Research Article

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SUSTAINABLE SEAPORT DEVELOPMENT AND STRATEGIC MODERNISATION OF MARITIME TRANSPORT INFRASTRUCTURE

Lyudmila Sotnychenko *
National University "Odesa Maritime Academy",
Odesa, Ukraine
ORCID iD: 0000-0003-4537-1553

Oleksandr Haichenia
National University "Odesa Maritime Academy",
Odesa, Ukraine
ORCID iD: 0000-0002-7899-4418

Inha Kucher
National University "Odesa Maritime Academy",
Odesa, Ukraine
ORCID iD: 0000-0002-1833-6632

Yana Staneva
National University "Odesa Maritime Academy",
Odesa, Ukraine
ORCID iD: 0009-0006-2585-571X

*Corresponding author
E-mail: l.sotnichenko@onma.edu.ua

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Background. Effective strategic management of maritime transport infrastructure development is impossible without creating conditions for sustainable development. The main risks to Ukraine's strategic management of maritime transport infrastructure development under martial law were examined, and prospects for its development were based on sustainable development principles.

Purpose. This study aims to examine strategic management in the maritime transport infrastructure of Ukraine, focusing on an indicative sustainability framework for ports and identifying the primary components of a performance-management system for sustainable development.

Findings. This study analysed the key factors influencing the competitiveness of Ukraine's maritime transport infrastructure and forecast potential developments for 2026–2030. Security factors account for 44.0% of strategic management issues, and environmental factors account for 9.0%, resulting in a low connectivity index for Ukraine's liner shipping industry (12.6% lower than the EU average). The analysis validated an indicative-integrated assessment model that includes two complementary systems: port sustainability indicators and management key performance indicators. The estimated Integrated Sustainability Index of the Port System for 2024 is 0.816 (high level), indicating adaptive stabilisation under martial law. The Sustainable Development Management Performance Index for the port system in 2024 is 0.768 (moderately high), confirming consistent policy implementation and adaptive capacity. The key performance indicators include an 8.5% increase in cargo turnover, a 6.0% increase in revenue, a 17.8% share of green investments, and a digital maturity level of 0.68, indicating operational stability and the potential for further sustainable development.

Implications. The current risks in the strategic management of Ukraine's maritime transport infrastructure development are predominantly security-related. However, risks require continuous monitoring of sustainable development and the effectiveness of its management, considering the potential negative impact of maritime transport infrastructure on environmental safety. A vision of the strategic development mechanism for maritime transport infrastructure in the context of sustainable development was formulated, and a quantitative assessment mechanism for the sustainable development process and its management effectiveness was defined.

Keywords: Green Port, Port Competitiveness, Risks, Sustainable Logistics, Transport Infrastructure.

1. Introduction.

Maritime transport infrastructure plays a significant role in maintaining the global balance of efficient maritime transport (Benamara et al., 2019). The economic development of a country and region as a whole depends on the effectiveness of implementing green technologies and ESG principles, as well as the level of digitalisation of port processes. Strategic management of maritime transport infrastructure development is based on the analysis and development of an assessment system for sustainable development of ports, grounded in the principles of comprehensiveness, systemic coherence, comparability, and feedback.

This system is implemented through the procedures of a closed, structural, and systematic model aimed at improving the methodological approach to the effectiveness evaluation of the management strategy for sustainable development processes.

Accordingly, this implies the following statement: when a new-format sustainable development management system is implemented in practice, it is necessary to measure not only the current level of efficiency in port operations (Li et al., 2023). However, it is also necessary to assess their capacity for long-term resilience has also been assessed across socio-ecological, economic, and governance dimensions.

This study examines the main issues of strategic management and develops a system for the sustainable development assessment of ports, a key component of Ukraine's maritime transport infrastructure.

According to the study, the main research questions are as follows:

RQ1: What are the main problems in Ukraine's maritime transport infrastructure development strategic management system?

RQ2: How can an indicative system for the sustainable development of ports as key elements of Ukraine's maritime transport infrastructure be developed and demonstrated in practice?

RQ3: What are the main components of a performance management system for sustainable development in the maritime transport infrastructure sector?

2. Literature Review.

The global interest in maritime transport as the most efficient means of transporting large cargo volumes has led to a constant need to modernise maritime transport infrastructure. Scholarly studies have focused on modernising maritime transport infrastructure while considering safety requirements and sustainable development principles.

First, attention should be paid to how researchers approach the problem of studying and developing systems for port operations analysis. Ducruet and Notteboom (2023) proposed the application of a system of dynamic indicators. In contrast, Russo and Musolino (2023) suggested assessing port problems and efficiency relative to the performance indicators of the adjacent transport infrastructure. Saswat et al. (2023), in their study of global experience in adaptation of port management modelling, highlight the forms and methods of index-based evaluation of port performance.

Vasheghani & Abtahi (2023) noted the growing demand for multimodal transport, the main challenges in handling such cargo, and emphasised the need to review strategic directions for the development of maritime transport infrastructure. Pencheva et al. (2022) highlighted the possibilities for implementing innovations in the maritime transport sector, particularly in multimodal and intermodal cargo transportation.

As maritime transport infrastructure operations create hazardous conditions in the surrounding environment, many researchers have focused on sustainable development. Among Barona et al. (2023) and Song (2024), who propose practical measures for sustainable development components and emphasise the need to organise management for their implementation.

Javed et al. (2026) and Issa et al. (2025) propose methods for combining various measures to model the organisation of a transport and logistics support system in line with sustainable development principles. Wang et al. (2025) propose reinforcing these models with digital tools, given the characteristics of both maritime and dry ports as integral components of transport infrastructure.

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However, despite significant research achievements in the field of maritime transport infrastructure performance evaluation and problem identification in the context of sustainable development, some problems remain unresolved.

Acciaro et al. (2014) and Żak (2023) highlight the importance of addressing these issues. Among the problems identified by these researchers, beyond the general challenges of sustainable development in maritime transport infrastructure is a lack of sufficient research on the analysis and process management of sustainable development during the modernisation of port infrastructure.

Balic et al. (2022), Mykytenko and Chupryna M.O. (2025) highlight the need to expand scientific enquiry in this sphere, given the ongoing improvement of scenario-based forecasting models for the development of various components of transport infrastructure, in general, and maritime transport infrastructure in particular.

Overall, previous studies require expansion and clarification in light of emerging threats and challenges that may slow the sustainable development of maritime transport infrastructure. The results identified earlier have limitations related to the specific features of sustainable development during the post-war period.

3. Methodology.

The methodology of this study is based on risk identification through expert evaluation, the development of a performance indicator system, and the determination of an integrated index for risk assessment. The analysis of these indices constitutes the research results. The assessment of the current condition and potential capabilities of the sustainable development management system of maritime transport infrastructure facilities is carried out in stages:

- normalisation of primary indicators using the “min–max” method with their classification into stimulative and destimulative indicators;
- aggregation of normalised indicators into group indices (economic, environmental, social, and institutional-digital);
- integration of the group indices into a single Sustainable Development Index of the Port System (ISPS) using a weighted aggregation model (1):

$$I_{SPS} = \sum_{i=1}^{n} w_i \cdot I_i \qquad (1)$$

where I_{SPS} – the unified (composite) index of sustainable development of the port system; $\sum_{i=1}^{n} w_i = 1$ – weights are normalised; I_i – the group sustainability index (economic, environmental, social, institutional-digital); w_i – the weighting coefficient of the i-th group.

Formula (1) is derived from the classical concept of constructing an integral index, which is widely applied in research on sustainable development, transport logistics, energy efficiency, and the socio-economic development of regions, among others. The model is based on the classical weighted-average scheme (Weighted Aggregation Model), which is widely used in studies of sustainable development and transport logistics (Mykytenko & Chupryna, 2025).

The weighting coefficients are set equal (w_i = 0.25) in accordance with the principle of structural parity of the sustainable development components (the integral indicator's resistance is confirmed by sensitivity analysis).

The assessment of management performance is based on a set of key performance indicators (KPIs) that reflect the effectiveness of management processes, the speed of adaptation, and the achievement of strategic objectives. The analytical consistency of the model was verified through correlation analysis, which confirmed the absence of multicollinearity among the integral structure components.

The empirical basis of the study was formed from official statistics, reporting materials from port administrations, international analytical sources and expert evaluations. Data processing was performed using normalisation procedures, weighted aggregation, and statistical verification of the internal consistency of the indicators.

The developed system of indicators covers the economic, environmental, social, and institutional-digital parameters of port operations. It complies with the principles of ESG monitoring and the European Green Deal guidelines.

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The proposed indicative-integral model for sustainable development and management performance assessment enables a comprehensive assessment of the financial stability, innovation dynamics, environmental responsibility, and managerial effectiveness of the port system amid increased instability (Mykytenko & Chupryna, 2025).

The primary data sources used in the study are publicly available information provided for general review by the Administration of Sea Ports of Ukraine, international organisations that cooperate in the maritime transport system, publicly released results of expert surveys, and other sources whose use does not require publication permission.

4. Results.

4.1. Risks and Strategic Management of Ukraine's Maritime Ports.

The development of maritime transport infrastructure is particularly significant for shaping the overall level of transport service provision across all sectors of an economic system.

The maturity and capacity for continuous renewal of maritime transport infrastructure facilities affect not only port competitiveness but also the level of local and global economic security. If Ukraine's port system is compared with other countries, it can be noted that, for example, according to the Liner Shipping Connectivity Index, Ukraine shows significantly lower results (Fig. 1).

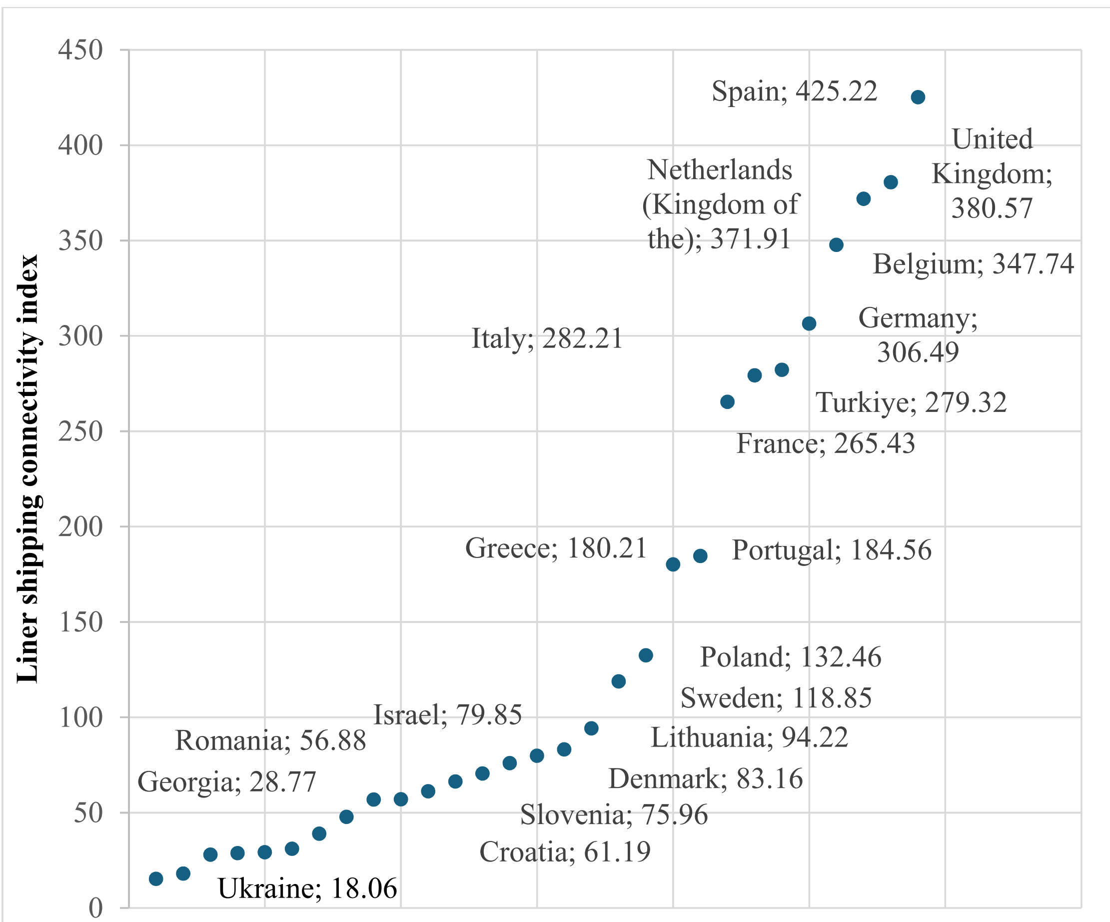

Fig. 1. Liner Shipping Connectivity Index of Selected Euro-Atlantic Countries, 2024. *Source: based on UNCTAD (2025).*

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It is essential to consider the risks that have fundamentally changed the conditions for the strategic management of maritime transport infrastructure development, as security-sphere uncertainty affects all components of development. This uncertainty is embodied in the inability to predict the stability of navigation, the preservation level of port infrastructure, and the safety of personnel and cargo. The security level determines the volume of operational ports, imposes limitations on their functioning, and affects investor interest and long-term development. Figure 2 shows the total cargo turnover in Ukrainian ports from 2019 to 2024. In 2019 and 2020, cargo turnover was approximately stable, and in 2021, it declined slightly (4% compared to the previous year). In 2022, due to port blockades during hostilities, cargo turnover fell 3 times compared to the previous year. However, in 2024, cargo turnover was only 60.75% of the 2019 value.

This distribution has been shaped by the current military threat, and a significant redistribution of risk is expected after the cessation of hostilities. It is necessary to determine a baseline level against which the components of uncertainty will be defined to identify the main manifestations of changes in the security situation.

Since most of the security-related uncertainties affecting maritime transport infrastructure emerged with the start of hostilities, the preceding period may be considered the baseline. Uncertainty in the security sphere is a key factor influencing the competitiveness of Ukraine's entire maritime transport system and the Black Sea region (Gechbaia & Tsilosani, 2023). Manifestations of security uncertainty vary in nature and origin. However, they all negatively affect the development of Ukraine’s maritime transport infrastructure.

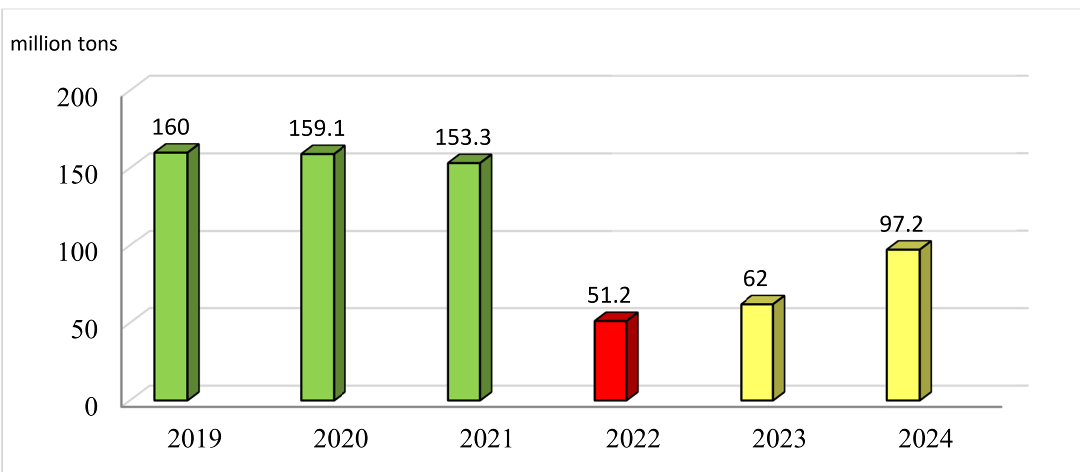

Fig. 2. Cargo Turnover in Ukrainian Ports, 2019-2024 (million tons).

Source: based on Center for Transport Strategies (2025).

Military actions have caused significant damage that led to the substantial destruction of Ukraine’s seaports. Traditional supply chains have also been severely affected by the blockade of sea routes, reliance on temporary grain corridors, and use of alternative routes via the Danube. Shipping risks are reflected in the uncertainty around navigational safety and cargo insurance complications, driven by restrictions on the activities of many insurance companies that traditionally operated in this economic region.

Port competitiveness and the investment attractiveness of maritime infrastructure modernisation projects are influenced by technological instability stemming from cyber threats, as there is a high risk of losing control over logistics processes through attacks on port information systems. Due to information inconsistencies, environmental threats have emerged, directly motivating the establishment of sustainable development principles within the strategic management of maritime transport infrastructure development.

4.2. Analysis of Sustainable Development of the Port System.

The study developed two complementary evaluation subsystems:

1. An indicative sustainability assessment system for ports (Table 1).

2. A system of performance indicators for managing the sustainable development of the port system or an individual port (Table 2).

The proposed indicator framework enables the derivation of quantitative measures that reflect the performance of governance actors and the priorities they establish. It also includes the management instruments applied in practice within the port system and allows for the assessment of mobilised and utilised reserves and resources of various types, aimed at ensuring the sustainability of the port system under polycrisis conditions.

In this context, the proposed Integrated Sustainability Index of the Port System (I_{SPS}) (formula 1) may serve as a core instrument in the new ESG monitoring framework. Simultaneously, the KPI system provides an early warning feedback mechanism for strategic planning, operational adjustments, and the achievement of positive socio-environmental, economic, and institutional governance outcomes (Quelhas & Meiriño, 2025).

The implementation of this indicator system may serve as a foundation for the transition to a resilience-based governance model, under which the port system will operate as a self-learning, continuous-improvement process with progressively increasing performance requirements grounded in measurable sustainability and effectiveness indicators.

Table 1. Development of an Indicative Sustainability Framework for Ukrainian Ports.

Indicator Group	Core Indicators	Expected Outcome (Analytical Implication)
Economic sustainability	Operating profitability (%); a share of profitable ports; revenue growth rate; handling rate (tonnes per employee).	Ensuring the competitiveness and financial sustainability of the port system
Financial sustainability	Equity ratio; liquidity level; share of “green” investments in total capital expenditures.	Enhancing investment attractiveness and diversifying funding sources.
Ecological sustainability	Annual CO_2 emissions (tons/year); share of energy derived from renewable energy sources; water and waste recycling ratio; compliance with ISO 14001 environmental certification.	Reducing environmental impact and integrating best-practice “Green Port” principles into operational activities.
Social Sustainability	Average industry wage; employment rate; occupational safety ratio; Corporate Social Responsibility Index (CSR Index).	Enhancing the quality of the labour environment and fostering social cohesion in port regions.
Institutional and digital sustainability	Number of implemented digital services; level of process automation; share of ports with ESG reporting; governance transparency index.	Establishing a digitally mature, effective, and objectively accountable port governance system.

Table 2. Sustainable Development Performance Indicators for Ukraine’s Port System.

Dimension	Key KPIs / Indices	Substantive Content
Management efficiency	Sustainable Development Management Performance Index (I_{RM}); proportion of strategic objectives implemented and achieved (%); average decision-making cycle (days).	Assesses the quality of managerial processes and the capacity of governance bodies to implement the sustainable development strategy within the port system.
Monitoring and control	Frequency of ESG audits; rate of achievement of planned KPIs (%); average response time to risks and emerging challenges.	Reflects the effectiveness of feedback mechanisms and the adaptability of the port system to the prevailing risk environment.
Adaptability and innovation	Innovative projects (%); digital maturity index; number of green technologies implemented.	Indicates modernisation and technological advancement in the port system.
Synergistic effect	Integrated Sustainability Index of the Port System (ISPS).	Measures the balance of socio-environmental and economic outcomes from the strategic roadmap.

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For the development of the indicative sustainability assessment system for ports and the system of performance indicators for managing the sustainable development of the port system (Tables 3 and 4), primary reliance will be placed on economic and statistical data for 2023–2024, including the following:

a) Financial and economic indicators covering cargo turnover, export–import operations, financial performance, investments, environmental expenditures and employment.

b) Operational and environmental indicators reflecting cargo handling dynamics, capital investment, revenue of state-owned and private ports, energy consumption, environmental emissions, and waste.

In addition, based on official statistical data from the Ministry for Communities, Territories, and Infrastructure Development of Ukraine, the State Enterprise "Ukrainian Sea Ports Authority", and UNCTAD, this study provides an interpretation of the calculated indicators of management performance for the sustainable development of the national port system.

Accordingly, the conducted economic and statistical analysis, based on indicators from the indicative sustainability assessment system and the sustainable development management performance system for Ukraine's port system as of 2024, revealed a moderately positive development trajectory for the sector.

Table 3. Development of the Indicative Sustainability Assessment System for Ukrainian Ports, 2024.

Sustainability Subsystem	Indicator	Unit of Measurement	Value (2024)	Indicative Assessment (Trend)
1. Economics	1.1. Total cargo throughput	million tonnes	132.4	+8.5% vs 2023
	1.2. Total port system revenue	billion EUR	1.02	Moderate growth (+6.0%)
	1.3. Return on Assets (ROA)	%	8.2	Stable
	1.4. Capital investment volume	billion EUR	0.13	Investment activation
2. Environmental	2.1. CO_2 emissions per tonne of cargo	kg CO_2/t	2.9	−7.0%
	2.2. Share of renewable energy use	%	14.7	Gradual increase
	2.3. Expenditure on environmental programs and water treatment	Million EUR	12.96	Stable
3. Social	3.1. Employment in the port sector	thousand people	31.4	Positive trend
	3.2. Average wage of port personnel	thousand euro/month	0.54	+12.0% vs 2023
	3.3. Share of employees in professional development programs	%	19.5	Increasing participation
4. Innovative Digital	4.1. Operations using electronic document management	%	78.0	Increasing digitalisation
	4.2. Ports with IoT monitoring systems	units	7 of 13	Moderate growth
	4.3. IT investments as share of total capital expenditure	%	9.3	Upward trend
5. Institutional-Managerial	5.1. Achievement of 2024 strategic objectives	%	83.5	High implementation
	5.2. Effectively implemented PPP projects	units	12	Positive trend

Source: based on International Finance Corporation (2021, 2023), Russo and Musolino (2023), and World Bank Group (2025).

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Table 4. Performance Indicator System for Managing the Sustainable Development of Ukraine's Port System, 2024.

Performance Criterion	Indicator	Formula (Unit)	Value (2024)	Interpretation
1. Financial	1.1. Net revenue growth rate	% vs previous year	106.2	Positive trend
	1.2. Cost ratio (expenses/revenue)	ratio	0.79	Structural optimisation
	1.3. Financial sustainability level	coefficient	0.65	Stable capitalisation
2. Investment	2.1. Share of private investment	%	36.8	Low PPP activation
	2.2. Investment efficiency (ROI)	%	11.5	Project effectiveness
3. Managerial	3.1. Roadmap implementation index	%	85.7	High implementation level
	3.2. Share of decisions aligned with ESG approaches	%	61.3	Strengthening environmental component
4. Socio-Environmental & Innovation	4.1. Reduction in production energy intensity	% vs 2020	−12.4	Improvement in energy efficiency
	4.2. Share of green projects in port portfolio	%	17.8	Rising ESG investment
	4.3. Digital maturity index	score (0–1)	0.68	Medium level with upward potential

Source: based on International Finance Corporation (2021, 2023), Russo and Musolino (2023), and World Bank Group (2025).

However, its adaptive potential remains highly dependent on external and institutional factors (Kholodenko & Gusak, 2022). The structural assessment indicates that the integral sustainability level of the port system amounts to approximately 0.816 out of 1.0.

The results show that even under war-induced conditions, the national port system retained sufficient resources and reserves to maintain operational stability. Regarding capital investments amounting to 0.13 billion EUR, their partial activation in 2024 (with an investment efficiency coefficient of 11.50%) indicates limited project effectiveness and a relatively low share of green projects in the port investment portfolio (17.80%).

Although these indicators appear acceptable from a governance perspective, they may also signal underlying institutional inefficiencies, including potential corruption-related risks in financial stabilisation activities and limited trust of private investors in public–private partnerships, as reflected by the relatively low share of private investment in total capital investment (36.80%). The financial sustainability level of the port system is estimated at 0.65, indicating near-stable capitalisation; however, this result is largely attributable to reconstruction investments from international partners.

Simultaneously, the investment block demonstrates renewed activity in public–private partnerships and emerging signs of project efficiency (ROI = 11.5%).

Managerial performance in 2024 was broadly aligned with the trends identified by UNCTAD (2025) regarding the adoption of ESG-based governance models in port systems. However, digitalisation remained incomplete, as reflected in the digital maturity level of 0.68 (on a scale of 0 to 1) and the absence of a unified digital infrastructure.

Simultaneously, the managerial performance criterion (roadmap implementation index at 85.7% and share of decisions incorporating ESG approaches at 61.3%) indicates a strengthening of the strategic capacity of both public and corporate actors and the formation of foundational elements of resilience-oriented governance.

It can be concluded that the current sustainable development management system of Ukraine's port system may demonstrate effectiveness during the post-crisis stabilisation and post-war recovery phases, provided that the reconstructive, socio-environmental, financial, and informational-cognitive potential is preserved at least at the 2024 level. However, achieving this will require the following:

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1. Deepening of institutional and financial coordination, including the identification and mobilisation of additional reserves.

2. Further strengthening of ESG-oriented governance practices.

3. The introduction of digital performance indicators in management processes.

4.3. Analysis of Sustainable Development Management of the Port System.

Governance actors of the national port system should identify, prioritise, and scientifically substantiate the most critical focal areas for the localisation of efforts to implement the "Resilient and Sustainable Port System of Ukraine" model in practice.

Such a model can ensure economic profitability, environmental safety, and social responsibility simultaneously, in accordance with European sustainability standards. Based on the proposed calculation formula (1), the sustainability index of the port system can be computed for 2024.

Accordingly, Table 5 presents five sustainability subsystems. Given the conditions of large-scale military actions currently affecting the country and the absence of a clearly defined expert consensus, the principle of equal significance of each subsystem's impact on sustainable development processes is applied. Therefore, equal weights are assigned (w_i = 0.2), as five evaluation components are considered (1/5 = 0.2).

Table 5. Average Sustainability Indices of Ukraine's Port System by Subsystem, 2024 (Observed Trends).

Subsystem	Trend Assessment (2024)	Normalised Value (Ii)
Economic	Moderate growth (+6.0%)	0.82
Environmental	High and stable, gradual increase	0.80
Social	Positive trend (+10–12%)	0.85
Innovation & Digital	Increasing digitalisation	0.78
Institutional & Governance	High implementation of sustainability policy	0.83

Thus, the Sustainability Index of Ukraine's Port System (I_{SPS}) is 0.82, calculated using Equation (2):

$$I_{SPS}=\sum_{i=1}^{5} w_i \cdot I_i = 0.816 \qquad (2)$$

The obtained quantitative value indicates a relatively high level of sustainability, suggesting that in 2024, Ukraine's port system operated in a state of adaptive stabilisation, with signs of gradual recovery.

However, different weighting coefficients assigned to the five subsystems may significantly affect the sustainability index, given that the operating conditions of the national port system vary considerably from 2023 to 2025. Second, the scale of destruction of ports and port-adjacent infrastructure, as well as the decline in socio-environmental security observed in 2025, is likely to reduce the ISPS value significantly. Therefore, the present calculations were primarily conducted to verify the proposed methodological approach.

Subsequently, by applying an analogous formula (1) to the four performance criteria (financial, investment, managerial, and socio-environmental-innovative) presented in Table 4, the Sustainable Development Management Performance Index of the port system for 2024 is calculated (Table 6).

The Sustainable Development Management Performance Index of the port system (I_{RM}) for 2024 was approximately 0.77, as calculated using formula (3):

$$I_{RM}=\sum_{j=1}^{4} w_j \cdot I_j = 0.768 \qquad (3)$$

The results suggest that in 2024, Ukraine's port system demonstrated a moderately high level of managerial effectiveness, with strategic objectives aligned with defined priorities implemented in a coordinated manner. However, additional opportunities to improve performance remain, particularly through expanding green, innovation-driven digital projects (Table 7).

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Table 6. Sustainable Development Management Performance Index (I_{RM}) of Ukraine's Port System, 2024.

Criterion	Average Normalised Value (Ii)	Description
Financial	0.77	Positive trend; structural optimisation
Investment	0.74	Activation of PPPs; investment efficiency
Managerial	0.80	High roadmap implementation level
Socio-Environmental & Innovation	0.76	Growth of ESG component

Table 7. Interpretation of Composite Sustainability and Management Performance Indices of the Port System.

Level	Value Range	Characteristics
High	0.81–1.00	Sustainable development is systematically ensured
Moderately High	0.71–0.80	System is stable but requires enhanced adaptability
Medium	0.61–0.70	Institutional or financial instability risks are present
Low	<0.60	System is destabilised

The impact of sustainable development on the financial performance of Ukrainian seaports, based on the initial conditions identified by the authors during the assessment of Ukraine's maritime port development opportunities. This assessment enabled the forecasting of the following financial outcomes (Fig. 3).

Thus, the index components of sustainability and sustainable development management performance proposed in this study may be applied to assess the overall condition of the sector and to evaluate the sustainable development and sustainable development management of individual maritime transport infrastructure facilities in Ukraine.

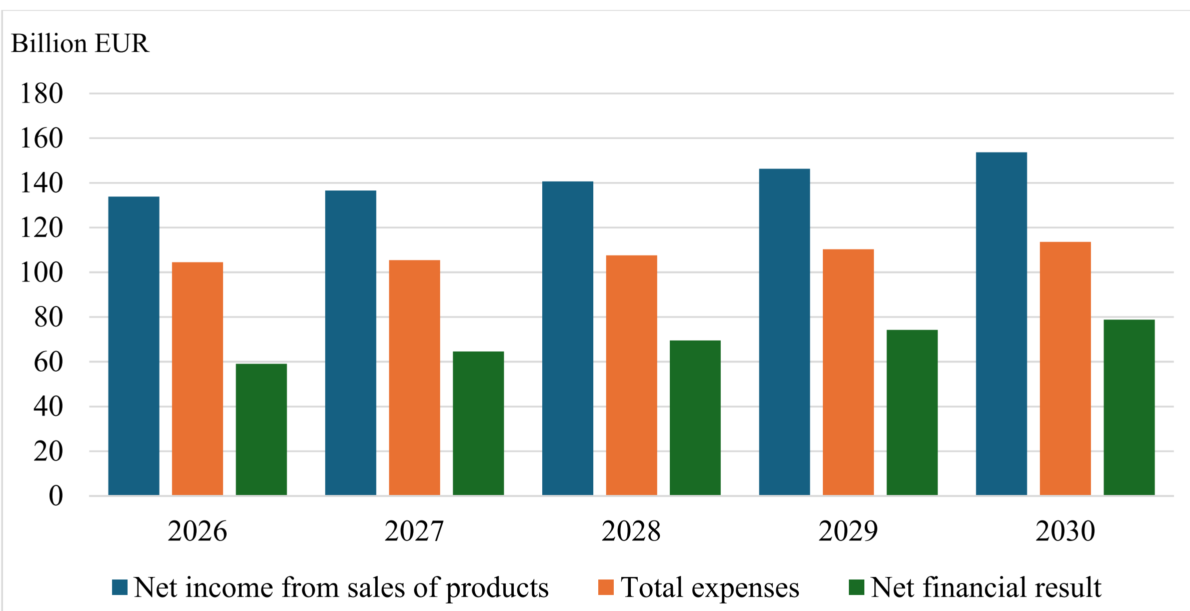

Fig. 3. Projected Financial Performance of Ukraine's Maritime Transport Infrastructure, 2026–2030.

5. Discussion.

The maritime transport infrastructure in Ukraine is currently exposed to a wide range of threats and risks that significantly affect its competitiveness in the regional and global transport service markets. The systematic impact of economic risks, insufficiently mitigated by strategic management measures, has resulted in several adverse consequences for Ukraine's maritime transport sector, including a decline in the competitiveness of Ukrainian ports relative to those of Poland, Romania, and Türkiye, increased dependence on external financial assistance and credit resources, and delays in implementing the National Transport Strategy of Ukraine until 2030 (Cabinet of Ministers of Ukraine, 2018).

In addition to economic risks, substantial environmental risks arise from military actions and technological and anthropogenic factors. The destruction of port infrastructure, fuel spills, and unauthorised waste discharges have led to pollution of port water areas. Rising sea levels and damage to hydraulic engineering structures have intensified coastal erosion and degraded adjacent zones. Military operations and the uncontrolled intensification of shipping activities in protected areas have disrupted local ecosystems. Ukraine continues to lag behind European environmental regulatory standards, resulting in limited implementation of green port principles and decarbonisation practices.

The emergence of environmental risks is largely attributable to insufficient monitoring and control of water pollution, inadequate implementation of environmentally sustainable shipping and waste management technologies, limited funding for environmental protection programs, and the absence of effective incentives for businesses to modernise in accordance with environmental requirements.

The consequences of these environmental threats for maritime transport infrastructure include increased environmental compliance costs in port operations, reputational losses at the international level, limited opportunities for integration into green transport corridors, health risks for populations in port-adjacent regions, and constrained prospects for the high-quality strategic development of coastal infrastructure.

Unlike the findings reported in the literature review, this study demonstrates that the existing subsystems used to assess the effectiveness of sustainable development and sustainable development management in maritime transport infrastructure must be further specified and adapted to the current risk conditions.

6. Conclusions.

To address the identified risks and ensure the continued sustainable development of maritime transport infrastructure, targeted measures must be introduced and implemented to manage sustainability across maritime transport infrastructure facilities. The indices calculated in this study (I_{SPS} = 0.816; I_{RM} = 0.768) indicate that Ukraine's port system in 2024 operated within the "sustainable recovery" phase, with a tendency toward a transition to the "innovative transformation" phase.

The governance model applied in 2024 features a relatively high level of integration of economic, social, and environmental factors. However, it requires substantial strengthening of strategic adaptability and improved effectiveness of digital and ESG projects. The indices were derived using a weighted aggregation model based on normalised (min–max) indicators. Five subsystems were employed for the I_{SPS} (economic, environmental, social, innovation-digital, and institutional-governance), each assigned equal weights. For the I_{RM}, four performance criteria (financial, investment, managerial, and socio-environmental-innovative) were applied with equal weighting.

The obtained values indicate that the port system reached a near-fully established level of sustainability in 2024 and demonstrated a coherent alignment of governance mechanisms. Simultaneously, they reveal additional potential to improve performance (I_{RM}), particularly through the possible expansion of green and digital projects and the further strengthening of institutional coordination. Overall, the calculated indices I_{SPS} and I_{RM} confirm a relatively high level of sustainability and a moderately high level of managerial performance of Ukraine's port system in 2024.

Future research should refine the proposed methodological framework, particularly regarding the integrated assessment of sustainable development and its management within the maritime transport infrastructure.

Particular attention will be given to incorporating the specific characteristics of future projects aimed at the comprehensive modernisation of maritime transport infrastructure based on sustainable development principles.

Conflict of Interest Statement.

The authors declare that there is no conflict of interest.

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This research received no funding.

Data Availability.

The data supporting this study are included in the article. Data are available from the corresponding author upon request.

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