

## TECHNOLOGY, CREATIVITY, IMPLEMENTATION

### PROSPECTS FOR IMPLEMENTING BLUE ECONOMY INSTRUMENTS FOR THE SUSTAINABLE DEVELOPMENT OF THE BLACK SEA REGION

**Roman Hnidoi**

Ph.D., Odesa National Maritime University, Ukraine  
e-mail: oxford.pal2018@gmail.com, orcid.org/0009-0001-9477-3076

#### Summary

The article examines the concept of the blue economy as a key direction in the transformation of maritime and inland waterway transport under conditions of global environmental challenges. It demonstrates that current regulatory initiatives of international organizations and the European Union establish new requirements for maritime and inland waterway carriers and ports aimed at decarbonization and ecological adaptation of the sector. Considerable attention is devoted to technological innovations – green corridors, shore power, alternative fuels, and logistics digitalization – which have already proven their effectiveness globally and have significant potential for implementation in the Black Sea region.

A special emphasis is placed on combining global practices with local developments, particularly research by Ukrainian scholars in the field of SMART ports. It is shown that the integrated use of international experience and national initiatives can create conditions for ecological port modernization, enhance competitiveness, and facilitate integration into European transport networks. The results indicate that implementing blue economy instruments in the Black Sea is not only feasible but necessary to ensure environmental resilience, economic growth, and social development in the region.

**Key words:** maritime transport, sustainable development, EU ETS, FuelEU Maritime, AFIR, green corridors, SMART port.

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#### 1. Introduction

Maritime and inland waterway transport have long been among the most important drivers of global economic development. Since ancient times, they have facilitated trade, technological exchange, and cultural interaction, and today they continue to serve as the primary means of international freight movement. In the twenty-first century, this role has only strengthened: most global cargo flows – from raw materials to finished goods – pass through seaports and transport corridors. This creates unique opportunities for countries and regions, while also generating new challenges related to environmental security and climate change.

The traditional approach to sector development – focused on maximizing transport volumes and economic benefit – is no longer sufficient. Today, maritime logistics faces the task

of integrating economic interests with environmental responsibility and social stability. This makes the blue economy concept, which combines efficiency and sustainability in maritime and coastal spaces, a crucial reference point for strategic planning.

The distinguishing feature of the blue economy lies in its consideration of business needs, societal interests, and environmental status. Its idea is not merely to reduce negative impacts, but to create a development model where innovation and technological solutions simultaneously enhance economic performance and environmental preservation. Examples include logistics digitalization in ports, the development of green corridors, or the transition to alternative fuels gradually replacing traditional ones.

Ukraine has also begun developing scientific contributions aligned with global discourse. For instance, research by Kyrylova O.V. on SMART ports demonstrates that the introduction of digital management technologies can serve not only as a local innovation but also as part of a broader blue-economy-oriented vision. This confirms that Ukrainian scientific thought can generate modern solutions with international potential.

For the Black Sea region, blue economy development is particularly relevant. The basin combines unique economic potential with high environmental vulnerability. On one hand, it is a transport hub connecting Europe, the Caucasus, and the Middle East; on the other hand, its limited self-purification capacity accelerates the accumulation of negative consequences from transport operations. In such circumstances, balancing infrastructure development with environmental conservation becomes a priority.

This article aims to analyze global blue economy practices and determine possibilities for adapting them to the Black Sea region. The objective is not only to describe current solutions but also to identify which instruments may be most effective within the regional context. In this sense, the Black Sea may be viewed as a testing platform for implementing innovations that reconcile economic efficiency and environmental sustainability.

## 2. Theoretical Foundations of the Blue Economy

The blue economy concept emerged at the intersection of global challenges and the local needs of countries developing their maritime and inland waterway transport systems. Its essence lies in forming a development model that simultaneously ensures economic gains, technological progress, and environmental protection (*European Commission, 2021b*). Whereas green economy principles emphasize ecological considerations across all sectors, the blue economy focuses specifically on maritime and coastal spaces with unique resource potential and geostrategic relevance (*European Environment Agency, 2020*).

International organizations have played a central role in shaping the blue economy. A notable example is the adoption of the 2023 International Maritime Organization (IMO) strategy, which for the first time set concrete timelines for reducing greenhouse gas emissions from shipping. According to the document, the sector must reach climate neutrality by 2050, effectively implying the transition to new fuels and large-scale implementation of innovative technologies (*International Maritime Organization, 2023*). The European Union has followed a similar course through legal mechanisms such as FuelEU Maritime, which not only establishes requirements for emission reduction but also incentivizes accelerated business adaptation to new competitive conditions (*European Commission, 2023*).

Innovation stands at the core of the blue economy. It encompasses renewable energy use, digital technologies in logistics, the development of alternative fuels, and port automation. This innovative component differentiates the blue economy from traditional transport

policy approaches. For instance, the SMART port concept-developed by Ukrainian researchers-demonstrates how digitalization can transform transport-flow management quality. These ideas confirm that national developments can be integrated into international discourse and contribute to broader environmentally oriented strategies (*Kyryllova & Kyryllova, 2024*).

At the same time, the blue economy extends beyond technologies or regulations. It has a significant socio-economic dimension manifested in job creation, the development of digital competencies, and the strengthening of regional cooperation. This enhances national economic resilience and facilitates integration into international transport systems where efficiency and ecological performance play a decisive role (*Jeong & Yun, 2024*). The multidimensional nature of the concept lies in its simultaneous response to environmental challenges and stimulation of economic modernization (*Belmoukari et al., 2023*).

The significance of the blue economy for the Black Sea region is especially notable. Its geographical position makes it a key transport corridor linking EU markets with the Caucasus and the Middle East. However, its semi-enclosed nature results in heightened environmental vulnerability: pollutants accumulate more rapidly, and climate change directly affects maritime and river ecosystems (*European Environment Agency, 2020*). Therefore, implementing blue economy principles in the Black Sea is not merely a theoretical possibility but a practical necessity influencing the region's competitiveness in the coming decades.

### 3. Overview of Modern Regulatory Initiatives

The development of the blue economy is largely shaped by regulatory frameworks established by international organizations and regional institutions. These documents define strategic directions while also creating practical operational conditions for shipping companies, ports, and public institutions. They serve both as pressure tools and as incentives for innovation, since compliance determines participation in global logistics chains (*UNCTAD, 2024*).

A key document of recent years is the IMO Strategy on Emission Reduction, adopted in 2023. It sets sector-wide emission-reduction targets and declares the achievement of carbon neutrality by mid-century. Unlike previous declarative approaches, this strategy includes specific timelines and intermediary milestones, compelling shipowners to invest in energy efficiency and consider alternative fuels as an inevitable development path (*International Maritime Organization, 2023*).

Particular attention should be paid to the policy of the European Union, where maritime transport has been fully integrated into the Emissions Trading System (EU ETS). This requires carriers to purchase emission allowances, making delays in fleet modernization directly affect financial performance. Such an approach transforms environmental requirements into economic incentives and creates new competitive dynamics favouring companies with faster innovation adoption (*European Union, 2023a*).

Another major initiative is the FuelEU Maritime Regulation, which will enter into force progressively from 2025. It sets minimum carbon-intensity reduction standards for marine fuels, fostering a gradual shift away from conventional energy sources. This levels the playing field for EU carriers and exerts pressure on external companies wishing to remain competitive in the European market (*European Union, 2023b*).

The Alternative Fuels Infrastructure Regulation (AFIR) further complements this framework. It requires key European ports to be equipped by 2030 with methanol, ammonia, and hydrogen bunkering facilities, as well as shore power infrastructure. Thus, the EU is not only imposing requirements on shipowners but also creating an environment where modern port

infrastructure becomes a standard. This makes port investment attractiveness directly dependent on ecological readiness (*European Union, 2023c*).

Inland waterway transport also receives significant attention. The NAIADES III Programme outlines EU inland navigation development for 2021–2027, with a strong focus on digitalization and energy efficiency. This highlights that the blue economy applies not only to seas and oceans but also to river transport destined to form part of sustainable logistics chains (*European Commission, 2021a*). The FAIRway Danube project—aimed at improving navigability and infrastructure harmonization along the Danube—is particularly important for the Black Sea region as it integrates river and maritime logistics into a unified system (*FAIRway Danube, 2025*).

Thus, modern regulatory initiatives create a new architecture for maritime and river transport, where environmental targets are mandatory and financial efficiency depends directly on innovation. For the Black Sea region, synchronizing with these standards is essential to remain integrated into global logistics networks.

#### 4. Technological Innovations of the Blue Economy

Blue economy development requires deep technological transformation. Technologies represent the driving force enabling the integration of economic gains with environmental responsibility. While regulatory initiatives establish necessary frameworks, innovations provide the tools to achieve them. These technologies have already demonstrated practical effectiveness: reducing emissions, optimizing costs, and reshaping logistics-system management (*Li et al., 2024*).

One key direction involves green corridors—transport routes applying standardized ecological technologies and procedures. A notable example is the Singapore–Rotterdam project, which demonstrated how biofuel use and digital vessel-coordination systems can simultaneously reduce logistics costs and emissions. This confirms that green corridors are not merely political declarations but functional technological models of cooperation between ports, ship-owners, and public authorities (*Port of Rotterdam Authority, 2022; Maritime and Port Authority of Singapore, 2022*). For the Black Sea, green corridors such as Odesa–Constanța–Istanbul may become both an environmental adaptation tool and a mechanism for deeper integration into the Trans-European Transport Network.

Another essential innovation is shore power (OPS), enabling ships to connect to onshore electricity while berthed, eliminating the need to run auxiliary engines. This significantly reduces air pollution in port cities. The European experience shows that OPS can be combined effectively with renewable sources—for example, the Bilbao port project integrating shore power with solar facilities (*Port Technology International, 2025*). For Black Sea ports, OPS may become a crucial factor in attracting international carriers under increasing environmental requirements.

Alternative fuels represent a transformative direction. Biofuels have proven their viability without requiring major modifications to ship structures. Trials in Singapore confirmed that such transitions can occur rapidly and cost-effectively (*Global Centre for Maritime Decarbonisation, 2024*). The next step is methanol, exemplified by Maersk’s launch of the first commercially operating green-methanol container vessels—a strong market signal confirming readiness for fleet modernization (*Maersk, 2023*). Medium- and long-term options such as ammonia and hydrogen are discussed widely, though their development remains costly and experimental (*Vakili et al., 2025*).

Digitalization also plays a major role. Port community systems, river information services, and electronic documentation have demonstrated their ability to reduce administrative costs and enhance operational transparency. Digital twins used in Rotterdam and Singapore enable real-time modelling of port infrastructure load, supporting optimal logistics decisions under dynamic conditions (Heikkilä *et al.*, 2022). For the Black Sea, such digital transformation may form the basis for enhanced regional cooperation through shared data systems and integrated digital platforms.

Technological innovation thus forms a coherent system shaping new sectoral dynamics. Green corridors, OPS, alternative fuels, and digitalization constitute interdependent elements that reinforce each other. Their integrated adoption transforms the blue economy from an abstract concept into a practical regional development mechanism requiring targeted investments.

## 5. Prospects for Implementing Blue Economy Instruments

Prospects should be viewed through the interaction of global trends and regional specificities. The Black Sea combines strong transport potential with considerable environmental vulnerability, making the search for balance crucial (European Environment Agency, 2020).

The environmental aspect is fundamental. As a semi-enclosed basin with limited water exchange, the Black Sea accumulates pollutants faster than open oceans. Implementing shore power, adopting biofuels and methanol, and developing green corridors can substantially reduce local emissions and improve living conditions in port cities (Sun *et al.*, 2025). EU examples show that environmental innovations enhance both ecological performance and investment attractiveness.

The economic dimension is equally important. Integrating the region into EU mechanisms such as EU ETS and FuelEU Maritime opens new opportunities for infrastructure financing. Estimates indicate that the maritime ETS market may reach tens of billions of euros by 2030, with part of these funds allocated to fleet renewal and port modernization (European Commission, 2023a; Transport & Environment, 2024). For Ukraine and neighbouring countries, this represents an opportunity to integrate into the TEN-T network and strengthen their transit role between Europe and Asia.

Technological development offers substantial advantages. Digital twins, electronic documentation, and integrated logistics platforms enable Black Sea ports to compete with major Mediterranean hubs. The successful cases of Rotterdam and Singapore confirm that digitalization reduces administrative costs and accelerates cargo handling-critical for transit-oriented regions (Heikkilä *et al.*, 2022). In Ukraine, these ideas appear in academic research on SMART ports, demonstrating the feasibility of adapting global solutions to local conditions (Kyryllova & Kyryllova, 2024).

Institutional integration presents another avenue. NAIADES III and FAIRway Danube provide models for forming unified standards across the Black Sea basin. Their implementation shows that harmonizing technical requirements and management practices enhances both efficiency and system stability (European Commission, 2021a). This enables coordinated development with EU member states and neighbouring non-EU countries.

The social dimension should not be overlooked. New jobs in green technologies, training for digital innovation, and strengthened regional cooperation can enhance societal resilience. For Ukraine, port modernization and integration into European initiatives can become not only an economic driver but also a societal catalyst, shaping port cities into centres of modern transport and environmental infrastructure (Jeong & Yun, 2024).

Overall, the prospects for implementing blue-economy instruments in the Black Sea depend on the region's ability to integrate global standards with local potential. Combining regulatory alignment, technological innovation, and socio-economic benefits creates a unique opportunity window that should not be missed.

## 6. Conclusions

The conducted research confirms that the blue economy should be regarded not as an abstract sustainability concept but as a practical strategic framework for transforming maritime and inland waterway transport under contemporary environmental and economic challenges. Its implementation reshapes the logic of sectoral development by integrating ecological responsibility, technological innovation, and long-term economic efficiency.

The analysis demonstrates that the Black Sea region possesses both significant transit potential and heightened environmental vulnerability, which together create a strong rationale for adopting blue economy instruments. Without such an approach, the region risks remaining a peripheral transport corridor with limited added value and increasing ecological pressure. In contrast, alignment with blue economy principles enables the Black Sea to strengthen its role within European and global transport networks.

The study shows that technological solutions—shore power systems, green corridors, alternative marine fuels, and digital logistics platforms—constitute the core operational instruments of the blue economy. Their effectiveness has already been demonstrated in leading maritime regions, indicating that the primary challenge for the Black Sea lies not in technological feasibility but in coordinated implementation and institutional support. Digitalization, in particular, emerges as a cross-cutting factor that enhances both environmental performance and operational competitiveness.

Institutional integration with international and European regulatory frameworks plays a decisive role in this process. Synchronization with initiatives such as EU ETS, FuelEU Maritime, AFIR, NAIADES III, and FAIRway Danube creates access to financial mechanisms, technological standards, and cooperative platforms that are essential for sustainable modernization. Fragmented or isolated national efforts are insufficient in a sector characterized by transboundary environmental and economic interactions.

The social dimension of the blue economy is also significant. The transition towards sustainable maritime and inland navigation can generate new employment opportunities, stimulate the development of digital and environmental competencies, and contribute to the modernization of port cities. For Ukraine, such transformation has additional importance in the context of economic recovery and integration into European transport systems.

Further research should focus on the quantitative assessment of economic and environmental effects of specific blue economy instruments in the Black Sea region, including cost-benefit analysis of shore power deployment, alternative fuel infrastructure, and digital port systems. Particular attention should be given to modelling scenarios of regional cooperation, investment mechanisms, and the interaction between maritime and inland waterway transport within integrated logistics chains.

Overall, the comprehensive application of blue economy principles offers a realistic pathway for enhancing the competitiveness, resilience, and environmental sustainability of the Black Sea transport system, provided that technological innovation, institutional alignment, and socio-economic considerations are addressed in an integrated manner.

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