit hasbeen established.

Table 5.13: Structural model indices

Indices	**Threshold Value(Hair et al. 2015)**	**Present study results**
Normed chi-square	>1 and <3	1.287
GFI	>0.90	0.937
AGFI	>0.90	0.911
CFI	>0.95	0.961
RMSEA	<0.08	0.036

Source: Primary data

5.20 Path Analysis

Path Analysis is a type of predictive modeling used to investigate the relationships between variables in a research model. Research study results were examined for identifying and analyzing the relationships between different dimensions of sustainability performance in seaports. The analysis indicates that all hypothesized relationships in the study were significant and aligned with the expected direction. Port internal sustainability performance was significantly associated with port customer sustainability performance (estimate = 0.151, CR = 2.946); which implies that when a seaport demonstrates higher internal sustainability performance, it is likely to also exhibit better sustainability performance from the perspective of its customers.

Port environmental sustainability performance was significantly associated with port economic sustainability performance (estimate = 0.116, CR = 7.096); which suggests that there is a positive relationship between a seaport's environmental sustainability performance and its economic sustainability performance. As the seaport's environmental sustainability improves, it tends to have positive effects on its economic sustainability. Port social sustainability performance was significantly associated with seaports economic sustainability performance (estimate = 0.612, CR = 7.294) and this finding indicates that when a seaport demonstrates higher social sustainability performance, it is likely to also exhibit better economic sustainability performance.

Port internal sustainability performance was significantly associated with port economic sustainability performance (estimate = 0.421, CR = 10.39), which suggests that there is a positive relationship between a port's internal sustainability performance and its economic sustainability performance. Improving internal sustainability practices can lead to better economic outcomes for the seaport. Port internal sustainability performance was significantly associated with port social sustainability performance (estimate = 1.246, CR = 8.763) and this finding indicates that a higher level of internal sustainability performance within a seaport is associated with better social sustainability performance. Internal sustainability practices can contribute to positive social outcomes.

Port internal sustainability performance was significantly associated with port environmental sustainability performance (estimate = 0.863, CR = 8.915) which suggests that higher internal sustainability performance within a seaport is associated with better environmental sustainability performance. Effective internal sustainability practices can have a positive impact on environmental performance. Port customer sustainability performance was significantly associated with port environmental sustainability performance (estimate = 0.394, CR = 4.793) which implies that when a seaport demonstrates better sustainability performance from perspective of its customers, it is likely to also exhibit better environmental sustainability performance.

Port customer sustainability performance was significantly associated with port social sustainability performance (estimate = 0.251, CR = 2.071) and this finding indicates that there is a positive relationship between a port's customer sustainability performance and its social sustainability performance. When customers perceive the seaport to be sustainable, it tends to have positive social outcomes. Port customer sustainability performance was significantly associated with port economic sustainability performance (estimate = 0.391, CR = 2.071) which suggests that there is a positive relationship between a port's customer sustainability performance and its economic sustainability performance. Positive customer perceptions of sustainability can contribute to better economic outcomes for the port.

In summary, the research study reveals significant and expected relationships between various dimensions of sustainability performance in seaports and the findings highlight inter-connectedness of different sustainability dimensions and suggest that improvements in one dimension can have positive spill-over effects on other dimensions of sustainability within a seaport. Further, findings of research results on mediation effects in the relationships between different dimensions of sustainability performance in seaports is analyzed which indicates as follows: Port environmental sustainability performance mediates the positive relationship between Port internal sustainability performance and Port economic sustainability performance (estimate = 0.054, Boot CI: 0.033 to 0.079; supported, significant at the 0.01 level) and this indicates that the positive relationship between Port internal sustainability performance and Port economic sustainability performance is partially explained by the mediating role of Port environmental sustainability performance. In other words, the effect of Port internal sustainability on Port economic sustainability is channelled through improvements in Port environmental sustainability.

Port social sustainability performance mediates the positive relationship between Port internal sustainability performance and Port economic sustainability performance (estimate = 0.456, Boot CI: 0.317 to 0.594; supported, significant at the 0.01 level) and this finding suggests that the positive relationship between Port internal sustainability performance and Port economic sustainability performance is partially mediated by Port social sustainability performance. It implies that Port social sustainability plays a role in transmitting the positive effects of Port internal sustainability to Port economic sustainability.

Furthermore, the analysis reveals that the relationship between the variables of Seaport Sustainability performance shows significant facilitating conditions between male and female employees of the port. The gender variable is considered a control variable in the study. The results indicate that the inclusion or exclusion of the gender variable does not substantially affect the fit of the research model (Comparative Fit Index, CFI = 0.99 with gender, and CFI = 1 without gender). Therefore, the research is deemed gender-neutral, as the findings remain consistent regardless of the inclusion or exclusion of the gender variable. Overall, these findings suggest that Port environmental sustainability and Port social sustainability play mediating roles in the relationships between Port internal sustainability and Port economic sustainability. The graphical presentation of path analysis Mediation Models (Indirect Relationships) and direct relationships for the research is illustrated in Figure 5.1 and 5.2. Results are presented in Table 5.14 and Table 5.15.

Table 5.14: Results of Path Analysis (Direct Relationships)

Hypothesis	Path Models			Estimates	t value (mod)	P value	Results
H1	PINSP	→	PCSP	0.151	2.946	<0.001	Supported (value is significant at the 0.01 level)
H2a	PENSP	→	PECSP	0.116	7.096	<0.001	Supported (value is significant at the 0.01 level)
H2b	PSOSP	→	PECSP	0.612	7.294	<0.001	Supported (value is significant at the 0.01 level)
H3a	PINSP	→	PENSP	0.421	10.39	<0.001	Supported (value is significant at the 0.01 level)
H3b	PINSP	→	PSOSP	1.246	8.763	<0.001	Supported (value is significant at the 0.01 level)
H3c	PINSP	→	PECSP	0.863	8.915	<0.001	Supported (value is significant at the 0.01 level
H4a	PCSP	→	PENSP	0.394	4.793	<0.001	Supported (value is significant at the 0.01 level)
H4b	PCSP	→	PSOSP	0.251	2.071	<0.001	Supported (value is significant at the 0.01 level)
H4c	PCSP	→	PECSP	0.391	2.071	<0.001	Supported (value is significant at the 0.01 level

Source: Primary Research data

Table 5.15: Results of Mediation Models (Indirect Relationships)

Hypothesis	Mediation Model	Estimate	Lower Bound (Boot CI)	Upper Bound (Boot CI)	P Value	Results
H5a	PINSP→PENSP→PECSP	0.054	0.033	0.079	0.001	Supported (value is significant at the 0.01 level)
H5b	PINSP→PECSP→PSOSP	0.456	0.317	0.594	0.001	Supported (value is significant at the 0.01 level)

Source: Primary data

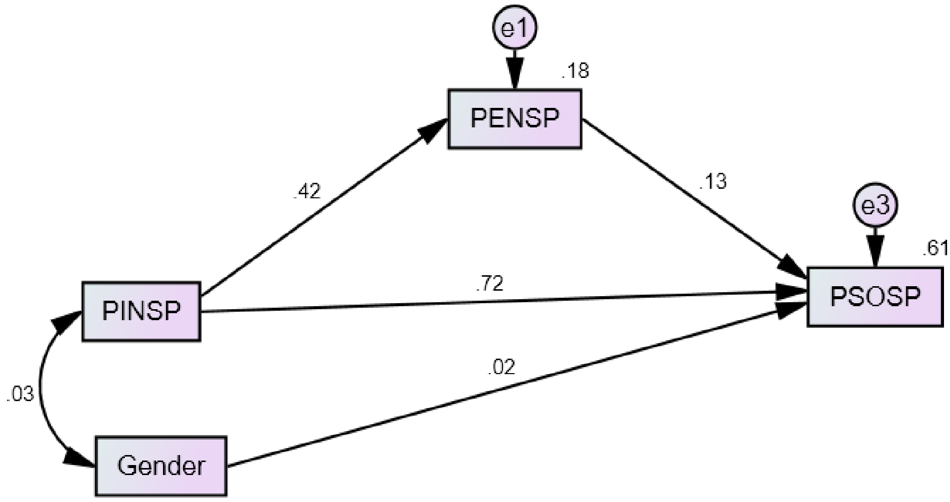

Figure 5.2: Mediation Model-1(Indirect Relationship)

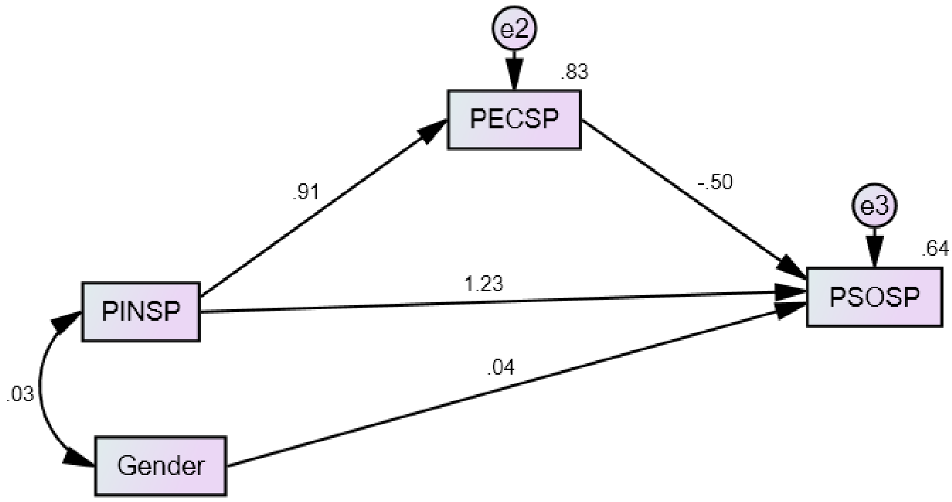

Figure 5.3: Mediation Model-2(Indirect Relationship)

5.21 Differences in Perceptions of Seaport Sustainability Assessment Dimensions among Major Seaports

To examine the perceived differences of seaport sustainability assessment related dimensions between four major seaports (DPA, Kandla; MPA. Mumbai; NMPA, Mangalore and CoPA, Cochin), ANOVA was performed based on a post hoc test of Scheffe by calculating the mean scores of all sustainability assessment dimensions for the four major seaports and is highlighted in Table 5.16.

Table 5.16: One-way ANOVA differences between west coast liquid cargo based major seaports of India

Port Sustainability assessment dimensions	DPA, Kandla	MPA. Mumbai	NMPA, Mangalore	CoPA, Cochin	F-ratio	Scheffe test
PENSP mean scores with ranks	4.26(3)	4.14()4	4.35(1)	4.31(2)	1.87**	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)
PSOSP mean scores with ranks	4.28(2)	4.11(4)	4.29(1)	4.22(3)	3.85**	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)
PECSP mean scores with ranks	4.43(1)	4.36(4)	4.41(2)	4.39(3)	4.15**	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)
PIPSP mean scores with ranks	4.35(2)	4.22(4)	4.28(3)	4.36(1)	2.19**	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)
PCSP mean scores with ranks	4.29(2)	4.24(4)	4.25(3)	4.31(1)	1.80**	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)

Source: Primary research data Note: **p <0.01

Results of an analysis of variance (ANOVA) conducted to compare the mean scores of sustainability assessment dimensions among the four major seaports under this research study. The results of the ANOVA are followed by post hoc tests using the Scheffe method to determine specific differences between the seaports. The Scheffe test is used to compare the mean scores between pairs of seaports. The results are highlighted as follows: -

Port Environmental Sustainability Performance (PENSP): The mean scores with ranks for the four ports are as follows: DPA, Kandla (4.26), MbPA, Mumbai (4.14), NMPA, Mangalore (4.35), and COPA, Cochin (4.31). The f-ratio of 1.87 indicates that there is a significant difference in the mean scores among the ports for environmental sustainability performance.

Port Social Sustainability Performance (PSOSP): The mean scores with ranks for the four ports are as follows: DPA, Kandla (4.28), MbPA, Mumbai (4.11), NMPA, Mangalore

(4.29), and COPA, Cochin (4.22). The f-ratio of 3.85 indicates a significant difference in the mean scores among the ports for social sustainability performance.

Port Economic Sustainability Performance (PECSP): The mean scores with ranks for the four ports are as follows: DPA, Kandla (4.43), MbPA, Mumbai (4.36), NMPA, Mangalore (4.41), and COPA, Cochin (4.39). The f-ratio of 4.81 indicates a significant difference in the mean scores among the ports for economic sustainability performance.

Port Internal Sustainability Performance (PINSP): The mean scores with ranks for the four ports are as follows: DPA, Kandla (4.35), MbPA, Mumbai (4.22), NMPA, Mangalore (4.28), and COPA, Cochin (4.36). The f-ratio of 2.19 indicates a significant difference in the mean scores among the ports for internal sustainability performance.

Port Customer Sustainability Performance (PCSP): The mean scores with ranks for the four ports are as follows: DPA, Kandla (4.29), MbPA, Mumbai (4.24), NMPA, Mangalore (4.25), and COPA, Cochin (4.31). The f-ratio of 1.80 indicates a significant difference in the mean scores among the ports for customer sustainability performance.

5.22 Key Recommendations for Enhancing Seaport Sustainability in Indian Major Seaports: Insights from Respondents

The research questionnaire survey also included an optional question regarding suggestions or opinions from the four seaport employees who were respondents for this research study regarding the topic of seaport sustainability aspects in Indian major seaports context. This question was additional suggestion's part and it was very vital because it is a valuable information source that seaport employees want to share what was happening in their seaport location involving sustainability aspects and issues in their respective seaport area. These aspects also included sharing the respondent's opinions about future changes and policies in seaport sustainability that could not be fully reflected in the question no.8 to 45 of the questionnaire surveys. The response to this question was responded by 138 respondents the questionnaire survey by providing opinions regarding ongoing measures and policies for sustainability related issues considering Indian major seaport context.

Overall Focus areas responded by respondents (seaport employees) for primary data research questionnaire towards improving seaport sustainability related aspects for major seaports in India. The research study respondents overall highlighted on several key focus areas to improve the sustainability of the seaport ecosystem and achieve the benchmarks for developing sustainable green seaports. The detailed 138 responses provided by were categorized on various focus areas of seaport sustainability and consolidated into 44 suggestion-based responses and is highlighted as follows:

1. Green Cover: Seaports should prioritize increasing the green area cover within the seaport premises to capture fugitive emissions and attenuate noise pollution. This can be achieved through effective plantation and landscape development. The green belt will support biodiversity, retain soil moisture, control erosion, protect coastal areas, recharge groundwater, and act as a carbon sink.
2. Electrification of Port Equipment's: Seaports should strive to achieve the targets for electrification of vehicles and port equipment. Seaports should develop plans to retrofit or convert diesel-powered equipment, cranes, forklifts, pay loaders, and vehicles to electric power. Future procurements of port vehicles and equipment should prioritize electric or low-carbon greener fuels such as CNG, methanol, ethanol, ammonia, and hydrogen fuel cells.
3. Port Crafts: Seaports should retrofit port crafts, including tugs, pilot boats, mooring boats, and survey boats, with available technologies for propulsion on cleaner and greener fuels such as green ammonia, green hydrogen, and green methanol. Seaports should develop action plans and projects to achieve the targets set by the National Green Hydrogen Mission, including the creation of infrastructure for storage, bunkering, and refuelling of green hydrogen and its derivatives. Green ammonia bunkers and refuelling facilities should be established at all major ports.
4. Renewable Energy: Seaports should work towards achieving the targets for renewable energy. Seaports should establish at least one LNG bunkering station and an adequate number of EV charging stations in the port area or nearby locations. Seaports should also upgrade their infrastructure to support offshore wind energy projects, including providing services for the assembly, staging, fabrication, storage, and loading of wind turbine generator components.
5. Shore to Ship Power Supply: Seaports should develop infrastructure to provide shore-to-ship power gradually. The first phase should target port crafts by 2023, followed by coast guard/navy and small coastal vessels and EXIM vessels.
6. Resource Utilization in Ports: Seaports should increase the capacity of water treatment plants and promote the use of treated water. The aim is to achieve reduction in fresh water consumption per ton of cargo and complete recycling and reuse of wastewater. Seaports should install sewage treatment plants and utilize the treated water for non-potable purposes, such as horticulture and sprinkling water on roads and yards. The possibility of installing desalination plants or utilizing

condensed water from LNG terminals should be explored. Seaports should also implement rainwater harvesting wherever feasible.

7. Use of Energy Efficient Equipment's and Digitization in Ports: Seaports should prioritize the use of energy-efficient equipment and materials, such as LED smart lighting systems and highest energy-rated appliances. Vehicles should not be allowed inside the port area without a valid pollution under control (PUC) certificate. Digital infrastructure, including systems like Sagar Setu-NLP-Marine, EBS, and RFID, should be utilized to increase operational efficiency and reduce the carbon footprint. All new buildings within the port area should be constructed following green building concepts.
8. Promotion of Coastal Shipping by Seaports: Seaports should support coastal shipping by developing infrastructure and implementing mechanisms that make this mode of transport economically viable. Promoting coastal shipping as a cost and energy-efficient alternative can help address carbon emissions and contribute to national carbon footprint reduction targets.
9. Effluent Discharge at seaports: Seaports must closely monitor the discharge of effluents from ships according to the regulations set by the International Maritime Organization (IMO) (MARPOL) and DG Shipping Rules. Vessels equipped with Exhaust Gas Cleaning Systems should switch to the closed-loop mode of operation if they have hybrid scrubbers, while vessels with open-loop scrubbers must switch to compliant fuel. Discharge of any wastewater, bilge water, oily bilge, or ship-generated wastewater is prohibited in the port waters. Vessels calling at the port must declare the type and approximate quantity of waste onboard and seek assistance from the seaport for its disposal.
10. Marine Ecosystem in Seaports: Seaports should develop programs to protect and conserve the shore, mangrove forests, and habitats. They should also prepare an Emergency Oil Pollution Response Management plan in accordance with the National Oil Spill Disaster Contingency Plan to combat oil pollution within the port limits. Seaports should implement Ballast Water Management as per the guidelines set by IMO/DG Shipping for all applicable ships calling at the port.
11. Waste Management at Ports: All seaports should provide shore reception facilities with approved vendors for ships to discharge waste in accordance with Indian rules.
12. Dedicated Port Environment Management Cell: Seaports should have approved Environment Management Guidelines, an Environment Management Plan, and a

dedicated Environment Cell responsible for reviewing and monitoring environmental compliance within the port. The Environment Cell should consist of competent and trained personnel who provide suggestions and recommendations to the management for effective implementation of environmental compliance. Seaports should conduct an independent annual environment audit by a credible agency and report the findings every year.

13. Carbon Credits: All seaports should strive to earn carbon credits by reducing greenhouse gas (GHG) emissions.
14. Incentive Measures from Ports to Stakeholders: To promote overall sustainability, seaports should introduce Green Ship incentives to foster a green culture. Vessels using cleaner fuel compared to conventional fuel and vessels equipped with shore power reception facilities accommodating the full load at berth, including cargo handling equipment, should receive incentives such as queue priority or rebates in berth dues. Private craft operators using green fuels such as methanol, ethanol, hydrogen fuel cell technology, etc., should also be incentivized. Operators using green fuel or electric fleets for their equipment/vehicles at the seaport should be identified, recognized through green certification, and incentivized. Truck operators using green fuels or electric fleets should also be identified and incentivized. Seaports should ensure that green and sustainability aspects are incorporated into Detailed Project Reports (DPRs) when formulating Public Private Partnership (PPP) projects. For existing PPP concessionaires, seaports should devise mechanisms to incentivize the adoption of greener and carbon-neutral designs and procedures in line with these guidelines.
15. Monitoring system for Environment Performance Indicators, waste management and sustainability: Seaports should develop a monitoring system for the following: Environment Performance Indicators (EPIs) related to air quality, water quality, effluent, and noise pollution; EPIs for waste management should include parameters such as hazardous waste, e-waste, solid waste, plastic waste, battery waste, construction and demolition waste, and biomedical waste; EPIs for sustainability should cover the percentage share of renewable energy consumption, electrification of port equipment/vehicles, area under green belt, reduction in CO2 emissions per ton of cargo, reduction in GHG emissions in vessels, reduction in fresh-water consumption per ton of cargo, water recycling and reuse, reduction in energy consumption per ton of cargo, establishment of LNG bunkering stations, and

the development of facilities for green hydrogen/ammonia bunkers and EV charging stations.

16. Online real-time monitoring stations for various environment related parameters in seaports with compliance: Seaports should develop and establish online real-time monitoring stations for ambient air quality, marine water quality, and effluent based on effluent parameters. Noise level and DG set noise level monitoring that should also be integrated into a real-time dashboard in compliance with applicable guidelines from the Ministry of Ports, Shipping and Waterways Environment, Forest, and Climate Change (MoEF&CC), Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB).
17. Ensure sustainability in seaport development by employing environmentally compatible designs that construct resilient infrastructure aligning with local energy dynamics, encompassing environmental, economic, and social aspects.
18. Ensure sustainability in seaport operations by adopting best practices and utilizing carbon-neutral and environmentally friendly technologies that are currently available.
19. Embrace an ecosystem-based approach in seaport development, operation, and maintenance, adhering to the Working with Nature concept and the Panchamrit Commitments, while minimizing the impact on the biotic components of the harbour ecosystem.
20. Maximize the use of clean and green energy sources in seaport operations, focusing on developing seaport capabilities for the storage, handling, and bunkering of greener fuels such as green hydrogen, green ammonia, green methanol/ethanol, among others.
21. Minimize carbon and other harmful emissions by adopting an Eliminate, Reduce, and Control (ERC) approach, aiming to protect the local community, ecology, and environment within and around the port areas.
22. Minimize waste generation by implementing the principles of Refuse, Reduce, Reuse, Repurpose, and Recycle- (5R concept) to achieve zero waste discharge from port operations.
23. Conduct appropriate environmental impact assessments for both seaport projects and seaport development plans to ensure the identification and mitigation of potential environmental impacts.

24. Encourage continuous improvement in the seaport environment and its environmental management practices.
25. Promote monitoring activities based on Environmental Performance Indicators to objectively measure progress in implementing environmentally sound practices within the seaport.
26. Facilitate environmental reporting as a means of effectively communicating the positive environmental achievements and behaviours of the seaports to stakeholders.
27. Enhance communication efforts to raise awareness with seaport stakeholders and highlight the environmental improvements accomplished by the seaports.
28. Seaports should strive for transparency by regularly reporting their sustainability efforts and progress. This includes publishing sustainability reports, disclosing environmental performance data, and communicating their sustainability achievements to stakeholders.
29. Employee Training and Awareness: Investing in employee training and awareness programs is essential for fostering a culture of sustainability within the seaport. Providing education on sustainable practices, promoting environmental/social awareness, and encouraging employee participation in sustainability initiatives can help create a more environmentally conscious workforce in seaports.
30. Collaboration and Stakeholder Engagement: Seaports should actively engage with stakeholders, including seaport users, local communities, and environmental organizations, to foster collaboration and gather input on sustainable practices. This collaborative approach can lead to the development of innovative solutions and ensure the implementation of sustainability initiatives that align with the needs and expectations of all seaport stakeholders.
31. Environmental Training and Certification: Seaports can invest in specialized training programs for employees to enhance their knowledge and skills in environmental management. Encouraging employees to obtain relevant certifications, such as ISO 14001 (Environmental Management System), can demonstrate the seaport's commitment to sustainability and ensure a systematic approach to environmental stewardship.
32. Environmental Research and Innovation: Seaports can support research and innovation in environmental sustainability by collaborating with universities, research institutions, and technology providers. This can lead to the development

and implementation of cutting-edge solutions for environmental challenges faced by seaports, such as alternative fuels, autonomous operations, and advanced waste management systems.

33. Continuous Improvement and Benchmarking: Seaports should regularly review and assess their sustainability practices against global maritime industry benchmarks and best practices. This enables them to identify areas for improvement, learn from other leading seaports, and strive for continuous improvement in their sustainability performance.
34. Incentive on the use of low-emission vehicles for cargo transport within the seaport area, promote intermodal transportation options to reduce truck congestion and emissions in port areas and implement efficient cargo handling processes to minimize idle times and optimize logistics operations.
35. Green Innovation and Pilot Projects: Seaports can encourage green innovation by supporting and promoting pilot projects that test and implement new sustainable technologies and practices are introduced in maritime sector/seaport operation based allied areas. This can include collaborating with technology providers, start-ups, and research institutions to pilot and showcase innovative solutions that can improve environmental performance and sustainability in port operations.
36. Collaboration and Knowledge Sharing: Seaports should actively participate in industry networks and collaborations to share best practices and lessons learned in these aspects. By engaging with other seaports, industry associations, and sustainability organizations, seaports can learn from each other, share success stories, and collectively drive positive change in the maritime sector.
37. Identify the potential for seaports to enhance disaster resilience and promote sustainable development in India. By adoption of disaster risk reduction strategies which includes early warning systems and evacuation plans, promotion of sustainable coastal development initiatives towards enhancing of the resilience of coastal regions and reduction in their vulnerability to natural disasters.
38. Adoption of sustainable corporate social responsibility practices could enhance seaport sustainability in India by promoting social and environmental responsibility and adoption of sustainable corporate social responsibility practices, such as enhancement of stakeholder engagement processes, development of sustainability-oriented business strategies, promotion of community development initiatives to enhance the economic, environmental and social performance of port operations.

39. Development of health, safety, and security aspects in port area through subsidizing medical supplies for the maritime workforce and medical facilities to seaport employees, dependents and all concerned stakeholders; providing safety equipment's to workers in port to avoid disasters/accidents and training workers/stakeholders on safety related aspects; ensure proper physical and virtual security around seaport area with proper monitoring of activities in seaport area.
40. Sustainable maritime development of stakeholders & collaboration activities through support for complete operational functionality of maritime chain, development of marine clusters, addressing of financial distress of the maritime stakeholders in case of COVID-19 type of situation by provisionally restoring the maritime transport services, environmental protection initiatives, community development, information sharing by various maritime stakeholders, training & education on COVID-19 through knowledge exchange & conference, job creation process, stakeholder support & participation, allocation of resources, proper decision making.
41. Developing proper shipping related policies, streamlining the process and strategic measures to fit diverse contingencies by complying with standard operational procedures, congestion reduction and capacity building.
42. Support with maritime resilience planning which includes development of maritime crisis cell, resilience infrastructure development, develop business continuity plan & disaster management plan for the emergency circumstances to handle critical activities of maritime supply chain and port logistics.
43. Enabling digitization & smart technologies in maritime chain activities through maritime service automation activities, accessing of the document in digital form across the supply chain, usage of intelligent systems -Artificial Intelligence, Internet-of-Things, big data, block-chain technologies for maritime chain activities.
44. Investment in maritime supply chain research & development projects &concept of innovation through reactivating/ new investment projects, Industry-academia inter-disciplinary research, and collaboration with all concerned seaport stakeholders.

5.23 Discussions & Implications

Sustainability development agendas are witnessing significant growth on a global scale. The idea of seaport sustainability in India has been commonly introduced to the area of the maritime and seaport industry from a financial and environmental viewpoint (PIB, 2021; IPA, 2020). Despite the progress made, a crucial question remains: how can major seaports in India achieve sustainability across various seaport practices and key performance indicators? This research study addresses this question through quantitative primary data analysis. The study focuses on developing a holistic sustainability framework based on initiatives and practices related to environmental, economic, and social dimensions.

Additionally, it includes sustainability performance assessment in seaport supply-chain aspects, considering both internal and external customers of the port. Key performance indicators are identified to evaluate and manage seaport sustainability performance initiatives effectively. Through this comprehensive approach, the study aims to provide valuable insights and guidance for seaports in India seeking to enhance their sustainability practices and performance (Senegar,2018; Gupta,2015).

The main focus of this research is to establish a connection between seaport sustainability performance dimensions and their corresponding key performance indicators in order to promote comprehensive seaport sustainable development. Through the utilization of exploratory factor analysis (EFA), key criteria for sustainable practices were identified across five dimensions: economic, environmental, social, port internal sustainability, and port customer sustainability. Additionally, thirty-seven KPIs associated with these dimensions were identified. Subsequently, through the application of structural modeling (SEM), the research established relationships between the relevant factors and key performance criteria, yielding significant results. This groundbreaking research study is the first of its kind in the Indian seaport context and maritime domain. It successfully identified key performance indicators (KPIs) related to comprehensive seaport sustainability aspects and examined their contribution to the sustainable development of major seaports in India. The findings of this study hold significant contributions and implications for universal seaport sustainability, as well as maritime and related sustainability programs in various nations.

The research results are also consistent with Lu et al. (2016, 2022) study at other international seaports or container terminal. This research also identified a positive and significant relationship between the internal port sustainability process and customer satisfaction. Nevertheless, it must be ensured that improvements in internal seaport processes related sustainability of seaport supply chain will be helpful in satisfying the customers, and port stakeholders (Yang,2019; Adegoke,2019). Customer satisfaction in seaport context also is essential in seaport sustainability performance of maritime seaport programs is directly related to the number of customers receiving the prescribed (Lu, 2016; Lam, 2019; Ha, 2018; Narasimha PT,2022; Roh,2012).

Thus, the research assessment structure will be positive for macro assessment basis to for the balanced vision of seaports responsibilities in local society and major seaport related stakeholders in India (IBEF, 2022). However, the research survey and expert discussions revealed certain challenges that hinder the improvement of seaport sustainability performance in India. These include resource constraints, inadequate adoption of modern technology, and limited knowledge sharing among maritime seaport stakeholders. The study confirms the positive relationship between internal port processes and the three dimensions of port sustainability. In particular, effective communication of sustainable development issues with port staff and active involvement of employees in sustainability policies are crucial for achieving sustainable outcomes.

Based on these findings, it is recommended that seaports collaborate closely with their staff to establish sustainability goals and regulations. Additionally, there should be a clear organizational structure that delineates responsibility for sustainability initiatives, and employees should be engaged in training programs to effectively implement sustainability practices. By fostering a culture of sustainability within seaport organizations and involving employees at various levels, the overall sustainability performance can be enhanced Acciaro et al. (2014). The findings reveal a positive association between internal and external sustainability collaboration and sustainability performance, encompassing environmental, social, and economic aspects. Notably, internal sustainability practices exhibit a stronger influence on sustainability performance compared to external sustainability collaboration. This underscores the significance of establishing robust internal sustainability practices as a means to enhance overall sustainability performance. Seaport management is therefore encouraged to formulate sustainability management strategies that integrate targeted internal resources, competences, and capabilities (Munagpan, 2019; Ku, 2021; Wang, 2019).

This study further conceptualizes a system for a seaport to widen into a holistic sustainably seaport based on improvement structure. Using this structure as a focal point, the assessment to formulate and execute specific sustainable seaport development practices which seaport manager needs to consider from various seaport related stakeholder's perspectives (MIV, 2030; Senegar, 2017; Balasubramiam, 2019; UNCATD, 2019). From the policy viewpoint, the findings of this research and the related recommendation decision framework of this research study offer valuable assistance to maritime researchers in broader aspects of sustainability in the Indian seaport context. Based on this research structure developed in this study; consideration of an all-inclusive and organized decision support system is possible towards the development of sustainable seaports.

Since, seaport sustainability-related dimensions are prioritized with significance by seaport managers, this research will assist in the areas of maritime research which should be decisive for the development of seaport sustainably. This research study contributes equally to existing literature and also to practices involved in various seaport organizations towards extending sustainably aspects along with the involvement of various seaport stakeholders.

However, with the COVID-19 epidemic, the maritime policy-making organizations and seaports emphasized on the evolution to an eco-friendly and inclusive economy considering social aspects and seaport supply chain stakeholders (WPSP, 2021; Zhang, 2020; Merouani, 2021; Devran Yazır et. Al (2020)). This research study framework can consequently support seaport managers and other maritime policymakers to manage this paradigm shift. For carrying out seaport sustainability assessment properly, attempts should be made to change and improve the seaport stakeholder's insights and understanding towards sustainable seaport development aspects.

Further from the comprehensive findings of this research study, a sustainable development seaport needs to formulate and execute seaport sustainable related activities involving stakeholders of the seaports. Seaport managers also need to decide on how to balance various sustainability-related practices and activities of seaports, considering the complex network of seaport related stakeholders and their views on sustainability aspects. In the present scenario in the seaport sector, investments in social dimension-related aspects overhead in investment and infrastructure are extremely been highlighted in priority considering sustainability. To construct efficient & effective infrastructure development for a sustainable seaport, it is significant to assess the sustainable seaport development dimensions and indicators involving structural and functional processes constantly. Considering the primary seaport dimensions and sustainability-related practices that have surfaced from the research results, policies that can sustain the abilities of the global major seaport organizations can be suggested.

The results of this research study can also further assist in developing medium and long-term sustainable strategies for each seaport organization by dynamically identifying responsibility to develop and progress on the seaport environment aspects and to contribute to the local society. The results of this research study will also support in making excellent macro decisions by seaport authorities to make the best use of the constructive effects of social and environmental values and also economic aspects of maritime supply chain collaboration in the present development plan of global seaports.

Seaport authorities can determine the impact on the local community caused by seaports to know how many society-related and local community-related changes have transpired due to attribution of seaport-related activities, to become general practices for all the seaports.

Seaports must also put more effort with the aim at developing a sustainability framework and guidelines for seaport stakeholders through preparing a business continuity plan, logistics policy, development of the consolidated seaport stakeholder institutional framework, and disaster management plan for the emergency circumstances arising in the seaport perspective (Lu, 2021; Wang,2019; Ha,2018, MIV 2030, 2019).

The basic framework that outlines the pathways for various seaport sustainability dimensions in this research study are as highlighted below: -

a. Seaport Sustainability Pathways: This includes Conceptual Framework encompasses several key components. It integrates Seaport Environmental indicators, covering Emissions Reduction, Energy Efficiency, Waste Management, and Water Quality. Additionally, Seaport Social indicators include Employee Well-being, Community Engagement, Diversity and Inclusion, and Labour Practices.

   Within this framework, there are distinct pathways for enhancing Seaport Economic and Operational Efficiency KPIs. This involves improved energy efficiency and emissions reduction, resulting in cost savings and regulatory compliance. Operational efficiency enhancements lead to reduced turnaround times, increased port capacity, and subsequently, boosted revenue and reduced costs.

b. Customer Relations Pathway: This emphasizes positive social indicators like community engagement and diversity, fostering a strong reputation which attracts responsible customers, opening avenues for increased business opportunities.

c. Employee Productivity and Satisfaction Pathway: This connects positive social indicators with higher job satisfaction and productivity. Enhanced employee performance benefits operational efficiency and productivity, improving coordination and communication with stakeholders.

d. Risk Mitigation and Regulatory Compliance: This are integral pathways. Robust environmental indicators lead to regulatory compliance, reducing risks of fines and operational disruptions, ensuring continuity.

e. Long-Term Resilience and Adaptability Pathway: This acknowledges the impact of environmental sustainability on climate change resilience. Positive social indicators forge a supportive local community, aiding the port in adapting to changing circumstances and challenges both internally and with external customers.

By understanding these seaport sustainability pathways, seaport management can make informed decisions, allocate required resources effectively, and design strategies that can leverage the interconnectedness of environmental, social, economic, port internal and, port customer related dimensions and its related key performance indicators. It is also essential that this framework should be adapted to the specific context of the seaport and its location, considering its unique stakeholders, operations, and goals leading to improvement in overall improvement in seaport sustainability performance.

In this research study it is also observed that there is indeed a trade-off between seaport economic sustainability and seaport environmental sustainability. Balancing these two seaport sustainability dimensions can be challenging due to conflicting priorities and resource limitations within the seaport settings. Some of the common trade-offs that might arise in seaport area are as follows: Investment Costs; Operational Efficiency (balance between seaport efficiency and emissions reduction complex in nature); Infrastructure Development; Regulatory Compliance; Technological Transition; Cargo Volume and Type; Land Use Conflict; Short-Term vs. Long-Term Gains; Stakeholder Expectations and Competitive Pressures. Managing the above trade-offs requires careful planning, innovative solutions, and a holistic view of seaport sustainability considering the port stakeholders. Integrated decision-making processes that consider economic, environmental, and social impacts can help identify win-win opportunities that align with both economic and environmental sustainability goals. It is also important to recognize that these trade-offs aren't always binary; creative strategies can often reconcile conflicting priorities and lead to outcomes that benefit both seaport environmental and seaport economic dimensions. Also, the relationship between environmental and social sustainability performance and their influence on internal and economic sustainability within a seaport domain is understood through a mediation framework:

- **Environmental sustainability performance:** Implementing environmentally friendly practices positively impacts various stakeholders' perception of the seaport. Improved environmental performance can result in compliance with stringent environmental regulations and standards, reducing the risk of fines and legal issues.

- **Social sustainability performance:** Ensuring health and safety measures, and community engagement and stakeholder interaction creates a positive social impact for stakeholders and local communities which can mitigate opposition to expansion plans or regulatory changes, contributing to long-term stability.
- **Internal sustainability performance:** Adopting environmentally and socially sustainable practices can optimize internal operations, leading to increased operational efficiency, increase in profits and reduced resource consumption of seaports. The relationship between internal sustainability performance and external sustainability performance in a seaport context is interconnected and crucial for achieving overall sustainability goals
- **Economic sustainability performance:** Combined effect of improved internal sustainability performance and positive stakeholder perceptions can lead to increased revenue streams, increased operational and logistics efficiency and reduced operational costs and stronger customer relationships with minimized regulatory risks contributing to improved operational/ financial stability.

Environmental and social sustainability performance of ports mediate the relationship between seaport operations and economic sustainability. Positive outcomes in environmental and social dimensions translate into improved internal processes and stakeholder relationships and drive economic benefits for the port. This holistic approach enhances ports profitability, resilience, reputation, and ability to adapt to changing market conditions and regulatory requirements.

5.24 Summary

To summarize, this chapter deals with the methodology applied in the proposed study, including a thorough discussion of the research design. Design of sampling, data gathering methods, research tools employed, and requirements for the SEM model to function systematically. This section also elaborates on the primary data research analysis and interpretation of the results. These are addressed using a measuring model, a structural model, and relating discussion of research question, objective, and hypotheses with the research results.

CHAPTER 6

DETERMINING PORT SUSTAINABILITY PERFORMANCE MEASUREMENT BY BENCHMARKING THE EFFICIENCY

6.1 Overview

This study provides an opportunity to assess the sustainability performance of major seaports on the west coast of India that primarily handle liquid cargo. It aims to identify best practices and benchmark these seaports, enabling other seaports to learn from their success and achieve higher performance improvements. The study utilizes a secondary-based quantitative data approach, focusing on evaluating the technical efficiencies of the seaports using the Data Envelopment Analysis (DEA) technique. This analysis involves examining various input and output variables related to the environmental, economic, and social dimensions that significantly influence the development of seaport sustainability.

By assessing environmental efficiency, economic efficiency, social efficiency, and overall sustainable efficiency within a specific timeframe of the seaports in terms of sustainability. The proposed DEA model considers both desirable and undesirable outputs for seaports. This comprehensive approach enables seaport management and other relevant stakeholders to make strategic and tactical decisions that will enhance their sustainability agendas. By understanding the factors that contribute to the overall sustainability performance, seaport authorities can identify areas for improvement and implement targeted measures to achieve better sustainability outcomes.

6.2 Identification of Seaport Sustainability Benchmarking Indicators

Selecting the appropriate variables is a fundamental step in developing the research model as it greatly influences the accuracy of the analysis (Wang et al., 2003). This process involves identifying and specifying two types of variables: input variables and output variables. In the context of liquid cargo seaports, it is logical to exclude the volume of cargo due to its collinearity with port throughput and the number of vessel calls. Therefore, previous research studies have focused on port throughput as a representative indicator. Regarding the environmental and social dimensions, indicators that align with these objectives include solid waste, water pollution, soil pollution, biodiversity, greenhouse gases, other air pollution gases, noise pollution, and congestion (Guimaraes et al., 2014; Strezov et al., 2016). Among these dimensions, the carbon dioxide equivalent (CO_2eq), comprising carbon dioxide (CO_2), methane (NH_4), and nitrogen oxide (N_2O), has been chosen. Additionally, previous research has also considered indicators such as sewage emissions, congestion, and accidents (Adgeoke, 2018).

The study encompasses both input and output variables, which are as follows:

a. ***Input Variables:*** Input variables can be categorized into labor, capital, and operational factors. Examples of indicators representing input variables include terminal area, quay length, berth length, storage capacity, piers, and handling equipment (e.g., gantry cranes, yard cranes, forklifts), berth accessibility, berth occupancy, operating hours, equipment age and maintenance, total number of equipment, annual cash investment, waiting time, and quayside water depth.

   However, due to the frontier characteristics of Data Envelopment Analysis (DEA) and collinearity among these variables, previous research studies have restricted the indicators to the major ones that best represent the model. The objectives of the study focus on a quantitative perspective, analyzing and examining the variables that have the most significant impact on seaport sustainability development. The indicators have been identified and categorized into three macro dimensions: economic, environmental, and social indexes as desirable/undesirable outputs (Adegoke, 2018).

b. ***Output Parameters:*** The primary objective revolves around sustainability. Consequently, the output aims to maximize the positive economic elements and minimize the harmful elements of the environmental and social dimensions that are simultaneously generated. These output parameters include profits, volume of cargo, seaport throughput, turnaround time of vessels, and the number of cruise passengers. The selection of output variables has been narrowed down to sets of variables representing economic, environmental, and social indexes as desirable/undesirable outputs, respectively (Adegoke, 2018).

6.3 Development of Data envelopment analysis (DEA) Model

In many research studies, various models have been employed to assess performance using Data Envelopment Analysis (DEA), a non-parametric mathematical programming method for frontier estimation introduced by Charnes, Cooper, and Rhodes (1978).

6.3.1 Overview of DEA Analysis

The objective of Data Envelopment Analysis (DEA) is to construct a non-parametric envelopment frontier that encompasses or lies below the data points. DEA is a non-parametric method that assesses the relative efficiency of homogeneous decision-making units (DMUs) with multiple inputs and multiple outputs. DEA is utilized to measure the productive efficiency of DMUs and has a strong connection to production theory in economics. It serves as a benchmarking method in various operations management contexts, where a set of events or operations is selected to benchmark performance of manufacturing or other service-related processes.

In benchmarking, the efficient DMUs, as determined by DEA, may not necessarily form the production frontier and may instead be relatively close to the best-practice frontier. Let's consider N seaports, also referred to as decision-making units (DMUs), with K inputs and M outputs. These inputs and outputs can be represented by the vectors xi and yi for the i-th DMU, respectively.

The input data for all N DMUs can be represented by the K*N input matrix X, and the output data by the M**N output matrix Y. DEA can be expressed in ratio form, where we calculate the ratio of all outputs to all inputs for each DMU. This can be mathematically represented as the equations in the given DEA framework can be represented as follows:

$$(1)\ n \geq \max\{3(m+s), m*s\}$$

where n, m, and s represent the number of decision-making units, inputs, and outputs, respectively.

The ratio form for each DMU in DEA is given by:

$$(2)\ u'yiv'xi$$

where u is an M*1 vector of output weights, v is a K*1 vector of input weights, and yi and xi represent the output and input vectors for the i-th DMU, respectively.

To determine the optimal weights, the linear programming system of equations is as follows:

(3) $maxu,(u'yiv'xi)$

subject to:

(4) $u'yjv'xj \leq 1$, for j = 1, 2, ..., N

(5) $u \geq 0$

In the duality form of linear programming, the equivalent system of equations is given by:

(6) $min\theta,\theta$

subject to:

(7) $subject\ to - yi + Y\lambda \geq 0$

(8) $\theta xi - X\lambda \geq 0$

(9) $\lambda \geq 0$

where θ is a scalar representing the efficiency score for the ith DMU, Y and X are matrices with columns yi and xi, respectively, and Λ is an N*1 vector of constraints. The value of θ represents the technical efficiency, and if it is equal to 1, the DMU is considered technically efficient according to Farrell (1957). The number of DMUs, N, determines the number of times the linear programming problem must be solved, with each solution generating a θ value for each DMU.

6.3.2 Variable Return to Scale Model using the BCC Approach & Scale Efficiency

Variable Return to Scale (VRS) model assumes that the input-to-output ratio can vary depending on the size of the seaports. This means that the VRS model allows for more or equal technically efficient decision-making units (DMUs) compared to the Constant Return to Scale (CRS) model. As a result, some ports that were considered inefficient under the CRS model can become efficient in the VRS model as highlighted in figure 6.1. To model this mathematically, the convexity constraint N1'λ=1 be added to the CRS model.

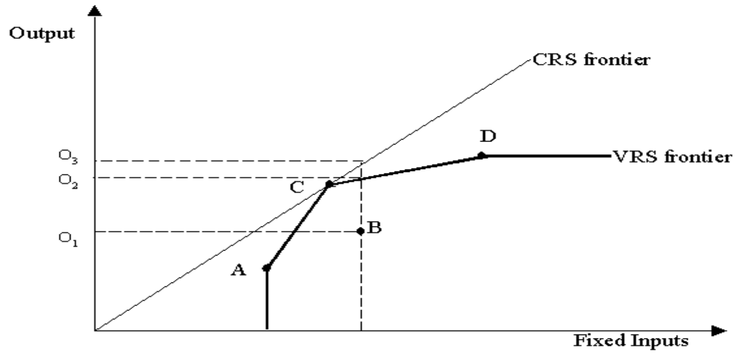

Figure 6.1: CRS and VRS frontiers; Source: Fare and Lovell, 1978

It must be distinguished that the input and output-oriented measures will produce the same technical efficiency when applied on CRS but different measures when applied to VRS (Fare and Lovell, 1978)

6.4 Seaport Sustainability Benchmarking with Results

This research study focuses on benchmarking the sustainability performance of four major liquid cargo seaports on the west coast of India. The study utilizes secondary data from the financial years 2016-17 to 2021-22, resulting in 24 observations for the four major seaports. The research aims to provide a modeling framework for benchmarking seaport sustainability performance and identifying areas for improvement. It analyzes ten input parameters and ten output parameters related to the social, economic, and environmental dimensions of sustainability.

Data Envelopment Analysis (DEA) is applied to evaluate the performance of the seaports, considering both desirable and undesirable outputs under constant returns to scale (CRS-CRR model) and variable returns to scale (VRS-BCC model). The goal is to minimize the undesirable attributes of seaport performance and gain insights into the evolutionary progress of these four major seaports over time. DEA allows for the estimation of potential improvements that can be made by inefficient seaports, thereby measuring their sustainability performance. By employing both the CRS-CRR and VRS-BCC methods, the study captures different scale assumptions and considers the changing nature of production technology, including increasing, constant, and decreasing returns to technical scale.

Table 6.1: Input & output parameters for seaport sustainability in Indian major seaport context

Seaport sustainability Input parameters	**Seaport sustainability Output parameters**	**References**
1. Number of vessels sailed in Port: Economic Dimension- operational 2. Number of Tugs, cranes and other machineries in Port: Economic Dimension- operational 3. Port Capital Assets (including Capital WIP) in Rs. Economic Dimension- operational 4. Number of Port Employees: Social/Economic Dimension 5.Number of Employees undergone Trainings Conducted by Port: Social/Economic Dimension 6. Port Medical related Expenditure in Rs.: Social/Economic Dimension 7.Port Security related Expenditure in Rs.: Social/Economic Dimension 8. CSR Expenditure in Rs.: Social/Economic Dimension	1. Annual cargo throughput in Tonnes: Economic Dimension-operational 2. Average Turn Round Time (ATRT) in days: Economic Dimension-operational 3.Average Output Per Berth Day (AOPB) in tonnes: Economic Dimension-operational 4. Annual Net Surplus/Profit of Port in Rupees: Economic Dimension 5. Number of Accidents in Port Area: Social/Economic Dimension 6. Average Noise Level (Ldn) at Port area in dB (A): Environment-Social Dimension 7. Port Health Facility Dependents (Total no. of In-patients and Out-patients to Port Hospital): Social/Economic Dimension	Jinag(2020);Lam (2018); Zhou(2007); Sun(2016); Kag(2017);Chen(2018); Adegoke(2018); Bergmans (2014); Hung (2010);Lee(2014); Lirn(2012); Perera(2016); Schipper(2017); Yan (2010); Zhang (2008); Zhou (2007

9. Port Electricity Charges in Rs.: Economic/Environment Dimension 10. Port Environmental monitoring expenditure in Rs.: Economic/ Environment Dimension	8. Air Quality Index (AQI) data in Port as per CPCB (PM10, PM2.5, CO, NO2, SO2 data): Environment Dimension 9.pH level of drinking Water in Port Area: Environment Dimension 10.pH level of Sewage effluent treated water in Port Area: Environment Dimension	

Source: Authors Secondary Data Research

6.4.1 Data Description

The input and output parameters provided are essential components for measuring seaport sustainability in the Indian major seaport context. Each input and output parameter used in this research study is detailed as below:

a. Input Parameters:

1. *Number of vessels sailed in port:* This parameter indicates the volume of maritime trade and the utilization of port infrastructure.
2. *Number of tugs, cranes, and other machineries in the port:* It reflects the level of mechanization and technological capabilities of the port, which can impact operational efficiency and productivity.
3. *Port capital assets:* This parameter represents the value of physical assets owned by the port, including land, buildings, equipment, and infrastructure. It is an indicator of the port's financial stability and capacity for future development.
4. *Number of port employees:* This parameter signifies the size of the port workforce and reflects the level of employment generated by the port.
5. *Number of employees undergone trainings conducted by the port:* It highlights the port's investment in human resource development and the enhancement of employee skills and knowledge.
6. *Port medical-related expenditure:* This parameter refers to the healthcare expenses incurred by the port for its employees and their dependents, indicating the port's commitment to employee well-being and occupational health.
7. *Port security-related expenditure:* It represents the resources allocated to ensure port security, including personnel, equipment, and infrastructure, to safeguard against potential threats and risks.
8. *Corporate Social Responsibility (CSR) expenditure*: This parameter indicates the port's contribution to social and environmental causes beyond its core operations, reflecting its commitment to sustainable and responsible practices.
9. *Port electricity charges:* It represents the energy consumption and associated costs of the port, which can be influenced by energy efficiency measures and the adoption of renewable energy sources.

10. *Seaport environmental monitoring expenditure:* This parameter signifies the resources allocated to monitor and assess environmental impacts in the port area, including air quality, water quality, noise levels, and adherence to environmental regulations.

b. Output Parameters

1. *Annual cargo throughput of the port in tonnes:* This parameter measures the total volume of goods handled by the port in a year, reflecting its role in facilitating trade and economic growth.
2. *Average Turnaround Time (ATRT) in days:* It represents the average time taken for a vessel to complete its operations in the port, including loading, unloading, and other related activities. A shorter ATRT indicates efficient port operations and improved vessel turnaround.
3. *Average Output per Berth Day (AOPB) in tonnes:* This parameter quantifies the efficiency of berth utilization, indicating the amount of cargo handled per day per berth. A higher AOPB suggests optimal utilization of port infrastructure.
4. *Annual net surplus/profit of the port:* It indicates the financial performance of the port, reflecting its revenue generation, operational efficiency, and cost management.
5. *Number of accidents in the port area:* This parameter measures the safety performance of the port and highlights the effectiveness of safety measures and protocols in place.
6. *Average noise level (Ldn) at the port area:* It represents the ambient noise levels in the port area and helps assess the potential impact on the surrounding environment and nearby communities.
7. *Port health facility dependents:* This parameter captures the number of individuals, including port employees and their dependents, utilizing the port's health facilities. It reflects the availability and accessibility of healthcare services in the port area.
8. *Air Quality Index (AQI) data:* It measures the quality of air in the port area, including the concentration of pollutants such as PM10, PM2.5, CO, NO2, and

SO2 and calculation of AQI format is illustrated in Appendix-E. AQI data helps assess the environmental impact and air pollution levels in the port vicinity.

Figure 6.2: EIA study in Ports to monitor Air Quality, Noise level detection and Water Quality; Source: Indian major seaports EIA data in port website

9. *pH level of drinking water in the port area:* This parameter assesses the quality of drinking water available within the port area, ensuring compliance with health and safety standards. As per CPCB guidelines, if Ph value is less than seven water quality is acidic and if value is greater than seven it is alkaline.
10. *pH level of sewage effluent treated water in the port area*: It reflects the effectiveness of the port's wastewater treatment processes and the quality of discharged effluent, indicating compliance with environmental regulations and protection of water resources. As per CPCB guidelines, if Ph value is less than seven water quality is acidic and if value is greater than seven it is alkaline

These input and output parameters provide a comprehensive framework for assessing seaport sustainability in the Indian major seaport context. Regular monitoring and improving these indicators can help seaports align their operations with sustainability goals, enhance their performance, and contribute to sustainable development.

6.4.2 Benchmarking of indicators for seaports under Research Study

This research examines the environmental management efficiency indicators, economic efficiency indicators and social management efficiency indicators for four major west coast seaports in India by identifying the values of environmental, social and economic key performance data. A comprehensive collection of secondary data related to seaport sustainability indicators was obtained from various sources. These sources included platforms of Indian major seaport authorities, sustainability and administrative reports specific to each seaport, environmental impact assessment reports, and pollution control board databases and related websites.

The resulting data was utilized to calculate the technical efficiency, which represents the performance of decision-making units (DMUs). A value of 1 or 100% indicates that the DMUs are technically efficient. If the value is less than 1 or less than 100%, it implies that the DMUs need to improve their efficiency by implementing strategies related to sustainability dimensions and key performance parameters. The aim is to enhance efficiency and strive towards achieving a value of 1 or 100% (Adegoke, 2018). The value of N represents the number of DMUs, which determines the number of times the linear programming problem needs to be solved. Each solution generates a θ value for each DMU, allowing for the assessment of efficiency.

Table 6.2: Input and Output Parameters of Seaport Sustainability for Four Major West Coast Liquid Cargo Ports: Analysis from FY 2016-17 to FY 2021-22

Parameters & Port -Years	Output Parameters (OP-1 to OP-10)										Input Parameters (IP-1 to IP-10)									
Data/ Port Name: C-CPA, cochin; D-DPA, Kandla; NMPA, Mangalore; M-MBPA-Mumbai	Port Annual Throughput in MT	Avg. Turn Round Time (ATRT) in Days	Avg. Output Per Berth day (AOPB) in Tonnes	Port Net Surplus in Crore Rs.	No of Accidents in Port area	Total no of In-patients & Out-patients visiting Port Hospital	Avg. Noise Level (Ldn)in Port Area dB(A)	Air Quality Level in Port area	Ph Level of Drinking/Ground/Surface Water	Ph Level of Seawater Water/Treated effluent in Port	No of Vessels sailed to Port	No of Tugs, cranes & other machineries in Port	Port Capital Assets (including Capital WIP) in Cr. Rs	No. of Port Employees	No. of Trainings Conducted in Port	Port Medical Expenditure in Crore Rs.	Port Security Expenditure in Cr. Rs.	Port contribution to CSR Fund in Crore Rs.	Port Electricity Charges in Crore Rs.	Environmental Monitor Expenditure in Cr. Rs
2016-17-C	25.07	1.99	17450	-27.17	2	87136	49.50	70	7.52	7.80	1653	36	713.69	1805	278	4.83	19.07	0.53	23.93	2.16
2016-17-D	105.4	2.06	18404	693.85	5	120492	51.10	68	8.17	7.57	2568	67	1522.67	2984	297	16.88	28.74	2.6	30.45	0.28
2016-17-M	63.05	2.49	8413	-326.85	14	192429	63.55	89	7.5	7.41	5225	80	970.06	9445	1636	37.46	29.91	0.69	23.7	1.4
2016-17-N	39.95	2.35	17094	144.25	0	61545	60.04	48	6.37	7.18	1455	22	1080.51	945	109	3.93	16.76	1.346	6.09	2.57
Mean	58.37	2.22	15340.25	121.02	5.25	115400.5	56.05	68.75	7.39	7.49	2725.25	51.25	1071.73	3794.75	580.00	15.78	23.62	1.29	21.04	1.60
Std. Dev	35.03	0.24	4651.17	428.65	6.18	56740.96	6.82	16.76	0.75	0.26	1735.58	26.85	337.62	3858.45	709.05	15.62	6.67	0.94	10.45	1.00
Min	25.07	1.99	8413.00	-326.85	0.00	61545.00	49.50	48.00	6.37	7.18	1455.00	22.00	713.69	945.00	109.00	3.93	16.76	0.53	6.09	0.28

Max	105.4	2.49	18404.00	693.85	14.00	192429.0	63.55	89.00	8.17	7.80	5225.00	80.00	1522.67	9445.00	1636.0	37.46	29.91	2.60	30.45	2.57
Skewness	0.95	0.22	-1.91	0.80	1.38	1.02	0.18	-0.09	-0.93	0.00	1.57	-0.03	0.78	1.73	1.91	1.26	-0.08	1.26	-1.44	-0.81
Range	80.33	0.50	9991.00	1020.7	14.00	130884.0	14.05	41.00	1.80	0.62	3770.00	58.00	808.98	8500.00	1527.0	33.53	13.15	2.07	24.36	2.29
2017-18-C	29.13	1.87	20880	13.55	4	84083	51.20	61	7.5	7.92	1555	42	709.61	1723	255	3.27	16.69	0.62	24.39	2.01
2017-18-D	110.9	2.07	18531	548.7	5	100502	54.70	66	8.29	7.64	2747	63	1754.75	2586	272	17.8	29.4	7.1	33.2	0.30
2017-18-M	62.83	2.29	9043	-416.5	9	197376	63.80	84	8.3	7.56	5756	79	1044.3	8629	1636	42.58	30.35	0.65	25.1	2.16
2017-18-N	42.06	2.04	16378	190.53	0	60467	61.20	48	6.8	7.45	1388	21	1071.03	837	350	4.05	17.72	2.84	2.97	3.66
Mean	61.25	2.07	16208.00	84.07	4.50	110607.0	57.73	64.75	7.72	7.64	2861.50	51.25	1144.92	3443.75	628.25	16.93	23.54	2.80	21.42	2.03
Std. Dev	35.95	0.17	5118.27	401.15	3.70	60134.61	5.79	14.91	0.72	0.20	2022.32	25.22	438.55	3529.81	673.11	18.36	7.34	3.05	12.93	1.37
Min	29.13	1.87	9043.00	-416.50	0.00	60467.00	51.20	48.00	6.80	7.45	1388.00	21.00	709.61	837.00	255.00	3.27	16.69	0.62	2.97	0.31
Max	110.9	2.29	20880.00	548.70	9.00	197376.0	63.80	84.00	8.30	7.92	5756.00	79.00	1754.75	8629.00	1636.0	42.58	30.35	7.10	33.20	3.66
Skewness	1.19	0.43	-1.26	-0.25	0.00	1.56	-0.13	0.48	-0.75	1.13	1.52	-0.23	1.13	1.76	1.98	1.31	0.00	1.39	-1.41	-0.22
Range	81.86	0.42	11837.00	965.20	9.00	136909.0	12.60	36.00	1.50	0.47	4368.00	58.00	1045.14	7792.00	1381.0	39.31	13.66	6.48	30.23	3.36
2018-19-C	32.02	1.94	22839	19.18	9	77062	50.80	70	7.12	8.13	1600	36	709.25	1574	291	3.88	18.7	0.67	24.48	2
2018-19-D	115.4	3.14	17383	797.35	1	81927	53.40	64	7.9	7.50	2903	51	2159.87	2446	164	18.74	32.4	6.74	10.84	1.78
2018-19-M	60.59	1.43	10409	-600.95	10	190814	62.70	77	7.8	7.00	5849	57	972.58	7597	1661	46.84	34.46	0.39	23.62	1.07
2018-19-N	42.51	1.93	18126	264.07	4	58238	60.04	47	8.17	7.30	1346	31	902.03	732	414	4.1	19.99	3.12	3.08	3.2
Mean	62.63	2.11	17189.25	119.91	6.00	102010.2	56.74	64.50	7.75	7.48	2924.50	43.75	1185.93	3087.25	632.50	18.39	26.39	2.73	15.51	2.01
Std. Dev	37.11	0.73	5125.31	580.08	4.24	60077.36	5.56	12.82	0.45	0.48	2065.52	12.26	658.76	3086.86	693.22	20.20	8.19	2.94	10.37	0.89
Min	32.02	1.43	10409.00	-600.95	1.00	58238.00	50.80	47.00	7.12	7.00	1346.00	31.00	709.25	732.00	164.00	3.88	18.70	0.39	3.08	1.07

Max	115.4	3.14	22839.00	797.35	10.00	190814.0	62.70	77.00	8.17	8.13	5849.00	57.00	2159.87	7597.00	1661.0	46.84	34.46	6.74	24.48	3.20
Skewness	1.44	1.33	-0.65	-0.21	-0.37	1.82	0.01	-1.03	-1.26	0.93	1.42	0.06	1.83	1.70	1.87	1.38	0.03	1.13	-0.46	0.79
Range	83.38	1.71	12430.00	1398.3	9.00	132576.0	11.90	30.00	1.05	1.13	4503.00	26.00	1450.62	6865.00	1497.0	42.96	15.76	6.35	21.40	2.13
2019-20-C	34.03	1.51	23709	21.3	16	73353	52.9	61	7.54	8.24	1600	30	704.83	1394	264	3.69	16.84	0.31	26.78	2
2019-20-D	122.0	2.72	16874	691.83	32	85037	57.8	69	7.33	7.8	3095	48	2279.03	2204	215	21.33	29.04	5.49	10.2	2.01
2019-20-M	60.69	2.56	10993	193.33	12	190531	63.8	80	8.1	7.35	6162	50	993.78	6470	1283	44.02	40.27	0.76	22.27	1.58
2019-20-N	39.14	1.9	15774	210.08	0	54151	60.7	48	8.02	7.20	1392	26	928.78	626	477	5.1	18.93	3 .04	1.06	3.17
Mean	63.98	2.17	16837.50	279.14	15.00	100768.0	58.80	64.50	7.75	7.65	3062.25	38.50	1226.61	2673.50	559.75	18.54	26.27	1.64	15.08	2.19
Std. Dev	40.40	0.57	5244.30	288.06	13.22	61181.66	4.63	13.48	0.37	0.47	2201.32	12.26	712.45	2611.72	495.40	18.78	10.75	2.87	11.68	0.68
Min	34.04	1.51	10993.00	21.30	0.00	54151.00	52.90	48.00	7.33	7.20	1392.00	26.00	704.83	626.00	215.00	3.69	16.84	0.31	1.06	1.58
Max	122.0	2.72	23709.00	691.83	32.00	190531.0	63.80	80.00	8.10	8.24	6162.00	50.00	2279.03	6470.00	1283.0	44.02	40.27	5.49	26.78	3.17
Skewness	1.55	-0.33	0.57	1.46	0.44	1.74	-0.50	-0.20	-0.23	0.61	1.37	-0.07	1.82	1.64	1.70	1.09	0.82	1.68	-0.38	1.47
Range	88.02	1.21	12716.00	670.53	32.00	136380.0	10.90	32.00	0.77	1.04	4770.00	24.00	1574.20	5844.00	1068.0	40.33	23.43	5.18	25.72	1.59
2020-21-C	31.50	2.13	22513	7.2	6	49051	48.4	57	6.8	8.38	1486	30	706.06	1246	107	3.04	16.33	0.639	25.38	1.14
2020-21-D	115.9	3.28	14479	343.2	29	61527	58.3	78	7.38	7.48	3047	47	2624.7	2023	37	18.08	33.6	18.46	13.2	2.38
2020-21-M	53.52	2.73	10694	97.01	13	8279	61.3	89	7.7	7.2	5140	48	1263	5368	178	55.74	39.27	31.72	18.06	1.48
2020-21-N	36.5	1.91	15960	216.09	0	27291	59.4	46	7.49	7.10	1267	30	888.45	482	97	6.16	17.73	3	2.42	3.51
Mean	59.36	2.51	15911.50	165.88	12.00	36537.00	56.85	67.50	7.34	7.54	2735.00	38.75	1370.55	2279.75	104.75	20.76	26.73	13.45	14.77	2.13
Std. Dev	38.86	0.6	4928.03	145.93	12.5	23559.17	5.77	19.5	0.3	0.5	1788.5	10.1	867.65	2152.8	57.79	24.2	11.4	14.52	9.63	1.06
Min	31.50	1.9	10694.0	7.20	0	8279.00	48.4	46.0	6.8	7.1	1267.0	30.0	706.06	482.00	37.00	3.04	16.3	0.64	2.42	1.14
Max	115.9	3.2	22513.0	343.20	29.0	61527.00	61.3	89.0	7.7	8.3	5140.0	48.0	2624.7	5368.0	178.00	55.7	39.2	31.72	25.3	3.51
Skewness	1.67	0.5	0.80	0.30	1.01	-0.30	-1.72	0.00	-1.2	1.5	1.03	0.01	1.60	1.50	0.28	1.60	0.19	0.65	-0.49	0.80
Range	84.40	1.3	11819.0	336.00	29.0	53248.00	12.9	43.0	0.9	1.2	3873.0	18.0	1918.6	4886.0	141.00	52.7	22.9	31.08	22.9	2.37
2021-22-C	34.50	1.91	24457.00	8.90	3.00	47491.00	47.60	54.70	7.39	7.61	1519.00	29.00	712.30	1879.00	23.00	3.02	13.76	0.73	26.07	1.13

20121-22-D	127.10	2.81	16143.00	714.50	4.00	45619.00	53.50	106.00	7.27	7.37	3151.00	38.00	1517.30	2678.00	29.00	15.18	24.27	2.58	30.45	2.36
2021-22-M	59.89	3.21	9507.00	-28.69	19.00	3076.00	61.30	94.50	7.39	7.48	5941.00	60.00	993.89	4583.00	36.00	56.68	40.22	3.16	18.43	1.55
2021-22-N	39.30	2.36	16645.00	281.00	2.00	33679.00	62.40	53.00	6.87	7.26	1326.00	22.00	1484.00	417.00	28.00	5.15	19.13	3.66	2.68	2.26
Mean	65.20	2.57	16688.00	243.93	7.00	32466.25	56.20	77.05	7.23	7.43	2984.25	37.25	1176.87	2389.25	29.00	20.01	24.35	2.53	19.41	1.82
Std. Dev	42.71	0.56	6116.18	342.72	8.04	20526.37	6.97	27.21	0.25	0.15	2134.4	16.5	391.38	1736.4	5.35	25.02	11.4	1.28	12.2	0.59
Min	34.50	1.91	9507.00	-28.69	2.00	3076.00	47.60	53.00	6.87	7.26	1326.0	22.0	712.30	417.00	23.00	3.02	13.7	0.73	2.68	1.1
Max	127.10	3.21	24457.00	714.50	19.00	47491.00	62.40	106.00	7.39	7.61	5941.0	60.0	1517.3	4583.0	36.00	56.6	40.2	3.66	30.4	2.3
Skewness	1.63	-0.1	0.29	1.18	1.94	-1.52	-0.56	0.15	-1.7	0.16	1.24	1.13	-0.42	0.35	0.55	1.75	1.20	-1.33	-1.11	-0.4
Range	92.60	1.30	14950.00	743.19	17.00	44415.00	14.80	53.00	0.52	0.35	4615.0	38.0	805.00	4166.0	13.00	53.6	26.4	2.93	27.7	1.2

Source: Authors Calculations based on Secondary source data of research from Port websites and EIA data of ports

C-CPA, cochin; D-DPA, Kandla; N-NMPA, Mangalore; M-MBPA-Mumbai; OP-1: Port Annual Throughput in MT; OP-2:Average Turn Round Time(ATRT) in Days; OP-3:Average Output Per Berth day(AOPB) in Tonnes; OP-4: Port Net Surplus in Crore Rs.; OP-5:No of Accidents in Port area; OP-6: Total no of In-patients & Out-patients visiting Port Hospital; OP-7: Avg. Noise Level (Ldn)in Port Area dB(A) ;OP-8: Air Quality Level in Port area; OP-9: Ph Level of Drinking/Ground/Surface Water in Port area; OP-10: Ph Level of Seawater Water/Treated sewage effluent in Port area; IP-1: No of Vessels sailed to Port; IP-2: No of Tugs, cranes & other machineries in Port; IP-3: Port Capital Assets (including Capital WIP) in Cr.Rs; IP-4: No. of Port Employees;IP-5: No. of Employees Trained in Port;IP-6: Port Medical Expenditure in Crore Rs.; IP-7: Port Security Expenditure in Cr. Rs.;IP-8: Port contribution to CSR Fund in Crore Rs.; IP-9: Port Electricity Charges in Crore Rs.;IP-10: Environmental Monitor Expenditure in Cr. Rs.

6.4.3 DEA Results and Analysis

In this research study, the problem of benchmarking efficiency of seaport sustainability performance in Indian four major liquid cargo west coast seaports were conducted for three port sustainability parameters of economic, social and environment from financial year 2016 to 2021.There is a significant correlation between input and output variables (value above 0.65 for year 2016 to 2021) in this secondary research along with significant R-squared values for input & output seaport sustainability parameters which is highlighted in Annexure F (Table F1 to F12). The input variables for the period 2016 to 2021 for four major seaports had a much stronger correlation in terms of economic dimension data values than environment dimension and social dimension data values.

These results indicate that, priority from seaport management perspective is primarily focusing on the economic dimension followed by environmental dimension and then on social dimension related indicators. DEA VRS methodology was used in this research study to indicate the measure of the performance improvements with respect to each indicator per seaport. The efficient input targets achieved for DEA-VRS method from the year 2016 to 2021 for four major seaports under study was also analyzed. The research results also indicated that all four major west coast liquid cargo seaports in this research study namely Deendayal Port; Mumbai Port; New Mangalore Port and Cochin Port are with relative efficiency/performance scores ranging from 72.37% to 96.32% values from the period 2016 to 2021. Efficiency and ranks were calculated for sustainability related input dimensions (environmental; social; economic) and overall sustainability performance for four major seaports from year 2016 to 2021 and has been highlighted in Table 6.3.

Table 6.3: VRS-DEA Analysis of Environmental, Social, Economic Efficiency, and Overall Sustainable Performance: Data for Four Major West Coast Seaport DMUs (FY 2016-2021)

Major Port Name	DPA, Kandla	MBPA, Mumbai	NMPA, Mangalore	COPA, Cochin	Average of four ports
Environmental Management Efficiency (FY 2021-22) (with respective ranks) (Post- COVID period)	0.578(4)	0.581(3)	0.791(1)	0.597(2)	**0.633**
Environmental Management Efficiency (FY 2020-21) (with respective ranks) (COVID period)	0.587(3)	0.576(4)	0.748(1)	0.616(2)	**0.631**
Environmental Management Efficiency (FY 2019-20) (with respective ranks) (Pre- COVID period)	0.573(4)	0.582(3)	0.725(1)	0.591(2)	**0.617**
Environmental Management Efficiency (FY 2018-19) (with respective ranks)	0.572(3)	0.566(4)	0.713(1)	0.682(2)	**0.632**
Environmental Management Efficiency (FY 2017-18) (with respective ranks)	0.538(4)	0.555(3)	0.689(1)	0.674(2)	**0.614**
Environmental Management Efficiency (FY 2016-17) (with respective ranks)	0.562(3)	0.527(4)	0.711(1)	0.669(2)	**0.617**
Social Efficiency (FY 2021-22) (with respective ranks) (post-COVID period)	0.647(2)	0.512(4)	0.801(1)	0.589(3)	**0.661**

Social Efficiency (FY 2020-21) (with respective ranks) (COVID period)	0.638(2)	0.534(4)	0.789(1)	0.591(3)	**0.645**
Social Efficiency (FY 2019-20) (with respective ranks) (pre-COVID period)	0.616(2)	0.513(4)	0.735(1)	0.548(3)	**0.603**
Social Efficiency (FY 2018-19) (with respective ranks)	0.602(2)	0.498(4)	0.728(1)	0.541(3)	**0.5922**
Social Efficiency (FY 2017-18) (with respective ranks)	0.615(2)	0.507(4)	0.715(1)	0.538(3)	**0.593**
Social Efficiency (FY 2016-17) (with respective ranks)	0.601(2)	0.515(4)	0.711(1)	0.532(3)	**0.5897**
Economic Efficiency (FY 2021-22) (with respective ranks) (post-COVID period)	0.647(2)	0.512(4)	0.801(1)	0.589(3)	**0.858**
Economic Efficiency (FY 2020-21) (with respective ranks) (COVID period)	0.638(2)	0.534(4)	0.789(1)	0.591(3)	**0.82**
Economic Efficiency (FY 2019-20) (with respective ranks) (pre-COVID period)	0.616(2)	0.513(4)	0.735(1)	0.548(3)	**0.871**
Economic Efficiency (FY 2018-19) (with respective ranks)	0.602(2)	0.498(4)	0.728(1)	0.541(3)	**0.812**

Economic Efficiency (FY 2017-18) (with respective ranks)	0.615(2)	0.507(4)	0.715(1)	0.538(3)	**0.825**
Economic Efficiency (FY 2016-17) (with respective ranks)	0.601(2)	0.515(4)	0.711(1)	0.532(3)	**0.8227**
Overall Sustainable Performance (FY 2021-22) (with respective ranks) (post-COVID period)	0.624(2)	0.535(4)	0.797(1)	0.591(3)	**0.717**
Overall Sustainable Performance (FY 2020-21) (with respective ranks) (COVID period)	0.621(2)	0.548(4)	0.775(1)	0.599(3)	**0.699**
Overall Sustainable Performance (FY 2019-20) (with respective ranks) (pre-COVID period)	0.601(2)	0.536(4)	0.7316(1)	0.562(3)	**0.697**
Overall Sustainable Performance (FY 2018-19) (with respective ranks)	0.592(2)	0.5206(4)	0.723(1)	0.588(3)	**0.679**
Overall Sustainable Performance (FY 2017-18) (with respective ranks)	0.589(2)	0.523(4)	0.706(1)	0.583(3)	**0.677**
Overall Sustainable Performance (FY 206-17) (with respective ranks)	0.588(2)	0.519(4)	0.711(1)	0.5776(3)	**0.676**
Pure Technical Efficiency _VRS (BCC efficient scores) from year FY-2016 to FY-2021-22	**0.8971**	**0.7237**	**0.9613**	**0.7352**	**0.829**

Sources: Authors Calculations based on Secondary source data of research

6.4.4 The Impact of COVID-19 on Seaport Sustainability Benchmarking

The research data examines and analyzes efficiency indicators for four major west coast seaports in India by identifying the Environmental Management Efficiency, Social Efficiency, Economic Efficiency and overall sustainability performance for the four major west coast seaports in different fiscal years from 2019 to 2021 (pre-COVID period, COVID period and post-COVID period) is analyzed. The interpretations are as follows: -

a. **Environmental Management Efficiency:** For FY 2021-22 (Post-COVID period) average Environmental Management Efficiency for the four major seaports is 0.633, indicating an above-average level of environmental management practices. NMPA, Mangalore stands out with the highest Environmental Management Efficiency score of 0.791, while DPA, Kandla has the lowest score of 0.578. For FY 2020-21 (COVID period) average Environmental Management Efficiency for the four ports is 0.631, similar to the year FY 2021-22. NMPA, Mangalore continues to have the highest score of 0.748, while MBPA, Mumbai has the lowest score of 0.576. For FY 2019-20 (Pre-COVID period) average Environmental Management Efficiency for the four ports is 0.617. Once again, NMPA, Mangalore has the highest score of 0.725, while DPA, Kandla has the lowest score of 0.573. Overall, the Environmental Management Efficiency scores have remained relatively consistent across the years.
b. **Social Efficiency:** For FY 2021-22 (Post-COVID period) average social efficiency for the four major seaports is 0.661. NMPA, Mangalore has the highest score of 0.81, while MBPA, Mumbai has the lowest score of 0.512. For FY 2020-21 (COVID period) average social efficiency for the four ports is 0.645. NMPA, Mangalore continues to have the highest score of 0.789, while MBPA, Mumbai has the lowest score of 0.534; For FY 2019-20 (Pre-COVID period) average social efficiency for the four major seaports is 0.603. NMPA, Mangalore has the highest score of 0.735, while COPA, Cochin has the lowest score of 0.548. Similar to Environmental Management Efficiency, the social efficiency scores have also remained relatively consistent over the years.
c. **Economic Efficiency:** For FY 2021-22 (Post-COVID period) average economic efficiency for the four major seaports is 0.858. NMPA, Mangalore has the highest score of 0.81, while MBPA, Mumbai has the lowest score of 0.512. The average economic efficiency is significantly higher than in previous years. For FY 2020-21

(COVID period) average economic efficiency for the four ports is 0.82. NMPA, Mangalore has the highest score of 0.789, while MBPA, Mumbai has the lowest score of 0.534. For FY 2019-20 (Pre-COVID period) average economic efficiency for four ports is 0.871. NMPA, Mangalore has the highest score of 0.735, while MBPA, Mumbai has the lowest score of 0.513. Overall, it appears that NMPA, Mangalore consistently performs well in terms of environmental, social, and economic efficiency across three fiscal years. DPA, Kandla and MBPA, Mumbai generally has lower scores, indicating room for improvement. Seaports have shown relatively stable environmental and social efficiency, while economic efficiency has seen some fluctuations, with a notable increase in FY 2021-22 (Post-COVID period).

d. **Overall Sustainability Performance:** For FY 2021-22 (Post-COVID period, among the four major ports, NMPA, Mangalore has the highest overall sustainable performance score of 0.797, indicating effective sustainable practices during this period; DPA, Kandla has a score of 0.624, which is relatively lower compared to NMPA, Mangalore but higher than the other two ports; MBPA, Mumbai and COPA, Cochin have scores of 0.535 and 0.591, respectively, indicating room for improvement in their sustainability efforts and the average score of the four ports is 0.717, suggesting an overall positive sustainable performance during this period; for FY 2020-21 (COVID period) NMPA, Mangalore again shows the highest overall sustainable performance score of 0.775, indicating consistent sustainability practices even during challenging circumstances; DPA, Kandla has a score of 0.621, which is slightly lower than the previous fiscal year but still relatively high; MBPA, Mumbai and COPA, Cochin have scores of 0.548 and 0.599, respectively, indicating a slight improvement in their sustainability performance compared to the previous year and average score of the four ports is 0.699, indicating a moderate level of overall sustainable performance during the COVID period; for FY 2019-20 (Pre-COVID period) NMPA, Mangalore continues to exhibit strong sustainable performance with a score of 0.7316, maintaining its position as the top-performing port; DPA, Kandla has a score of 0.601, indicating a relatively lower sustainable performance compared to NMPA, Mangalore but higher than the other two ports; MBPA, Mumbai and COPA, Cochin have scores of 0.536 and 0.562, respectively, showing a moderate level of sustainability performance and average score of the four ports is 0.697, suggesting a positive sustainable performance before the COVID period.

6.4.5 Analyzing the data on Pure Technical Efficiency (BCC efficient scores) and R-square values for the four major seaports from FY 2016 to FY 2021-22

Pure Technical Efficiency score (BCC efficient score) for DPA, Kandla is 0.7237. This score indicates the level of technical efficiency achieved by DPA, Kandla in utilizing its resources to produce outputs; score of 0.7237 suggests that there is room for improvement in optimizing the technical efficiency of DPA, Kandla over the analyzed period; Pure Technical Efficiency score (BCC efficient score) for MBPA, Mumbai is 0.8971. This score indicates a relatively higher level of technical efficiency compared to DPA, Kandla. MBPA, Mumbai has demonstrated a better utilization of its resources to produce outputs compared to DPA, Kandla; Pure Technical Efficiency score (BCC efficient score) for NMPA, Mangalore is 0.9613. This score suggests a significantly higher level of technical efficiency compared to both DPA, Kandla and MBPA, Mumbai.; NMPA, Mangalore has consistently achieved a high level of technical efficiency in utilizing its resources over the analyzed period; Pure Technical Efficiency score (BCC efficient score) for COPA, Cochin is 0.7352.

This score indicates a level of technical efficiency similar to DPA, Kandla but lower than that of MBPA, Mumbai and NMPA, Mangalore. COPA, Cochin has room for improvement in optimizing its technical efficiency. The average Pure Technical Efficiency score (BCC efficient score) for the four ports is 0.829. The average score represents the overall technical efficiency achieved by the ports collectively over the analyzed period. It indicates a moderate to high level of technical efficiency, with NMPA, Mangalore being the most efficient among the ports. Overall, NMPA, Mangalore consistently demonstrates the highest level of technical efficiency among the four ports, followed by MBPA, Mumbai. DPA, Kandla and COPA, Cochin show relatively lower levels of technical efficiency, although efforts can be made to improve their performance. The average score of 0.829 suggests an overall positive level of technical efficiency for the four ports combined. R-squared values and correlation between input sustainability indicator and its corresponding output sustainability indicator is very significant and play important roles in sustainability benchmarking of seaports by providing insights into the strength and significance of relationships between various seaport sustainability indicators.

Higher R-squared values in this research study indicate that the chosen seaport sustainability indicators have a stronger relationship with sustainability related outcomes can be considered robust and reliable for seaport benchmarking purpose. Indicators with higher R-squared values & significant correlations indicate stronger relationships with sustainability related outcomes, suggesting they are influential seaport sustainability factors which should be prioritized in sustainability improvement efforts. And thus, focusing on these key drivers, seaport organizations can target specific areas for improvement and allocate resources more effectively.

6.5 Validation of Sustainability of Seaports under Research Study

To verify the findings of this research, a quantitative approach was employed, which involved cross-checking the results with real-life scenarios at four major liquid cargo seaports on the west coast. The investigation revealed that seaports have been acknowledged for their adherence to international environmental, economic, and social dimensions of sustainability. This recognition is evident in various instances, such as the publication of environmental impact analysis (EIA) reports before the commencement of projects and the annual display and compliance of environmental data to government agencies like the Central Pollution Control Board (CPCB) and State Pollution Control bodies.

Moreover, it is imperative for major seaports in India and shipping operations to comply with international shipping conventions and regulations set forth by organizations like the International Maritime Organization (IMO), International Labour Organization (ILO), and respective national governments. These conventions encompass vital agreements such as the International Convention for the Prevention of Pollution from Ships (MARPOL), International Safety Management Code (ISM Code), International Convention for the Safety of Life at Sea (SOLAS), and Maritime Labour Convention (MLC), along with relevant national acts and policies like the Indian Ports Act of 1908, Water (Prevention and Control of Pollution) Act of 1974 and its subsequent amendments in 1988, Environment Protection Act of 1986, New Draft National Forest Policy of 2018, Coastal Regulation Zone (CRZ) Notifications of 1991, 2011, and 2018, and Waste Management Rules of 2016 and its amendments in 2018 and 2019, which address environmental aspects related to seaport operations. Seaports in India also align themselves with ISO 14001, which entails the implementation of Environmental Management Systems for ports.

Furthermore, in compliance with the requirements of the Government of India, seaports are obligated to allocate 30% of green belt land in seaport areas and allocate budgets for green projects on an annual basis. The EIA reports also shed light on social aspects concerning ports, emphasizing local community involvement in port projects and corporate social responsibility (CSR) initiatives aimed at supporting the local maritime community in areas such as occupational health, safety, and security. Table 6.4 highlights on validation of Seaport Sustainability Aspects of Four Major Ports in India

Table 6.4: Validation of Seaport Sustainability Aspects of Four Major Ports in India (Source: Respective Major Port Websites of India)

Proposed Results/Ports	**Deendayal Port Authority (DPA), Kandla**	**Mumbai Port Authority (MbPA), Mumbai**	**New Mangalore Port Authority (NMPA), Mangalore**	**Cochin Port Authority (CoPA), Cochin**
ISO Certification	ISO 14001:2015; ISO 9001:2015; ISPS Compliant	ISO 14001:2015; ISO 9001:2015; ISPS Compliant; ISO/IEC 27001	ISO 14001:2015; ISO 9001:2015; ISO 45001:2018; ISPS Compliant	ISO 9001:2015; ISPS Compliant
Environment Monitoring works and fund allocation	Yes	Yes	Yes	Yes
Environment related information/EIA reports and compliance	Yes	Yes	Yes	Yes
Mission, Vision, Policies, Guidelines, procedures & Management	Yes	Yes	Yes	Yes
Ease of doing business	Yes	Yes	Yes	Yes
Performance reports and achievement details	Yes	Yes	Yes	Yes
Stakeholders' information related details and facilities	Yes	Yes	Yes	Yes
Capital Works	Yes	Yes	Yes	Yes
Swachh Bharath & ATR on Green Port initiatives	Yes	Yes	Yes	Yes
Usage of ICT for effective communications	Yes	Yes	Yes	Yes
Safety Audit	Yes	Yes	Yes	Yes
Security status	Yes, CISF	Yes,	Yes, CISF	Yes, CISF

	Protection	CISF Protection	Protection	Protection
Public Grievance Redressal mechanism/ Citizens'/ Clients' Charter/Internal Compliant Committee / Transparency Plans	Yes	Yes	Yes	Yes
Utility Services of Port	Yes	Yes	Yes	Yes
Solar Power Plant	Yes	Yes	Yes	Yes
Medical Facilities & Capacity	Yes, Adequate	Yes, Adequate	Yes, Adequate	Yes, Adequate
Employee related Benefits	Yes, Provided	Yes, Provided	Yes, Provided	Yes, Provided
Dredging	Yes	Yes	Yes	Yes
Corporate Social Responsibility (CSR) support details and information	Yes	Yes	Yes	Yes
Pollution Control Measures	Yes	Yes	Yes	Yes
Management Development Programs & Trainings	Yes	Yes	Yes	Yes
Equipment & Facility Handling	Yes, Adequate	Yes, Adequate	Yes, Adequate	Yes, Adequate
Right to Information (RTI) Act, 2005	Yes	Yes	Yes	Yes

Also, validation that support seaport sustainability for four major west coast seaports of DPA, Kandla; MBPA, Mumbai; NMPA, Mangalore and COPA, Cochin with liquid cargo profile as major cargo for the seaport is illustrated in Figure 6.3 to 6.6.

Figure 6.3: Sustainability Views of Port Area at DPA, Kandla

(Source: DPA, Kandla Website)

Figure 6.4: Sustainability Views of Port Area at MbPA, Mumbai

(Source: MbPA, Mumbai Website)

Figure 6.5: Sustainability Views of Port Area at NMPA, Mangalore

(Source: NMPA, Mangalore Website)

Figure 6.6: Sustainability Views of Port Area at CoPA, Cochin

(Source: CoPA, Cochin Website)

6.6 Strategies and Recommendations for Seaport Sustainability Benchmarking in Major Seaports of India

Based on the secondary data research analysis the research study provides suggestion on sustainability improvement strategies for major seaports in India encompass various aspects of port operations, technology, infrastructure, human resources, environmental management, and community engagement. These strategies aim to enhance sustainability performance and address key indicators. The analysis of the strategies and their potential impact is highlighted as below: -

a. **Improvement in port productivity & efficiency:** This strategy focuses on streamlining processes, reducing waiting times, and optimizing resource utilization. It can positively impact indicators such as the number of vessels sailed in the port, annual cargo throughput in tonnes, ATRT (Average Turnaround Time) in days, and AOPB (Average Output per Berth) in tonnes. By improving efficiency, seaports can handle more cargo, reduce congestion, and enhance overall operational performance.
b. **Best operating practices & policies**: Implementing industry best practices and robust policies can lead to improved performance in various areas. This strategy can positively impact indicators such as port capital assets, the number of port employees, and the number of employees undergoing training. By adopting efficient practices and policies, seaports can enhance their operational capabilities and the skills of their workforce.
c. **Improvement in technology/business strategies:** Embracing technological advancements and implementing effective business strategies can drive sustainability improvements. This strategy can impact indicators such as the number of machineries in the port, port electricity consumption, and annual net surplus/profit of the port. The use of automation, alternate power sources, and innovative business models can lead to reduced energy consumption, cost savings, and improved financial performance.
d. **Environmental protection and monitoring:** This strategy focuses on protecting the environment and monitoring port areas to ensure compliance with sustainability standards. It can positively impact indicators such as air quality index (AQI) data, water condition in port areas, and port environmental monitoring expenditure. By implementing effective environmental management practices, seaports can minimize their ecological footprint and contribute to sustainable development.
e. **Community engagement and CSR support:** Involving the local community in port activities and decision-making processes, along with corporate social responsibility (CSR) initiatives, can create positive social impacts. This strategy can impact indicators such as port health, CSR expenditure, and port security-related expenditure. By engaging with the community, providing adequate healthcare

facilities, supporting local development, and ensuring security, seaports can foster positive relationships and contribute to social sustainability.

It's important to note that the effectiveness of these strategies will depend on the specific context, resources, and priorities of each seaport. Additionally, regular monitoring, evaluation, and continuous improvement efforts are necessary to ensure the long-term success of sustainability initiatives.

6.7 Discussions and Implications

Seaports play a vital role in India's economy, contributing approximately 1% to the country's GDP growth. However, the maritime sector faces various challenges such as limited port infrastructure, sub-optimal transport modal mix, inadequate hinterland transport linkages, low access to coastal and inland shipping, limited digitization and mechanization, and procedural bottlenecks. In order to address these challenges, the Government of India has developed the Maritime India Vision-2030, a 10-year blueprint aimed at transforming the Indian maritime sector. The vision includes plans for substantial investment in port projects and the generation of employment opportunities.

The research findings based on Data Envelopment Analysis (DEA) provide objective and reliable insights into the sustainability of major seaports in India. These findings enable comparisons over different time intervals and serve as a reflection of the maritime industry's societal and economic activities, as well as the interactions among seaport stakeholders. Efforts should be focused on mitigating the potential consequences of the COVID-19 pandemic by improving operational efficiency, reducing costs through pricing reconsideration, enhancing asset utilization and productivity, upgrading seaport capabilities and support infrastructure, streamlining and automating processes, and promoting stakeholder participation.

Analyzing sustainability shifts of four major Indian seaports involves tracking environment, economic, and social metrics over time and can provide a link between actions and performance on long-term/medium-term or short-term related impacts. Feedback from seaport stakeholders informs perception and regulatory compliance ensures alignment with legal requirements. Competitive positioning, operational improvements, innovation, and management decisions gauge progress. Validation in Table 6.4 ensures that the insights gained from the analysis in Table 6.3 are accurate, meaningful, and grounded in real-world practices and outcomes.

The current crisis presents an opportunity to reassess the sustainability of seaports and the maritime ecosystem in India, which have relied on outdated processes. Seaports need to be prepared and adaptable to new operational patterns, aligning their infrastructure and operations accordingly. It is crucial to improve forecasting and prediction tools to anticipate disruptions and enhance transparency and flexibility in maritime supply chains. Developing smart and agile maritime supply chains is essential for building a resilient global trade and investment framework capable of withstanding future pandemics. The government should evaluate recovery programs' effectiveness and impact through robust assessment capabilities.

In addition, the government should implement sustainable and inclusive measures to promote maritime trade and labour growth, foster innovation, and encourage private sector participation. Reducing barriers to industrial development and promoting the localization of maritime supply chains are also important steps for sustainable growth in the sector.

This research study represents a pioneering effort to comprehend the economic, environmental, and social dimensions associated with seaports. By analyzing various indicators and values, the study identifies the need for sustainable strategies in seaport management. Additionally, the study highlights the interconnectedness of seaport indicators, where improvements in one area can lead to enhancements in others. The validation of findings is accomplished through quantitative research methods using secondary data, and real-life scenarios are cross-checked for sustainability aspects. The study aims to benchmark seaport sustainability efficiency, identify best practices, and establish reference points for other ports in the region.

To assess seaport sustainability and efficiency, this study employs quantitative methods, specifically Data Envelopment Analysis (DEA) to evaluate scale efficiencies. By utilizing DEA, the study measures the relative performance of four major west coast liquid cargo seaports. The results provide insights into the efficiency levels of these ports and allow for the identification of best practices specific to the region. Furthermore, the study examines the variables that have the most significant impact on sustainability development in seaports. By understanding these key variables, seaport management can prioritize their efforts and focus on areas that yield the highest potential for improvement. This research study represents a crucial step in comprehending the economic, environmental, and social dimensions of seaport sustainability. By employing quantitative method of DEA analysis and evaluates the efficiency and performance of four major west coast liquid cargo seaports.

The findings serve as a benchmark for seaport sustainability and identify best practices that can enhance overall performance. By understanding the variables that impact sustainability development, seaport management can prioritize strategies and make informed decisions to drive improvements. This research lays the foundation for future studies and provides valuable insights for seaport managers seeking to incorporate sustainable practices into their operations (Ha,2020; Hossain,2021; Lam,2021; Notteboom,2022).

This research study examines the sustainability performance of four major liquid cargo seaports on the west coast of India. By analyzing longitudinal panel quantitative data from 2016 to 2021, the study employs Data Envelopment Analysis (DEA) to evaluate seaport practices across three sustainability dimensions. The aim is to identify areas for improvement and propose strategies that enhance efficiency and sustainability, taking a holistic approach to seaport operations.

International recognition of seaports' sustainability efforts can be observed in their adherence to environmental, economic, and social dimensions. Seaport organizations demonstrate their commitment through various practices, including the publication of Environmental Impact Analysis (EIA) reports before project commencement and the annual reporting of environmental data to governmental agencies such as the Central Pollution Control Board (CPCB) and State Pollution Control bodies.

Furthermore, major seaports in India and shipping operations comply with international shipping conventions and regulations set by organizations like the International Maritime Organization (IMO) and the International Labour Organization (ILO). These conventions encompass important aspects such as pollution prevention (MARPOL), safety management, and labour standards. Additionally, national legislation, including the Indian Ports Act of 1908 and environmental acts such as the Water (Prevention and Control of Pollution) Act of 1974 and the Environment Protection Act of 1986, shape seaport operations.

Indian seaports prioritize sustainability through compliance with international and national regulations. This study explores the environmental, social, and economic dimensions of seaport sustainability. It highlights the affiliation of seaports in India with ISO 14001, which emphasizes environmental management systems. Additionally, the Government of India mandates that ports allocate 30% of seaport areas for green belt land and allocate budgets for green projects annually. The study also recognizes the social aspects highlighted in Environmental Impact Assessment (EIA) reports, focusing on local community orientation and corporate social responsibility (CSR) initiatives related to occupational health, safety, and security (OHSS) (Laxe, 2017; Dviao, 2019).

Indian seaports adhere to ISO 14001 standards for environmental management systems. Moreover, government regulations require seaports to maintain 30% green belt land in seaport areas and allocate funds for green projects each year (ISO,2015). The EIA reports of ports emphasize social aspects, highlighting the engagement with the local community in port projects and CSR support for the maritime community regarding OHSS concerns. Under the Major Ports Authority (MPA) Act 2021, the administration, control, and management of the 12 major ports in India are vested in the Boards of Major Port Authorities. These boards consist of representatives from various organizations, enabling effective regulation, operation, and planning. The MPA Act grants ports the authority to establish Scale of Rates for port services and assets, empowering them to set pricing structures (MoPSW,2021).

Seaports in India are guided by six core principles that emphasize responsible management, societal prosperity, stimulating work environments, reduced environmental footprints, safety and security, and economic mission. The Indian government has developed the Maritime India Vision (MIV) 2030 to strengthen the Ports, Shipping, and Waterways sectors through targeted interventions. MIV 2030 is a comprehensive blueprint for enhancing the maritime sector in India. It aims to lead the world in safe, sustainable, and green ports by introducing strategic interventions. These interventions encompass various aspects, such as renewable energy, air emissions reduction, water usage optimization, solid waste management improvement, zero accident safety programs, and centralized monitoring. The National Centre of Excellence for Green Port & Shipping (NCoEGPS) is one such initiative that provides green solutions to transform ports practices. MIV 2030 comprises more than 150 initiatives, each targeting specific segments of the maritime sector.

India's commitment to sustainability is demonstrated by its pledge to reduce emissions intensity per unit GDP by 33-35% below the 2005 level by 2030. Additionally, the country has set a target of achieving 40% national energy through renewable sources by 2030. Indian seaports align their green initiatives with the broad vision of the nation, ensuring adherence to the International Maritime Organization's alignment with nine United Nations Sustainable Development Goals (SDGs) concerning safe, efficient, and sustainable ports.

Under MIV 2030, numerous initiatives have been identified to drive the transition towards a greener maritime sector. These interventions address critical areas, including carbon emissions reduction, waste reduction and recycling, air pollution mitigation, resource management, preservation of marine biodiversity, and productivity improvement to reduce greenhouse gas emissions. This research study is in line with Maritime India Vision 2030 of India so as to set a progressive roadmap for sustainable practices in Indian seaports.

Also, the input and output indicators that can be reconsidered or potentially exclude from this research study are as follows: -

Input Parameters: Port Capital Assets (including Capital Work in Progress): While it is crucial for management but its direct sustainability impact may be relatively limited. Port Medical expenses has impact on sustainability and is likely to be indirect compared to other indicators. Port Security expenditures are vital, but not a direct seaport sustainability driver. Port Electricity charges have variable direct impact on sustainability over time.

Output Parameters: Average Output Per Berth Day (AOPB) in tonnes indicator is of relevance but its direct effect on seaport sustainability may be less evident. Average Noise Level (Ldn) at Port area in dB (A) may be relevant but its direct sustainability impact might be less than other seaport sustainability indicators. Ph level of drinking Water in Port Area is relevant, yet not a primary seaport sustainability driver. Ph level of Sewage effluent treated water in Port Area may be significant but its direct connection to seaport sustainability may be less evident than other indicators.

The significance of seaport sustainability input and output indicators depends on their direct influence on seaport sustainability goals, implementation simplicity, and alignment with seaport objectives. Prioritizing measurable, impactful indicators that align with strategy is crucial for enhancing sustainability.

6.8 Summary

This study focuses on benchmarking the sustainability performance of four major seaports on the west coast of India, specifically those dealing with liquid cargo. The research objective involves evaluating the technical efficiencies of these seaports using the Data Envelopment Analysis (DEA) technique. The study examines input and output variables related to the environmental, economic, and social dimensions, which significantly influence seaport sustainability development. The analysis aims to determine environmental efficiency, economic efficiency, social efficiency, and overall sustainable efficiency from 2016 to 2021. The research findings are highlighted and interpreted accordingly.

This research study also analyzes and interprets the sustainability aspects of the four major seaports during the pre-COVID-19 period, the COVID-19 period, and the post-COVID-19 period. Additionally, the research addresses the validation of seaport sustainability aspects for these major seaports in India. It proposes improvement strategies and recommendations for benchmarking seaport sustainability. The implications of this research study are significant as they guide seaport management and relevant stakeholders in making strategic or tactical decisions to enhance seaport sustainability agendas. The findings and recommendations can assist in shaping the future direction of seaport operations and contribute to the overall sustainability of the seaport industry.

CHAPTER 7
CONCLUSION

7.1 Summary

This chapter presents the main conclusions derived from the findings obtained throughout all stages of this research study which effectively address the research objectives and are the result of comprehensive empirical studies encompassing both qualitative and quantitative approaches. Furthermore, this chapter also demonstrates how this study successfully filled the knowledge gaps identified in the existing literature and was supported through the adoption of a suitable research methodology, which facilitated the generation of valuable insights.

Additionally, the chapter emphasizes the contributions to knowledge made by this study, highlighting its significance in advancing the field. Alongside these contributions, the limitations of the study are acknowledged and discussed. Finally, suggestions for future research directions are provided to further build upon the findings and expand the knowledge base in the field.

7.2 Research Findings

7.2.1 RO1: To identify and analyze the crucial dimensions, port performance indicators, and key performance indicators for assessing sustainability practices in seaports.

The findings of the study indicate that maritime domain experts and seaport professionals in India highly value seaport sustainability assessment measures. This is evident from the ratings received by key performance indicators, which were above four on a five-point Likert scale, suggesting significant importance attached to these measures. The high ratings of attribute performance further reinforce the perception that seaport sustainability performance across various criteria is considered to be at a high level. Moreover, the study reveals a consensus among maritime experts and seaport professionals, with over 85% of respondents agreeing on the need for seaports in India to adopt all proposed seaport sustainable development practices across the five sustainability dimensions. This indicates a shared belief in the importance of incorporating these practices to enhance sustainability performance.

The ranking of key performance indicators and sustainability dimensions provides additional insights. Based on the mean importance level, port economic sustainability performance was ranked highest, followed by port social sustainability, port environmental sustainability, port internal sustainability, and finally, port customer sustainability. This implies that stakeholders perceive economic sustainability as the most important dimension, emphasizing the significance of economic factors in seaport sustainability. On the other hand, considering the mean performance level, port environmental sustainability performance received the highest ranking, followed by port economic sustainability, port social sustainability, port customer sustainability, and port internal sustainability. This suggests that, in terms of actual performance, environmental sustainability is perceived as the strongest aspect, while internal sustainability requires more improvement. Overall, these findings contribute to our understanding of seaport sustainability performance in India, highlighting the perceived importance and performance levels of different sustainability dimensions. They provide valuable insights for policymakers, seaport authorities, and industry professionals to prioritize efforts and strategies aimed at enhancing seaport sustainability.

7.2.2 RO2: To analyze the relationship between various dimensions and port key performance indicators that are relevant to seaport sustainability performance.

The findings of this research study indicate that all hypothesized relationships between different dimensions of seaport sustainability performance were significant and aligned with expectations. The following significant associations were observed: port internal sustainability performance was significantly associated with port customer sustainability performance; port environmental sustainability performance was significantly associated with port economic sustainability performance.; port social sustainability performance was significantly associated with port economic sustainability performance.; port internal sustainability performance was significantly associated with port economic sustainability performance.; port internal sustainability performance was significantly associated with port social sustainability performance.; port internal sustainability performance was significantly associated with port environmental sustainability performance.; port customer sustainability performance was significantly associated with port environmental sustainability performance.; port customer sustainability performance was significantly associated with port social sustainability performance and finally port customer sustainability performance was significantly associated with port economic sustainability performance.

Additionally, the study found that port environmental sustainability performance mediates the positive relationship between port internal sustainability performance and port economic sustainability performance. Similarly, port social sustainability performance mediates the positive relationship between port internal sustainability performance and port economic sustainability performance. This suggests that the impact of internal sustainability on economic sustainability is partially explained by the mediating role of environmental and social sustainability.

Furthermore, the research examined the perceived differences in seaport sustainability assessment dimensions across four major seaports (DPA, Kandla; MPA, Mumbai; NMPA, Mangalore; and CoPA, Cochin). The mean scores for each sustainability dimension were calculated for each port. The results indicate the following rankings based on mean scores:

On environmental seaport sustainability performance (PENSP): respondents from NMPA, Mangalore tended to have higher mean scores, followed by CoPA, Cochin; DPA, Kandla; and MPA, Mumbai; On social seaport sustainability performance (PSOSP): respondents from NMPA, Mangalore tended to have higher mean scores, followed by DPA, Kandla; CoPA, Cochin; and MPA, Mumbai; On economic seaport sustainability performance (PECSP): respondents from DPA, Kandla tended to have higher mean scores, followed by NMPA, Mangalore; CoPA, Cochin; and MPA, Mumbai; On seaport internal sustainability performance (PISP): respondents from CoPA, Cochin tended to have higher mean scores, followed by DPA, Kandla; NMPA, Mangalore; and MPA, Mumbai; On seaport customer sustainability performance (PCSP): respondents from CoPA, Cochin tended to have higher mean scores, followed by DPA, Kandla; NMPA, Mangalore; and MPA, Mumbai. These findings provide insights into the relationships and differences in seaport sustainability performance dimensions, allowing for a better understanding of the factors influencing sustainability in each port.

7.2.3 RO3: To determine the methodology for measuring port sustainability performance, including the evaluation criteria, and propose improvement or optimal strategies.

The findings of this research study focused on benchmarking the efficiency of seaport sustainability performance in four major liquid cargo west coast seaports in India from 2016 to 2021. The study revealed significant correlations between input and output variables, indicating a relationship between the factors influencing seaport sustainability. R-squared values for the input and output seaport sustainability parameters also demonstrated a significant level of explained variance. Analysis of the input variables showed a stronger correlation with the economic dimension data values compared to the environment and social dimension data values.

This suggests that seaport management has prioritized the economic dimension, followed by the environmental and social dimensions. The research utilized the DEA-VRS methodology to measure performance improvements for each indicator per seaport, providing insights into the efficiency of each seaport.

The results indicated that all four major west coast liquid cargo seaports under study (Deendayal Port, Mumbai Port, New Mangalore Port, and Cochin Port) exhibited relative efficiency or performance scores ranging from 72.37% to 96.32% from 2016 to 2021. Efficiency and ranks were calculated for sustainability-related input dimensions (environmental, social, and economic) and overall sustainability performance for the four major ports over the specified time period.

This research study specifically examined the efficiency indicators related to environmental management, operational/economic efficiency, and social management for the four major west coast seaports in India. Data from the pre-COVID-19, COVID-19, and post-COVID-19 periods were analyzed to understand the performance and changes in the seaports' sustainability dimensions. This study provides a valuable first attempt to analyze seaport economic, environmental, and social dimensions. The findings suggest that improvement in one indicator can have a positive impact on other seaport indicators due to the high correlation observed among them. Seaport management can incorporate specific strategies related to sustainable dimensions based on the reported improvements highlighted by the research.

The research validated the results through cross-checking with real-life scenarios and compared the findings with secondary data from major west coast liquid cargo seaports in India. The study not only benchmarked seaport sustainability efficiency performance but also identified best practices specific to the region. The identified peers or dominating ports can serve as references for other ports, and the recommended practices have the potential to enhance performance. Overall, this quantitative research approach using DEA analysis contributes to understanding seaport sustainability development and identifies key variables that influence it.

7.3 Concluding Remarks and Policy Implications

By the completion of this research, all the research objectives have been successfully achieved. A comprehensive and practical sustainability framework for major west coast liquid cargo-based seaports in India has been developed, which includes factor groups and prioritization of indicators. The study also identified the interrelationships between sustainability factors and their associated efficiency through the analysis of influential powers. It is evident that a holistic approach to sustainability is necessary, encompassing the economic, social, and environmental dimensions. Seaport organizations need to adopt regulations and restrictions that consider sustainability in all aspects of their operations and port structure, not solely focusing on environmental concerns. The influence of local communities and stakeholders on seaport organizations cannot be ignored, as they can have both positive and negative impacts.

Implementing sustainability measures in seaport organizations brings various benefits, such as cost savings, avoidance of government penalties, collaboration with local authorities, and fostering a positive reputation within the community. Stakeholder influence plays a crucial role in shaping the actions of port organizations. To achieve their sustainability goals, seaport organizations must plan strategically, taking into account their specific sustainability priorities and different time periods. This research contributes to the existing knowledge by highlighting that the priorities of seaport organizations vary depending on their governance and administrative structures. It emphasizes the importance of adjusting the significance of seaport sustainability indicators based on the governance and administrative type of the port organization. This adjustment will provide a more accurate benchmark and reliable self-assessment tool for seaport organizations, ultimately aiding them in achieving their sustainability objectives.

Sustainability development is gaining prominence on a global scale, and the concept of seaport sustainability in India has primarily focused on financial and environmental aspects. However, this study addresses the question of how major seaports in India can achieve sustainability across various practices and key performance indicators. The research employed a combination of qualitative and quantitative methods, including primary data research analysis and secondary data analysis. Specifically, this research study proposes a holistic validation of the sustainable seaport development framework in the context of four major west coast Indian seaports that handle a significant portion of liquid bulk cargo.

This research primarily focused on qualitative studies of port sustainability through literature reviews and conducted Important-Performance analysis and expert assessment to rank port dimensions and Key Performance Indicators (KPIs) related to seaport sustainability. The study aimed to establish a connection between seaport sustainability performance and relevant KPIs, facilitating comprehensive seaport sustainable development. By employing exploratory factor analysis (EFA), the study identified key practice criteria in five dimensions (economic, environmental, social, port internal sustainability, and port customer sustainability), along with 37 KPIs corresponding to each dimension. Structural modeling (SEM) was then utilized to establish the relationship between the relevant factors and key performance criteria.

Furthermore, this research collected longitudinal panel quantitative data for four major liquid cargo seaports on the west coast of India, assessing seaport sustainability performance across three dimensions using real-time value-based data (secondary data) from the financial year 2016 to 2021. The analysis employed DEA (Data Envelopment Analysis) to determine efficiency in sustainability aspects and propose improvement strategies within a holistic seaport approach.

In addition, suggestions and policy implications regarding seaport sustainability aspects were gathered from port employees and are highlighted for real time perception and understanding of sustainability related aspects in seaports in India. This research underscores the criticality of seaport sustainability factors and their impact on seaport sustainability, taking into account the involvement of all seaport stakeholders in sustainability practices within Indian seaport organizations. It is noteworthy that this study is the first of its kind in the Indian seaport context and maritime domain, identifying KPIs related to comprehensive seaport sustainability and examining their contribution to the sustainable development of major seaports in India. The findings of this study hold various contributions and implications for universal seaport sustainability and sustainability programs in the maritime sector across different nations.

The first contribution of this research study is the identification of a positive relationship between three sustainability dimensions, internal process, and customer perspective of seaport-related KPIs in the maritime supply chain and is the first step towards seaport sustainability improvement. The research results are also consistent with Lu et al. (2016, 2022) study at other international seaports or container terminals. This research also identified a positive and significant relationship between the internal port sustainability process and customer satisfaction.

Nevertheless, it must be ensured that improvements in internal seaport processes related sustainability of the seaport supply chain will help satisfy the customers, and seaport stakeholders (Yang,2019; Adegoke,2019). Customer satisfaction in the seaport context also is essential in the seaport sustainability performance of maritime seaport programs and is directly related to the number of customers receiving the prescribed (Lu, 2016; Lam, 2019; Ha, 2018). Thus, the research assessment structure will be constructive for macro assessment basis for the balanced vision of seaport responsibilities in local society and major seaport-related stakeholders in India.

However, from the research study survey and discussion with the experts, it was observed that there is a shortage of resources, a lack of modern technology, and knowledge sharing between maritime seaport stakeholders in India are important barriers that hamper the improvement in seaport sustainability performance. This positive relationship between internal port processes on three dimensions- social/economic/environmental dimensions of port sustainability was accepted in all other research areas, concerning port internal sustainability practices items, it is important for seaports to effectively communicate sustainable development issues with their staff and to allow the employees to be involved in the sustainable development policy.

This research also suggests that ports should work with their staff to design sustainability goals and regulations, develop a clear organization of responsibility, and engage employees in training programs for implementing sustainability in practice Acciaro et al. (2014). The results indicate that internal and external sustainability collaboration were positively associated with sustainability performance, including environmental, social, and economic performance. Port management must develop sustainable management strategies that incorporate specific internal resources, competencies, and capabilities (Munagpan, 2019; Ku, 2021; Wang, 2019).

This study further conceptualizes a system for a seaport to widen into a holistic sustainable seaport based on improvement structure. Using this structure as a focal point, the assessment to formulate and execute specific sustainable seaport development practices which seaport manager needs to consider from various seaport related stakeholder's perspectives (MIV, 2030; Senegar, 2017; Senegar,2018; Gupta,2016; UNCATD, 2019).

From a policy perspective, the findings and recommendation decision framework of this research study provide valuable guidance to maritime researchers in the broader context of sustainability within Indian seaports.

The research structure developed in this study allows for the consideration of a comprehensive and organized decision support system for the sustainable development of seaports. Given that seaport managers prioritize the dimensions of seaport sustainability, this research will aid in identifying crucial areas for maritime research that are pivotal to the sustainable growth of seaports. The study makes a significant contribution to the existing literature and offers practical insights for seaport organizations in their efforts to enhance sustainable practices with the involvement of various stakeholders.

However, with the COVID-19 epidemic, the maritime policy-making organizations and seaports emphasized the evolution to an eco-friendly and inclusive economy considering social aspects and seaport supply chain stakeholders (WPSP, 2021; Zhang, 2020; Merouani, 2021; Devran Yazır et. Al ,2020; Prathvi et.al,2021; Narasimha PT,2022). The framework presented in this research study can provide valuable support to seaport managers and maritime policymakers in navigating this paradigm shift. In order to effectively assess seaport sustainability, efforts should be made to enhance the insights and understanding of seaport stakeholders regarding sustainable seaport development.

Drawing from the comprehensive findings of this study, it is crucial for a sustainable seaport to establish and implement activities that promote sustainability, with the active involvement of seaport stakeholders. Seaport managers must also make informed decisions on how to strike a balance among various sustainability practices and activities, taking into account the intricate network of seaport stakeholders and their perspectives on sustainability aspects. In the current seaport sector, there is a growing emphasis on investments in the social dimension, which involves prioritizing sustainability in infrastructure development. To ensure the construction of efficient and effective infrastructure for sustainable seaports, it is crucial to consistently assess the dimensions and indicators of sustainable seaport development, both in terms of structure and function. Based on the identified primary seaport dimensions and sustainability practices from the research findings, policies can be recommended to enhance the capabilities of global major seaport organizations.

Furthermore, the findings of this research study can contribute to the development of medium and long-term sustainable strategies for each seaport organization. This involves taking on the responsibility of advancing and improving seaport environmental aspects and actively contributing to the local society. The results of this study can guide seaport authorities in making informed decisions that maximize the positive effects of social, environmental, and economic aspects in the current development plans of global seaports.

By assessing the impact of seaports on the local community, seaport authorities can understand the societal and community-related changes brought about by seaport activities, leading to the adoption of common practices across all seaports.

Moreover, seaports should make dedicated efforts to develop a sustainability framework and guidelines for seaport stakeholders. This includes establishing a business continuity plan, formulating a logistics policy, developing an integrated institutional framework for seaport stakeholders, and implementing a disaster management plan to address emergency situations that may arise in the seaport context (Lu, 2021; Wang,2019; Ha,2018; MIV 2030, 2019).

The research findings revealed that seaports in India have demonstrated recognition and compliance with international environmental, economic, and social sustainability dimensions in various instances. This includes conducting environmental impact analyses (EIA) prior to project commencement, annual reporting and compliance with environmental data to government agencies such as CPCB and State Pollution Control bodies, and adherence to international shipping conventions and regulations set by organizations. These conventions encompass areas such as pollution prevention, safety management, life at sea, and maritime labor standards.

Seaports in India also adhere to ISO 14001 standards for environmental management systems. Additionally, government regulations mandate that ports allocate 30% of their land as green belts and allocate budgets for green projects each year. Social aspects are also highlighted in port projects through community-oriented initiatives and corporate social responsibility (CSR) support for occupational health, safety, and security (OHSS) related aspects (Laxe, 2017; Dviao, 2019). Overall, the research highlights the proactive measures taken by seaports in India to promote sustainability in environmental, economic, and social aspects. The government's MIV 2030 and related interventions provide a roadmap for the greening of the maritime sector and emphasize the importance of safe, sustainable, and green seaport practices.

Further, a comprehensive and inclusive framework for sustainability was developed, focusing on the initiatives and practices related to sustainability performance in the environmental, economic, and social dimensions. This framework also encompasses the assessment of sustainability performance in seaport supply-chain aspects, including key performance indicators for evaluating and managing seaport sustainability initiatives. The framework considers both the internal operations of the port and the external stakeholders, such as customers involved in the port's supply chain.

In summary, this research study provides a reliable and practical seaport sustainability framework for future management of liquid cargo-based seaports in India. The empirical results offer valuable guidance and a roadmap for seaport sustainability practitioners, maritime researchers, and seaport policymakers.

Based on primary and secondary research findings, Indian major seaports can adopt specific sustainability strategies, including Port Emission Control Zones, LNG Bunkering Infrastructure, Zero-Emission Equipment powered by renewables, Water Quality Enhancement via treatment tech, Waste-to-Energy Conversion, Biodiversity Conservation, Green Procurement, Sustainable Design/Construction, Data Analytics, Collaborative Logistics, Waste Segregation, Eco-Friendly Dredging, Port Circular Economy, Renewable Energy Integration. Tailored to each seaport's characteristics, these strategies target diverse sustainability dimensions, fostering an environmentally, socially, and economically sustainable operation within internal and external contexts.

Achieving a sustainable seaport demands meticulous governance and administrative adaptations that encompass environmental, social, economic, and internal-external communication concerns. Essential considerations for sustainability entail: Environmental Compliance and Regulations; Renewable Energy and Energy Efficiency; Waste Management; Green Infrastructure; Community Engagement; Social Welfare and Labor Practices; Innovation and Technology; Economic Diversification; Adaptive Planning; Collaboration and Partnerships; Transparent Reporting and Incentive Schemes.

7.4 Limitations of the Study and Future Research Direction

It is important to acknowledge the limitations of the present research study. Further, this study can be further expanded considering the scope of the topic of seaport sustainability in literature search can be achieved by leveraging the resources of Web of Science and Google Scholar. This approach, must avoid duplicating articles and hold the significant value in ensuring thorough coverage and confirming the credibility of article sources. In case of expert assessment on sustainability efficiency evaluation of seaports, different experts at various geographical locations based on port size, domain knowledge and features might interpret the same data related to importance and performance differently on aspects of seaport sustainability dimensions and its related indicators, so that there will be variation in sustainable dimensions and efficiency assessment.

Further, qualitative research study can focus on conducting comparative expert assessment studies between different types of cargo-oriented seaports at various geographical locations.

In case of primary-based quantitative research the significant limitation is scenario where the majority of the responses (67.4%) were obtained through an online technique from employees of the four major seaports of India. This limitation was primarily due to the impacts of the COVID-19 pandemic, which restricted direct data collection. Also, dependency on the respondents' perceptions of sustainability performance in port operations introduces the possibility of bias, as respondents may be reluctant to report actual quantitative performance for fear of repercussions or lawsuits.

Despite these limitations, this research study lays the groundwork for future studies aiming to conduct primary-based quantitative research assessments of sustainability in seaports. The findings can provide valuable insights for informing strategies to improve sustainability in future seaport expansion and development. Also, it is essential to note that the data responses gathered in this research work only represents a sample of four major west coast liquid cargo-based seaports in India and does not encompass all types of seaports (dry bulk ports container, liquid bulk and cruise ports) in the country to explore their specific needs and requirements for seaport sustainability management systems.

Further, related to the secondary-based quantitative research, focus can be on conducting comparative assessment studies between different types of cargo-oriented Indian major seaports/minor seaports under respective state governments at various geographical locations and also east coast Indian major seaports to assess their overall sustainability performance benchmarking seaports in India and worldwide using real-time data on sustainability-related initiatives. Also, Environmental Impact Analysis (EIA) of seaports value used in secondary based research study may not capture all potential environmental impacts, especially those that are complex, interconnected, or require long-term monitoring. The depth of analysis can vary and can lead to inaccuracies or uncertainties in the assessment of potential impacts and actual outcomes might differ from the predictions and also involves subjective judgments in terms of impact significance, mitigation measures, and alternatives. The focus on a specific time frame and spatial scale can limit the assessment. While public participation is an integral part of EIA, the degree of influence stakeholders has on the decision-making process can vary. Meaningful engagement might not always occur. Even if significant impacts are identified, regulatory enforcement might be weak, leading to limited actual mitigation or corrective actions.

Also, it is important to note that environmental conditions can vary significantly along coastlines due to local variations in geography, climate, and human activities. Hence, seaports need to implement effective environmental management practices to mitigate impacts on marine and coastal ecosystems, air and water quality, and overall sustainability. This research study overall opens up opportunities for future researchers interested in developing a universal seaport sustainability management system that can cater to the diverse needs of seaports across various sustainability aspects, geography and port size with features.

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Appendix A: Questionnaire

Google form Link of the Research Questionnaire: https://forms.gle/SX3LJbqUhbjb35bi8

Hard Copy format of the Research Questionnaire:

Sustainability Initiatives Assessment of Major Seaports in India

Dear Respondents,

I Prathvi TN, Ph.D. Scholar from the National Institute of Technology-Karnataka, Surathkal (Reg.No.187097SM500) kindly request you to fill this questionnaire and help in pursuing my Ph.D. in the area of Seaport Sustainability.

Kindly provide perception regarding the Seaport Sustainability initiatives/practices in Indian major seaport context.

Instructions

Section one: The demographic information. For this section, please check (√) and fill in questions to indication your personal information about gender, age, position, education and monthly income, responsibility and composition in Sea Port Sustainability in Indian Seaport Context

Section two: This section indicates influential determinants, measures and key performance indicators on Sea Port Sustainability Performance. For this section, please check (√) in the important indicators for Sea Port Sustainability in Indian Seaport Context that corresponds to your opinion.

The questionnaire form is estimated with 5 - level of Likert scale including:

5 = **Strongly Agree** relates the important indicators that Very strongly affect Sea Port Sustainability Performance Assessment in Indian Seaport Context.
4 = **Agree** relates the important indicators that moderately affect Sea Port Sustainability Performance Assessment in Indian Seaport Context.
3 = **Neither agree nor disagree** relates the important indicators that affect or neither affect

Sea Port Sustainability Performance Assessment in Indian Seaport Context.

2 = **Disagree** relates the important indicators that that moderately do not affect Sea Port Sustainability Performance Assessment in Indian Seaport Context.

1 = **Strongly disagree** relates the important indicators that Very strongly do not affect Sea Port Sustainability Performance Assessment in Indian Seaport Context.

Section 1 : Please check (√) and fill in questions to indication your personal information.

1. Age

( ) 20 – 29 years

( ) 30 – 39 years

( ) 40 – 49 years

( ) 50 – 59 years

( ) 60 years or more

2. Gender

( ) Male

( ) Female

( ) Others

3. Education

( ) Not Professionally Educated

( ) Primary

( ) Secondary

( ) Diploma

( ) Bachelor’s Degree

( ) Master’s Degree

( ) Doctorate’s Degree

4. Port Organization

( ) Deendayal Port Authority (DPA), Kandla

( ) Mumbai Port Authority (MPA), Mumbai

( ) New Mangalore Port Authority (NMPA), Mangalore

( ) Cochin Port Authority (CPA), Cochin

5. Position

( ) Port -Top Level Manager

( ) Port-Middle Level Manager

( ) Port- Operation Level Employee

6. Monthly Income

( ) Less than Rs.20,000

( ) Rs.20,000 – Rs.39,999

( ) Rs.40,000 – Rs.59,999

( ) Rs.60,000 – Rs.79,999

( ) Rs.80,000 – Rs.99,999

( ) Above Rs.1,00,000

7. Job Responsibility

( ) Administration

( ) Marine Operations

( ) Traffic Operations

( ) Engineering

( ) Finance

( ) Medical

( ) Maritime/Port Supply chain

( ) Sustainable development

8. Professional Experience

( ) 1 – 9 years

( ) 10 – 19 years

( ) 20 – 29 years

( ) 30 – 39 years

( ) 40 years or more

Section2 : Please check (√) and fill in questions to indicate the level of Sustainability key practices/initiatives area in Indian Major Sea Ports

Port Environmental Sustainability Performance (PENSP)	**Level of indicators**				
	5	4	3	2	1
1. Environmental level & Pollution (ELP)					
I perceive that there is reduction in greenhouse gas emissions & exhaust of gases/particles in port area (ELP1)					
I perceive that there is provision for air quality level assessment & emission inventory tracking in port area (ELP2)					
I perceive that there is provision for water quality level assessment and mechanism for reduction in water consumption					
I perceive that there is reduction in smoke& dust pollution level in port area (ELP4)					
I perceive that there is reduction in smell pollution level in port area (ELP5)					
I perceive that there is reduction in noise level in port area (ELP6)					
2. Effluents & waste (EW)					
I perceive that port has developed innovative waste-management strategies with prevention mechanism for spillage reduction & proper treatment for disposing effluents (EW1)					
I perceive that port has implemented safe and environmentally sound disposal procedures through reuse, recycling and recovery mechanism (EW2)					
3. Energy (EN)					
I perceive that installation of renewable energy sources has led to reduced energy consumption/ Optimal Utilization in port area (EN1)					
I perceive that port supports Eco-friendly environmental initiatives for energy reduction (EN2)					
4. Environmental compliance (EC)					
I perceive that there is increase in preparedness level in port towards mitigating rapid climate change & its related impacts (EC1)					
I perceive that there is more support & compliance towards improvement in port Sustainable aspects by developing& maintaining mangroves gardens and landscape usage in the port area (EC2)					
I perceive that there is Improvement in conservation level of port environment, coastal habitats resulting in reduction of non-compliance with laws & regulation considering port expansion (EC3)					

Port Social Sustainability Performance (PSSP)	Level of indicators				
	5	4	3	2	1
1. Health and safety (HS)					
I perceive that port has established health & safety committees that help monitor, collect feedback and advise on occupational health safety & security programs (HS1)					
I perceive that there is reduction in incidents of non-compliance concerning the health, safety& security impacts in port areas (HS2)					
2. Training and education (TE)					
I perceive that port has a better internal &external training courses or education to improve the skill and education of employee (TE1)					
I perceive that port conducts a regular performance and career development reviews for the employees (TE2)					
3. Employee Engagement (EE)					
I perceive that port supports equal salary& remuneration to promote diversity, job security and social equality (no gender bias, and equal opportunity without discrimination) (EE1)					
I perceive that there is improvement in employee engagement & welfare initiatives in port organization (EE2)					
4. Local communities (LC)					
I perceive that port supports sustainable livelihood, engages in Corporate Social Responsibility& strongly engages with local communities to understand expectations& needs for development programs (LC1)					
I perceive that port has good proportionate representation from all stakeholders along with increased support level towards government support & stakeholder engagement activities (LC2)					
I perceive that port has effectively managed negative impacts of port expansion activities through local community consultation, grievance processes and involving local community in port socio-environmental impact assessment development programs (LC3)					

Port Economic sustainability Performance (PECSP)	**Level of indicators**				
	5	4	3	2	1
1. Economic performance &impacts (ECI)					
I perceive that there is reduction in total operational costs/ expenditure with port positively maintaining changes in productivity, performance & efficiency parameters, lower operational costs, Optimal utilization of infrastructure, land & space (ECI1)					
I perceive that port is committed towards increase in employment generation along with support and increasing the no of community development plans & trade facilitation activities (ECI2).					
I perceive that there has been significant development in port infrastructure, facilities investments& cruise tourism services (ECI3)					
I perceive that there has been reduction in economic impacts of deteriorating social or environmental conditions in port area through usage of Information Technology & optimized routing for the vehicles in Port area (ECI4)					
2. Supply-Chain Activities (SCA)					
I perceive that port has adequate operability & well-developed port intermodal connectivity services (road /railways/ship/inland waterways) with more proximity to Special Economic Zone & for seamless logistics & supply chain operations (SCA1)					
I perceive that port has increased its capacity level (bunkering operations/Channel/Quay/yard space/storage tanks/warehouses) to handle diverse cargo with improved service quality level (SCA2)					
I perceive that there has been reduction in cargo damage & delay incidence in port area with preference to more vessel calls (SCA3)					

Port Internal Sustainability Performance (PISP)	**Level of indicators**				
	5	4	3	2	1
1. Agility & Resource Utilization (AGRU)					
I perceive that there is improvement in agile service responsiveness in port services which includes easy tracking of Cargo in port area (AGRU1)					
I perceive that there is increase in utilization percentage of equipment's(tugs/cranes/carriers) functioning & infrastructure capacity through one-stop logistics solutions, additional services, error free documentation & services for enabling quick decision making (AGRU2)					
I perceive that Port has ISO certification for its services & there is reduction in waste involving various process activities (AGRU3)					

2. Management & Innovation (MGI)					
I perceive that there is increase in frequency of developing new port related services (differentiated/ value addition) leading to enhancement in creativity and innovation development in port activities (MGIN1)					
I perceive that there is improvement in port sustainability management policies, processes, procedures and training w.r.t legal & regulatory systems considering risk assessment aspects (MGIN2)					

Port External Sustainability Performance (PESP)	**Level of indicators**				
	5	4	3	2	1
1. Customer communication & satisfaction degree (CS)					
I perceive that Infrastructure/Shipping service/Local terminal charges at port are is reasonable in rates& there is improvement in port services & port workers attitude towards stakeholders (CS1).					
I perceive that port has increased initiative levels for simple customs clearance procedures & solving port incident related issues by mitigating of congestion & providing valued added/ high quality services (CS2)					
I perceive that port handles customer issues effectively and provides better knowledge with information sharing to port stakeholders towards enhance their awareness on port related activities leading to increase in port customer satisfaction level (CS3)					

Suggestions for Improving sustainability aspects of the seaport (Any suggestions that you would like to share for improving the seaport sustainability w.r.t your port organization)

****Thank You*****

Appendix B: Details of experts involved in face validity of the Questionnaire

Expert's Name and Affiliation	Details on Expertise
Dr.Pradyot Ranjan Jena Associate Professor, School of Management (SOM), NITK.	Academic expert involved in the various research activities in the area economics, marketing and consumer behaviour studies.
Dr.Ritanjali Majhi Associate Professor, School of Management (SOM), NITK.	Academic expert involved in the various research activities in the area economics, marketing and consumer behaviour studies.
Dr. Dayananda Shetty, AE,NMPT	Expert with vast experience in both industry and research in the area of seaports.
Mrs. Swapna, Deputy Director(Research & Management Services),Cochin Port Trust	Expert with vast experience in both industry and research in the area of seaports.
Dr. Ropashree ,Environment Officer, NMPT	Expert with vast experience in both industry and research in the area of seaport environment.
Dr. N.M.Bhatta. (Ph.D. in Management) Professor, XLRI, Bangalore.	Academic expert with expertise in port management
Col. Biju Warrier Chief Purchase Officer, IIM Kozhikode	Technical expert involved in the port management of various Maritime government projects
Dr. P.Tamailvanan	Technical expert involved in the port management of various Maritime government projects
Mr. Vikash AC, Executive Engineer, Kandla Port Trust	Expert with vast experience in both industry and research in the area of seaports.
Mrs. Nisha Shetty (M.A., M.Phil. in English Literature) Principal & Assistant Professor, Mahesh PU College	An expert in English Language

Appendix C

Table C.1: Results of Literature Search for keyword seaport sustainability with title, year and source article from Scopus database

Sl No	Title of the article	Year	Journal (Source title)
1	Managing supply chain uncertainty by building flexibility in container port capacity: a logistics triad perspective and the COVID-19 case	2022	Maritime Economics and Logistics
2	Classifying maritime port emissions reporting	2022	Maritime Transport Research
3	Use of Delphi-Ahp Method to Identify and Analyze Risks in Seaport Dry Port System	2022	Transactions on Maritime Science
4	Port institutional responses and sustainability performance: a moderated mediation model	2022	Maritime Policy and Management
5	Difference in port cooperation between motivations: Cooperation for regional welfare and for competition	2022	Maritime Transport Research
6	The role of seaports in regional development in the East Coast of Peninsular Malaysia: An evaluation through an exploratory factor analysis	2022	Journal of Transport and Supply Chain Management
7	Developing a smart port architecture and essential elements in the era of Industry 4.0	2022	Maritime Economics and Logistics
8	A new approach for the identification of strategic Italian ports for container traffic	2022	Transport Policy
9	Prevention and adaptation to diversified risks in the seaport–dry port system under asymmetric risk behaviors: Invest earlier or wait?	2022	Transport Policy
10	Risk management and market structures in seaport–dry port systems	2022	Maritime Economics and Logistics
11	Barriers of social sustainability: an improved interpretive structural model of Indian textile and clothing supply chain	2022	Sustainable Development
12	Port performance evaluation and selection in the Physical Internet	2022	Transport Policy
13	The impact of specialization, ownership, competition and regulation on efficiency: a case study of Indian seaports	2022	Maritime Economics and Logistics
14	Good Practices in Strategic Port Performance	2022	Transactions on Maritime Science
15	Responding to the barriers in climate adaptation planning among transport systems: Insights from the case of the port of Montreal	2022	International Journal of Sustainable Transportation
16	Evolution of Industrial Revolution 4.0 in seaport system: an interpretation from a bibliometric analysis	2022	Australian Journal of Maritime and Ocean Affairs

17	INSTITUTIONAL IMBALANCE OF INTERESTS IN MARITIME TRANSPORT AND SUSTAINABLE DEVELOPMENT;	2022	Transformations in Business and Economics
18	Maritime business performance, economic diversification and real gross domestic product growth in emerging economies: A study of the Nigerian maritime transportation sector.	2022	Journal of Maritime Research
19	Project Green Ports: Are Indian ports on the right track?	2022	Maritime Affairs
20	Anticipated innovations for the blue economy: Crowdsourced predictions for the North Sea Region	2022	Marine Policy
21	Ranking measures to improve the sustainability of Mediterranean ports based on multicriteria decision analysis: a case study of Souda port, Chania, Crete	2022	Environment, Development and Sustainability
22	Assessing the implementation of governance best practices by Latin American ports	2022	Maritime Economics and Logistics
23	Challenging a sustainable port. A case study of Souda port, Chania, Crete	2022	Case Studies on Transport Policy
24	Transhipment port's competitiveness forecasting using analytic network process modelling	2022	Transport Policy
25	A systemic risk framework to improve the resilience of port and supply-chain networks to natural hazards	2022	Maritime Economics and Logistics
26	EVALUATION OF STRUCTURAL FACTORS IN A THIRDGENERATION PORT: Methods and applications	2022	International Journal of Transport Development and Integration
27	Social media and CSR communication in European ports: the case of Twitter at the Port of Rotterdam	2022	Maritime Business Review
28	Socioeconomic Characteristics and Perspectives on Cargo Handling: A Study of Tin Can Island Port, Apapa, Nigeria	2022	Transactions on Maritime Science
29	Digitalization and new technologies for sustainable business models at the ship–port interface: a bibliometric analysis	2022	Maritime Policy and Management
30	The central tendency of the seaport-fulcrum supply chain risk in Indonesia using a rough set	2022	Asian Journal of Shipping and Logistics
31	Maritime governance after COVID-19: how responses to market developments and environmental challenges lead towards degrowth	2022	Maritime Economics and Logistics

32	Port performance factors and their interactions: A systems thinking approach	2022	Asian Journal of Shipping and Logistics
33	Modal shift ambitions of large North European ports: A contract-theory perspective on the role of port managing bodies	2022	Maritime Transport Research
34	Adapting environmental management systems for African ports	2022	WMU Journal of Maritime Affairs
35	An analysis on the triadic connection between seaports, inland terminals and hinterland market	2021	Australian Journal of Maritime and Ocean Affairs
36	Visibility and verifiability in port governance transparency: exploring stakeholder expectations	2021	WMU Journal of Maritime Affairs
37	Evaluating the role of dry ports in the port-hinterland settings: Conceptual framework and the case of Vietnam	2021	Asian Journal of Shipping and Logistics
38	A framework for the impact analysis on earthquakes and tsunamis on seaport operations by using evidential reasoning	2021	Australian Journal of Maritime and Ocean Affairs
39	A conceptual model of smart port performance and smart port indicators in Thailand	2021	Journal of International Logistics and Trade
40	Impact of COVID-19 on the Indian seaport transportation and maritime supply chain	2021	Transport Policy
41	Identifying port maritime communities: application to the Spanish case	2021	European Transport Research Review
42	Container barge (un)reliability in seaports: A company case study at the port of Antwerp	2021	International Journal of Shipping and Transport Logistics
43	Port activity and technical efficiency: determinants and external factors	2021	Maritime Policy and Management
44	Sustainable development of port cities from the perspective of transition management	2021	Transactions on Maritime Science
45	Value-added services at dry ports: Balancing the perspectives of different stakeholders	2021	Transportation Journal
46	Port service quality (PSQ) and customer satisfaction: an exploratory study of container ports in Vietnam	2021	Maritime Business Review
47	Adapting our sea ports to the challenges of climate change: Development and validation of a Port Resilience Index	2021	Marine Policy
48	Port cities within port regions: Shaping complex urban environments in gdańsk bay, poland	2021	Urban Planning

49	What drives ports around the world to adopt air emissions abatement measures?	2021	Transportation Research Part D: Transport and Environment
50	DLT-BASED SUSTAINABLE BUSINESS MODELS FOR THE SHIPPING INDUSTRY	2021	International Journal of Transport Economics
51	An evaluation model of cruise ports using fuzzy analytic hierarchy process	2021	Maritime Business Review
52	Hindrances in port digitalization? Identifying problems in adoption and implementation	2021	European Transport Research Review
53	Multi-aspect applications and development challenges of digital twin-driven management in global smart ports	2021	Case Studies on Transport Policy
54	Green port performance evaluation under uncertainty: A multiple attribute group decision analysis	2021	International Journal of Shipping and Transport Logistics
55	Blockchain applications and architectures for port operations and logistics management	2021	Research in Transportation Business and Management
56	Theoretical highlights in container port logistics systems	2021	Journal of Marine and Island Cultures
57	Towards sustainability in the port sector: The role of intermediation in transition work	2021	Environmental Innovation and Societal Transitions
58	Technological trajectories and scenarios in seaport digitalization	2021	Research in Transportation Business and Management
59	Evaluation of the eco-efficiency of territorial districts with seaport economic activities	2021	Utilities Policy
60	Prioritizing environmental justice in the port hinterland policy: Case of Busan New Port	2021	Research in Transportation Business and Management
61	Sustainable inland port development: Integrated framework applied to Modjo Dry Port Ethiopia	2021	World Review of Intermodal Transportation Research
62	The emergence of very large container vessel (VLCV) in maritime trade: implications on the Malaysian seaport operations	2021	WMU Journal of Maritime Affairs
63	Disruptions and resilience in global container shipping and ports: the COVID-19 pandemic versus the 2008–2009 financial crisis	2021	Maritime Economics and Logistics

64	Improving seaport competitiveness by creating a connection to the national rail network	2020	Transport Problems
65	Deep adaptation to climate change in the maritime transport sector–a new paradigm for maritime economics?	2020	Maritime Policy and Management
66	The meaning of corporate social performance in seaports: the managers' perspective	2020	WMU Journal of Maritime Affairs
67	Innovation and maritime transport: A systematic review	2020	Case Studies on Transport Policy
68	Adapting ports to sea-level rise: empirical lessons based on land subsidence in Indonesia and Japan	2020	Maritime Policy and Management
69	A sustainable framework for the analysis of port systems	2020	European Transport - Trasporti Europei
70	Container terminal layout design: transition and future	2020	Maritime Economics and Logistics
71	Do specialisation and port size affect port efficiency? Evidence from cargo handling service in Spanish ports	2020	Transportation Research Part A: Policy and Practice
72	Monitoring of air emissions in maritime ports	2020	Transportation Research Part D: Transport and Environment
73	Climate change adaptation in the port industry: A complex of lingering research gaps and uncertainties	2020	Transport Policy
74	Automatic information exchange between interoperable information systems: Potential improvement of access management in a seaport terminal	2020	Research in Transportation Business and Management
75	Seaport adaptation to climate change-related disasters: terminal operator market structure and inter- and intra-port coopetition	2020	Spatial Economic Analysis
76	Port disruptions due to natural disasters: Insights into port and logistics resilience	2020	Transportation Research Part D: Transport and Environment
77	Assessing anthropogenic vulnerability of coastal regions: DEA-based index and rankings for the European Atlantic Area	2020	Marine Policy
78	A global approach to mapping the environmental risk of harbours on aquatic systems	2020	Marine Policy
79	Dry ports and related environmental benefits: a case study in Italy	2020	Case Studies on Transport Policy

80	An analysis of port networks and improvement strategies for port connections in the Ho Chi Minh area	2020	Asian Journal of Shipping and Logistics
81	Factors contributing to the imbalances of cargo flows in Malaysia large-scale minor ports using a fuzzy analytical hierarchy process (FAHP) approach	2020	Asian Journal of Shipping and Logistics
82	The role of port authorities in the promotion of logistics integration between ports and the railway system: The Italian experience	2020	Research in Transportation Business and Management
83	Growth in the docks: ports, metabolic flows and socio-environmental impacts	2020	Sustainability Science
84	A review of corporate sustainability drivers in maritime ports: a multi-stakeholder perspective	2020	Maritime Policy and Management
85	Seaports as drivers of regional economic development: The case of Saint Petersburg and Leningrad Province	2020	Case Studies on Transport Policy
86	Service purchasing and market-entry problems in a shipping supply chain	2020	Transportation Research Part E: Logistics and Transportation Review
87	Lean, agile, resilience and green (LARG) paradigm in supply chain operations: a trial in a seaport system	2020	Australian Journal of Maritime and Ocean Affairs
88	The impact of port community systems (PCS) characteristics on performance	2020	Research in Transportation Economics
89	Innovation in the maritime sector: aligning strategy with outcomes	2020	Maritime Policy and Management
90	Risk in port logistics: Risk classification and mitigation framework	2020	International Journal of Shipping and Transport Logistics
91	Seaport climate change impact assessment using a multi-level methodology	2020	Maritime Policy and Management
92	Institutional efficiency factors of adriatic seaports	2020	Transformations in Business and Economics
93	Spanish container ports integration in the maritime network	2020	Journal of Maritime Research
94	Smaller ports’ evolution towards catalysing sustainable hinterland development	2020	Maritime Policy and Management
95	Decision makers’ barriers to climate and extreme weather adaptation: a study of North Atlantic high- and medium-use seaports	2020	Sustainability Science

96	A citation network analysis of sustainability development in liner shipping management: a review of the literature and policy implications	2020	Maritime Policy and Management
97	Human resource management of logistics in vietnam: Status and policy solutions	2020	International Journal of Innovation, Creativity and Change
98	Shipping-collaboration model for the new generation of container port in innovation district: A case of Eastern Economic Corridor	2020	Asian Journal of Shipping and Logistics
99	Quantitative evaluation of dual operational-environmental port performance in the Pearl River Delta	2020	International Journal of Shipping and Transport Logistics
100	Overview of status and priorities for sustainable management of european seaports	2020	Journal of Maritime Research
101	A Review of Port Research using Computational Text Analysis: A Comparison of Korean and International Journals	2020	Asian Journal of Shipping and Logistics
102	Port-city development: The Spanish case	2020	Transactions on Maritime Science
103	Sustainable development of logistics in vietnam in the period 2020-2025	2020	International Journal of Innovation, Creativity and Change
104	The effect of weather conditions on port technical efficiency	2020	Marine Policy
105	Improving competitiveness level of Turkish intermodal ports in the Frame of Green Port Concept: a case study	2020	Maritime Policy and Management
106	Stakeholder salience and prioritization for port master planning, a case study of the multi-purpose port of isafjordur in Iceland	2019	European Journal of Transport and Infrastructure Research
107	A multi-objective mixed robust possibilistic flexible programming approach for sustainable seaport-dry port network design under an uncertain environment	2019	Transportation Research Part E: Logistics and Transportation Review
108	Evaluating the key factors of green port policies in Taiwan through quantitative and qualitative approaches	2019	Transport Policy
109	Critical success factors of supply chain integration in container shipping: an application of resource-based view theory	2019	Maritime Policy and Management
110	Conceptual framework of life-cycle performance measurement: Ensuring the resilience of transport infrastructure assets	2019	Transportation Research Part D: Transport and

			Environment
111	Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports?	2019	Transportation Research Part D: Transport and Environment
112	Evaluating determinants of attractiveness and their cause-effect relationships for container ports in Taiwan: users' perspectives	2019	Maritime Policy and Management
113	A serving innovation typology: mapping port-related innovations	2019	Transport Reviews
114	Port sustainability and performance: A systematic literature review	2019	Transportation Research Part D: Transport and Environment
115	Examining stakeholder participation and conflicts associated with large scale infrastructure projects: the case of Tema port expansion project, Ghana	2019	Maritime Policy and Management
116	Optimizing private and public mode of operation in major ports of India for better customer service	2019	Indian Growth and Development Review
117	Management Control Systems in port waste management: Evidence from Italy	2019	Utilities Policy
118	Green port marketing for sustainable growth and development	2019	Transport Policy
119	Sustainability initiatives in Canadian ports	2019	Marine Policy
120	Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports—a case study in Copenhagen-Malmö Port (CMP)	2019	WMU Journal of Maritime Affairs
121	Sustainability at Spanish ports specialized in liquid bulk: evolution in times of crisis (2010–2015)	2019	Maritime Policy and Management
122	Analysing sustainability changes in seaports: Experiences from the Gävle Port Authority	2019	Sustainable Development
123	Exploring the development of Malaysian seaports as a hub for tourism activities	2019	Maritime Business Review
124	The Sustainable Port Classification Framework for Enhancing the Port Coordination System	2019	Asian Journal of Shipping and Logistics
125	Framing stakeholder involvement in sustainable port planning	2018	Transactions on Maritime Science

126	Consistency in the development of performance assessment methods in the maritime domain	2018	WMU Journal of Maritime Affairs
127	Impact of the smart port industry on the Korean national economy using input-output analysis	2018	Transportation Research Part A: Policy and Practice
128	The role of seaports in regional employment: evidence from South Korea	2018	Regional Studies
129	The impact of supply chain relationship quality on performance in the maritime logistics industry in light of firm characteristics	2018	International Journal of Logistics Management
130	Self-management of greenhouse gas and air pollutant emissions in Taichung Port, Taiwan	2018	Transportation Research Part D: Transport and Environment
131	Risk and cost evaluation of port adaptation measures to climate change impacts	2018	Transportation Research Part D: Transport and Environment
132	Evaluating economic and environmental value of liner vessel sharing along the maritime silk road	2018	Maritime Policy and Management
133	Are the innovation processes in seaport terminal operations successful?	2018	Maritime Policy and Management
134	Strategic responses to institutional forces pressuring sustainability practice adoption: Case-based evidence from inland port operations	2018	Transportation Research Part D: Transport and Environment
135	Developing the fifth generation port concept model: an empirical test	2018	International Journal of Logistics Management
136	Exploring the conditions for inclusive port development: the case of Indonesia	2018	Maritime Policy and Management
137	Dynamics of supply environment and information system: Integration, green economy and performance	2018	Transportation Research Part D: Transport and Environment
138	Drivers of maritime green supply chain management	2018	Sustainable Cities and Society
139	Port governance in China since 2004: Institutional layering and the growing impact of broader policies	2017	Research in Transportation Business and Management
140	Portfolio of port-centric supply chain disruption threats	2017	International Journal of Logistics Management

141	A methodological approach for environmental characterization of ports	2017	Maritime Policy and Management
142	Environmental reform of West and Central Africa ports: the influence of colonial legacies	2017	Maritime Policy and Management
143	Institutionalizing environmental reform with sense-making: West and Central Africa ports and the ‘green port’ phenomenon	2017	Marine Policy
144	A systems framework for the sustainable development of a Port City: A case study of Singapore's policies	2017	Research in Transportation Business and Management
145	Strategic beliefs of port authorities	2017	Transport Reviews
146	The influence of organisational green climate on employees’ green behaviours: Evidence from the Eco Port of Kaohsiung	2017	International Journal of Shipping and Transport Logistics
147	An empirical test of the balanced theory of port competitiveness	2017	International Journal of Logistics Management
148	A literature review of port competition research	2017	International Journal of Shipping and Transport Logistics
149	Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)	2017	Sustainability Science
150	Evolution of national port governance and interport competition in Chile	2017	Research in Transportation Business and Management
151	Evaluating air emission inventories and indicators from cruise vessels at ports	2017	WMU Journal of Maritime Affairs
152	The drivers of port competitiveness: a critical review	2017	Transport Reviews
153	International trade logistics costs in South Africa: Informing the port reform agenda	2017	Research in Transportation Business and Management
154	Investigating the strategies for Australian regional ports' involvement in regional development	2016	International Journal of Shipping and Transport Logistics
155	A literature review on port sustainability and ocean's carrier network problem	2016	Research in Transportation Business and Management
156	Towards Sustainable ASEAN Port Development: Challenges and Opportunities for Vietnamese Ports	2016	Asian Journal of Shipping and Logistics

157	Multi-dimensional service improvement under the multi-customer nature of container terminals	2016	International Journal of Shipping and Transport Logistics
158	International emission regulation in sea transport: Economic feasibility and impact	2016	Transportation Research Part D: Transport and Environment
159	Analysis of the potential contribution of value-adding services (VAS) to the competitive logistics strategy of ports	2016	Maritime Economics and Logistics
160	Port expansion and negative externalities: a willingness to accept approach	2016	Maritime Policy and Management
161	New evidence on the determinants of efficiency at Brazilian ports: A bootstrapped DEA analysis	2016	International Journal of Shipping and Transport Logistics
162	Competitiveness in a Multipolar Port System: Striving for Regional Gateway Status in Northeast Asia	2016	Asian Journal of Shipping and Logistics
163	Examining sustainability performance at ports: port managers' perspectives on developing sustainable supply chains	2016	Maritime Policy and Management
164	Identifying crucial sustainability assessment criteria for container seaports	2016	Maritime Business Review
165	Port supply chain integration: analyzing biofuel supply chains	2016	Maritime Policy and Management
166	Managing people and technology: The challenges in CSR and energy efficient shipping	2015	Research in Transportation Business and Management
167	The role of port authorities in the development of LNG bunkering facilities in North European ports	2015	WMU Journal of Maritime Affairs
168	Sustainable development in seaports: A multi-case study	2014	WMU Journal of Maritime Affairs
169	Environmental sustainability in seaports: a framework for successful innovation	2014	Maritime Policy and Management
170	An integrated fuzzy risk assessment for seaport operations	2014	Safety Science
171	Port vulnerability assessment from the perspective of critical infrastructure interdependency	2014	Maritime Policy and Management
172	Environmental innovation and the role of stakeholder collaboration in West Coast port gateways	2013	Research in Transportation Economics

173	Key factors of seaport competitiveness based on the stakeholder perspective: An Analytic Hierarchy Process (AHP) model	2013	Maritime Economics and Logistics
174	Performance and quality indexes in the evaluation of the terminal activity: A dynamic approach	2013	Research in Transportation Business and Management
175	Port sustainability and stakeholder management in supply chains: A framework on resource dependence theory	2012	Asian Journal of Shipping and Logistics
176	Why are maritime ports (still) urban, and why should policy-makers care?	2012	Maritime Policy and Management
177	Port risk management and public private partnerships: Factors relating to risk allocation and risk sustainability	2010	World Review of Intermodal Transportation Research
178	Sustainable port innovations: Barriers and enablers for successful implementation	2010	World Review of Intermodal Transportation Research
179	Strategic intent: Guiding port authorities to their new world?	2010	Research in Transportation Economics
180	The business paradigm for corporate social reporting in the context of Australian seaports	2007	Maritime Economics and Logistics
181	A critical review of conventional terminology for classifying seaports	2005	Transportation Research Part A: Policy and Practice
182	Simulation and the lean port environment	2005	Maritime Economics and Logistics
183	Measuring lean ports performance	2003	International Journal of Transport Management
184	Technology, intermodal transportation, and port productivity: Throughput maximization and environmental sustainability	1996	Journal of Urban Technology

Source: Literature Review- Research Study

Appendix-D

Table D1: Age, gender, education, designation, department and location of the marine experts for Research study

Sl No	Gender	Designation	Department	Educational qualifications	Location	Experience	PENSP-Importance	PSOSP-Importance	PECSP-Importance	PINSP-Importance	PCSP-Importance	PENSP-Performance	PSOSP- Performance	PECSP- Performance	PINSP- Performance	PCSP- Performance
1	Male	Envt. Officer	Civil	BE(Civil) M.Sc (Envt. Science)	Cochin	16	5	5	5	5	5	5	4	5	5	4
2	Male	DTM	Traffic	BBM, MBA(Logistics)	Mumbai	10	5	5	5	5	4	4	4	5	5	4
3	Male	Dy.CAO	Finance	BCOM, MBA(Finance)	Mumbai	15	5	5	5	5	5	3	4	5	4	4
4	Female	CMO	Medical	MBBS, MD	Mangalore	21	5	5	5	5	5	5	5	5	4	4
5	Male	Envt Officer	Civil	BE(Civil),M.Sc (Envt. Science)	Mangalore	17	5	5	5	5	4	5	4	5	3	4
6	Female	Dy Marine Engineer	Marine	BE(Mech),MSc(Marine)	Mumbai	22	5	5	5	5	5	4	5	5	4	5
7	Male	Sr.DTM	Traffic	BSc, MBA (Marketing Management)	Kandla	29	4	4	5	5	5	4	4	5	5	5
8	Female	Safety Officer	Mechanical	BE(Mech), PGDIP (Safety Management)	Mangalore	26	5	5	5	5	4	5	5	5	4	4
9	Female	AO(Finance)	Finance	BCOM, MBA(Finance)	Kandla	21	5	5	4	5	5	4	4	4	4	4
10	Female	Sr.Dy Secretary	Administration	BA, MA, LLB, PGDHR-Labour Law	Cochin	25	5	5	5	5	5	4	4	5	4	3
11	Male	Dy Marine Engineer	Marine	BE(Mech) ,MSc (Marine)	Mangalore	31	5	5	4	5	5	5	5	4	4	4
12	Male	Envt Officer	Civil	BE(Civil), M.Sc(Envt. Science), PhD (Envt Science)	Mumbai	13	5	5	5	5	5	4	4	5	4	4

13	Female	Sr.Dy Secretary	Administration	BA,MA,LLB,PGDHRM	Mangalore	17	5	5	5	4	4	5	4	4	5	5
14	Male	ATM Gr1	Traffic	BSc, MBA (Logistics Management)	Cochin	11	5	5	5	5	5	4	4	5	4	4
15	Male	Harbour Master	Marine	BE(Mech), MSc (Marine)	Mangalore	19	4	5	5	4	5	5	4	4	3	4
16	Female	AEE(Ele)	Mechanical	BE(Electrical), M.Tech (Digital Communications)	Mumbai	25	5	5	5	5	5	5	5	3	4	4
17	Male	Sr AO	Finance	BCOM, MBA(Finance), CA	Mumbai	30	4	4	5	5	5	4	4	5	4	4
18	Female	Dy Secretary	Administration	BA, LLB, PGDHR-Labour Law	Kandla	26	5	5	5	4	5	4	4	4	4	4
19	Male	Envt Officer	Civil	BE(Civil),M.Sc (Envt. Science)	Kandla	14	5	4	5	5	5	4	5	3	4	5
20	Female	Sr Dy CAO	Finance	M.Com, CA	Cochin	17	4	4	5	4	5	5	4	4	4	4
21	Female	Secretary	Administration	BA,MA,LLB	Cochin	19	5	5	5	5	4	5	4	5	4	4
22	Female	FA&CAO	Finance	M.Com, CA	Mangalore	29	5	5	5	4	5	5	5	3	3	4
23	Male	Fire Officer	Marine	BE(Mech), PGDIP (Fire & Safety Management)	Kandla	23	5	5	4	5	5	4	4	4	4	4
24	Male	EE(Ele)	Mechanical	BE(Electrical),M.Tech(Power Electronics)	Cochin	21	5	5	5	5	5	4	5	4	4	4
25	Male	Dy CAO	Finance	M.Com, CA	Kandla	12	4	5	4	5	4	4	5	3	4	4
26	Female	AEE(Civil)	Civil	BE(Civil), M.Tech (Civil Structures)	Mumbai	16	5	5	5	4	4	3	4	5	4	4
27	Male	EE(Civil)	Civil	BE(Civil), M.Tech(Construction Technology)	Mumbai	28	5	5	5	4	5	5	4	4	5	4
28	Male	Sr. DTM	Traffic	BE(E&CE), MBA	Mangalore	23	4	5	5	5	5	4	4	3	4	4
29	Female	Dy Secretary	Administration	BBM,MBA(HR)	Kandla	16	5	5	5	5	4	5	5	4	5	4
30	Male	SE(Civil)	Civil	BE(Civil), M.Tech (Civil Structures)	Cochin	19	5	5	5	5	5	4	3	5	3	5
31	Female	AO(Finance)	Finance	M.Com, CA	Mangalore	11	5	5	5	5	5	4	4	5	5	5
32	Male	Harbour Master	Marine	BSc (Marine),MSc(Marine)	Mumbai	18	5	5	5	5	5	4	5	4	4	4
33	Male	Dock Master	Marine	BSc (Marine),MSc (Marine),MBA	Mangalore	24	5	5	5	5	5	5	4	3	5	4

34	Male	EE(Civil)	Civil	BE(Civil), MBA (HR),M.Tech (Civil),PhD(Port Management)	Mangalore	26	5	4	5	5	5	4	4	4	5	5
35	Male	DTM	Traffic	BSc, MBA (Marketing Management)	Cochin	22	5	5	5	5	4	4	5	5	4	4
36	Male	AO(Finance)	Finance	M.Com, ICWA	Kandla	19	5	5	4	5	5	5	4	4	4	4
37	Male	EE(Civil)	Civil	BE(Civil), M.Tech (Construction Technology)	Mumbai	25	5	5	5	5	5	4	4	4	5	5
Mean Values							**4.84**	**4.86**	**4.87**	**4.8**	**4.77**	**4.35**	**4.28**	**4.29**	**4.15**	**4.18**

Source: Research Study- Expert Assessment of sustainability dimension

Appendix-E

Calculation of AQI data for DEA Analysis

Calculation of AQI

Date		Station	NSIT
DD-MM-YYYY		City	Delhi
		State	Delhi

Pollutants		concentration in µg/m3 (except for CO)	Sub-Index	check		Air Quality Index
PM10	24-hr avg		0	0		
PM2.5	24-hr avg		0	0		
SO2	24-hr avg		0	0		
NOx	24-hr avg		0	0	AQI =	Atleast 3 inputs*
*CO (mg/m3)	max 8-hr		0	0		
O3	max 8-hr		0	0		
NH3	24-hr avg		0	0		

* Concentrations of minimum three pollutants are required; one of them should be PM10 or PM2.5

* The check displays "1" when a non-zero value is entered

Good (0–50)	Minimal Impact	Poor (201–300)	Breathing discomfort to people on prolonged exposure
Satisfactory (51–100)	Minor breathing discomfort to sensitive people	Very Poor (301–400)	Respiratory illness to the people on prolonged exposure
Moderate (101–200)	Breathing discomfort to the people with lung, heart disease, children and older adults	Severe (>401)	Respiratory effects even on healthy people

AQI calculation; Source: CPCB Website

APPENDIX F

i. Analysis for FY 2016-17

Table F1: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2016-17 for 4 major seaports in India

FY 2016-17 Data Port Name: D,M,N,C	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	-0.04	1.00																		
OP-3	0.02	-0.79	1.00																	
OP-4	0.65	-0.58	0.77	1.00																
OP-5	0.36	0.56	-0.90	-0.47	1.00															
OP-6	0.42	0.48	-0.85	-0.39	0.99	1.00														
OP-7	-0.07	1.00	-0.78	-0.58	0.53	0.45	1.00													
OP-8	0.23	0.22	-0.75	-0.47	0.91	0.92	0.19	1.00												
OP-9	0.66	-0.48	0.01	0.37	0.41	0.50	-0.52	0.61	1.00											
OP-10	-0.04	-0.79	0.25	0.08	-0.02	0.05	-0.80	0.39	0.70	1.00										
IP-1	0.35	0.63	-0.92	-0.48	1.00	0.98	0.60	0.87	0.34	-0.11	1.00									
IP-2	0.68	0.26	-0.63	-0.07	0.90	0.94	0.22	0.86	0.72	0.16	0.88	1.00								
IP-3	0.92	-0.07	0.29	0.82	0.02	0.07	-0.09	-0.18	0.38	-0.26	0.03	0.35	1.00							
IP-4	0.26	0.64	-0.94	-0.56	0.99	0.98	0.61	0.88	0.30	-0.08	1.00	0.85	-0.06	1.00						
IP-5	0.14	0.67	-0.97	-0.66	0.97	0.94	0.65	0.87	0.21	-0.10	0.98	0.78	-0.18	0.99	1.00					
IP-6	0.45	0.60	-0.88	-0.39	0.99	0.99	0.57	0.85	0.40	-0.11	0.99	0.92	0.13	0.98	0.95	1.00				
IP-7	0.78	0.22	-0.53	0.07	0.84	0.89	0.18	0.78	0.74	0.12	0.82	0.99	0.48	0.78	0.69	0.87	1.00			
IP-8	0.84	-0.28	0.51	0.94	-0.20	-0.13	-0.30	-0.32	0.38	-0.14	-0.20	0.18	0.97	-0.28	-0.40	-0.09	0.32	1.00		
IP-9	0.58	-0.46	-0.07	0.25	0.46	0.55	-0.49	0.69	0.99	0.74	0.39	0.73	0.27	0.37	0.28	0.44	0.74	0.26	1.00	
IP-10	-0.94	0.22	0.02	-0.56	-0.45	-0.53	0.25	-0.45	-0.87	-0.27	-0.41	-0.78	-0.75	-0.34	-0.22	-0.50	-0.86	-0.70	-0.82	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F2: R-squared values for Input & Output Seaport Sustainability parameter data for FY-2016-17 for 4 major seaports in India

FY 2016-17 Data Port Name: D,C,N,M	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.00	1.00																		
OP-3	0.00	0.63	1.00																	
OP-4	0.42	0.33	0.59	1.00																
OP-5	0.13	0.32	0.81	0.22	1.00															
OP-6	0.18	0.23	0.72	0.15	0.99	1.00														
OP-7	0.01	1.00	0.60	0.34	0.28	0.20	1.00													
OP-8	0.05	0.05	0.57	0.22	0.82	0.86	0.04	1.00												
OP-9	0.43	0.24	0.00	0.14	0.17	0.25	0.27	0.37	1.00											
OP-10	0.00	0.62	0.06	0.01	0.00	0.00	0.64	0.15	0.49	1.00										
IP-1	0.12	0.40	0.85	0.23	0.99	0.97	0.37	0.75	0.11	0.01	1.00									
IP-2	0.46	0.07	0.39	0.00	0.82	0.89	0.05	0.74	0.52	0.02	0.77	1.00								
IP-3	0.84	0.00	0.08	0.68	0.00	0.01	0.01	0.03	0.14	0.07	0.00	0.12	1.00							
IP-4	0.07	0.40	0.89	0.31	0.99	0.95	0.37	0.78	0.09	0.01	0.99	0.72	0.00	1.00						
IP-5	0.02	0.45	0.95	0.43	0.94	0.89	0.42	0.76	0.04	0.01	0.95	0.60	0.03	0.98	1.00					
IP-6	0.20	0.36	0.77	0.15	0.98	0.97	0.32	0.73	0.16	0.01	0.99	0.84	0.02	0.96	0.90	1.00				
IP-7	0.61	0.05	0.28	0.01	0.71	0.79	0.03	0.60	0.55	0.01	0.67	0.98	0.23	0.60	0.48	0.76	1.00			
IP-8	0.71	0.08	0.26	0.88	0.04	0.02	0.09	0.10	0.14	0.02	0.04	0.03	0.94	0.08	0.16	0.01	0.10	1.00		
IP-9	0.33	0.21	0.00	0.06	0.22	0.30	0.24	0.47	0.98	0.55	0.15	0.54	0.07	0.13	0.08	0.19	0.54	0.07	1.00	
IP-10	0.89	0.05	0.00	0.32	0.20	0.28	0.06	0.20	0.76	0.08	0.17	0.61	0.57	0.11	0.05	0.25	0.73	0.49	0.67	1.00

Sources: Authors Calculations based on Secondary source data of research

ii. Analysis for FY 2017-18

Table F3: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2017-18 for 4 major seaports in India

FY 2017-18 Data Port Name: D,M,N,C	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.39	1.00																		
OP-3	-0.09	-0.95	1.00																	
OP-4	0.52	-0.48	0.71	1.00																
OP-5	0.34	0.64	-0.60	-0.55	1.00															
OP-6	0.22	0.83	-0.84	-0.71	0.94	1.00														
OP-7	0.00	0.85	-0.90	-0.52	0.21	0.53	1.00													
OP-8	0.33	0.71	-0.68	-0.59	0.99	0.97	0.31	1.00												
OP-9	0.70	0.53	-0.36	-0.12	0.89	0.74	0.00	0.87	1.00											
OP-10	-0.25	-0.65	0.60	0.00	0.16	-0.13	-0.85	0.07	0.15	1.00										
IP-1	0.32	0.90	-0.88	-0.64	0.90	0.99	0.61	0.94	0.75	-0.26	1.00									
IP-2	0.55	0.68	-0.57	-0.36	0.97	0.89	0.20	0.97	0.97	0.06	0.89	1.00								
IP-3	0.96	0.30	0.01	0.68	0.08	0.00	0.02	0.09	0.48	-0.38	0.12	0.32	1.00							
IP-4	0.19	0.86	-0.88	-0.74	0.91	1.00	0.59	0.94	0.69	-0.19	0.99	0.86	-0.02	1.00						
IP-5	0.02	0.87	-0.95	-0.83	0.78	0.95	0.74	0.83	0.49	-0.33	0.94	0.70	-0.15	0.97	1.00					
IP-6	0.39	0.92	-0.88	-0.58	0.89	0.97	0.62	0.93	0.76	-0.31	1.00	0.89	0.20	0.97	0.92	1.00				
IP-7	0.80	0.80	-0.61	-0.09	0.78	0.76	0.38	0.80	0.89	-0.31	0.82	0.90	0.65	0.74	0.60	0.86	1.00			
IP-8	0.85	-0.02	0.33	0.88	-0.20	-0.32	-0.22	-0.21	0.25	-0.24	-0.21	0.04	0.94	-0.35	-0.47	-0.13	0.38	1.00		
IP-9	0.61	0.11	0.06	0.09	0.73	0.45	-0.43	0.66	0.90	0.52	0.42	0.79	0.40	0.38	0.14	0.42	0.64	0.30	1.00	
IP-10	-0.79	-0.02	-0.23	-0.42	-0.50	-0.21	0.49	-0.44	-0.81	-0.39	-0.22	-0.63	-0.65	-0.14	0.11	-0.25	-0.61	-0.60	-0.94	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F4 : R-squared values for Input & Output Seaport Sustainability parameter data for FY-2017-18 for 4 major seaports in India

FY 2017-18 Data Port Name: D,C,N,M	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.83	1.00																		
OP-3	-0.25	-0.73	1.00																	
OP-4	0.96	0.78	-0.26	1.00																
OP-5	0.84	0.52	0.20	0.70	1.00															
OP-6	0.10	0.55	-0.69	-0.07	0.06	1.00														
OP-7	0.10	0.61	-0.99	0.14	-0.36	0.63	1.00													
OP-8	0.44	0.67	-0.46	0.22	0.51	0.88	0.33	1.00												
OP-9	-0.58	-0.05	-0.65	-0.52	-0.84	0.46	0.76	-0.01	1.00											
OP-10	0.06	-0.38	0.85	-0.08	0.58	-0.28	-0.92	0.07	-0.79	1.00										
IP-1	0.29	0.71	-0.76	0.13	0.17	0.98	0.68	0.91	0.38	-0.33	1.00									
IP-2	0.73	0.90	-0.58	0.57	0.63	0.75	0.44	0.92	-0.11	-0.08	0.86	1.00								
IP-3	0.98	0.75	-0.17	0.99	0.80	-0.07	0.03	0.27	-0.62	0.05	0.12	0.59	1.00							
IP-4	0.16	0.59	-0.70	-0.02	0.10	1.00	0.64	0.90	0.43	-0.28	0.99	0.79	-0.02	1.00						
IP-5	-0.19	0.37	-0.79	-0.29	-0.36	0.91	0.81	0.60	0.79	-0.58	0.86	0.47	-0.33	0.89	1.00					
IP-6	0.38	0.78	-0.80	0.23	0.21	0.95	0.72	0.90	0.34	-0.38	0.99	0.89	0.22	0.96	0.82	1.00				
IP-7	0.44	0.83	-0.82	0.31	0.25	0.92	0.73	0.88	0.31	-0.40	0.98	0.91	0.29	0.94	0.79	1.00	1.00			
IP-8	0.98	0.66	-0.12	0.99	0.96	-0.35	0.02	-0.01	-0.65	-0.07	-0.12	0.49	1.00	-0.29	-0.47	0.01	0.10	1.00		
IP-9	-0.22	-0.19	0.29	-0.46	0.25	0.49	-0.34	0.59	-0.13	0.63	0.37	0.26	-0.35	0.47	0.26	0.28	0.21	-0.98	1.00	
IP-10	-0.33	-0.41	0.11	-0.07	-0.59	-0.74	0.01	-0.93	0.22	-0.41	-0.72	-0.77	-0.16	-0.75	-0.40	-0.69	-0.66	0.45	-0.81	1.00

Sources: Authors Calculations based on Secondary source data of research

iii. Analysis for FY 2018-19

Table F5: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2018-19 for 4 major seaports in India

FY 2018-19 Data Port Name: D,M,N,C	**OP-1**	**OP-2**	**OP-3**	**OP-4**	**OP-5**	**OP-6**	**OP-7**	**OP-8**	**OP-9**	**OP-10**	**IP-1**	**IP-2**	**IP-3**	**IP-4**	**IP-5**	**IP-6**	**IP-7**	**IP-8**	**IP-9**	**PI10**
OP-1	1.00																			
OP-2	0.30	1.00																		
OP-3	-0.16	-0.97	1.00																	
OP-4	0.53	-0.59	0.61	1.00																
OP-5	-0.04	0.25	-0.06	-0.54	1.00															
OP-6	0.25	0.92	-0.82	-0.70	0.60	1.00														
OP-7	-0.01	0.81	-0.93	-0.51	-0.27	0.56	1.00													
OP-8	0.16	0.60	-0.42	-0.63	0.92	0.86	0.07	1.00												
OP-9	0.79	0.69	-0.50	-0.09	0.48	0.77	0.20	0.72	1.00											
OP-10	-0.35	-0.59	0.71	-0.03	0.63	-0.24	-0.84	0.28	-0.21	1.00										
IP-1	0.30	0.95	-0.85	-0.65	0.54	1.00	0.60	0.82	0.79	-0.32	1.00									
IP-2	0.60	0.79	-0.61	-0.34	0.61	0.90	0.29	0.85	0.97	-0.15	0.91	1.00								
IP-3	0.96	0.19	-0.10	0.67	-0.32	0.04	0.04	-0.11	0.60	-0.48	0.11	0.39	1.00							
IP-4	0.19	0.93	-0.84	-0.74	0.58	1.00	0.60	0.84	0.72	-0.26	0.99	0.87	-0.01	1.00						
IP-5	-0.01	0.93	-0.90	-0.85	0.47	0.95	0.72	0.73	0.54	-0.32	0.94	0.72	-0.17	0.97	1.00					
IP-6	0.37	0.96	-0.86	-0.59	0.49	0.99	0.61	0.79	0.82	-0.37	1.00	0.92	0.19	0.98	0.92	1.00				
IP-7	0.78	0.76	-0.59	-0.12	0.41	0.80	0.31	0.68	0.99	-0.32	0.83	0.96	0.61	0.76	0.59	0.86	1.00			
IP-8	0.85	-0.15	0.21	0.88	-0.45	-0.29	-0.21	-0.36	0.34	-0.32	-0.22	0.09	0.94	-0.34	-0.49	-0.15	0.33	1.00		
IP-9	0.63	0.17	0.08	0.09	0.72	0.43	-0.43	0.71	0.79	0.40	0.42	0.74	0.40	0.37	0.14	0.43	0.71	0.30	1.00	
IP-10	-0.80	-0.03	-0.20	-0.42	-0.44	-0.21	0.49	-0.44	-0.74	-0.27	-0.22	-0.61	-0.65	-0.14	0.11	-0.25	-0.67	-0.61	-0.94	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F6: R-squared values for Input & Output Seaport Sustainability parameter data for FY-2018-19 for 4 major seaports in India

FY 2018-19 Data Port Name: D,C,N,M	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.09	1.00																		
OP-3	0.02	0.94	1.00																	
OP-4	0.28	0.35	0.38	1.00																
OP-5	0.00	0.06	0.00	0.30	1.00															
OP-6	0.06	0.85	0.68	0.48	0.36	1.00														
OP-7	0.00	0.66	0.87	0.26	0.07	0.32	1.00													
OP-8	0.03	0.36	0.18	0.39	0.85	0.74	0.01	1.00												
OP-9	0.62	0.48	0.25	0.01	0.23	0.59	0.04	0.52	1.00											
OP-10	0.12	0.35	0.50	0.00	0.40	0.06	0.71	0.08	0.04	1.00										
IP-1	0.09	0.90	0.72	0.42	0.29	0.99	0.36	0.67	0.62	0.10	1.00									
IP-2	0.36	0.62	0.37	0.12	0.38	0.81	0.08	0.72	0.93	0.02	0.82	1.00								
IP-3	0.92	0.04	0.01	0.45	0.10	0.00	0.00	0.01	0.36	0.23	0.01	0.15	1.00							
IP-4	0.04	0.87	0.71	0.54	0.34	1.00	0.36	0.71	0.52	0.07	0.99	0.75	0.00	1.00						
IP-5	0.00	0.86	0.81	0.71	0.22	0.90	0.52	0.54	0.29	0.11	0.89	0.51	0.03	0.94	1.00					
IP-6	0.14	0.92	0.74	0.35	0.24	0.97	0.37	0.63	0.68	0.14	0.99	0.84	0.04	0.96	0.85	1.00				
IP-7	0.61	0.58	0.35	0.01	0.17	0.63	0.09	0.47	0.99	0.10	0.68	0.93	0.37	0.57	0.35	0.74	1.00			
IP-8	0.72	0.02	0.05	0.78	0.20	0.08	0.04	0.13	0.12	0.10	0.05	0.01	0.89	0.11	0.24	0.02	0.11	1.00		
IP-9	0.40	0.03	0.01	0.01	0.52	0.19	0.18	0.51	0.63	0.16	0.17	0.55	0.16	0.14	0.02	0.18	0.51	0.09	1.00	
IP-10	0.64	0.00	0.04	0.18	0.19	0.04	0.24	0.20	0.55	0.07	0.05	0.37	0.42	0.02	0.01	0.06	0.45	0.37	0.88	1.00

Sources: Authors Calculations based on Secondary source data of research

iv. Analysis for FY 2019-20

Table F7: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2019-20 for 4 major seaports in India

FY 2019-20 Data Port Name: D,M,N,C	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.83	1.00																		
OP-3	-0.25	-0.73	1.00																	
OP-4	0.96	0.78	-0.26	1.00																
OP-5	0.84	0.52	0.20	0.70	1.00															
OP-6	0.10	0.55	-0.69	-0.07	0.06	1.00														
OP-7	0.10	0.61	-0.99	0.14	-0.36	0.63	1.00													
OP-8	0.44	0.67	-0.46	0.22	0.51	0.88	0.33	1.00												
OP-9	-0.58	-0.05	-0.65	-0.52	-0.84	0.46	0.76	-0.01	1.00											
OP-10	0.06	-0.38	0.85	-0.08	0.58	-0.28	-0.92	0.07	-0.79	1.00										
IP-1	0.29	0.71	-0.76	0.13	0.17	0.98	0.68	0.91	0.38	-0.33	1.00									
IP-2	0.73	0.90	-0.58	0.57	0.63	0.75	0.44	0.92	-0.11	-0.08	0.86	1.00								
IP-3	0.98	0.75	-0.17	0.99	0.80	-0.07	0.03	0.27	-0.62	0.05	0.12	0.59	1.00							
IP-4	0.16	0.59	-0.70	-0.02	0.10	1.00	0.64	0.90	0.43	-0.28	0.99	0.79	-0.02	1.00						
IP-5	-0.19	0.37	-0.79	-0.29	-0.36	0.91	0.81	0.60	0.79	-0.58	0.86	0.47	-0.33	0.89	1.00					
IP-6	0.38	0.78	-0.80	0.23	0.21	0.95	0.72	0.90	0.34	-0.38	0.99	0.89	0.22	0.96	0.82	1.00				
IP-7	0.44	0.83	-0.82	0.31	0.25	0.92	0.73	0.88	0.31	-0.40	0.98	0.91	0.29	0.94	0.79	1.00	1.00			
IP-8	0.98	0.66	-0.12	0.99	0.96	-0.35	0.02	-0.01	-0.65	-0.07	-0.12	0.49	1.00	-0.29	-0.47	0.01	0.10	1.00		
IP-9	-0.22	-0.19	0.29	-0.46	0.25	0.49	-0.34	0.59	-0.13	0.63	0.37	0.26	-0.35	0.47	0.26	0.28	0.21	-0.98	1.00	
IP-10	-0.33	-0.41	0.11	-0.07	-0.59	-0.74	0.01	-0.93	0.22	-0.41	-0.72	-0.77	-0.16	-0.75	-0.40	-0.69	-0.66	0.45	-0.81	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F8: R-squared values for Input & Output Seaport Sustainability parameter data for FY-2019-20 for 4 major seaports in India

FY 2019-20 Data Port Name: D,C,N,M	**OP-1**	**OP-2**	**OP-3**	**OP-4**	**OP-5**	**OP-6**	**OP-7**	**OP-8**	**OP-9**	**OP-10**	**IP-1**	**IP-2**	**IP-3**	**IP-4**	**IP-5**	**IP-6**	**IP-7**	**IP-8**	**IP-9**	**PI10**
OP-1	1.00																			
OP-2	0.83	1.00																		
OP-3	-0.25	-0.73	1.00																	
OP-4	0.96	0.78	-0.26	1.00																
OP-5	0.84	0.52	0.20	0.70	1.00															
OP-6	0.10	0.55	-0.69	-0.07	0.06	1.00														
OP-7	0.10	0.61	-0.99	0.14	-0.36	0.63	1.00													
OP-8	0.44	0.67	-0.46	0.22	0.51	0.88	0.33	1.00												
OP-9	-0.58	-0.05	-0.65	-0.52	-0.84	0.46	0.76	-0.01	1.00											
OP-10	0.06	-0.38	0.85	-0.08	0.58	-0.28	-0.92	0.07	-0.79	1.00										
IP-1	0.29	0.71	-0.76	0.13	0.17	0.98	0.68	0.91	0.38	-0.33	1.00									
IP-2	0.73	0.90	-0.58	0.57	0.63	0.75	0.44	0.92	-0.11	-0.08	0.86	1.00								
IP-3	0.98	0.75	-0.17	0.99	0.80	-0.07	0.03	0.27	-0.62	0.05	0.12	0.59	1.00							
IP-4	0.16	0.59	-0.70	-0.02	0.10	1.00	0.64	0.90	0.43	-0.28	0.99	0.79	-0.02	1.00						
IP-5	-0.19	0.37	-0.79	-0.29	-0.36	0.91	0.81	0.60	0.79	-0.58	0.86	0.47	-0.33	0.89	1.00					
IP-6	0.38	0.78	-0.80	0.23	0.21	0.95	0.72	0.90	0.34	-0.38	0.99	0.89	0.22	0.96	0.82	1.00				
IP-7	0.44	0.83	-0.82	0.31	0.25	0.92	0.73	0.88	0.31	-0.40	0.98	0.91	0.29	0.94	0.79	1.00	1.00			
IP-8	0.98	0.66	-0.12	0.99	0.96	-0.35	0.02	-0.01	-0.65	-0.07	-0.12	0.49	1.00	-0.29	-0.47	0.01	0.10	1.00		
IP-9	-0.22	-0.19	0.29	-0.46	0.25	0.49	-0.34	0.59	-0.13	0.63	0.37	0.26	-0.35	0.47	0.26	0.28	0.21	-0.98	1.00	
IP-10	-0.33	-0.41	0.11	-0.07	-0.59	-0.74	0.01	-0.93	0.22	-0.41	-0.72	-0.77	-0.16	-0.75	-0.40	-0.69	-0.66	0.45	-0.81	1.00

Sources: Authors Calculations based on Secondary source data of research

v. *Analysis for FY 2020-21*

Table F9: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2020-21 for 4 major seaports in India

FY 2020-21 Data Port Name: D,M,N,C	**OP-1**	**OP-2**	**OP-3**	**OP-4**	**OP-5**	**OP-6**	**OP-7**	**OP-8**	**OP-9**	**OP-10**	**IP-1**	**IP-2**	**IP-3**	**IP-4**	**IP-5**	**IP-6**	**IP-7**	**IP-8**	**IP-9**	**PI10**
OP-1	1.00																			
OP-2	0.92	1.00																		
OP-3	-0.41	-0.52	1.00																	
OP-4	0.81	0.56	-0.44	1.00																
OP-5	0.96	0.98	-0.38	0.60	1.00															
OP-6	0.52	0.32	0.56	0.38	0.49	1.00														
OP-7	0.35	0.35	-0.95	0.56	0.23	-0.54	1.00													
OP-8	0.55	0.82	-0.68	0.11	0.71	-0.20	0.43	1.00												
OP-9	0.26	0.32	-0.96	0.45	0.17	-0.64	0.99	0.47	1.00											
OP-10	-0.22	-0.16	0.86	-0.56	-0.05	0.55	-0.97	-0.21	-0.96	1.00										
IP-1	0.35	0.64	-0.81	0.02	0.49	-0.49	0.58	0.95	0.64	-0.40	1.00									
IP-2	0.73	0.90	-0.79	0.40	0.81	-0.12	0.60	0.95	0.61	-0.40	0.90	1.00								
IP-3	1.00	0.92	-0.44	0.82	0.95	0.50	0.38	0.55	0.30	-0.25	0.36	0.74	1.00							
IP-4	0.15	0.49	-0.71	-0.20	0.33	-0.59	0.47	0.90	0.56	-0.30	0.98	0.78	0.16	1.00						
IP-5	-0.62	-0.30	-0.32	-0.70	-0.46	-0.90	0.19	0.30	0.32	-0.15	0.53	0.10	-0.60	0.68	1.00					
IP-6	0.17	0.47	-0.83	-0.08	0.30	-0.67	0.63	0.86	0.71	-0.48	0.98	0.80	0.19	0.98	0.67	1.00				
IP-7	0.61	0.82	-0.85	0.31	0.70	-0.28	0.66	0.96	0.68	-0.47	0.95	0.99	0.62	0.86	0.25	0.88	1.00			
IP-8	0.46	0.71	-0.87	0.18	0.56	-0.44	0.68	0.95	0.72	-0.50	0.99	0.94	0.47	0.93	0.42	0.95	0.98	1.00		
IP-9	-0.11	0.16	0.38	-0.67	0.17	0.17	-0.65	0.37	-0.58	0.79	0.24	0.11	-0.14	0.35	0.28	0.16	0.09	0.11	1.00	
IP-10	0.11	-0.20	-0.22	0.68	-0.18	-0.01	0.51	-0.49	0.42	-0.67	-0.40	-0.23	0.14	-0.52	-0.42	-0.34	-0.23	-0.27	-0.98	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F10: R-squared values for Input & Output Seaport Sustainability parameter data for FY-2020-21 for 4 major seaports in India

FY 2020-21 Data Port Name: D,C,N,M	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.85	1.00																		
OP-3	0.17	0.27	1.00																	
OP-4	0.65	0.31	0.19	1.00																
OP-5	0.92	0.96	0.14	0.36	1.00															
OP-6	0.28	0.10	0.31	0.14	0.24	1.00														
OP-7	0.12	0.12	0.90	0.32	0.05	0.29	1.00													
OP-8	0.30	0.67	0.47	0.01	0.50	0.04	0.18	1.00												
OP-9	0.07	0.10	0.93	0.20	0.03	0.40	0.98	0.22	1.00											
OP-10	0.05	0.03	0.73	0.31	0.00	0.30	0.95	0.05	0.92	1.00										
IP-1	0.12	0.41	0.65	0.00	0.24	0.24	0.34	0.90	0.42	0.16	1.00									
IP-2	0.53	0.82	0.63	0.16	0.65	0.01	0.36	0.91	0.37	0.16	0.80	1.00								
IP-3	1.00	0.85	0.19	0.67	0.90	0.25	0.15	0.31	0.09	0.06	0.13	0.54	1.00							
IP-4	0.02	0.24	0.51	0.04	0.11	0.35	0.22	0.81	0.31	0.09	0.95	0.62	0.03	1.00						
IP-5	0.38	0.09	0.10	0.50	0.21	0.80	0.04	0.09	0.10	0.02	0.28	0.01	0.36	0.47	1.00					
IP-6	0.03	0.22	0.69	0.01	0.09	0.45	0.40	0.74	0.50	0.23	0.95	0.63	0.03	0.96	0.45	1.00				
IP-7	0.37	0.67	0.73	0.10	0.49	0.08	0.43	0.92	0.47	0.22	0.91	0.97	0.39	0.75	0.06	0.78	1.00			
IP-8	0.21	0.50	0.76	0.03	0.31	0.20	0.46	0.89	0.52	0.25	0.97	0.88	0.22	0.86	0.17	0.91	0.97	1.00		
IP-9	0.01	0.03	0.15	0.44	0.03	0.03	0.43	0.14	0.34	0.63	0.06	0.01	0.02	0.12	0.08	0.03	0.01	0.01	1.00	
IP-10	0.01	0.04	0.05	0.46	0.03	0.00	0.26	0.24	0.18	0.44	0.16	0.05	0.02	0.27	0.18	0.11	0.06	0.07	0.96	1.00

Sources: Authors Calculations based on Secondary source data of research

vi. Analysis for FY 2021-22

Table F11: Co-relation values for Input & Output Seaport Sustainability parameter values for FY-2021-22 for 4 major seaports in India

FY 2021-22 Data Port Name: D,M,N,C	**OP-1**	**OP-2**	**OP-3**	**OP-4**	**OP-5**	**OP-6**	**OP-7**	**OP-8**	**OP-9**	**OP-10**	**IP-1**	**IP-2**	**IP-3**	**IP-4**	**IP-5**	**IP-6**	**IP-7**	**IP-8**	**IP-9**	**PI10**
OP-1	1.00																			
OP-2	0.30	1.00																		
OP-3	-0.16	-0.97	1.00																	
OP-4	0.53	-0.59	0.61	1.00																
OP-5	-0.04	0.25	-0.06	-0.54	1.00															
OP-6	0.25	0.92	-0.82	-0.70	0.60	1.00														
OP-7	-0.01	0.81	-0.93	-0.51	-0.27	0.56	1.00													
OP-8	0.16	0.60	-0.42	-0.63	0.92	0.86	0.07	1.00												
OP-9	0.79	0.69	-0.50	-0.09	0.48	0.77	0.20	0.72	1.00											
OP-10	-0.35	-0.59	0.71	-0.03	0.63	-0.24	-0.84	0.28	-0.21	1.00										
IP-1	0.30	0.95	-0.85	-0.65	0.54	1.00	0.60	0.82	0.79	-0.32	1.00									
IP-2	0.60	0.79	-0.61	-0.34	0.61	0.90	0.29	0.85	0.97	-0.15	0.91	1.00								
IP-3	0.96	0.19	-0.10	0.67	-0.32	0.04	0.04	-0.11	0.60	-0.48	0.11	0.39	1.00							
IP-4	0.19	0.93	-0.84	-0.74	0.58	1.00	0.60	0.84	0.72	-0.26	0.99	0.87	-0.01	1.00						
IP-5	-0.01	0.93	-0.90	-0.85	0.47	0.95	0.72	0.73	0.54	-0.32	0.94	0.72	-0.17	0.97	1.00					
IP-6	0.37	0.96	-0.86	-0.59	0.49	0.99	0.61	0.79	0.82	-0.37	1.00	0.92	0.19	0.98	0.92	1.00				
IP-7	0.78	0.76	-0.59	-0.12	0.41	0.80	0.31	0.68	0.99	-0.32	0.83	0.96	0.61	0.76	0.59	0.86	1.00			
IP-8	0.85	-0.15	0.21	0.88	-0.45	-0.29	-0.21	-0.36	0.34	-0.32	-0.22	0.09	0.94	-0.34	-0.49	-0.15	0.33	1.00		
IP-9	0.63	0.17	0.08	0.09	0.72	0.43	-0.43	0.71	0.79	0.40	0.42	0.74	0.40	0.37	0.14	0.43	0.71	0.30	1.00	
IP-10	-0.80	-0.03	-0.20	-0.42	-0.44	-0.21	0.49	-0.44	-0.74	-0.27	-0.22	-0.61	-0.65	-0.14	0.11	-0.25	-0.67	-0.61	-0.94	1.00

Sources: Authors Calculations based on Secondary source data of research

Table F12: R-squared values for Input & Output Seaport Sustainability parameter data for FY-2021-22 for 4 major seaports in India

FY 2021-22 Data Port Name: D,C,N,M	OP-1	OP-2	OP-3	OP-4	OP-5	OP-6	OP-7	OP-8	OP-9	OP-10	IP-1	IP-2	IP-3	IP-4	IP-5	IP-6	IP-7	IP-8	IP-9	PI10
OP-1	1.00																			
OP-2	0.09	1.00																		
OP-3	0.02	0.94	1.00																	
OP-4	0.28	0.35	0.38	1.00																
OP-5	0.00	0.06	0.00	0.30	1.00															
OP-6	0.06	0.85	0.68	0.48	0.36	1.00														
OP-7	0.00	0.66	0.87	0.26	0.07	0.32	1.00													
OP-8	0.03	0.36	0.18	0.39	0.85	0.74	0.01	1.00												
OP-9	0.62	0.48	0.25	0.01	0.23	0.59	0.04	0.52	1.00											
OP-10	0.12	0.35	0.50	0.00	0.40	0.06	0.71	0.08	0.04	1.00										
IP-1	0.09	0.90	0.72	0.42	0.29	0.99	0.36	0.67	0.62	0.10	1.00									
IP-2	0.36	0.62	0.37	0.12	0.38	0.81	0.08	0.72	0.93	0.02	0.82	1.00								
IP-3	0.92	0.04	0.01	0.45	0.10	0.00	0.00	0.01	0.36	0.23	0.01	0.15	1.00							
IP-4	0.04	0.87	0.71	0.54	0.34	1.00	0.36	0.71	0.52	0.07	0.99	0.75	0.00	1.00						
IP-5	0.00	0.87	0.81	0.71	0.22	0.90	0.52	0.54	0.29	0.11	0.89	0.51	0.03	0.94	1.00					
IP-6	0.14	0.92	0.74	0.35	0.24	0.97	0.37	0.63	0.68	0.14	0.99	0.84	0.04	0.96	0.85	1.00				
IP-7	0.61	0.58	0.35	0.01	0.17	0.63	0.09	0.47	0.99	0.10	0.68	0.93	0.37	0.57	0.35	0.74	1.00			
IP-8	0.72	0.02	0.05	0.78	0.20	0.08	0.04	0.13	0.12	0.10	0.05	0.01	0.89	0.11	0.24	0.02	0.11	1.00		
IP-9	0.40	0.03	0.01	0.01	0.52	0.19	0.18	0.51	0.63	0.16	0.17	0.55	0.16	0.14	0.02	0.18	0.51	0.09	1.00	
IP-10	0.64	0.00	0.04	0.18	0.19	0.04	0.24	0.20	0.55	0.07	0.05	0.37	0.42	0.02	0.01	0.06	0.45	0.37	0.88	1.00

Sources: Authors Calculations based on Secondary source data of research

Research Details

1. Conferences attended & Paper presented

Title of the Conference	Organizers	Date	Title of Paper
27th Annual Conference of International Association of Maritime Economists (IAME)	Athens University of Economics and Business, Athens, Greece	June 25^{th} -28^{th}, 2019	Study on Port Performance dimensions and evaluation for Indian Major Sea Ports –A Conceptual Model.
28th Annual Conference of International Association of Maritime Economists (IAME)	Hong Kong Polytechnic University-Online Presentation	10^{th} June 2020	Comprehensive Sustainability Performance Assessment of Seaports in India.
2nd International Conference on Industrial Engineering and Operations Management (IEOM) India Conference on Industrial Engineering and Operations Management,	National Institute of Technology (NIT), Warangal & Jawaharlal Nehru Technological University, Hyderabad (JNTUH) -Online Presentation	August 16-18, 2022,	1^{st} Prize to paper "Enhancing Sustainable Maritime Business through Lean, Agile, Resilience and Green (LARG) Performance Model in Indian Seaport Supply chain Operations" IEOM Supply Chain & Logistics.
11th Congress of the Asian Association of Environmental and Resource Economics (AAERE): A pathway towards Carbon Neutrality in Asia.	University of Economics Ho Chi Minh City, Vietnam-Online Presentation	August 19-20, 2022	Poster "Evaluation of operational efficiency and environmental management: A benchmarking study of Indian major seaports".
20th AIMS International Conference on Management	Indian Institute of Management Kozhikode & AIMSI, Houston, USA	December 28-31, 2022,	Factors of Digital Transformation in Indian Maritime Sector Post Covid-19 Era.

ICBDS – 2023 (International Conference on Business, Digitalization, and Sustainability	UPES Dehradun Uttarakhand, India	February 2-4, 2023	Measuring the impact of Indian major seaports on environment & effectiveness of remediation towards port environmental pollution.
International Conference: Emerging Trends in Operations and Analytics (ICETOA_2023)	TAPMI, Manipal	March 17-19, 2023	Intermodal service supply chain and logistics performance of major seaports in India.

1. Conferences Paper Communicated

Title of the Conference	Organizers	Date	Title of Paper
The 10th World Sustainability Forum	Goals-sciforum-074459-under Singapore, Basel, Toronto Hub -virtual	September 14,2023	"Framework for Seaport Sustainable Operations Management for major seaports in India and its Contribution to the United Nation's Sustainable Development Goals" sciforum-074459- Basel Hub – Corporate Sustainability-Track B (Abstract Accepted)
Global Cleaner Production Conference 2023	Fudan University, Shanghai, China & Paulista University, São Paulo, Brazil	9th to 12 November 2023	Influence of Information communication technologies on operational efficiency of Indian major seaports (Abstract Submitted)

3. Journal Papers

Sl. No	Title of the Journal	Journal Details	Title of Paper	Status
1	Transport Policy (CiteScore:6.9; Impact Factor: 4.674)	Special Edition Elsevier JTRP VSI Proposal "Transport Policy in Post COVID-19 World". Volume 110, doi.org/10.1016/j.tranpol.2021.05.011	COVID-19: Impact on Seaport Transportation and Maritime Supply Chain	Paper Published
2.	International Journal of Sustainable Development and Planning (Cite Score: 1.8; SJR: 0.284; SNIP:0.699	Vol. 17, No. 2, April, 2022, pp. 693704, https://www.iieta.org/journals/ijsdp/paper/10.18280/ijsdp.170235	Sustainability Performance Assessment Framework for Major Seaports in India	Paper Published
3	Journal of Cleaner Production (Cite Score:18.5; Impact Factor: 11.1)	Elsevier	A Comparative Study of Operational and Environmental Efficiency in Major Indian Seaports: Assessing Pre- and Post-COVID-19 Pandemic Performance	Paper Submitted & Under Review
4	Maritime Studies; Impact Factor: 1.987 (2021)	Springer	Maritime Transportation Systems in India Post COVID-19: Analysis of Impacts and Policy Implications	Paper Submitted & Under Review

5	International Journal of Sustainable Engineering (IJSE); Cite Score: 2.9 (2021) SNIP: 0.901; SJR: 0.516	Taylor & Francis	Study on Port Performance dimensions and evaluation for Indian Major Sea Ports –A Conceptual Model	Paper Submitted & Under Review

4. Courses & Certifications completed

1. Completed introductory eLearning Course Oil Pollution Preparedness Response and Co-operation (OPRC) from INTERNATIONAL MARITIME ORGANIZATION.
2. Completed Certificate Introductory Course on SDG14 and Clean Governance by InforMEA, United Nations Environmental Law and Conventional Portal
3. Completed Certificate Course on introduction to Environment Governance by InforMEA, United Nations Institute for Training & Research
4. Completed Certificate Introductory Course on International Legal Framework on Environment Impact Assessment by InforMEA, UN Environmental Law and Conventional Portal
5. Completed Certificate Introductory Course on International Legal Framework on Marine Pollution by InforMEA, United Nations Environmental Law and Conventional Portal
6. Completed Certification course on SEM Using SPSS & AMOS by Dept of Research & Publications, A2Z Edu Learning Hub LLP (4th to 6th August 2022)
7. Data Analysis and Decision Making - I-Online 12 weeks Course through SWAYAM programme through IIT Kanpur
8. Data Analysis & Decision Making - II - Online 12 weeks Course through SWAYAM programme through IIT Kanpur
9. Energy Resources, Economics and Environment- Online 12 weeks Course through SWAYAM programme through IIT Bombay

10. Environment Sustainability- Online 8 weeks Course through SWAYAM programme through IGNOU, New Delhi
11. Introduction to Climate Change- Online 15 weeks Course through SWAYAM programme through IGNOU, New Delhi
12. MSD-017: Challenges to Sustainable Development- Online 12 weeks Course through SWAYAM programme through IGNOU, New Delhi
13. MEV-002: Environmental and Occupational Hazards- Online 12 weeks Course -SWAYAM programme through IGNOU, New Delhi
14. Operations Research- Online 15 weeks Course through SWAYAM programme through Jadavpur University
15. Environment Natural resources and Sustainable Development- Online 10 lectures through SWAYAM programme -University of Hyderabad

Bio-Data

PERSONAL DETAILS:

Name**:** PRATHVI.T. N

DOB**:** 15/11/1984

Present Work**:** Deputy Director (IT), Finance Department, New Mangalore Port Authority, Autonomous Body under Ministry of Ports, Shipping & Waterways, Govt. of India, Panambur, Mangalore, Karnataka, India-575010

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Mobile**:** 9008907202/7829972694

Place**:** Thumbe, Bantwal, Dakshina Kannada, Karnataka, India

EDUCATIONAL QUALIFICATIONS:

- **Bachelor of Engineering:** Information Science Engineering (ISE) - Vivekananda College of Engineering & Technology, Puttur in 2006.
- **M.Tech:** Engineering Management- Sri Jayachamarajendra College of Engineering, Mysore in 2009.
- **Ph.D.:** School of Humanities, Social Sciences & Management, National Institute of Technology Karnataka, Surathkal Karnataka, as part-time research scholar as a sponsored candidate under the supervision of Dr. Pradyot Ranjan Jena & Dr. Ritanjali Majhi
- **Others Degrees:** BA (Hindi), Dakshina Bharath Hindi Prachar Samithi, Chennai**;** PG Diploma in Intellectual Property Management, Asian School of Cyber Law, Pune**;** PG Diploma in Cyber Law Management, Asian School of Cyber Law, Pune**.**

EXPERIENCE:

- Working as Deputy Director, IT Division, Finance Department, New Mangalore Port Authority, Autonomous Body under Ministry of Ports, Shipping and Waterways, Govt. of India, Panambur, Mangalore from August 2020 to till date.
- Worked as Asst Director, IT Division, Finance Department, New Mangalore Port Authority, Autonomous Body under Ministry of Ports, Shipping and Waterways, Govt. of India, Panambur, Mangalore from August 2012 to August 2020.
- Worked as Asst Professor in Alva's Institute of Engineering, Mijar from February

2011 to July 2012.

- Worked as Lecturer in Sahyadri College of Engineering & Management, Mangalore from January 2010 to January 2011.
- Worked as Intellectual Property Management Consultant at Larsen & Toubro Limited, Mysore from July 2009 to December 2010.
- Worked as Lecturer in Canara Engineering College, Mangalore from July 2006 to June 2007.
- Worked as Infosys Campus Connect Trainer - IT related subjects from July 2006 to June 2007.

MEMBERSHIPS:

- International Association of Ports and Harbors (IAPH)
- International Association for Maritime Economist (IAME)
- Indian Society for Technical Education (ISTE)
- All India Management Association (AIMA)
- Institution of Engineers (IEI)

ACHIEVMENTS:

- Qualified GATE 2007 in Computer Science Stream.
- 2nd Rank in M. Tech (Engineering Management) in VTU, Belgaum - Year 2009.
- Presented M. Tech Project Paper in National Research Development & Corporation, New Delhi which was published in NRDC Journal.
- 10+ Technical & Management Talks at various Engineering Colleges & Management Institutes in India on IT/Management/Logistics/Soft skills related Topics.
- Member of DAC, Department of Information Science Engineering, Canara Engineering College from 2017 to till date.
- Member of DAC, Department of Computer Science Engineering, Yenepoya Institute of Technology, Mangalore from 2020 to till date.

INTERESTS:

- Software Developing &Testing,
- Training activities,
- Traveling,

- Social Networking Consultant /Guide in Education domain.

GOOGLE SCHOLAR CITATIONS: (As of 25th August 2023)

- Citations: 79
- h-index: 1
- i10-index: 1