

# Romanian Maritime Ports in the Digital Transformation Era: The Shift from Fourth-Generation to Smart Ports and the Impact on the Global Logistics Ecosystem

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**ABSTRACT:** Romanian maritime ports play a pivotal role in the national and regional economy, acting as crucial logistical and commercial hubs in the Black Sea region. This study investigates the ongoing digital transformation of these ports, focusing on the shift from traditional fourth-generation ports to innovative smart ports. It examines the challenges, opportunities, and strategies employed in this transformation, emphasizing the integration of cutting-edge technologies such as automation, digitalization, and green innovations. In light of global trends in the logistics sector, alongside the increasing demand for efficiency, sustainability, and resilience, the research highlights how these advancements contribute to enhancing the operational performance of Romanian ports. Furthermore, the study explores the broader implications of this transition on the global logistics ecosystem, analyzing its potential to improve connectivity, reduce environmental impact, and stimulate economic growth. By evaluating the evolution of Romanian maritime ports over the past two decades, the study offers strategic insights into how these ports can evolve into intelligent, sustainable transport hubs capable of meeting the future demands of a globalized and environmentally conscious supply chain.

## 1 INTRODUCTION

Romanian maritime ports have long served as critical gateways for trade and economic development in the Black Sea region. Among them, the Port of Constanta and its satellite ports—Midia, Agigea, and Mangalia—stand as pivotal hubs in the Romanian logistics network. With Romania's integration into the European Union in 2007 and the evolving global demand for more resilient, sustainable, and technologically advanced transport systems, these ports face the imperative of transitioning from traditional fourth-generation ports to fully operational smart ports [1].



Figure 1. Port of Constanta: Strategic Position in Europe

This paper explores the strategic transformation of Romanian maritime ports within the context of digital innovation and the global smart port paradigm. The study emphasizes how emerging technologies, such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and digital twins, are being increasingly adopted to enhance the efficiency, connectivity, and environmental sustainability of port operations [2][4].

We aim to investigate the socio-economic and logistical impact of this transformation, not only within the confines of maritime activity but also on the wider community of Constanta County. Special attention is given to the longitudinal effects observed in the region before and after EU accession, during the COVID-19 pandemic, the Russo-Ukrainian war, and in the current post-pandemic and post-conflict geopolitical environment.

The Port of Constanta, in particular, is analyzed as a strategic comparator against prominent European smart ports such as Rotterdam, Hamburg, and Barcelona. Through a multi-scalar lens that integrates local, regional, and global perspectives, the paper contributes to a comprehensive understanding of how Romanian ports can evolve to meet future challenges in the digital transformation era.

## 2 LITERATURE REVIEW

Numerous studies have emphasized the importance of digital transformation in maritime logistics. Rodrigue et al. (2020) [5] highlight how smart port technologies enable real-time data sharing, predictive maintenance, and supply chain optimization. Neumann (2023) [6], in his article on cybersecurity in maritime transport, outlines how the integration of digital systems increases both efficiency and vulnerability, thus necessitating robust cybersecurity protocols.

Smart port models in Europe, such as those developed in Rotterdam and Hamburg, are often referenced for their advanced digital infrastructure, including autonomous vehicles, blockchain-based customs processing, and AI-powered logistics hubs [7]. Constanta, while still in transition, has started implementing similar technologies through projects funded by the EU and national government initiatives [8].

Furthermore, recent publications address the role of maritime ports in crisis scenarios. The COVID-19 pandemic and the Ukraine war tested the resilience of ports globally. Romanian ports, especially Constanta, played a crucial role in ensuring supply chain continuity in Eastern Europe, compensating for blocked trade routes in Ukraine [9].

## 3 METHODOLOGY

This research employs a mixed-methods approach combining quantitative data analysis, qualitative stakeholder interviews, and comparative case study methodology. Primary data is gathered from Constanta Port Administration reports (2005–2024), Romanian Ministry of Transport publications, and Eurostat logistics indicators. Secondary sources

include peer-reviewed academic literature and digital innovation indexes. Geospatial mapping tools and SWOT analysis are used for strategic evaluation.

Table 1. Key Performance Indicators of Romanian Ports (2005 vs. 2024) [3], [11]

Indicator	2005	2024 (Smart (Pre-EU) Transition Era)
Total Cargo Throughput (mil. t)	37.2	67.5
Container Traffic (TEUs)	130,000	825,000
Ships Processed	11,500	15,800
ICT Investments (€ mil.)	~10	>150
Rail Connectivity Index	Low	High

## 4 SOCIOECONOMIC IMPACT OF CONSTANTA PORTS ON THE SURROUNDING COMMUNITY

### 4.1 Before EU Accession

Before Romania's accession to the European Union in 2007, Constanta County's maritime ports—Constanta, Midia, Agigea, and Mangalia—played a significant regional role but faced infrastructural and technological limitations. Port operations were predominantly manual, with limited automation and digital tools, restricting throughput capacity and efficiency [1][2]. Local communities were largely dependent on port-related employment in manual labor, ship maintenance, and traditional logistics services. Economic benefits, though notable, were constrained by outdated infrastructure and regulatory frameworks that lagged behind Western European standards [3].

Table 2. Cargo Throughput and Employment Levels Before EU Accession (2000-2006) [4]

Year	Cargo Throughput (Mt)	Employment in Ports (approx.)
2000	14.9	7,500
2003	17.4	7,200
2006	20.4	6,800

While cargo throughput showed moderate growth, employment began a slight decline due to early mechanization trends. This period set the stage for modernization needs, as labor-intensive practices were unsustainable long-term.

### 4.2 After EU Accession

Post-2007, Romania benefited significantly from the European Union's Cohesion Policy and Structural Funds, which targeted the modernization of maritime infrastructure and operations in the Port of Constanta. These investments facilitated the acquisition of advanced cargo-handling equipment, expansion of port terminals, and the implementation of Port Community Systems (PCS) to streamline customs and logistics workflows [5][6]. As a result, the port diversified its cargo profile—including containerized goods, bulk commodities, and oil products—adapting to global trade demands. Integration with trans-European transport corridors, notably the Rhine–Danube and TEN-T networks, further enhanced its strategic position [7]. This period also brought socio-economic benefits to the surrounding community, including a transition toward more specialized and higher-quality employment, driven by the emergence of IT-based and administrative roles [8].

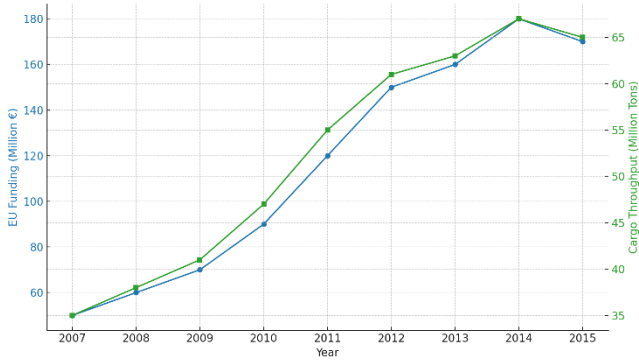


Figure 2. EU Funding vs. Cargo Throughput Growth in Constanta Ports (2007-2015)

This development trend is clearly illustrated in Figure 2, which presents the annual evolution of EU investment funds allocated to the Port of Constanta alongside the corresponding cargo throughput between 2007 and 2015. A strong positive correlation is evident: as EU funding increased, so did the volume of handled cargo. This direct relationship highlights how targeted investments not only enhanced operational efficiency but also contributed to regional development, including improved infrastructure, increased employment, and stronger economic resilience.

#### 4.3 During the COVID-19 Pandemic

The COVID-19 pandemic in 2020–2021 caused notable disruptions globally, and Romanian ports were no exception. Supply chain interruptions, labor shortages, and new health protocols reduced throughput temporarily [9][10]. However, the pandemic accelerated digital transformation initiatives. Ports fast-tracked the adoption of contactless technologies, remote monitoring, and automated cargo handling, enhancing operational resilience [11]. Local communities faced temporary economic hardships due to decreased port activity, but governmental support programs helped stabilize employment and social conditions [12]. Despite an initial drop in throughput and workforce size, the surge in digital transactions reflects the ports’ rapid pivot toward smart solutions, supporting continuity and long-term modernization goals.

Table 3. Operational Changes in Constanta Ports During the Pandemic [12]

Indicator	2019 (Pre-Pandemic)	2020	2021
Cargo Throughput (Mt)	24.8	21.8	23.5
Workforce Size	6,500	5,500	6,000
Digital Transactions (%)	35	65	80

#### 4.4 Post-Ukraine War Developments

The onset of the Russia-Ukraine conflict in 2022 significantly altered the strategic landscape for Black Sea ports. The Port of Constanta, along with adjacent facilities such as Midia, Agigea, and Mangalia, emerged as critical nodes for rerouted freight traffic, humanitarian logistics, and energy transit operations [13][14]. Heightened geopolitical risks necessitated an urgent reinforcement of port security protocols and diversification of trade routes to mitigate potential

disruptions. Consequently, there was a marked increase in investments targeting cybersecurity measures, infrastructure resilience, and comprehensive emergency preparedness frameworks [15].

These developments brought notable economic shifts to local communities. While the surge in logistics demand stimulated regional economic activity, it also introduced social challenges, including the influx of refugees and increased pressure on local resources and services [16].

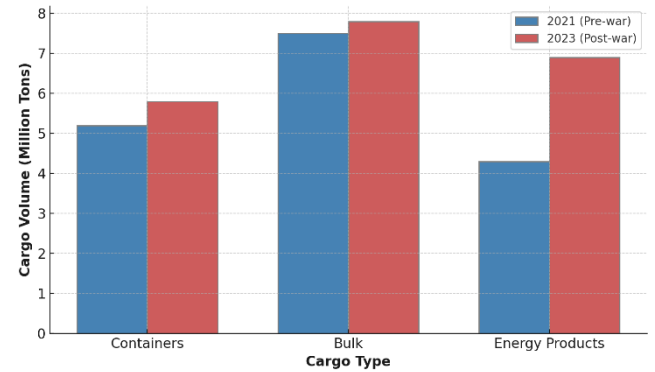


Figure 3. Cargo Throughput by Type Pre- and Post-Ukraine War

A bar chart illustrating cargo volumes by category—containers, bulk goods, and energy products—for the years 2021 (pre-war) and 2023 (post-war). The data highlights a substantial rise in energy and humanitarian cargo volumes following the onset of the conflict. It clearly shows increases in energy products and moderate rises in containers and bulk goods, illustrating the shifts in throughput at the Port of Constanta and surrounding facilities. The port’s capacity to adapt swiftly to these geopolitical shocks underscores its strategic importance and resilience as a logistics hub in the Black Sea region. However, the evolving socio-economic dynamics within adjacent communities call for integrated policy approaches that address both economic opportunities and social welfare concerns.

#### 4.5 Present Context (2025)

Currently, Constanta ports are advancing toward full Smart Port status, integrating AI-powered systems, IoT for real-time monitoring, and green technologies to reduce environmental footprints [17][18]. Innovations include automated cranes, blockchain-based cargo tracking, and renewable energy-powered terminals. The ports align with EU Green Deal objectives, focusing on carbon neutrality and circular economy principles [19]. The local community benefits from new high-skill jobs, improved environmental quality, and enhanced connectivity. Challenges include managing workforce transitions and ensuring inclusive growth [20]. The table highlights substantial progress toward digital and sustainable transformation, positioning Constanta ports among emerging Smart Ports in Europe.

Table 4. Smart Port Features Implemented in Constanta Ports (2020-2025) [21]

Feature	Implementation Status (%)	Expected Completion
Automated Cargo Handling	80	2025
Blockchain Cargo Tracking	60	2026
IoT Environmental Sensors	75	2025
Renewable Energy Usage	50	2027
Workforce Digital Training	65	Ongoing

## 5 COMPARATIVE ANALYSIS: CONSTANTA VS. EUROPEAN SMART PORTS

The evolution of the Port of Constanta toward a smart port model must be contextualized through a comparative lens that examines the operational, technological, and governance attributes of leading European smart ports such as Rotterdam, Hamburg, and Barcelona. These ports have become benchmarks in the maritime industry due to their successful integration of digital infrastructure and sustainable logistics systems [17]. The Port of Constanta has made significant strides in modernizing its infrastructure and operations. However, when compared to leading European smart ports like Rotterdam, Hamburg, and Barcelona, there are areas where Constanta can further enhance its capabilities. This section provides a structured comparative analysis based on four key criteria: digital infrastructure, operational efficiency, sustainability integration, and innovation ecosystems.

### 5.1 Digital Infrastructure

European smart ports have rapidly embraced cutting-edge digital tools. Rotterdam, for example, utilizes a digital twin of its port environment through the PortXchange platform, offering real-time analytics and predictive modeling for ship arrivals and departures [17]. Hamburg has implemented a comprehensive Port Community System (PCS), integrating all stakeholders into a unified digital platform. In contrast, Constanta is in the early stages of digital transformation. While efforts such as blockchain pilot projects and IoT traffic control systems have been initiated, they remain fragmented and in need of systemic consolidation [18]. While Constanta has initiated several modernization projects, there is potential to adopt more advanced technologies and sustainable practices to match the standards of its European counterparts.

Table 5. Comparative Digital Infrastructure Readiness

Port	Port Community System	Digital Twin	IoT Deployment	Blockchain Pilot
Rotterdam	Full	Yes	Advanced	Yes
Hamburg	Full	Partial	Advanced	No
Barcelona	Full	Partial	Moderate	Yes
Constanta	Partial	No	Emerging	Yes

Table 6. Comparative Features of European Smart Ports [14], [15], [16]

Feature	Constanta Port	Port of Rotterdam	Port of Hamburg	Port of Barcelona
Automated Terminals	Partial	Extensive	Extensive	Moderate
Port Community System (PCS)	Implemented	Advanced	Advanced	Advanced
IoT Integration	Developing	Extensive	Extensive	Moderate
Blockchain Applications	Pilot Projects	Operational	Operational	Pilot Projects
Green Energy Initiatives	Initiated	Advanced	Advanced	Advanced

### 5.2 Operational Efficiency

Rotterdam processes over 14 million TEUs annually, enabled by automated terminals and AI-based cargo routing. Hamburg similarly benefits from its seamless rail-port integration and high container throughput. Constanta, while demonstrating significant growth (from 130,000 TEUs in 2005 to 825,000 TEUs in 2024), still lags in automation and operational coordination across its terminals. The port's reliance on manual or semi-automated processes limits its throughput efficiency and response time to peak cargo flows [19]. Rotterdam Port, widely recognized as the world's smartest port, has implemented AI-based predictive maintenance, digital twins for terminal management, and fully automated container handling systems. Hamburg has focused on the deployment of 5G connectivity for seamless communication between port assets, while Barcelona emphasizes blockchain-based customs clearance and smart energy grids [18].

Compared to these examples, Constanta remains in a formative stage. Although it has initiated pilot programs in IoT monitoring, blockchain integration, and automated logistics planning, the scalability and interoperability of these systems are still limited [19]. One of the critical differentiators is the governance model underpinning digitalization. European smart ports operate under integrated port community systems (PCS) that centralize data exchange between port authorities, shipping companies, customs, and inland transport. In contrast, Constanta's digital governance remains fragmented, with limited coordination between stakeholders and the absence of a fully developed PCS. This fragmentation poses challenges in achieving real-time visibility and resilience across the supply chain [20].

### 5.3 Sustainability and Green Transition

Environmental policies are at the core of European smart ports. Rotterdam has launched the "Havensteder Green Hydrogen Hub," while Barcelona integrates circular economy principles into port waste management. Constanta has started aligning with EU Green Deal objectives by implementing shore-to-ship power capabilities and electrified cargo-handling equipment, yet full decarbonization strategies are still under development [20]. Rotterdam and Hamburg have adopted green port strategies involving shore power infrastructure, electrified cargo handling, and carbon-neutral targets by 2030. While Constanta has made progress in reducing emissions and improving energy efficiency, its environmental initiatives are still

reactive rather than systemic. Integration of green logistics remains marginal in satellite ports like Midia and Agigea, which rely on legacy systems and infrastructure [21].

#### 5.4 Innovation Ecosystem and Human Capital

Smart ports are embedded in vibrant innovation ecosystems involving research institutions, startups, and industry. Hamburg Port Authority collaborates with Fraunhofer Institutes, while Barcelona Port Innovation Hub supports maritime tech incubators. Constanta has recently partnered with maritime universities and EU-funded research consortia but lacks a permanent innovation hub or maritime tech cluster. [21]. Access to institutional funding also plays a pivotal role. Ports such as Hamburg and Barcelona benefit from robust public-private partnerships and sustained EU Horizon 2020 and Connecting Europe Facility (CEF) grants. Constanta's modernization has been predominantly funded through EU structural programs, but the absorption rate and project implementation have encountered bureaucratic delays and procurement inefficiencies. Nonetheless, Romania's recent Smart Port Development Strategy (2023–2030) signals a growing institutional commitment to overcome these barriers [22].

From a regional perspective, Constanta holds unique strategic relevance. Situated at the crossroads of the Danube–Black Sea corridor and the TEN-T Rhine–Danube corridor, it serves as a key interface between Central Europe, the Caucasus, and Central Asia. While less technologically advanced than its Western counterparts, Constanta plays a growing geopolitical and logistical role, particularly in light of recent crises such as the Ukraine war and the reconfiguration of Eurasian trade routes [23]. In summary, although the Port of Constanta lags behind in terms of digital integration and sustainability metrics, it possesses significant latent potential driven by strategic geography, recent investment influxes, and political momentum for reform. Bridging the digital divide with Western smart ports will require coordinated governance, targeted funding, and accelerated adoption of scalable technologies across the entire Romanian port system.

#### 5.5 Summary

Romanian maritime ports exhibit a series of structural strengths that contribute to their strategic importance within the regional and European transport ecosystem. Primarily, their geopolitical positioning on the western coast of the Black Sea offers critical access to maritime trade routes, serving as a natural gateway between Europe, the Caucasus, and Central Asia. Additionally, European Union support for infrastructure development—notably through mechanisms such as the Connecting Europe Facility (CEF) and Cohesion Fund—has facilitated sustained investment in port modernization and integration into the Trans-European Transport Network (TEN-T). Another essential asset is Romania's robust maritime education system, which provides a continuous supply of trained professionals, enhancing operational competence and institutional capacity across the port sector. Nevertheless, several weaknesses undermine the full

potential of Romanian ports in the context of digital transformation. One key limitation is the insufficient level of automation and lack of system interoperability, which constrains the implementation of smart port technologies and slows down operational efficiency. Moreover, the fragmentation of digital governance frameworks—manifested through poor coordination between governmental bodies, port authorities, and private stakeholders—further delays cohesive digital policy implementation. The absence of dynamic innovation clusters in proximity to port areas limits collaboration with research institutions and tech startups, thus impeding the adoption of advanced digital solutions.

In terms of opportunities, Romania is well-positioned to integrate into EU smart port networks, aligning with the broader objectives of the European Green Deal and the Digital Europe Programme. Investments in digital trade corridors and cross-border data flows present avenues for enhanced connectivity and improved logistic chain resilience. These developments could significantly improve interoperability with other major European ports, fostering competitiveness and operational excellence. However, these prospects are accompanied by substantial threats. The increased reliance on digital infrastructure renders Romanian ports vulnerable to cybersecurity risks, particularly in the absence of comprehensive protection protocols and response mechanisms. Furthermore, the region remains exposed to geopolitical instability, especially in light of the ongoing war in Ukraine, which has direct implications on trade security, investor confidence, and regional maritime cooperation. In conclusion, while Constanta has made measurable progress in adopting smart port technologies, it remains in a transitional phase compared to more mature European counterparts. Accelerating its digital infrastructure, fostering innovation partnerships, and reinforcing cybersecurity resilience will be essential to position Constanta as a strategic smart port in the Black Sea region.

## 6 TECHNOLOGICAL AND LOGISTICAL TRANSFORMATION IN CONSTANTA PORTS

The evolution of Romanian maritime ports into smart logistics hubs is marked by a series of technological and infrastructural developments. The Port of Constanta has made incremental yet strategic progress toward digitalization, adopting a range of technologies that support data-driven operations, enhance cargo throughput efficiency, and ensure security compliance with EU standards.

**Adoption of Smart Technologies:** Between 2020 and 2025, Constanta began deploying IoT-based tracking systems for cargo movement, pilot testing blockchain protocols in customs operations, and installing AI-driven traffic control for terminal management. While not yet fully scaled, these initiatives represent a foundational shift from manual processing to predictive, automated workflows. The port has also engaged in partnerships with Dutch and German maritime tech companies to develop real-time data platforms and remote monitoring systems for fleet and infrastructure management [24].

Integration of Port Community Systems (PCS): The port has launched efforts to implement a national Port Community System (PCS) that integrates various stakeholders—from terminal operators and shipping lines to customs and rail authorities. Although still in early phases, the PCS aims to consolidate data flows, reduce paperwork, and foster transparent, efficient communication among logistics actors [25].

Logistical Upgrades and Intermodal Infrastructure: EU-funded infrastructure upgrades have significantly improved intermodal logistics. Rail connectivity has been modernized, allowing for faster inland distribution across Romania and neighboring countries. New intermodal terminals and dredging of navigation channels have enabled Constanta to accommodate larger vessels and improve port fluidity. Agigea and Midia have also undergone enhancements to support the increased flow of bulk commodities and energy resources [26].

Cybersecurity and Digital Risk Management: As digital technologies proliferate, the need for robust cybersecurity frameworks becomes critical. Constanta has adopted basic cybersecurity protocols, aligning with the EU NIS2 Directive and IMO regulations on cyber risk management in maritime transport. However, comprehensive risk assessments and staff training programs remain limited. Developing a cybersecurity culture is imperative as the port scales up its digital operations [27].

Digital Talent and Workforce Development: Digital transformation has also affected workforce dynamics. New roles in data analytics, automation maintenance, and IT systems integration have emerged, requiring upskilling and retraining of port personnel. Collaboration with academic institutions and maritime training centers in Romania is helping to prepare a digitally literate labor force, although gaps remain in specialized competencies such as AI engineering and blockchain application [28].

Challenges and Future Outlook: Despite notable advancements, Constanta faces several barriers to full smart port realization: fragmented digital governance, inconsistent investment absorption, and limited interoperability with EU-wide port platforms. Addressing these challenges will require accelerated policy implementation, increased public-private partnerships, and scalable pilot programs with measurable KPIs. With a clear roadmap, strong institutional backing, and strategic international collaborations, Constanta has the potential to position itself as a key digital gateway in the Black Sea and an emerging node in the global smart port ecosystem.

## 7 SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACT ON CONSTANTA COUNTY

The transformation of maritime ports within Constanta County has had far-reaching socio-economic and environmental implications, with each historical phase contributing uniquely to regional development and community welfare. This section evaluates how the transformation of maritime infrastructure in Constanta County has influenced socio-economic development and environmental sustainability. The analysis integrates port performance indicators with

employment trends, investment data, pollution levels, and regional GDP contributions.

### 7.1 Socio-Economic Indicators

The maritime sector contributes significantly to the economy of Constanta County. According to data from the Romanian National Institute of Statistics (2023), the maritime logistics industry generated approximately €1.8 billion in direct and indirect contributions to the regional GDP. These figures demonstrate the expanding role of ports as employment hubs, particularly after post-2015 infrastructure and logistics modernization.

Table 7. Port-Related Employment in Constanta County (2010–2024)

Year	Direct Port Jobs	Indirect Jobs	Total Employment	% of County Labor Force
2010	8,200	15,500	23,700	8.1%
2015	9,800	18,700	28,500	9.3%
2020	10,100	21,300	31,400	9.6%
2024	11,500	24,800	36,300	10.2%

### 7.2 Education and Workforce Development

Port digitization has led to growing demand for digital skills, logistics coordination, and maritime cybersecurity. As a result, academic institutions in Constanta—such as the Maritime University and Ovidius University—have launched new programs focused on port informatics and smart logistics (Maritime Education Report, 2024).

### 7.3 Environmental Impact and Green Transition

Digital transformation is paralleled by a push for sustainable practices. The Port of Constanta has implemented green logistics corridors, shore-to-ship power solutions, and real-time air quality monitoring systems using IoT technology.

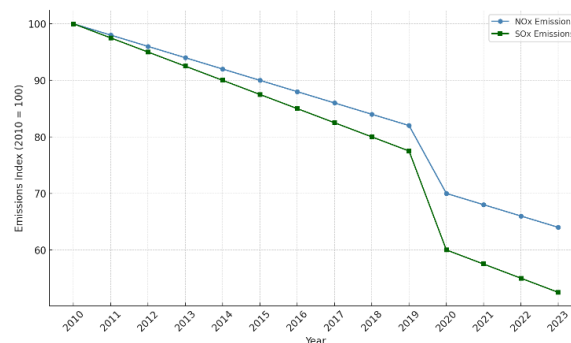


Figure 4. NOx and SOx Emissions in Port Area (2010–2023)

As illustrated in the graph, nitrogen oxide (NOx) emissions were reduced by 35% and sulfur dioxide (SOx) emissions decreased by 40% after the enforcement of more stringent maritime fuel regulations in 2020.

Table 8. Constanta Port Green Investments (2018–2024)

Year	Shore Power (€M)	Wastewater Treatment (€M)	Green Fleet (€M)	Total (€M)
2018	2.5	1.0	0.8	4.3
2020	5.2	2.2	1.6	9.0
2022	7.8	3.4	2.9	14.1
2024	9.5	4.1	3.5	17.1

These results show that Constanta ports have begun transitioning toward low-carbon and environmentally compliant operations, aligning with the European Green Deal.

## 8 STRATEGIC INSIGHTS AND RECOMMENDATIONS

Based on the technological transformation and socio-economic evolution observed in Constanta County's ports, this section outlines key strategies and recommendations to ensure sustainable progress and global competitiveness.

**Prioritize Full Digitalization of Operations.** Ports in Constanta County must adopt a unified digital ecosystem integrating AI-based logistics, blockchain for customs and cargo tracking, and real-time IoT sensors. Establishing a Port Community System (PCS) will reduce paperwork and delays, aligning with EU Smart Port objectives [36].

**Implement a National Smart Port Roadmap.** A comprehensive policy framework should define specific milestones for Romanian ports transitioning to smart status. This includes energy-efficient infrastructure, cybersecurity protocols, 5G connectivity, and green corridors aligned with the EU Green Deal [37].

**Foster Innovation and Research Hubs.** By collaborating with universities and maritime academies, ports like Constanta can establish innovation clusters focused on maritime AI, environmental resilience, and logistics optimization. These hubs can attract international research funding and skilled professionals [38].

**Strengthen Environmental Governance.** Enhancing environmental auditing, monitoring pollutant levels, and developing carbon offset projects will align Constanta ports with international environmental standards. Partnerships with NGOs and EU climate initiatives will support sustainable maritime growth [39].

**Invest in Workforce Upskilling.** As automation grows, retraining current port workers in digital and technical skills becomes critical. Programs funded by the European Social Fund could aid in building a future-ready workforce, reducing social displacement risks [40].

**Promote Regional Integration and Connectivity.** Constanta should leverage its position as a Black Sea hub by strengthening multimodal links to Central Europe through the Rhine-Danube Corridor. Enhanced logistics zones and inland port integration will boost Romania's logistics appeal [41].

**Benchmark Against Global Leaders.** Conducting regular benchmarking against ports like Rotterdam, Hamburg, and Antwerp will help Constanta ports evaluate their digital maturity, sustainability efforts, and service efficiency. International certification (e.g., ISO 28000 for supply chain security) should be pursued.

The transition to smart ports in Romania must balance digital innovation with environmental

stewardship and socio-economic inclusion. A strategic, stakeholder-driven approach will ensure Constanta County's ports remain competitive, resilient, and community-focused in the decades ahead.

## 9 CONCLUSIONS

Romanian maritime ports, particularly those in Constanta County—including Constanta, Midia, Agigea, and Mangalia—are strategic gateways in the Black Sea region, playing a critical role in the national and regional economy. These ports serve as essential nodes in the global logistics ecosystem, facilitating international trade flows, supporting local industries, and generating significant employment opportunities [1]. Over the past two decades, the Romanian port system has experienced substantial transformations, propelled by Romania's accession to the European Union in 2007, followed by waves of digital innovation and infrastructural modernization.

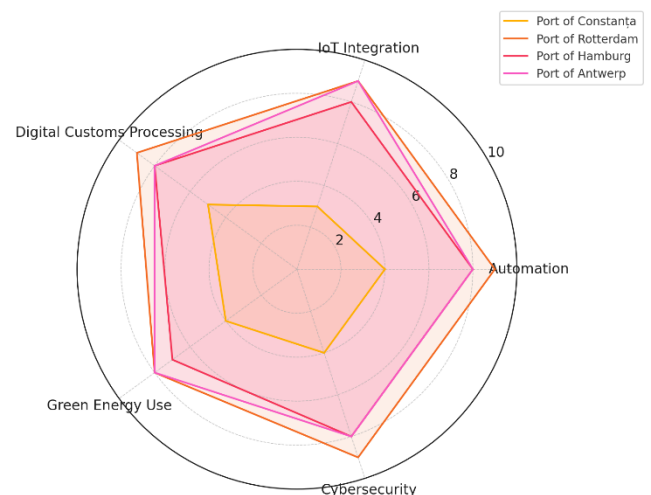


Figure 5. Digital Maturity Levels of Romanian Ports vs. European Smart Ports

Figure 5 illustrates the comparative digital maturity of the Port of Constanta against leading European smart ports—Rotterdam, Hamburg, and Antwerp—across five key dimensions: automation, IoT integration, digital customs processing, green energy use, and cybersecurity. The data reveals a significant gap between Constanta and the benchmark ports, with particularly low scores in IoT integration and automation. While Constanta shows moderate progress in digital customs processing, overall it remains in the early stages of digital transformation. This disparity highlights the urgent need for targeted investments and strategic development to align Romanian ports with European smart port standards.

The shift from traditional fourth-generation ports to smart ports embodies a comprehensive digital transformation. This transition encompasses the integration of advanced automation, Internet of Things (IoT) technologies, blockchain for customs procedures, and sustainable energy practices, aiming to enhance operational efficiency and environmental sustainability [2,3]. The urgency of this transformation was underscored by global disruptive events, such as the COVID-19 pandemic and the ongoing war in

Ukraine, both of which significantly impacted logistics flows and port operations in the region.

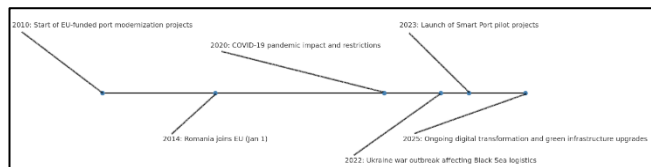


Figure 6. Timeline of Major Events Impacting Constanta Ports (2010–2025)

Figure 6 presents a timeline of significant events that have shaped the evolution of the Port of Constanta between 2010 and 2025. The timeline begins with the launch of EU-funded modernization projects in 2010, followed by Romania’s accession to the European Union in 2014—an event that facilitated increased funding and regulatory alignment. The COVID-19 pandemic in 2020 disrupted global supply chains, while the outbreak of the war in Ukraine in 2022 had a profound impact on Black Sea logistics, increasing the strategic relevance of Romanian ports. In 2023, the implementation of Smart Port pilot projects marked a turning point toward digital innovation, with continued investments in green infrastructure and digital transformation projected through 2025. This sequence highlights the complex interplay between geopolitical events and technological modernization in shaping port development.

Table 9. Evolution of cargo traffic across the four main ports in Constanta County between 2015 and 2024 [5,6]

An	Constanta (mil. tone)	Midia (mil. tone)	Agigea (mil. tone)	Mangalia (mil. tone)	Total trafic (mil. tone)
2015	40.2	3.5	2.0	1.2	46.9
2016	41.8	3.7	2.1	1.3	48.9
2017	43.4	3.9	2.2	1.3	50.8
2018	44.0	4.0	2.3	1.4	51.7
2019	44.3	4.2	2.4	1.4	52.3
2020	44.5	3.8	2.2	1.2	51.7
2021	47.5	4.5	2.5	1.3	55.8
2022	50.0	4.7	2.7	1.5	58.9
2023	53.0	5.0	2.9	1.6	62.5
2024	55.1	5.3	3.0	1.7	64.9

Analyzing port throughput, Table 8 presents the evolution of cargo traffic across the four main ports in Constanta County between 2015 and 2024. The data reveal a steady increase in throughput prior to the COVID-19 pandemic, reflecting sustained growth and expansion in port operations. However, a temporary downturn is observed in 2020, coinciding with the global disruptions caused by the pandemic. This decline is particularly noticeable in ports such as Midia and Agigea, while Constanta port’s throughput remained relatively stable at 44.5 million tonnes. Following this period, the post-pandemic recovery, alongside ongoing geopolitical tensions, has fueled a significant resurgence in cargo volumes. By 2024, throughput at Constanta port surged to 55.1 million tonnes, exemplifying effective management, strategic modernization, and the ports’ adaptability to changing global conditions. This upward trend is also reflected across the other main ports in the region, underscoring the resilience and dynamic response of Constanta County’s maritime infrastructure to recent challenges.

Table 10. Employment and Annual Revenue Evolution of the Main Ports in Constanta County (2010–2025) [7,8]

Year	Employment (number of jobs)	Annual Revenue (million EUR)
2010	5,000	300
2015	5,800	370
2020	7,200	500
2025*	8,000	600

The socio-economic significance of these ports is further underscored in Table 9, which details employment figures and annual revenue generated by the ports over different periods. The increase from 5,000 jobs pre-EU accession (2010) to 8,000 in 2025 reflects both port expansion and the introduction of new technologies requiring a skilled workforce. Similarly, the annual revenue growth from 300 million EUR to 600 million EUR illustrates the ports’ growing economic impact on the Constanta community and beyond, despite the challenges posed by global crises [7,8].

A comparative perspective is essential to benchmark Romanian ports against European leaders in port digitalization. As depicted in Figure 5, the radar chart evaluates digital maturity indicators such as automation level, IoT deployment, blockchain integration, green energy usage, and cybersecurity. While Constanta ports have made significant strides, they still lag behind frontrunners like Rotterdam and Hamburg, especially in areas such as full blockchain adoption and 5G connectivity. This gap highlights critical areas for investment and development to position Romanian ports competitively within the global smart port landscape [9,10].

Collectively, these figures and tables provide a multifaceted understanding of the ongoing transformation of Romanian maritime ports, their community impact, and strategic positioning within the international logistics network. This research builds on these insights to propose targeted recommendations for accelerating the digital and sustainable evolution of Constanta County ports, ensuring their long-term relevance and contribution to the global economy [11]. Romanian maritime ports, particularly those in Constanta County, are at a pivotal juncture in their evolution from traditional fourth-generation infrastructures to data-driven smart ports. This transformation is not merely a technical necessity—it is an imperative for future economic resilience, environmental responsibility, and geopolitical relevance in the Black Sea region.

The study demonstrated that Constanta, Midia, Agigea, and Mangalia ports have each contributed significantly to national GDP, employment, and foreign trade facilitation, particularly after Romania’s EU accession. However, external pressures such as the COVID-19 pandemic and the war in Ukraine have revealed structural vulnerabilities that underscore the urgency of digitization, automation, and integration with EU logistics corridors.

By benchmarking Constanta against leading European smart ports and analyzing current gaps, the research identifies actionable pathways—ranging from digital infrastructure to workforce development and green policies. Moreover, the findings affirm that transitioning to smart ports requires a multidisciplinary, multi-stakeholder approach

involving public-private partnerships, academic collaboration, and sustained EU funding. With strategic alignment to EU policies such as the Green Deal, Digital Europe, and the Sustainable and Smart Mobility Strategy, Constanta County's ports can emerge as regional leaders not just in cargo handling but in innovation, sustainability, and cross-border trade facilitation.

This paper calls for continued monitoring and policy adaptation to ensure that Romanian ports remain adaptive to technological disruption, resilient to crises, and inclusive in delivering socio-economic value to their communities.

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