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Maritime Energy Efficiency: Emerging Trends and Key Performance Indicators

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ABSTRACT

The shipping industry plays a crucial role in global trade, yet it faces significant challenges in balancing economic growth with environmental sustainability. Regulatory measures such as those introduced by the International Maritime Organisation (IMO) aim to curb emissions through various strategies. These regulations also promote the adoption of cleaner fuels and energy efficiency measures. Although there are many proven solutions to enhance energy efficiency and reduce CO_2 emissions, their adoption across the shipping sector remains in the early stages. This work reviews emerging trends in maritime energy efficiency and identifies relevant Key Performance Indicators (KPIs) for assessing green innovations in shipping. By mapping energy efficiency advancements in shipping, the review sets a foundational understanding of the domain's current innovations. Subsequently, it embarks on an exhaustive exploration of extant literature to articulate a set of KPIs that embody the effectiveness and impact of these green solutions. These indicators not only cover traditional metrics like fuel consumption and greenhouse gas emissions but also include modern measures. The study highlights the importance of adopting a multi-dimensional approach to evaluate the effectiveness of energy-efficient innovations in the maritime sector, by providing a framework for stakeholders to guide policy, decision-making, and the adoption of sustainable practices in shipping.

1. INTRODUCTION

The importance of energy efficiency in maritime shipping is multifaceted, impacting environmental, economic, and safety concerns comprehensively. Maritime shipping significantly contributes to global greenhouse gas (GHG) emissions. By enhancing energy efficiency, the industry can reduce fuel consumption, which directly lowers carbon dioxide and other harmful emissions, playing a crucial role in mitigating the effects of global warming and air pollution. Economically, higher energy efficiency translates into reduced fuel costs, a major expenditure for shipping companies. Implementing energy-efficient technologies and practices allows these companies to achieve considerable financial savings and enhances their competitiveness in the global market.

Furthermore, the International Maritime Organisation (IMO) and other regulatory bodies have established stringent emissions and energy efficiency standards.

Improving energy efficiency helps shipping companies comply with these regulations, avoiding penalties and preparing for future regulations. From a safety perspective, research indicates that ships with higher energy efficiency often have better safety records. Moreover, energy-efficient designs and operations improve ship manoeuvrability and stability, which reduces the risk of accidents.

As societal awareness of environmental issues increases, companies are expected to show a commitment to sustainable practices.

Energy efficiency in shipping addresses not only regulatory and economic pressures but also aligns with broader goals of corporate social responsibility and sustainable development. Overall, the push for energy efficiency in maritime shipping is vital for protecting the environment, maintaining economic viability, adhering to regulations, enhancing safety, and promoting sustainability in industry.

The importance of energy efficiency in maritime shipping is widely recognised due to its economic and environmental impacts.

Utilising specific characteristics of maritime channels and user mobility, especially shipping lane information, can significantly reduce power consumption through optimised resource allocation over time [1].

Implementing real-time monitoring frameworks can enhance the verification of fuel consumption and carbon dioxide emission data, leading to improved energy efficiency [2].

Extensive electrification of ship propulsion and shipboard power systems is proposed as a strategy to enhance onboard energy systems, which is crucial in meeting stringent environmental regulations [3].

Transitioning to smart design, manufacturing, and operations of ships can revolutionise the marine industry towards achieving more energy-efficient vessels [4].

The primary objective of this paper is to conduct a comprehensive review of the latest trends and evaluate the effectiveness of Key Performance Indicators (KPIs) in the domain of green innovations. This involves a systematic analysis of emerging technologies and sustainable practices that contribute to environmental conservation and reduced ecological footprints. By mapping out historical and current advancements, and assessing these through carefully selected KPIs, the paper aims to identify successes, challenges, and gaps in the implementation and impact of green innovations across various industries. This review seeks not only to understand the trajectory of green technologies but also to provide actionable insights that can guide future strategies and policymaking in sustainable development.

2. BACKGROUND AND CONTEXT: EMERGING TRENDS IN MARITIME ENERGY EFFICIENCY

Recent studies [5] highlight the shipping industry's capacity for adopting sustainable practices by integrating various technological innovations. The technologies discussed in these studies can be categorised into different groups, each targeting specific elements of ship design and operation to enhance energy efficiency and lower CO_2 emissions.

Current trends in energy efficiency within the maritime shipping sector emphasise significant innovations and regulatory responses aimed at reducing fuel consumption and emissions.

The maritime sector is actively implementing various strategies to enhance vessel efficiency and environmental sustainability. These include improvements in design, hydrodynamics, machinery, and the use of alternative energy sources. Enhancements in machinery for better efficiency encompass the adoption of energy-efficient lighting, engine derating and tuning, as well as advanced management of pumps and fans. Innovations like common rail fuel injection, high-efficiency boilers, and diverse power generation technologies, including hybrid and electric propulsion systems, are being investigated to reduce energy consumption and emissions. Additionally, waste heat recovery and improvements in internal combustion engines are other avenues for increased efficiency.

Exploring alternative energy sources such as hydrogen, ammonia, methanol, and liquefied natural gas offers numerous advantages and poses challenges related to emissions, storage, and safety. Renewable energy options like wind propulsion and solar power are also being considered, although they encounter specific challenges in implementation.

Emerging technologies in the maritime industry, such as fuel cells, advanced battery systems, gas turbines that can adapt to alternative fuels, nuclear propulsion, and carbon capture, are at the forefront of maritime innovation. These categories and technologies are outlined in the table later in the text.

Design enhancements such as bulbous bows, extended aft waterlines, and optimised vessel shapes decrease resistance and drag, boosting fuel efficiency. Innovations in propulsion systems, including shaft line configurations and lightweight materials, as well as strategies like reducing vessel speed and designing aerodynamic superstructures, also contribute to energy conservation.

Hydrodynamic improvements continue to advance this efficiency by employing devices that optimise the flow of water around the hull and propeller. Additionally, integrated systems that combine propellers and rudders, along with advanced propulsion technologies like pod drives and thrusters, enhance navigational performance and energy usage.

The maritime industry has devised a series of operational solutions and incentive initiatives aimed at reducing emissions through a combination of technological advancements and improved operational efficiencies.

Strategies such as slow steaming reduce fuel consumption by operating ships below their maximum speed, though this can increase fouling and resistance due to longer travel times. Speed optimisation tailors ship speeds to achieve maximum fuel efficiency and minimum emissions, considering factors like sea-state and route conditions, and requires specific crew training and tools like trim optimisers.

Optimising a ship's trim and draft can significantly decrease resistance and thus fuel consumption. Similarly, efficient planning of ship movements—including better cargo handling and weather routing, along with optimised port arrivals and departure - minimises unnecessary fuel use. Cold ironing, which involves powering ships via shore-based sources while docked, reduces onboard emissions, provided the shore power is derived from renewable sources.

Digitalisation supports these efforts significantly [6]. Technologies like big data and artificial intelligence optimise routing and manage fuel consumption effectively. Digital twins of ships allow for real-time monitoring and maintenance, while blockchain enhances the transparency and efficiency of cargo movements. Advanced communications technologies such as cloud solutions and 5G networks enable more efficient remote operations and data transfer. Autonomous technologies and the Internet of Things further refine operational decisions, reducing reliance on fossil fuels through improved routing and speed management. Moreover, 3D printing reduces logistical emissions by allowing on-demand production of parts, and environment-sensing devices optimise operations based on real-time data. Together, these innovations mark a significant transformation towards a more efficient, sustainable, and technologically equipped maritime industry.

Market and incentive initiatives in the maritime industry include a variety of market-based measures such as carbon trading schemes and fuel levies. These are designed to encourage the adoption of environmentally friendly technologies and practices [7].

Under the "Poseidon Principles," a framework has been established where banking finance is provided primarily to those shipowners who meet specific emission standards, integrating climate considerations directly into lending decisions. This not only promotes the use of green technologies but also ensures financial backing is aligned with environmental objectives.

Reduced taxation is another strategy being employed. Ships that implement green technology and comply with environmental standards benefit from reduced port dues, which can significantly decrease their operational costs.

The Green Fund, established through carbon credits, motivates further emission reductions. It requires each flag state to show measurable decreases in emissions. Those failing to meet their targets must buy carbon credits from more efficient states, thus fostering a collective push towards global emission reduction [8].

In addition, broader regulatory measures like the evaluation of the Energy Efficiency Design Index (EEDI) and the Carbon

Intensity Indicator (CII) are implemented. National and regional policies that include carbon pricing and incentives for adopting green technologies play a crucial role in accelerating the decarbonisation efforts in the maritime sector.

The research across various studies highlights the integration of efficiency evaluation models in promoting sustainable practices within the maritime industry, emphasising the critical interplay between environmental management, technological innovation, and regulatory frameworks.

The research articles provided explore a range of innovative strategies and technologies aimed at advancing the sustainability and efficiency of the maritime industry.

Various studies focus on the environmental and technical viability of zero-carbon fuels like ammonia, hydrogen, and electricity, as well as methanol and LNG [9-11]. These fuels are evaluated for their potential to reduce greenhouse gas emissions in different types of vessels and operational conditions. These studies also address the broader economic and policy frameworks necessary to support the maritime sector's transition to greener practices, including the strategic production of ammonia in response to global shortages and the role of government subsidies in promoting eco-friendly technologies [12].

The transition to cleaner maritime operations is supported by infrastructure development like LNG bunkering stations and the adoption of shore power technology, which reduces [13] emissions from ships while docked but while alternative fuels present environmental benefits, they also introduce challenges such as the high flammability of LNG, requiring new safety assessments and technologies to ensure safe bunkering and operations [14]. Innovations such as improved hull designs, advanced propulsion systems, and the adoption of alternative fuels like LNG and biofuels are crucial. These technological advances are complemented by operational strategies like slow steaming and weather routing to reduce energy use and emissions [15].

Additionally, the role of green port initiatives emphasises the need for technical innovations, operational enhancements, and supportive policies to foster sustainable port operations [16].

Research on hull coatings [17] and modernisation of propulsion systems in ships highlights potential fuel savings and emission reductions [12, 18]. The integration of photovoltaic panels and hybrid electric systems is also explored [19].

Innovative approaches for ship efficiency are discussed [20], and the integration of circular economy principles into maritime operations through data-driven technologies such as IoT and data analytics to optimise ship operations for energy efficiency and emission reduction, indicating potential for reduced environmental impacts and operational costs.

3. IDENTIFICATION OF KEY PERFORMANCE INDICATORS (KPIS)

In order to conduct a cutting-edge analysis of the utilisation of Key Performance Indicators in the shipping industry, the present study embarked on an extensive literature review. The goal was to pinpoint the most reliable and impactful KPIs for evaluating the greening processes in shipping.

Indeed, advanced analytical models and decision-support systems represent useful tools for aligning operational practices with environmental and economic objectives thus, to enhance the overall sustainability and efficiency of maritime operations. Several studies highlight different approaches and tools to achieve this alignment.

For instance, Koilo [21] introduces a new optimisation tool that adopts mathematical models to track and improve CO_2 emissions and the Sustainable Development Index, promoting zero-emission solutions like alternative fuels and autonomous ships. Similarly, Franchi and Vanelslander [22] advocate for "green ports" using Discrete Choice Analysis to balance economic and environmental responsibilities, assessing factors such as air quality and port capacity.

Goal-Based Measures are presented by Psaraftis and Zis [23] and set specific annual emission targets for ships, offering flexibility in operational or technical solutions while emphasising the importance of effective enforcement mechanisms. Xing et al. [24] confirm that such practices positively impact the environmental, financial, and competitive performance of shipping companies (Figure 1).

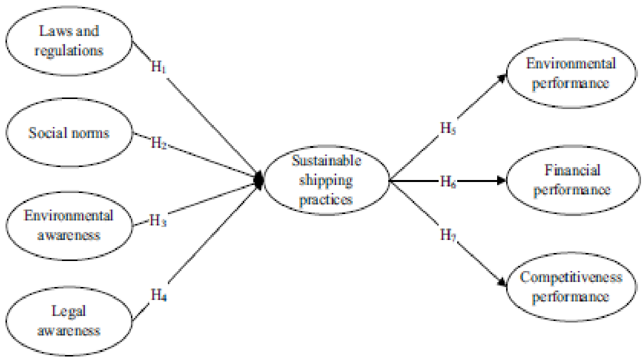

Figure 1. A sustainable shipping practices model
Source: [24]

Life cycle assessments [25, 26] provide a comprehensive view of the environmental footprint of alternative fuels and technologies throughout their lifespan. Karountzos et al. [27] employ spatial analysis for similar assessments. Additionally, Olaniyi and Prause [28] explore waste heat recovery systems, while Zhen et al. [29] implement a nonlinear mixed integer programming model to optimise fleet deployment and green technology selection, validated through computational experiments with real-world data.

The adoption of shore power technology, despite its high initial costs, is discussed by Lu and Huang [30] through a multi-period, dual-objective optimisation model, considering government subsidies to balance cost control and environmental protection. Wagner and Wiśnicki [31] evaluate emerging technologies' impact on corporate sustainability, using diverse methods to evaluate the integration of environmental and social considerations in maritime operations.

Prominent shipping companies are increasingly adopting green technologies like cold ironing, scrubbers, and gas engines to enhance environmental protection and management systems, with China leading in sustainable shipping innovations. However, maritime students perceive a lesser impact on environmental protection despite acknowledging the economic and social benefits [31].

Market competitiveness of ports, particularly in the context of environmental practices, is analysed by Munim et al. [32] using the Analytic Network Process (ANP) model, highlighting Singapore's leading role. Lun et al. [33] introduce the concept of Greening and Performance Relativity (GPR) to measure the effectiveness of green shipping practices on firm performance, suggesting a positive correlation between better environmental practices and financial gains.

Choudhary et al. [34] present an analytical model combining D-Number theory and Intuitionistic Fuzzy Set theory to address the complexities and uncertainties in assessing sustainability risks, providing insights for enhancing sustainability in freight shipping. Lam and Notteboom [35] compare tools used by port authorities to promote green port development, emphasising the role of local governance and regulatory compliance.

Finally, Pangalos [36] discusses sustainable financing within the maritime shipping industry, emphasising innovative funding solutions to support environmental and regulatory demands. This comprehensive approach to measuring and enhancing performance in the maritime sector is crucial for achieving long-term sustainability and competitiveness.

3.1 Methodology for KPI selection

Evidence provided by the literature review described above has shown that in the shipping industry, measuring the performance of technologies and practices in terms of economic, market, and environmental and energy efficiency is extremely relevant in terms of sustainability and competitiveness. Hence, the present subsection is dedicated to describing the process through which suitable KPIs have been selected and included by means of the literature review analysis.

3.1.1 Criteria for KPI inclusion

This was achieved by identifying various categories, representing adoptable strategies and tools aimed at advancing green shipping, and attributes determined by considering a wide array of performance measures. The attributes include a set of metrics and qualities critical for evaluating both strategy and performance across various dimensions—from operational efficiency to sustainability, and considering economic, market, and environmental impacts. This inclusion of keywords spanning economic, environmental, technological, and safety aspects guarantees a comprehensive review that captures diverse perspectives on KPIs. The integration of quantitative indicators, such as KPIs, with qualitative aspects like competitiveness, offers a holistic view, with quantitative metrics providing tangible data for analysis and qualitative attributes adding context and depth to these figures. The items and attributes considered in the study are outlined as Table 1:

Table 1. Items and attributes used for the literature review

Items	Attributes
Green Technologies in shipping,	Competitiveness, Efficiency,
Green Practices in shipping,	Effectiveness, Performance,
Sustainability in shipping,	Economic KPI,
Green Innovations in shipping,	Market KPI, Environmental KPI,
Green Investments in shipping,	Economic Impact, Market Impact,
Green solutions in shipping,	Environmental Impact, Economic Assessment,
Green operations in shipping.	Market Assessment, Environmental Assessment.

3.1.2 Process of literature review and analysis

The selection of these categories and attributes has guided the literature review procedure search. Data collection was conducted primarily through desk research, utilising the Scopus database extensively. Known for its vast repository of scientific literature, Scopus provided an ideal platform for an exhaustive literature review.

The search process was enhanced by cross-referencing both items and attributes within the titles, abstracts, and keywords of the sources, and then reciprocally, ensuring a thorough and comprehensive review of the relevant literature.

The methodology and design of the research, including the data collection and analysis strategy, are depicted in a conceptual map shown in Figure 2. This map illustrates the study's overall framework and methodological approach, offering a graphical depiction of the research process. A table is developed to extract relevant data from each study, including author, year of publication, type of green solution evaluated, related shipping sector, KPIs used and main findings.

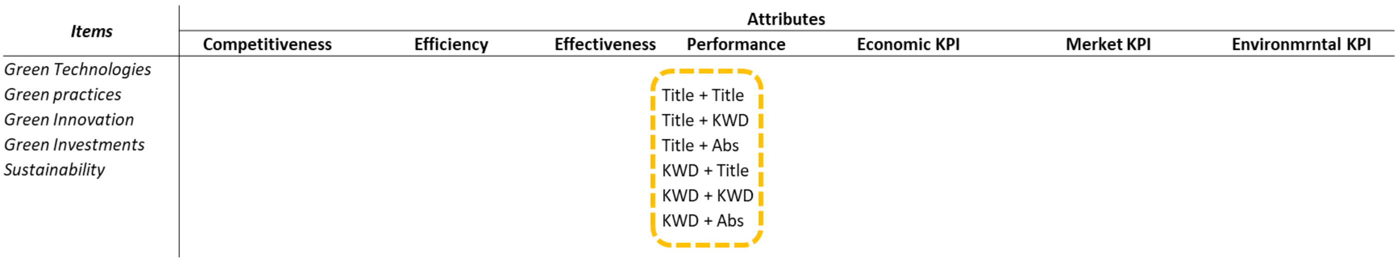

Figure 2. Research framework summarising the matching items and the related attributes

4. SELECTED KPIS

Considering the outcomes drawn by the analysis conducted in the present research, and shown in Table 2, the selected KPIs have been grouped and classified according to three main categories, referring to energy, environmental impact, and traditional/alternative KPIs, respectively. Each of the mentioned categories is described in the following sub-sections.

Table 2. Results of the literature review

Ref.	Energy Efficiency KPIs	Environmental KPIs	Economic KPIs	Market/Managerial Efficiency KPIs
[15]		Energy Efficiency Design Index (EEDI) Ship Energy Efficiency Management Plan (SEEMP) Energy Efficiency Operational Indicator (EEOI) Energy Efficiency Existing Ship Index (EEXI) Carbon Intensity Indicator (CII)		
[37]		Energy Efficiency Design Index (EEDI) Energy Efficiency Operation Index (EEOI)		
[21]		Environment protection expenditure to GDP (%) Emissions of CO_2 (t) Emissions of NO_x (t)	Value-added growth rate (%) Contribution to GDP (%)	Exports of goods and services (US$) Expenditure on training skills growth rate (%)
[22]	Resource Consumption	Air Pollution Noise Pollution Water Pollution Port Environmental Improvement and Development	Costs and charges	Port Capacity and Productivity
[38]	Amount of shore power electricity used Reduction in at-berth fuel consumption			
[23]		Carbon Intensity Indicator (CII): Schedule of annual nominal required carbon intensity reduction factors (Xnr)		
[24]	Decrease in energy consumption	Reduction in carbon footprint Lowered amount of waste generated by ships Reduced frequency of environmental accidents	Improved profit margins Higher return on assets Reduced overall cost Enhanced cash flow capacity	Enhanced company's reputation Improved company's image Better market position Increased customer satisfaction
[29]			Fuel Costs Initial Investment and Operating Costs Transshipment Costs Penalty Costs for Service Level Deviations Extra Costs for Using Berths without Shore Power	
[39]	Cogeneration Efficiency	Carbon Intensity Indicator (CII) Energy Efficiency Design Index (EEDI)	Operational Expenditure (OPEX) and Capital Expenditure (CAPEX)	
[40]		Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP)		
[25]		Global Warming Potential (GWP), Toxicity, Eutrophication Potential (EP)		
[17]	Fuel savings	Reductions in CO_2 emissions	Cost savings	
[18]	Energy Efficiency Fuel Consumption Operational Flexibility	Noise Emissions CO_2 Emissions and Air Pollution		
[41]			NPV ROV FVaR	
[12]	Power demand of the ship propulsion system Efficiency of the screw propeller Electric power consumption and	Estimated reduction in exhaust emissions for different propulsion variants	Investment and Operational cost implications of adopting different propulsion systems	

	efficiency of the propulsion systems			
[28]			Capital Expenditure (CapEx) and Annual Maintenance Costs Net Present Value (NPV) The Real Option Value (ROV)	
[27]	Fuel consumption changes	Emission reductions		
[30]		Minimizing CO_2 Emissions Efficiency of Environmental Improvement through Government Subsidies	Minimizing Operating Costs	
[19]	Fuel Savings Operational Efficiency			
[11]			.	Operational costs at the terminal The number of ships served within considered time horizons
[32]			Costs	Connectivity Port Efficiency
[26]		Emission reductions	Investment increases	
[13]		Pollution reduction	Cost savings Profitability	
[42]				Internal and External Digitalization Ownership Diversification Operational Efficiency and Financial Ratios
[43]		Carbon Footprint Monitoring Air and Water Quality Monitoring Environmental Management Systems (EMS)		Policy and Procedure Shipping Documentation Shipping Equipment Timeliness and Perceived Value

4.1 Energy related KPIs

Energy efficiency KPIs in the maritime sector focus on managing and reducing the consumption of fuel and power efficiency. These metrics include the efficiency of propulsion systems, the power demand of ship propulsion systems, and fuel consumption of various systems. Additionally, advanced propulsion technologies, like hybrid propulsion systems and Wind Assisted Ship Propulsion (WASP), aim to enhance operational flexibility and optimise fuel savings under different conditions such as wind speed and wave height, further contributing to energy efficiency in maritime operations.

Another critical aspect is represented by resource management, which involves monitoring the consumption of electric energy, fuel, and water, alongside waste management on ships. Metrics in this category emphasise reducing overall consumption and improving the efficiency of systems that convert fuel into electrical and thermal energy, particularly in cruise ships. For instance, the cogeneration efficiency KPI measures the efficiency of power plants onboard in converting fuel into useful energy forms, which is crucial for optimising onboard energy utilisation.

Operational KPIs also include the use of shore power to reduce fuel consumption at berths and the optimisation of propulsion systems. These strategies not only reduce the environmental impact but also lead to significant cost savings. The use of advanced technologies like shore power enables ships to minimise their reliance on onboard fuel, resulting in decreased emissions and better fuel efficiency. A systematic evaluation of changes in fuel consumption under various operational scenarios can contribute to the understanding of the effectiveness of the applications mentioned technologies in the shipping context.

4.2 Environmental impact KPIs

Environmental impact KPIs in the maritime industry mainly focus on emission and pollution reduction, monitoring, performance evaluation, and assessing broader environmental impacts. Key metrics include the Carbon Intensity Indicator (CII), which measures the efficiency of ships in terms of CO_2 emissions per cargo-carrying capacity and nautical mile, and the Energy Efficiency Existing Ship Index (EEXI), targeting emission reductions through design improvements.

Specific KPIs such as the Energy Efficiency Design Index (EEDI) measure the efficiency of ship designs in reducing CO_2 emissions, while the Energy Efficiency Operational Indicator (EEOI) evaluates the operational performance of ships in terms of GHG emissions per tonne-mile of cargo transported. These KPIs are part of comprehensive strategies to reduce specific pollutants like CO_2 and NO_x and manage overall environmental impacts.

Ports play a significant role in monitoring and managing environmental performance. Environmental management systems (EMS), certified by standards like ISO 14001, are implemented to monitor air and water quality, as well as greenhouse gas emissions. For instance, ports like Rotterdam monitor various environmental parameters, including oxygen and nutrient concentrations in water, as part of their quality initiatives. Such systems provide a framework for evaluating and recording environmental performance, which is crucial for continuous improvement.

Additionally, global environmental impacts are assessed through Life Cycle Assessment (LCA) metrics such as Global Warming Potential (GWP) and Eutrophication Potential (EP).

These measures help quantify the broader environmental consequences of maritime activities, providing a basis for developing strategies to mitigate adverse impacts. By incorporating these comprehensive assessment tools, maritime operators can better understand and address the environmental footprint of their operations.

4.3 Traditional/Alternative KPIs

Traditional and alternative KPIs related to maritime energy efficiency encompass economic, managerial, and environmental dimensions. Economic KPIs include macroeconomic indicators like value-added growth rate and contribution to GDP, as well as specific cost categories such as operational expenditure (OPEX), capital expenditure (CAPEX), and fuel costs. Financial metrics like Net Present Value (NPV), Real Option Value (ROV), and Financial Value at Risk (FVaR) are used to evaluate profitability, investment sustainability, and risk. These metrics help in understanding the economic implications of adopting green technologies and optimising operational costs.

Furthermore, environmental KPIs, which include both traditional and innovative measures, emphasise the reduction of emissions and resource consumption. Traditional KPIs like emissions of CO_2 and NO_x and newer measures like the Energy Efficiency Design Index (EEDI) and the Carbon Intensity Indicator (CII) provide a comprehensive view of the environmental impact. Advanced propulsion technologies, such as hybrid systems and WASP, offer alternative solutions for improving energy efficiency and reducing environmental impact. These KPIs collectively guide the maritime industry towards more sustainable and efficient operations.

5. DISCUSSION AND CONCLUSIONS

The maritime industry is increasingly embracing the best technical and operational practices to improve energy efficiency. This includes the adoption of advanced propulsion systems, improved vessel design, and better operational strategies. Research shows that adopting these best practices could significantly reduce CO_2 emissions despite expected growth in freight movements.

Stringent regulations from the IMO have been key drivers in promoting energy efficiency. The implementation of the EEDI and the EEOI are examples of effective measures that have pushed the industry towards lower emissions and improved fuel efficiency.

Looking forward, there is a focus on integrating more renewable energy sources and alternative fuels such as hydrogen and LNG to further enhance the energy efficiency of shipping operations. This is supported by both technological advancements and evolving regulatory frameworks, which aim to significantly lower the maritime sector's environmental footprint.

The research outcomes have led to the classification of Key Performance Indicators (KPIs) into two main categories: energy-related, environmental impact. Moreover, these two have been classified as traditional/alternative KPIs.

Energy-related KPIs focus on fuel and power efficiency, crucial for reducing both operational costs and environmental footprint. Resource management involves monitoring the consumption of electric energy, fuel, and water, alongside waste management on ships, with cogeneration efficiency being a critical metric. Shore power usage is also emphasized to reduce fuel consumption at berths, decreasing emissions and improving fuel efficiency.

Environmental impact KPIs concentrate on monitoring and reducing emissions and pollution, assessing the broader environmental consequences of maritime activities. This is done through environmental management systems (EMS), certified by standards like ISO 14001, monitor air and water quality and greenhouse gas emissions. Life Cycle Assessment (LCA) metrics, help quantify the broader environmental impacts, providing a basis for developing mitigation strategies.

Economic and financial KPIs are included in the majority of the evaluations since they are considered traditional metrics to consider in performance assessments. Economic KPIs include indicators like value-added growth rate, contribution to GDP, and cost categories such as operational expenditure (OPEX), capital expenditure (CAPEX), and fuel costs. Financial metrics like Net Present Value (NPV), Real Option Value (ROV), and Financial Value at Risk (FVaR) evaluate profitability, investment sustainability, and risk. Newer measures like EEDI and CII.

Overall, these KPIs guide maritime operators towards enhanced efficiency, reduced environmental impact, and sustainable growth, providing a structured approach to evaluating and improving maritime operations.

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NOMENCLATURE

ANP	Analytic Network Process
CAPEX	Capital Expenditure
CII	Carbon Intensity Indicator
CO_2	Carbon Dioxide
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEXI	Energy Efficiency Existing Ship Index
EMS	Environmental Management Systems
EP	Eutrophication Potential
FVaR	Financial Value at Risk
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPR	Greening and Performance Relativity
GWP	Global Warming Potential
IMO	International Maritime Organisation
IoT	Internet of Things
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LNG	Liquefied Natural Gas
NPV	Net Present Value
OPEX	Operational Expenditure
ROV	Real Option Value
WASP	Wind Assisted Ship Propulsion