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Diego Rossit
Pedro Moreno-Bernal
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Chapter 26

Policies Towards Zero-Emission Maritime Port Infrastructure and Buildings



Carmen Luisa Vázquez , Rodrigo Ramírez-Pisco, Luís Manuel Navas, and Teresa Batista

Abstract This article synthesizes the regulatory frameworks and public policies aimed at achieving carbon neutrality in maritime port infrastructure and buildings. It focuses on a wide range of port facilities—including cargo and passenger terminals, warehouses, administrative offices, passenger stations, maintenance workshops, fire stations, control centers, fishing and recreational terminals, and auxiliary installations. Although these structures contribute a relatively small share of total maritime emissions, they are subject to an increasingly robust set of international and regional regulations. The analysis spans from the decarbonization strategies promoted by the International Maritime Organization to the European Union’s legislative efforts targeting zero-emission maritime port infrastructure and buildings by 2050. The study highlights how these policies not only address carbon neutrality but also promote resilience and sustainability within port ecosystems, positioning port infrastructure as a key component in the broader energy transition.

Keywords Carbon neutrality · Maritime port infrastructure and buildings · Zero-emission

C. L. Vázquez (✉) · T. Batista
Universidade de Évora, Évora, Portugal
e-mail: carmen.vasquez@uevora.pt

C. L. Vázquez · R. Ramírez-Pisco · L. M. Navas · T. Batista
Tecnologías habilitadoras para edificaciones casi cero en Iberoamérica (TRAPECIO), Málaga, Spain

R. Ramírez-Pisco
Universitat Carlemany, Andorra, Andorra

L. M. Navas
Universidad de Valladolid, Valladolid, Spain

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411

26.1 Introduction

Various international organizations, including the International Maritime Organization (IMO) [1], the European Union (EU) [2], and multilateral alliances [3], have established regulatory and strategic frameworks to accelerate the decarbonization of the maritime sector, an essential component in the global fight against climate change. This transformation not only encompasses maritime or land transport but also Port Infrastructure and Buildings (PIB), which must transition towards zero-emission models by 2050 [4].

Although these policies are ambitious and interconnected, the path toward a carbon-neutral port ecosystem faces significant challenges [5]. The success of this transition will depend on an interdisciplinary approach that strategically aligns regulatory mandates, financial incentives, and technological innovation. The EU's strategy of linking its Emissions Trading System (ETS) with a specific innovation fund represents a complex financial model [2], which seeks to reinvest the fees imposed on emission contributors into the development of low-carbon technologies.

The IMO has set global goals to achieve carbon neutrality in international maritime transport by 2050, which requires ports to adapt their facilities to receive and operate with clean fuels and sustainable technologies [1]. Furthermore, the report highlights the role of Public–Private Partnerships (PPP), especially within the model of conceding the administration of port terminals, to leverage private sector expertise [6]. Finally, the emergence of the so-called Green Shipping Corridors [7] is presented as a model for ecosystem-wide collaboration, demonstrating that the transition towards climate neutrality requires a coordinated effort across the entire logistics chain rather than a series of isolated projects [8].

In the context of the energy transition and decarbonization of the maritime sector, PIB cannot remain on the sidelines. PIB are essential for the operational, logistical, and administrative functioning of ports and are subject to review and transformation under sustainability criteria [6]. Both the EU [2] and the IMO [1] have driven strategies that, directly or indirectly, mandate that constructions in port areas be carbon neutral, incorporating clean technologies, improving their energy efficiency, and adapting to new climate resilience standards.

As facilities located in coastal environments, PIB must cope with extreme conditions such as constant humidity, air salinity, and material corrosion, which represents an additional technical challenge for achieving carbon neutrality [9]. From cargo terminals to control centers and service stations, each must transition towards solutions that combine sustainability with resistance in vulnerable marine areas [10].

PIB are constructed within the jurisdictional boundaries of a maritime port, designed to support and facilitate the logistical, commercial, administrative, and service operations carried out there. These include cargo and passenger terminals, warehouses, customs control offices, port management centers, maintenance workshops, surveillance stations, and other technical or auxiliary facilities. In addition to their operational function, these buildings must meet criteria for safety, energy

efficiency, and sustainability, especially in the current context of transition toward greener and more resilient ports against climate change [11, 12].

The decarbonization of maritime ports demands the rigorous integration of policies and guidelines, a fundamental task for promoting the structural transformation of the sector in the face of climate neutrality imperatives. However, current scientific literature shows a clear fragmentation in the analysis of this normative integration [13, 14], which prevents the formulation of coherent and replicable strategies. This gap is exacerbated by the fact that the implementation of regulations for net zero buildings faces significant challenges in technological and normative integration [15], and that international maritime sector guidelines have yet to be translated into specific and applicable frameworks for PIB [16, 17]. Furthermore, although technical and operational advances are reported, the absence of holistic analytical frameworks that articulate the political, economic, and technological dimensions limits the effectiveness of actions, as most studies focus on isolated initiatives without offering a vision of how decarbonization policies interact with port planning, investment, and governance [6]. Therefore, this study contributes to consolidating the dispersed knowledge, offering a more solid and replicable theoretical and regulatory basis, which is essential for guiding strategic decisions and accelerating the transition towards sustainable ports.

This article synthesizes the regulatory frameworks and public policies aimed at achieving carbon neutrality in maritime PIB. It focuses on a wide range of port facilities—including cargo and passenger terminals, warehouses, administrative offices, passenger stations, maintenance workshops, fire stations, control centers, fishing and recreational terminals, and auxiliary installations.

26.2 Methodologic

The sustainability of maritime ports, particularly concerning regulatory frameworks for carbon-neutral PIB, constitutes an emerging field that requires being addressed through semi-systematic reviews. This type of review combines the methodological rigor of systematic reviews with the interpretive flexibility of narrative reviews, allowing for the analysis of not only the available empirical evidence but also the normative, political, and technological context surrounding the phenomenon. Unlike purely systematic reviews, semi-systematic reviews enable the integration of qualitative studies, public policy documents, grey literature, and diverse theoretical frameworks, which is essential for complex and multidimensional topics such as port decarbonization. The steps include:

1. Selection of Diverse Sources. This includes scientific articles, grey literature (technical reports, institutional documents), regulatory frameworks, and case studies. It is not limited to traditional academic databases but incorporates sources such as reports from the IMO, the EU, the Global Maritime Forum (GMF), etc.

2. Interpretive Analysis. A critical and comparative reading of the sources is performed, identifying convergences, gaps, tensions, and contradictions between policies and practices.
3. Structured Narrative Synthesis. A narrative is constructed that articulates the findings around the defined themes, without aiming for statistical exhaustiveness, but rather for analytical depth.

26.3 Result and Analysis

The main focus of this research is not centered on the vulnerability and adaptation of PIB to climate change. However, it is crucial to expose the critical impact elements identified in the literature. These findings underscore the urgency of ensuring the structural and operational resilience of ports, validate the pressure to transform PIB, and reinforce the importance of decarbonization, as the new buildings and facilities designed for carbon neutrality must be inherently robust and adapted to these concurrent climate threats.

PIB faces critical threats due to changes in climate patterns, which directly impact both the main structures and operations. Sea Level Rise (SLR) and coastal flooding are the most significant risks, as they compromise the functionality of cargo and passenger terminals by inundating docks, reducing vertical clearance beneath platforms, and causing structural failures in foundations due to erosion [18, 19]. This threat is compounded by the increase in wave intensity and storm surge, which accelerates erosion beneath structures and causes failures in coastal defenses (breakwaters and jetties), leading to operational closures. Furthermore, extreme weather events affect terrestrial structures and internal functionality. Cyclones and strong winds cause structural damage to auxiliary buildings (warehouses, offices) and interrupt essential services such as electricity and telecommunications, a risk addressed by [19, 20]. Thermal stress harms control stations and workshops by affecting the performance of electronic equipment (HVAC) and staff health. At the subterranean level, accelerated corrosion due to increased salinity and saline intrusion rapidly deteriorates pipes and cabling. Operationally, changes in navigation patterns induce maneuvering delays and require more frequent dredging. These multifaceted challenges compel ports to adopt vulnerability and resilience guidelines from organizations such as ECLAC [21, 22].

Port decarbonization presents a duality: although the majority of emissions come from terminal operations and machinery, the carbon neutrality strategy demands a transformation in land-based infrastructure. This shift is because ports are adopting a new strategic role as clean fuel hubs, which requires a massive investment in net zero facilities and buildings for storage, bunkering, and support. However, this cannot be limited to operational efficiency; it must include the integration of technological solutions and regulatory frameworks to ensure that this new supporting infrastructure is inherently carbon neutral, overcoming the current fragmentation between maritime transport regulations and those governing port facilities, as shown in Table 26.1.

Table 26.1 Key finding and argument

Year	Key finding and argument
2016	Provides the technical and design principles of port infrastructure, establishing the technical basis upon which future carbon-neutral guidelines must be applied (e.g., structural analysis of construction materials) [23]
2020	A Life Cycle Assessment (LCA) study reveals that 85% of emissions come from operational machinery, while construction materials for the infrastructure/buildings represent only 15% [24]
2023	Focuses on the new strategic role of ports as hubs for the production, import, and distribution of green hydrogen. This role requires massive investment in new facilities and buildings (electrolyzers, storage, bunkering) whose carbon footprint must be neutral, directly linking operations with infrastructure [25]
2023	Focuses on policies for the production of renewable marine fuels. The implementation of these policies fundamentally depends on port infrastructures (new tanks, pipelines, and processing/storage plants), demanding regulatory coordination between fuel and infrastructure [26]
2023	Reviews the use of green composites for maritime engineering. It is a key technological reference that offers material solutions (alternative to cement and steel) to reduce the carbon footprint in the construction of port infrastructure and buildings [27]
2025	As a bibliometric analysis, it evidences a growing, yet still fragmented, academic attention to climate neutrality strategies in the shipping sector. It suggests a misalignment between the urgency of decarbonizing maritime transport (shipping) and the specific implementation of regulations for the land-based infrastructure that supports it (ports) [16]
2025	Results show that more than 99% of the port's total energy consumption and carbon footprint is due to terminal operations and activities. The focus on emission reduction is heavily directed towards these operations, leaving the building component as marginal in the total [28]
2025	Addresses comprehensive strategies for sustainable port development. It recognizes that environmental resilience requires not only operational improvements but also investment in green infrastructure and low-impact building design, expanding the focus beyond Scope 1 and 2 [11]
2025	Analyzes the literature on green corridors, highlighting the need for collaboration among stakeholders and political alignment. Implicitly, green corridors require terminal ports to not only manage clean operations but also have net zero supporting infrastructure and buildings [8]
2025	Highlights that most research focuses on isolated initiatives or case studies, without offering a holistic view of how decarbonization policies interact with port planning. It underscores the need for analytical frameworks that articulate the operational, technological, and regulatory dimensions [6]

Table 26.2 synthesizes the conceptual framework and thematic axes that guide the analysis of port decarbonization policies and regulations. These thematic categories encompass everything from international regulatory frameworks and technological solutions for new fuels and automation, to governance models and green financing mechanisms. In particular, the regulatory separation between traditional port infrastructure and the Zero Emission Buildings (ZEB) category is highlighted, illustrating

Table 26.2 Thematic category

Thematic category	Includes
International and regional regulatory frameworks	• IMO Strategies [1], FuelEU Maritime [29], Maritime ETS [30], AFIR [31], National Legislation, and their alignment • Renewable Energy Directive (RED III) [32], Green Shipping Corridor MoU [33]
Port infrastructure and energy transition	• Terminal electrification, OPS (Onshore Power Supply), renewable energy, resilient design in marine environments • H₂/NH₃/Methanol supply and storage, Cold Ironing, adapting berths for new LNG/Hydrogen carriers, Port Smart Grids
Governance and management models	• PPP (Public–Private Partnerships), landlord port model, interinstitutional coordination, collaborative governance • Unified Port Authority (One-Stop-Shop), Port–City coordination mechanisms, Green Concessions, environmental performance clauses in contracts [34]
Green shipping corridors and ecosystem collaboration	• Green Shipping Corridors, integration of logistics actors, intersectoral synergies • Fuel value chains (from production to consumption), Shore-to-Ship collaboration, joint financing models for infrastructure, Digital Twin for bunkering optimization
Green financing and incentive mechanisms	• Green taxonomy, Poseidon Principles, innovation funds, mitigation of financial risks • Green Bonds, Sustainability-Linked Loans (SLLs), eco-friendly port fee discounts, Maritime Compensation Funds (e.g., IMO Fund)
Indicators, monitoring, and reporting	• CII (Carbon Intensity Indicator), EEXI (Energy Efficiency Existing Ship Index), SEEMP (Ship Energy Efficiency Management Plan), MRV (Monitoring, Reporting, Verification), transparency in emissions and environmental performance • Emission Scopes (Scope 1, 2, 3), Embodied Carbon of Buildings, Terminal Performance Metrics (TPM), ISO 50001 Certification (Energy Management) [35]

(continued)

Table 26.2 (continued)

Thematic category	Includes
Technological innovation and operational adaptation	• New fuels (H₂, NH₃, methanol), automation, digitalization, carbon capture (CCUS) • Smart Charging of batteries, Just-In-Time (JIT) operations, Port Energy Management Systems (EMS), carbon capture in both ships and onshore facilities
Zero-emission building regulatory framework	• EPBD (Energy Performance of Buildings Directive), ZEB (Zero Emission Building) standards, Nearly Zero-Energy Buildings (NZEB), Green building certifications (e.g., LEED, BREEAM) [36–39] • Net-Zero Energy/Carbon Standards, Embodied Carbon Requirements, passive and active design guidelines for coastal environments, climate resilience and material efficiency standards

the need to integrate civil construction regulations (Net-Zero Building Standards) with the requirements for maritime facilities.

26.4 Conclusion

The regulatory fragmentation represents the most significant obstacle to the coherent implementation of Net Zero in PIB. Despite ambitious decarbonization strategies promoted by bodies like the IMO and the European Union, the analysis reveals a disconnection between maritime sector regulations and civil construction standards, such as the EPBD Directive. While maritime regulations focus on operational emissions (vessels and terminals), Zero-Emission Building (ZEB) standards are not adapted to the technical complexities and vulnerability of the port coastal environment. This lack of integration prevents the formulation of replicable strategies, demonstrating that the mere existence of global targets does not automatically translate into specific and applicable requirements for new infrastructure investment.

The new strategic role of ports as clean energy hubs mandates a re-evaluation of the importance of physical infrastructure in the energy transition. Although carbon footprint studies minimize the contribution of PIB to total emissions, the transition towards alternative fuels requires a massive investment in new Net Zero buildings and facilities for storage, processing, and bunkering. Therefore, the regulatory focus must expand: infrastructure ceases to be a marginal component and becomes a critical enabler. Policies must prioritize the integration of technological solutions and regulatory frameworks that ensure this supporting infrastructure is not only carbon neutral but also capable of sustaining the logistics of the new maritime energy matrix.

Finally, the PIB decarbonization strategy must be inseparable from climate change adaptation and resilience. The location of port facilities in high-risk compound areas

means that any new Net Zero investment that fails to incorporate resilience guidelines will result in vulnerable assets with a compromised lifespan. Consequently, port decarbonization policies must be conceived as dual-objective frameworks that ensure carbon neutrality (mitigation) and, simultaneously, structural resilience (adaptation). This guarantees that new constructions are durable and capable of maintaining operational continuity in the face of concurrent climate threats.

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