NOVA SCHOOL OF LAW

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SUSTAINABLE PORT STRATEGIES; THE ROLE OF INTERMODALITY

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Declaration of Originality

I, Laura Valladares Porrero, hereby declare that this dissertation is my own original work and has not been submitted in any form for a degree or diploma at any other university or institute of higher learning. All contributions and texts from other authors have been duly referenced and acknowledged, with a clear distinction made between my own work and the contributions of others. The information contained within this document is, to the best of my knowledge, accurate and true.

Laura Valladares Porrero

14 September 2025

Dedication and Acknowledgments

I would like to extend a word of thanks to everyone who supported and, in some way, helped me with my dissertation.

I first want to express my deepest gratitude to my family. Your support, help, and love have been so important during this and every other stage of my life.

To my dear Professor, Dr. Duarte Lynce de Faria, I am profoundly grateful. Your invaluable guidance on this master's dissertation was essential but, more importantly, I thank you for cultivating an interest in me that has now become the foundation of my professional career.

Finally, I would like to express my heartfelt gratitude to my beloved Jagger, who for the past twelve years has been my constant companion through every adventure and, in these final months, has sat with me through countless late-night study sessions after long workdays, giving me the love, comfort, and strength that made this thesis possible.

I dedicate this work to the loving memory of my grandparents, who continue to inspire me to put my best effort into everything I do and to work hard to achieve my dreams.

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- **Citation style:** All in-text citations follow the author-date system, indicating the author's last name and year of publication. For works by three or more authors, the first author's last name is followed by "et al.". The complete reference for each work is provided in the "Bibliography" section at the end of this dissertation.
- **Bibliography:** The bibliography is listed in alphabetical order by the last name of the first author. When a work has no author, it is listed alphabetically by its publishing organisation or authority.
- **Abbreviations:** All abbreviations used in this work are defined in the "List of abbreviations" section. Each abbreviation is defined the first time it is used in the text.
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- **Tables and figures:** All tables and figures are numbered consecutively and include a descriptive title. The source is referenced directly below the table or figure.

List of Abbreviations

AFIR: Alternative Fuels Infrastructure Regulation

APEC: Asia-Pacific Economic Cooperation

CO2: Carbon Dioxide

EEA: European Economic Area

EIA: Environmental Impact Assessment

ESPO: European Sea Ports Organisation

EU: European Union

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GPAS: Green Port Award System

GT: Gross Tonnage.

HGV: heavy goods vehicle

ICAO: International Civil Aviation Organisation

IEA: International Energy Agency

IMO Net-zero Framework (NZF)

IPCC: Intergovernmental Panel on Climate Change

ISO: International Organization for Standardisation

LNG: Liquefied Natural Gas

OPS: Onshore Power Supply

PERS: Port Environmental Review System

SDGs: Sustainable Development Goals

SDM: Self-Diagnosis Method

S.M.A.R.T: Specific, Measurable, Achievable, Relevant and Time-Bound

SWOT: analysis (of strengths, weaknesses, opportunities and threats)

UNCTAD: United Nations Conference on Trade and Development

UNEP: United Nations Environment Programme

Number of characters in the dissertation.

The body of this dissertation contains a total of 115,944 characters, including spaces and footnotes.

Abstract

This dissertation examines the landscape of sustainable strategies within the port sector, with a specific focus on the role of intermodality as a fundamental component of the industry's ecological transition. Far from being a mere logistical decision, intermodality is presented in this research as a crucial tool for achieving Europe's and, overall, global environmental sustainability targets, responding to an increasingly regulatory pressure and market demand for greener supply chains.

The present paper has employed a combination of desk research and qualitative research, as well as quantitative data analysis, to culminate in the development of three practical cases, empirically demonstrating the findings of this work. These three hubs, the Port of Rotterdam, Barcelona and Hamburg, all with different characteristics and particularities, demonstrate how ports in Europe are not only effectively deploying intermodal solutions to reduce their environmental footprint, but also relying upon them as a competitive and differentiating strategy to better position themselves in the market.

In this line, the optimisation of the logistical flows through intermodality, highlighting rail as a key sustainable mode given its reduced emission intensity, in detriment of road transport, far more polluting, has been proven to have a direct and significant effect in the decrease of emissions within the ports implementing it.

The Port of Hamburg stands as a paradigmatic case study, whose established position as Europe's largest rail port is a clear testimony of how a strategic and sustained focus on intermodality translates into a measurable mitigation of its environmental impact, while enhancing its competitiveness, its operational resilience and its ability to offer more reliable and efficient supply chains.

In conclusion, this work proves that intermodality is a necessary pillar in the ecological transition of ports. The findings suggest that continued investment in intermodal network development, supported by enhanced infrastructure and actor collaboration, will be crucial for ports to meet regulatory demands and position themselves as key agents in the fight against climate change.

Resumo

Esta dissertação examina o panorama das estratégias sustentáveis no setor portuário, com foco específico no papel da intermodalidade como componente fundamental da transição ecológica do setor. Longe de ser uma mera decisão logística, a intermodalidade é apresentada nesta investigação como um instrumento crucial para alcançar os objetivos de sustentabilidade ambiental da Europa e, de um modo geral, global, respondendo a uma pressão cada vez mais regulamentar e à procura do mercado por cadeias de abastecimento mais ecológicas.

O presente artigo utilizou uma combinação de pesquisa documental e pesquisa qualitativa, bem como análise quantitativa de dados, para culminar no desenvolvimento de três casos práticos, demonstrando empiricamente os resultados deste trabalho. Estes três hubs, o Porto de Roterdão, Barcelona e Hamburgo, todos com características e singularidades diferentes, demonstram como os portos na Europa não só estão a implementar eficazmente soluções de intermodalidade para reduzir a sua pegada ambiental, mas também a contar com ela como uma estratégia competitiva e diferenciadora para melhor se posicionarem no mercado.

Nesta linha, a otimização dos fluxos logísticos através da intermodalidade, destacando o ferroviário como um modo sustentável fundamental dada a sua reduzida intensidade de emissões, em detrimento do transporte rodoviário, muito mais poluente, tem demonstrado ter um efeito direto e significativo na diminuição das emissões dentro dos portos que o implementam.

O Porto de Hamburgo apresenta-se como um caso de estudo paradigmático, cuja posição consolidada como o maior porto ferroviário da Europa é um testemunho claro de como uma aposta estratégica e sustentada na intermodalidade se traduz numa mitigação mensurável do seu impacto ambiental, ao mesmo tempo que aumenta a sua competitividade, a sua resiliência operacional e a sua capacidade de oferecer cadeias de abastecimento mais fiáveis e eficientes.

Em conclusão, este trabalho comprova que a intermodalidade é um pilar necessário na transição ecológica dos portos. Os resultados sugerem que o investimento contínuo no desenvolvimento de redes intermodais, apoiado por infraestruturas

reforçadas e colaboração entre os intervenientes, será crucial para que os portos satisfaçam as exigências regulamentares e se posicionem como agentes-chave na luta contra as alterações climáticas.

1. Introduction

There exists another world beyond solid ground; a vast, fluid realm ruled by winds and tides, criss-crossed by an invisible web of sea lanes stretching across the globe. Along these water highways sail the carriers of global trade: shipping vessels that glide across oceans, maybe unnoticed by those who inhabit the land, yet indispensable, as they carry nothing less than the world.

Shipping has been a synonym of trade and development across history and, since the settlement of the early societies, ports have signified far more than harbours for vessels and goods, but the entrance door to commerce, becoming neuralgic centres of civil life, where different cultures merged and interacted. Their first establishment is greatly tied to the Mediterranean, tracing back to civilisations such as the Greeks, the Romans and even the Phoenicians. As studied by Princeton University, the Phoenicians's "little ports of the Bronze Age Levant", which included Tyre, Sidon, and Byblos, laid between the great empires of Egypt, Anatolia, and Mesopotamia, ferrying "goods and gifts along the coasts between them"[1].

Ever since then, most of the major cities around the world have built their identity around their access to water bodies and, in essence, the status of their ports, which then meant the firmest sign of a nation's prosperity. The port industry has evolved as humanity progressed, but the single most impactful milestone that has determined the shape of the current maritime trade industry is the "**containerisation**".

This event implied a complete revolution of shipping as it was known, entirely redefining the logic of maritime commerce by standardising the cargo handling with the introduction of the "container unit". Malcom Mclean, in 1956, launched the "world's first modern shipping container", designed to "be loaded onto trucks, ships, and trains with minimal handling", which allowed for "a seamless transition from land to sea to rail transport, significantly reducing the time and labour involved in cargo handling. By using

[1] Quinn, J. "All at sea: The maritime lives of the ancient Phoenicians". Princeton University Press. (2020). Available at: All at sea: The maritime lives of the ancient Phoenicians | Princeton University Press

these containers, McLean was able to streamline operations, reduce costs, and improve the security of the cargo during transit”[2].

In essence, containers converted ports from centres of cargo handling to complex and sophisticated logistics hubs, capable of levels of freight management without precedents, and propelling global commerce exponentially[3]. Nevertheless, this has not come without a cost. Nowadays, amid the climate crisis that the planet is facing, ports find themselves at a difficult crossroads. Even though vital to the global economy, these hubs also contribute significantly to the overall greenhouse gas emissions, polluting the air and negatively impacting the marine ecosystem.

However, modern ports are not only demonstrating a strong consciousness of their damaging consequences to the environment, but are positioning themselves as frontrunners in the transition, leading the way towards sustainability. Many are the innovative strategies currently being implemented, but a particular one demonstrates an only recently tapped potential to reduce emissions: **intermodality**. Just as Mclean’s container unit, intermodality targets the same objective: efficiency - though, in this case, from an environmental perspective.

In this light, the fundamental question for the future of global logistics now is this: could such a shift towards optimised intermodal networks mark the next great revolution in the shipping industry?

1.1. Objectives and Methodology of the Study

The objective of this paper is to analyse and evaluate the main sustainability strategies adopted in the port sector to reduce their environmental footprint, with a focus on the role of intermodality as a catalyst for port decarbonisation through operational efficiency. Specifically, it aims to examine how ports, as essential hubs in the global logistics chain, can leverage this strategy to achieve the wider international climate goals.

[2] Kely, C. “The History of Shipping Containers: From Inception to Global Trade Revolution”. (2024). The History of Shipping Containers: From Inception to Global Trade Revolution - National Self Storage
[3] Levinson, Marc. “*The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger - Second Edition with a New Chapter by the Author*”. REV-Revised, 2, Princeton University Press, 2016. *JSTOR*, https://doi.org/10.2307/j.ctvcszztg. Accessed 9 Sept. 2025.

Although the maritime sector has been progressively assimilating the international dynamics of environmental consciousness, adopting various sustainability-oriented measures, the relevance of this work lies in the fact that the role of intermodality as a key strategy within this process has so far received little attention or recognition in the specialised literature. However, its importance has been growing exponentially in recent years, driven by increasing regulatory pressure to move towards more sustainable and integrated transport systems.

This study addresses this issue in a critical and informed manner, specifically aiming to prove the consecutive hypothesis:

i. To identify and **evaluate which sustainable solutions are ports currently integrating within their infrastructures and operations**, highlighting best practices and challenges in their implementation.
ii. To assess **whether intermodality, in combination with other sustainable port strategies, can significantly contribute to the decarbonisation** goals set by international organisations and regional bodies, such as the International Maritime Organization (IMO) and the European Union.
iii. Ultimately, **leverage if intermodality effectively serves as a strategic tool for enhancing the sustainability** of port operations, having as a result optimised logistic flows, lesser greenhouse gas emissions and, overall, reduction of the environmental footprint of activities.

Three main methodological approaches have been followed in the development of this work:

- First, a **systematic review of existing academic literature on sustainable port strategies and intermodality** has been conducted, with particular focus on their environmental, economic, and logistical implications. This approach has helped to structure the theoretical framework and provide a formal basis for the analysis.
- Second, **policy documents and strategic communications** from relevant international and European institutions, such as the European Commission and the IMO, have been analysed to frame the issue within the context of current climate action efforts and regulatory developments.

- Finally, a **case study approach** has been selected to illustrate practical applications of intermodality in three major European ports: the Port of Rotterdam, the Port of Barcelona, and the Port of Hamburg. Official reports, port authority communications, and recent industry seminars and conferences have served as primary sources for this part of the analysis.

The research methodology employed in this study is primarily theoretical and deductive. The process commences with a comprehensive review of academic literature, regulatory frameworks, and industry reports to establish a robust theoretical foundation. Subsequently, a deductive approach is used to evaluate the central hypotheses by applying established concepts to specific contexts. To complement the theoretical analysis, the study incorporates empirical data from case studies of leading ports with different backgrounds. This multifaceted methodology design ensures that the conclusions are both theoretically substantiated and validated through practical examples.

Ports are recognised as key facilitators of global trade. However, their exposure as significant contributors to greenhouse gas emissions is dimming their positive impacts. As a result, they are under growing pressure to transition towards more sustainable models of operation.

The Environmental European Agency (EEA) and institutions such as the European Sea Ports Organisation (ESPO) have highlighted the urgent need for decarbonisation strategies targeting both shipping activities and port infrastructure. Decarbonisation of the transport sector has been, in fact, identified as one of the "most important factors that may contribute to reduce the carbon footprint..."[4]

While progress has been made in certain areas, including energy efficiency improvements and the adoption of renewable energies, the integration of intermodal transport solutions stands out as a particularly promising, yet scarcely developed and recognised, strategy until recent years.

Thus, evaluating the current state of intermodality and its potential to accelerate the ecological transition of ports is both timely and essential.

[4] Bielenia, M. et al., "Methodological Introduction to the Carbon Footprint Evaluation of Intermodal Transport," *Frontiers in Environmental Science* 11 (2023): 10.3389/fenvs.2023.1237763. [Frontiers | Methodological introduction to the carbon footprint evaluation of intermodal transport]

The international shipping industry is at the core of the global economy, solely responsible for the carriage of 90% of the goods entering world's trade[5], and, in the European Union, sea transportation accounted for 47% in 2023 of goods traded between the EU and the rest of the world; measured by volume, the share was 74%[6].

As of January 2023, the world's merchant fleet numbered over 105,500 ships of at least 100 gross tons, forming the backbone of international commerce, linking continents, fuelling economies, and shaping the modern world[7]. Globalisation, therefore, is "primarily shipped", enabling intercontinental commerce, the transportation of materials and resources around the world, and delivering manufactured goods to business and households. Driven by increasing efficiency and greater economic liberalisation, the industry's growth prospects are only expected to grow. The UN foresees that the sector will grow by "2% in 2024 and an average of 2.4% annually through 2029"[8].

However, this incremental growth comes with a cost. As reported by the European Commission, "in 2018, global shipping emissions represented 1.076 million tonnes of CO2, and was responsible for around 2.9% of global emissions caused by human activities" and, if unattended, these could increase by up to 130% in 2025 when compared to 2008's baseline[9].

At EU level, around 75% of all international trade in and out of the EU is transported by sea. While considered the most energy-efficient way of moving large quantities of cargo, the maritime sector has a noticeable impact on the environment. The shipping sector accounts for around 14% of the EU's transport emissions[10]. As of 2021, maritime transport represented 3 to 4% of the EU's total CO2 emissions[11], but, in order to contribute

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[5] European Environment Agency. "EU maritime transport: first environmental impact report acknowledges good progress towards sustainability and confirms that more effort is needed to prepare for rising demand". News. Published 01 Sep 2021. https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental.

[6] FuelsEurope. "Maritime Transport". https://www.fuelseurope.eu/maritime-transport.

[7] UNCTAD Handbook of Statistics 2023. Available at: UNCTAD Handbook of Statistics 2023.

[8] European Environment Agency. "EU maritime transport: first environmental impact report acknowledges good progress towards sustainability and confirms that more effort is needed to prepare for rising demand". News. Published 01 Sep 2021. https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental.

[9] IMO, "Climate Action". https://www.imo.org/en/ourwork/environment/pages/decarbonization%20of%20shipping.aspx.

[10] Transport and Environment. "State of European Transport 2024". (2024). https://www.transportenvironment.org/state-of-european-transport/state-of-transport/ships

[11] European Commission, "Reducing Emissions from the Shipping Sector". N/D. Reducing emissions from the shipping sector - European Commission

to the EU's climate neutrality objectives by 2050, the European Commission's projections show that total CO_2 emissions from EU-related international maritime transport will have to be reduced from 131 Mt CO_2 in 2030 to nearly zero by 2050[12,13].

After analysing the environmental costs of the shipping industry, the European Environment Agency classified the main environmental damages into 5 groups. These are:

1. **"Greenhouse gas emissions**: in total, ships calling at EU and European Economic Area ports generated around 140 million tonnes of CO_2 emissions in 2018 (approximately 18 % of all CO_2 emissions generated by maritime transport worldwide that year).
2. **Air pollution**: in 2019, sulphur dioxide (SO_2) emissions from ships calling in European ports amounted to around 1.63 million tonnes, approximately 16 % of the global SO_2 emissions from international shipping.
3. **Underwater noise**: ships create noise which can affect marine species in different ways. It is estimated that between 2014 and 2019, the total accumulated underwater radiated noise energy more than doubled in EU waters. Container ships, passenger ships and tankers generate the highest noise energy emissions from propeller use.
4. **Non-indigenous species**: overall, since 1949, the maritime transport sector has accounted for the largest proportion of non-indigenous species introduced into seas around the EU — close to 50 % of all species, with the largest number found in the Mediterranean. A total of 51 species are all classified as high impact, meaning that they can affect ecosystems and native species. The report also notes the limited data available in assessing the full impact on habitats and species.
5. **Oil pollution**: out of a total of 18 large accidental oil spills in the word since 2010, only three were located in the EU (17 %); better monitoring, enforcement and

[12] EEA. "EU maritime transport: first environmental impact report acknowledges good progress towards sustainability and confirms that more effort is needed to prepare for rising demand". (2021) https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental.com

[13] 2030 and 2050 data retrieved from Direct CO_2 emissions from the EU transport sector for international navigation (Mt CO_2) under Scenario S3, Commission Staff Working Document: Impact Assessment Report Accompanying Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society SWD(2024) 63 final – Part 3 (Figure 76, p. 99). Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:6c154426-c5a6-11ee-95d9-01aa75ed71a1.0001.02/DOC_3&format=PDF

awareness is helping to reduce oil pollution events even though the amount of oil transported by sea has been steadily growing for the past 30 years"[14].

Despite these, it is relevant to note that the sector has parallelly become aware of the detrimental impacts that its own activity generates, evolving consciously alongside the incremental international attention to environmental issues and the harmful effects of emissions.

1.2. Policy Context and Sustainability Framework in the Port Industry

Environmental concerns trace back to the 1960s and 70s, when the scientific community first started studying its impact[15]. The widespread use of fossil fuels quickly made transport a central focus of research, as it was identified early on as a major contributor to greenhouse gas emissions.

Although these studies did not immediately lead to policy action, the 1990s saw a first wave of international responses to the growing climate threat. In 1988, the World Meteorological Organization and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC), which released its first assessment report in 1990. This report, based on the contributions of 400 scientists, confirmed that global warming was real and urged immediate action.

As a result of these findings, governments adopted the United Nations Framework Convention on Climate Change (UNFCCC), which was opened for signature at the 1992 United Nations Conference on Environment and Development — more commonly known as the Earth Summit — held in Rio de Janeiro. It set out the goal of stabilising greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system"[16].

[14] European Environment Agency., "EU maritime transport: first environmental impact report acknowledges good progress towards sustainability and confirms that more effort is needed to prepare for rising demand". News. Published 01 Sep 2021. https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental.

[15] IMO. "Historic Background". Historic Background

[16] United Nations. "What is the United Nations Framework Convention on Climate Change?". Climate Change. UNFCCC Process. Last accessed 18/03/2023. https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change.

Building on this momentum, the Kyoto Protocol was adopted in 1997 and entered into force in 2005, setting legally binding targets for greenhouse gas emissions reductions in industrialised countries. One of its key contributions was recognising the need to address emissions from international aviation and maritime transport.

This milestone marked a turning point, as the international environmental protection objectives encompassed maritime transport for the first time. However, it did so in a unique manner. The Protocol, overall, commits "countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets."[17] In other words, it establishes national targets for the reduction of emissions.

However, there are two sectors that were separated from this dynamic: the aviation and maritime transport. They are treated as industries altogether, instead of delegating their regulation to each country. In this sense, the Kyoto Protocol "contains provisions for reducing GHG emissions from international aviation and shipping and treats these sectors in a different way to other sources due to their global activities that is, pursuing through the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO) respectively"[18].

This implies that it assigned the regulatory responsibility of these sectors to these two organisations. Since then, the IMO sets the international rules for reducing air-polluting emissions from shipping.

In this sense, at the global level, the IMO has been developing strategies to address GHG emissions from ships and the port sector. The 2023 **IMO Strategy on Reduction of GHG Emissions from Ships**[19], adopted on 7th July 2023, sets out clear climate targets. Compared to 2008 levels, the international shipping industry must reduce total annual GHG emissions by at least 20% (with a 30% aim) by 2030 and by at least 70% (with an 80% aim) by 2040. The strategy also commits to phasing out GHG emissions in line with the Paris Agreement's 1.5°C goal, reaching net zero by or around 2050.

[17] United Nations Climate Change. "The Kyoto Protocol". The Kyoto Protocol | UNFCCC
[18] IMO. "Historic Background". Historic Background
[19] IMO (2023). "2023 IMO Strategy on Reduction of GHG Emissions from Ships". https://www.imo.org/en/ourwork/environment/pages/2023-imo-strategy-on-reduction-of-ghg-emissions-from-ships.aspx

To support these objectives, the IMO approved a draft **IMO Net-zero Framework (NZF)**[20] for global shipping on 11th April 2025. Key measures include a new fuel standard combined with a pricing mechanism for emissions. The IMO NZF will be proposed for adoption in October 2025 and, if successfully adopted, will enter into force in 2027 with its inclusion into a new Chapter 5 of MARPOL Annex VI[21]. These pieces of legislation will be mandatory for large ocean-going ships, requiring them to reduce their annual greenhouse gas fuel intensity.

The needed transformation in the EU maritime sector is being strongly encouraged through robust policies and regulations, financial incentives and infrastructure investment, spanning from fuel production to operational deployment. The EU's strategy towards achieving climate neutrality and mitigating the impacts of climate change led to the adoption of a series of legislative acts under the **European Green Deal**[22] and the **European Climate Law**[23]. The Green Deal[24] aims to make Europe the first climate-neutral continent by 2050. The defined goals under this agreement are written into law through the European Climate Law, which also sets intermediate targets for reducing GHG emissions by at least 55% by 2030, compared to 1990 levels[25].

In line with these commitments arises the **Fit for 55 Package**[26], aiming at (1) ensuring a just and socially fair transition, (2) maintaining and strengthening the innovation and competitiveness of EU industry while ensuring a level playing field, and (3) underpinning the EU's position as leading the way in the global fight against climate change. Both the Green Deal and the Fit for 55 are essential, as they reflect that the promotion of sustainability in the maritime industry is not an isolated aim but a core

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20 IMO (2025). "IMO approves net-zero regulations for global shipping". https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-approves-netzero-regulations.aspx

21 Safety4Sea (2024). "IMO MEPC 81 Proposes new Chapter 5 of MARPOL Annex VI". https://safety4sea.com/imo-mepc-81-proposes-new-chapter-5-of-marpol-annex-vi/

22 European Commission (2019) "The European Green Deal". https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

23 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R1119

24 European Commission (2019). "The European Green Deal". https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

25 European Commission (2021). "European Climate Law". https://climate.ec.europa.eu/eu-action/european-climate-law_en

26 Council of the European Union: Fit for 55 (https://www.consilium.europa.eu/en/policies/fit-for-55/)

element of a wider, legally binding EU strategy to achieve climate neutrality. In other words, sustainability is not a choice strategy, but a mandatory transition.

Under this package, the following proposals are particularly relevant to the maritime sector.

The EU has rolled out a package of policy instruments to decarbonise maritime transport and accelerate the shift to alternative fuels. The **FuelEU Maritime Regulation**[27] has been fully applied since 1st January 2025. The Regulation promotes the use of renewable and low-carbon fuels in maritime transport to support the decarbonisation of the sector[28]. It mandates a progressive reduction in the yearly average GHG intensity of the energy used by ships above 5 000 gross tonnages (GT) calling at European ports, starting with a 2% decrease by 2025 and reaching up to an 80% reduction by 2050. The targets cover not only CO_2 but also methane (CH_4) and nitrous oxide (N_2O) emissions over the full lifecycle of the fuels used onboard, on a Well-to-Wake (WtW)[29] basis. The Regulation fully covers the energy used during intra-EEA voyages, but only half of non-EU voyages. Additionally, the Regulation will require passenger and container ships to use Onshore Power Supply (OPS) or other zero-emission alternatives from 1st January 2030 onwards in all ports covered in Art. 9 of the Alternative Fuels Infrastructure Regulation (AFIR) and, from 1st January 2035, in all EU ports that develop OPS capacity[30].

The **AFIR**[31] entered into force in September 2023 and has been applicable in the maritime sector since April 2024. It sets mandatory deployment targets for shore-side electricity supply and alternative fuel infrastructure in maritime and inland ports. This

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27 Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1805

28 *Ibid*.

29 Well-to-Wake (WtW), as explained by IMO, is a "life cycle assessment methodology that accounts for all greenhouse gas (GHG) emissions associated with a fuel, from its primary production (the "well") to its combustion in a vehicle or ship (the "wake")". https://www.imo.org/en/ourwork/environment/pages/lifecycle-ghg---carbon-intensity-guidelines.aspx#:~:text=The%20life%20cycle%20assessment%20(LCA)%20methodology%20refers%20to%20the%20assessment,of%20emissions%20to%20other%20sectors'.

30 European Commission (2024). "Decarbonising maritime transport – FuelEU Maritime". https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en

31 Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. https://eur-lex.europa.eu/eli/reg/2023/1804/oj/eng

supports the sector's energy transition, aims to boost investor confidence and support the availability of alternative fuels, thus indirectly supporting the FuelEU Maritime Regulation[32,33].

The extension of the **EU ETS maritime**[34] applies the "polluter pays" principle to the maritime sector by requiring shipping companies to purchase allowances for their GHG emissions. The EU ETS covers CO_2, CH_4 and N_2O emissions, the latter two only as of 2026.

In 2021, the European Commission proposed to revise the existing **Energy Taxation Directive (ETD)**[35] as part of the Fit for 55 package. The proposed revisions aim to support the energy transition by reflecting more accurately the climate impact of the EU's various sources of energy and raising revenues for Member States to incentivise the investment and use of low-carbon technologies. The proposal is still under discussion.

Nonetheless, for the particular topic addressed in this work, a single piece of legislation stands out: the **Combined Transport (CT) Directive** (Council Directive 92/106/EEC). As the European Commission indicates, the Directive seeks to "promote Combined Transport operations through the elimination of authorisation procedures and quantitative restrictions for Combined Transport operations…". In essence, it offers "direct support for intermodal transport… aiming to increase the competitiveness of the combined transport (defined as intermodal transport with a strictly limited road leg)"[36].

All these regulatory pieces demonstrate the strong policy background against which intermodality is being built, establishing firm foundational pillars for intermodality to not only fit within the sustainable pursuit of the port industry, but becoming an essential part of it.

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32 Lagouvardou & Psaraftis (2022). "Implications of the EU Emissions Trading System (ETS) on European container routes: A carbon leakage case study". https://www.sciencedirect.com/science/article/pii/S2666822X22000107

33 Cullinane & Yang (2022). "Evaluating the Costs of Decarbonising the Shipping Industry: A Review of the Literature". https://www.researchgate.net/publication/361905604_Evaluating_the_Costs_of_Decarbonizing_the_Shipping_Industry_A_Review_of_the_Literature

34 EC (2023). Directive (EU) 2023/959 amending Directive 2003/87/EC)

35 European Commission (2021). "Revision of the Energy Taxation Directive". https://taxation-customs.ec.europa.eu/taxation/excise-taxes/revision-energy-taxation-directive_en

36 European Commission. "Multimodal and combined transport". Multimodal and combined transport - European Commission

1.3. Defining Intermodality

In literature, the concepts of "intermodality" and "multimodality" are often seamlessly interchanged, and, though correlated, they do not share the exact same meaning. In the context of shipping, both refer to the movement of cargo that employs several modes of transport, namely road, rail, or even air, within the transportation chain. However, multimodality relates to a broader strategy, intermodality being one of its types.

In this line, therefore, intermodality (in freight transport), as defined by the European Court of Auditors, is a type of multimodality which "*consists of transporting goods in a single loading unit (such as a container) using a combination of modes of transport: road, rail, waterways or air. It has the potential to optimise the relative strengths of each of the modes in terms of flexibility, speed, costs and environmental performance*"[37].

One main difference between intermodality and other types of multimodal transport is based upon the number of contracts and, most often, carriers that are employed in the shipping process. Multimodal transport, in general terms, is ruled by a single contract, which facilitates the management of the chain overall and the identification of responsibilities, using a single "bill of lading". Intermodality, on the other hand, "involves multiple contracts, with each carrier responsible for their respective leg of the journey. This allows for greater flexibility but requires the shipper to coordinate the logistics between carriers"[38]

Intermodal transport provides more flexibility, better rates, and a reduction in the environmental footprint, while also allowing the "potential reduction in CO2 emissions through carrier choice"[39], as it permits the implementation of several contracts and not a unified one. This contractual diversification allows shippers to strategically choose the most fuel-efficient or environmentally conscious carrier (like rail or sea freight) for the longest part of a journey, thereby reducing the reliance on less-efficient options like long-haul trucking.

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[37] European Court of Auditors, "Special Report. Intermodal Freight Transport". 2023. Available at: Special report 08/2023: Intermodal freight transport

[38] Jxx Logistics, "Difference between Intermodal and Multimodal Transport". https://www.jjxlogistics.co.uk/difference-between-intermodal-and-multimodal-transport/.

[39] Nexxiot, "Intermodal vs Multimodal Transportation". June 2023. Intermodal vs Multimodal Transportation - Nexxiot

However, the key to intermodality, as indicated by Maersk is that *"the cargo stays in the same container throughout the entire journey, even when switching between transport modalities — thanks to standardised shipping containers that comply with the International Organization for Standardization (ISO). These containers are easily transferred between ships, barges, trains, and trucks, reducing loading and unloading times, minimising cargo damage, and enhancing security. This process leverages the strengths of different transportation modes to achieve an efficient, cost-effective, and environmentally friendly transfer of goods. Since many shippers or consignees do not have direct rail or barge terminal access, often a combination of transport modes is used to leverage the strength of each one: e.g. rail combined (rail as the main leg and truck for final delivery) or barge combined with truck services"*.

The following image represents a possible intermodal chain of transport of goods, reflecting the different modes in which the same container will be loaded and carried without the need to exchange units:

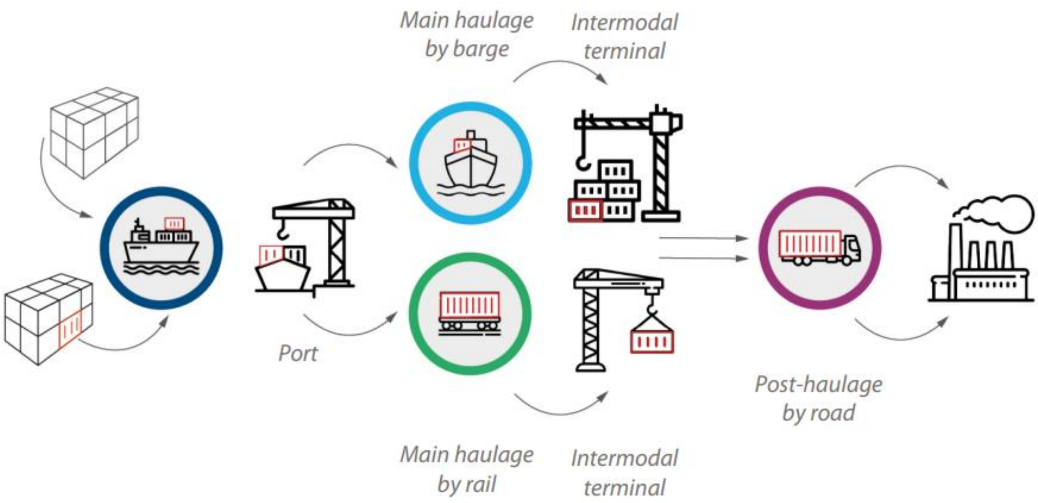

Figure 1- Illustration of a possible intermodal chain. Source: European Court of Auditors

2. Sustainable Port Strategies: Current Status and Key Challenges

2.1. Key Environmental Challenges in Ports

One of the biggest challenges the IMO faces in its efforts to tackle its contribution to climate change is the decarbonisation of the industry; that is, "the process of reducing greenhouse gas (GHG) emissions from the global maritime sector" After its moderate start, decarbonisation ambitions have continued to increase, leading IMO to set goals to fully-scale decarbonisation by 2050, establishing a 20% reduction by 2030 and up to a 70% by 2040[40].

This process in the maritime sector has deployed two main lines of action: the decarbonisation of the fleet and the decarbonisation of the maritime infrastructure, which naturally primarily encompasses ports altogether. The first implies the construction of new ships capable of operating with what is generally regarded as green or sustainable fuels, as well as the retrofitting of the existing ones, adapting already existing vessels. The second, which is the objective of this work, focuses on the process of reducing greenhouse gas emissions from an operational perspective. It signifies preparing the maritime infrastructure to transition to cleaner energy sources, improving energy efficiency, and adopting sustainable logistics strategies and technologies to progressively reduce its environmental impact.

The decarbonisation of port terminals arises as a main catalyst for change in the maritime transport, but also, a strategic challenge aimed at reshaping the sector's operations[41]. As key hubs in the global supply chain, ports are significant producers of GHG, mainly due to their necessary reliance on fossil fuels and energy-intensive machinery.

[40] UN Trade and Development, "Net-zero by 2050: Achieving shipping decarbonization through industry momentum and the new ambition at IMO". September 2023. Net-zero by 2050: Achieving shipping decarbonization through industry momentum and the new ambition at IMO | UN Trade and Development (UNCTAD)
[41] Sener, *Decarbonisation of Ports: Strategies and Technologies to Transform the Industry*. November, 2024. https://www.group.sener/en/insights/decarbonisation-of-ports-strategies-and-technologies/.

The main sources of pollution derive mainly from four general activities. These are:

- Cargo handling equipment: Cranes and handling equipment, such as gantry cranes and spreaders, operate continuously and, using diesel engines, generate high carbon emissions.
- Internal transport vehicles: Vehicles such as straddle carriers and tractors, needed for container movement, consume large quantities of fossil fuels and face technological limitations in transitioning to cleaner alternatives.
- Emissions from docked ships: Ships often operate their auxiliary engines to maintain systems while docked, leading to significant pollution.
- Energy infrastructure: Ports often rely on local electrical grids, which in many cases are largely powered by fossil fuels[42].

Conscious of this and in the context of increasingly stringent climate policies and international commitments to reduce pollution, the port sector is committed to achieving a drastic transformation, implementing a comprehensive strategy that integrates technology development, renewable energy sources and, at the epicentre of operations, optimisation of processes.

2.2. Emerging Opportunities: The Green Port Concept.

2.2.1. Introduction

As essential operational centres within the shipping industry, ports have the potential to emerge as the most significant promoters of transformation. However, they are necessarily "power-hungry" hubs, traditionally fed by fossil fuels and constantly requiring high-intensity energy injections.

Therefore, the transition towards achieving net-zero operations implies a practically complete reconversion of the status quo of these hubs, necessitating the development of a complex framework for coordinated actions, and the settling of more sustainable, energy-efficient models becomes imperative. Some of these actions include

[42] Sener, *Decarbonisation of Ports: Strategies and Technologies to Transform the Industry*. November, 2024. https://www.group.sener/en/insights/decarbonisation-of-ports-strategies-and-technologies/

reducing pollution from both air and water by implementing renewable energy sources (solar, wind, green fuels...). Nonetheless, at the core of all, there is an overarching strategy: optimising effectiveness in operations to reduce energy consumption[43].

In this context, the concept of "green ports" emerged, encapsulating the willingness of those hubs to minimise their environmental footprint. As defined by the Union Civil Protection Knowledge Network, "*Green ports refer to seaports or harbours that prioritise environmental sustainability and adopt practices to minimise their ecological footprint. These practices often involve reducing air and water pollution, optimising energy efficiency, and promoting the use of renewable energy sources.*"[44] Green ports, consequently, tackle emission reduction from different angles, including "measures to decrease air pollution from ships, trucks, and other vehicles, as well as stationary sources like power plants[45], among others.

The operations at the focal point of efforts are the most energy-intensive ones, that is, loading and unloading cargo, managing container terminals, and providing vessel facilities. Green ports, as a result, integrate energy-efficient strategies, embrace and bet on the incorporation of new, renewable energy sources, and, especially, "implement smart energy management systems to reduce overall energy consumption"[46], the very field in which intermodality's critical role is defined.

Green ports are, indeed, exponentially gaining momentum and becoming a key aspect of governmental strategies of ports and authorities to contribute to the mitigation of climate change. They are symbolising the transition in an industry as complex to decarbonise as the maritime, joining both economic growth and environmental consciousness, driving the sector towards a "more sustainable and resilient future"[47].

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[43] Union Civil Protection Knowledge Network, "The Green Ports Concept and PROMPT Project". Febryary 2024. https://civil-protection-knowledge-network.europa.eu/stories/green-ports-concept-and-prompt

[44] Union Civil Protection Knowledge Network, "The Green Ports Concept and PROMPT Project". Febryary 2024. https://civil-protection-knowledge-network.europa.eu/stories/green-ports-concept-and-prompt

[45] *Ibid*.

[46] Union Civil Protection Knowledge Network, "The Green Ports Concept and PROMPT Project". Febryary 2024. https://civil-protection-knowledge-network.europa.eu/stories/green-ports-concept-and-prompt

[47] Union Civil Protection Knowledge Network, "The Green Ports Concept and PROMPT Project". Febryary 2024. https://civil-protection-knowledge-network.europa.eu/stories/green-ports-concept-and-prompt

2.2.2. Key Global Initiatives in Sustainable Ports

The concept of "green ports", as introduced above, is enjoying the attention of worldwide initiatives that aim to support it through, for instance, the public recognition by the authorities of those hubs committing to its implementation.

A. Asia-Pacific Economic Cooperation (APEC) region's Green Port Award System (GPAS) programme

Among these initiatives is the APEC region's Green Port Award System (GPAS) programme, a "green evaluation system" for ports in the region, aiming to promote the "green growth" of its port industry[48].

As indicated by the APEC, "applicants for GPAS can be any port (port authorities or port operators) that are implementing green programs to improve the environmental sustainability of their operation in the last three or more years."[49] The goal is to support environmentally conscious development in the port industry, providing a "platform for sharing of best practices among ports in the APEC region, to raise the profile of ports committed to green practices, and to improve their capacity for sustainable development."[50]

For evaluating if a port is indeed "green", the APEC has developed a GPAS indicator system, which weights the following indicators defined by reference standards[51]:

[48] APEC Port Services Network, "About GPAS". N/D. https://www.apecpsn.org/apsn/GPAS/index.jhtml
[49] APEC, "GPAS". N/D. https://www.apecpsn.org/apsn/GPAS2.jhtml.
[50] *Ibid*.
[51] APEC, "GPAS Indicator system". N/D. https://www.apecpsn.org/apsn/GPASINDICATORSYSTEM.jhtml

PRIMARY INDICATOR	SECONDARY INDICATOR	REFERENCE STANDARD
COMMITMENT AND WILLINGNESS (25%)	GREEN PORT AWARENESS AND WILLINGNESS (60%)	(1)Green strategy or development plans (2)Green support funding (3)Green annual reports (4)Others
	GREEN PORT PROMOTION (40%)	(1)Green training programs (2)Green promotion campaigns (3)Others
ACTION AND IMPLEMENTATION (50%)	Clean Energy (15%)	(1)Using renewable energy sources (2)Using of LNG (3)Using cold ironing (shore power) (4)Others
	Energy Saving (30%)	(1)Using energy-saving devices & technologies (2)Optimizing power supply system (3)Others
	Environmental Protection (40%)	(1)Air pollution prevention (2)Noise control (3)Waste treatment (liquid and solid) (4)Others
	Green Management (15%)	(1)Green environment management system (2)Green performance assessment (3)Others
EFFICIENCY AND EFFECTIVENESS (25%)	Energy Saving (40%)	(1)Energy consumption reduction (2)Renewable energy increment (3)Others
	Environmental Protection (60%)	(1)Air quality improvement (2)Noise control result (3)Liquid & solid pollution control (4)Others

Figure 2 – Primary Indicators, Secondary Indicators and Reference Standards used by the APEC to evaluate a "Green Port". Source: APEC GPA's Indicator System[52].

The ten awarded ports in 2024 by the initiative include Bangkok Port in Thailand, Port of Cagayan de Oro and Port of General Santos in the Philippines, with the country with the highest number of awarded ports being China, with a total of 6.

B. EcoPorts, Europe.

Shifting geographies to the European continent, a similar initiative is in place. *EcoPorts* "is the main environmental initiative of the European port sector. It was initiated by a number of proactive ports in 1997 and has been fully integrated into the European Sea Ports Organisation (ESPO) since 2011. The overarching principle of *EcoPorts* is to raise

[52] APEC, "GPAS Indicator system". N/D. https://www.apecpsn.org/apsn/GPASINDICATORSYSTEM.jhtml

awareness on environmental protection through cooperation and sharing of knowledge between ports and improve environmental management"[53].

The *EcoPorts* initiative works with two different types of assessment methods:

a) The **"Self Diagnosis Method (SDM)"[54]:** a checklist crafted for port managers to self-assess, in an accessible and friendly manner, their environmental performance, identifying their climate risks and reflecting on the fitness of their sustainability practices in place or to be in place. Completing the SDM is a necessary prerequisite for a Port to be able to eventually integrate the *EcoPort* network.

   The SDM is divided into three main phases. Firstly, there is the self-assessment questionnaire, which allows for an environmental diagnosis of the port. Through this form, the port managers identify the main environmental risks associated with their operations and their level of compliance in different key areas of sustainability. The data collected is used to feed into a European benchmark of port environmental performance, allowing ports to benchmark themselves against their continental counterparts. Once completed, the SDM is valid for two years and grants the port the official "*EcoPor*t" membership status.

   The second phase consists of benchmarking, an additional option whereby ports can compare their score with the European average for the sector. This benchmarking tool gives managers a clearer picture of their environmental strengths and weaknesses, helping to prioritise actions based on objective and proven criteria.

   Finally, the SDM review service allows ports to receive a detailed technical analysis by industry experts, which includes both an assessment of gaps with respect to international environmental management standards and a SWOT analysis (of strengths, weaknesses, opportunities and threats) adapted to the port's specific needs.

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[53] EcoPorts, "EcoPorts. Green your Port, Join EcoPorts". Last consulted 12/05/2025. https://www.ecoports.com/#:~:text=EcoPorts%20is%20the%20main%20environmental,Organisation%20(ESPO)%20since%202011.

[54] EcoPorts, "Self-Diagnosis Method (SDM): The user-friendly environmental checklist". SDM - EcoPorts | ESPO

b) **Port Environmental Review System (PERS):** the PERS is the "only port sector-specific environmental standard"[55], which combines the "main general requirements of recognised environmental standards" such as ISO 14001 with the specific characteristics of ports, building upon" policy recommendations of ESPO" and establishing clear targets.

The following image reflects the current network of *EcoPorts*[56]:

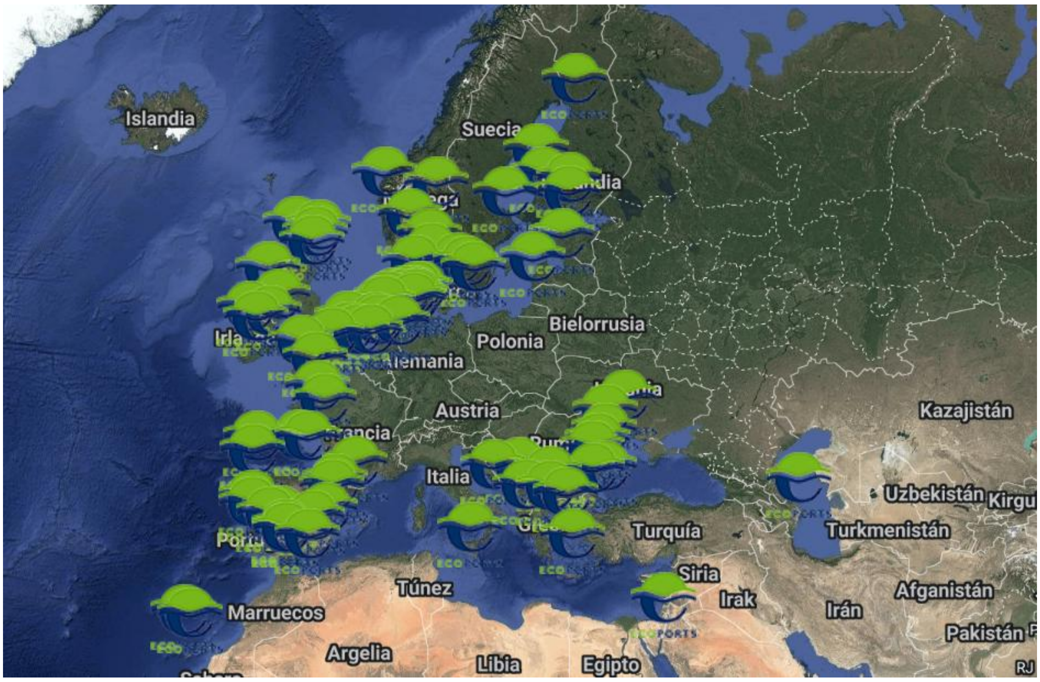

Figure 3 - Current Network of EcoPorts. Source: EcoPorts

C. *Green Marine Initiative - North America.*

The *Green Marine Initiative*, in North America, stands out as the "leading environmental certification program for the maritime industry". Very similar to the previous initiatives, it is a voluntary participation scheme that guides its participants toward improving their environmental performance. Currently, it enjoys the membership of more than 490 green ports.

The certification process involves a series of steps, starting with an annual auto-evaluation of the participants' environmental performance. It is based on a scale of levels,

[55] EcoPorts, "Port Environmental Review System (PERS): the only port sector-specific environmental management standard". N/D. https://www.ecoports.com/pers.
[56] EcoPorts, "EcoPorts Network". https://www.ecoports.com/network.

from 1 to 5, measuring the level of attainment of the indicators that are allocated to each activity type[57]. This indicators refer to 4 variables/actors (ship owners, ports and seaway, terminals and shipyards) and cover a wide range of environmental aspects, relevant for the maritime sector, such as emission of pollutants, aquatic ecosystems protection, prevention of expansion of invasive species, waste management or reduction of submarine noise, among others, where efficiency and green leadership are also rewarded[58].

All the above presented initiatives effectively bring to light how the concept of green port is gaining momentum, positioning itself at the vanguard of the environmental movement in the shipping sector and becoming a fundamental concept in its ecological transition.

2.3. Comprehensive Overview of Sustainable Port Strategies

As evidenced by the previous section, a port's green transition may encompass a diversity of strategies. In this sense, DNV identified 10 Key transitions (strategies) to reduce the CO_2 emissions at ports and turn them into decarbonisation hubs[59].

[57] Green Marine, "Certification Process". N/D. https://green-marine.org/certification/certification-process/
[58] Green Marine, "Performance Indicators". N/D. https://green-marine.org/certification/performance-indicators/.
[59] DNV (2020). "Ports can be the front runners of the energy transition, if port authorities and industry sectors join forces". https://www.dnv.com/news/ports-can-be-the-front-runners-of-the-energy-transition-if-port-authorities-and-industry-sectors-join-forces-179736/.

The following figure reflects the abovementioned transitions:

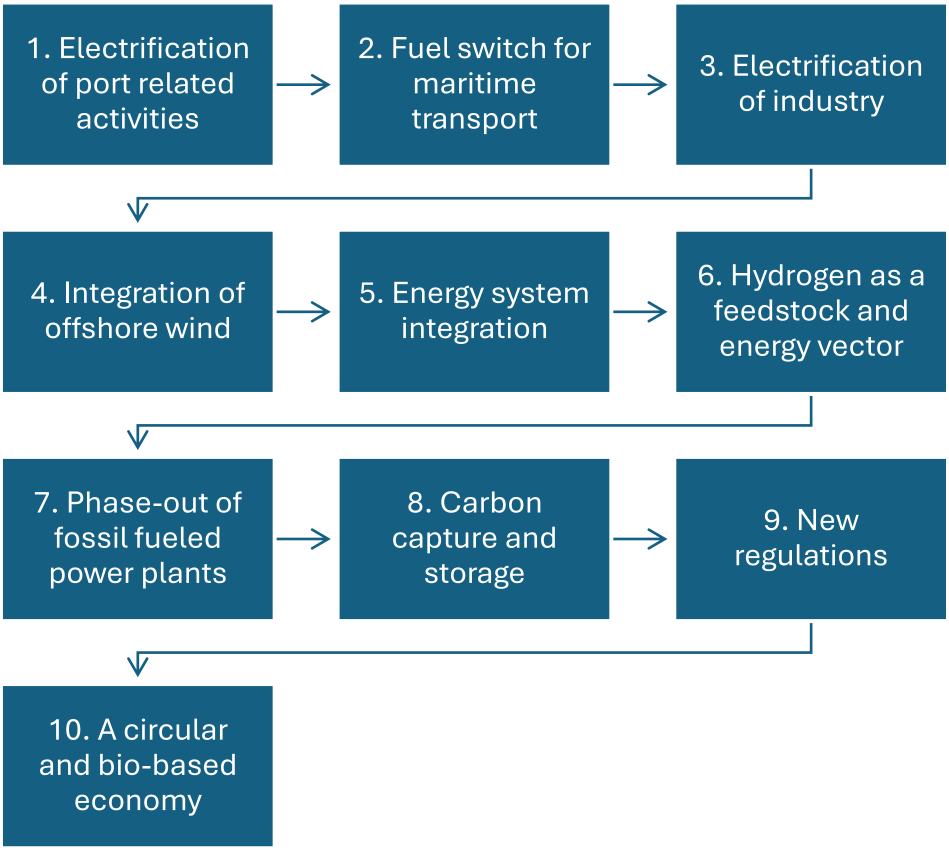

Figure 4- 10 Key transitions to reduce the CO2 emissions at ports.

As evidenced, carrying out these transformations not only entails physical changes in the port infrastructure itself, but also regarding their adherence to greater electrification trends, fossil fuel employment reduction and even onsite, new fuels generation.

Delving into them in detail, it is perceivable that even though they are clearly defined in a specific, measurable, achievable, relevant and time-bound (S.M.A.R.T) manner, which helps clarify the goals, target efforts and evaluate the progress done, these transitions entail different levels of complexity and, consecutively, challenges:

1. The **electrification** of the ports and its related activities presents both challenges and opportunities. It consists of substituting the current equipment and processes that use traditional fossil fuel for cleaner alternatives, such as wind or solar energy. This allows for the reduction of harmful emissions to the atmosphere, along with many other benefits, namely better local air quality, increased reliability of the systems, and lower maintenance costs with electric motors. Among the port

activities that are first susceptible to undergo this transition is the bunkering of the port, the cargo handling or the electrification of the buildings and offices in the hub[60].

Electrification is, in essence, "one of the major players in the decarbonisation of the economy. In the context of ports, basing activities and processes on electrical energy from renewable sources can reduce greenhouse gas emissions, increase the credibility of port operators and reduce maintenance costs, among other advantages."[61]

A recurrent term that is commonly highlighted in literature addressing the electrification of port activities is the "coldironing" or "shore-to-ship power (SSP)". As defined by Port Economics, Coldironing "implies that a ship at berth uses shore power for the auxiliary engines instead of bunker fuel. This reduces emissions from the ships by a substantial margin, although the reduction in pollution occurs only when the ship is stationary at berth."[62] Currently, it is more prominent in the cruise shipping industry, as the pressure for decarbonising these terminals has been higher[63].

A stamp initiative within the electrification of ports is the **Nexigen,** the "Port of Barcelona's dock electrification plan that will contribute to a 22% reduction in greenhouse gas emissions from its operations and will be completed by 2030"[64]. By implementing innovative on-shore power infrastructure (OPS), the project will allow ships to connect to the port's electricity grid while at berth, drastically reducing greenhouse gas emissions, noise, and air pollution[65]. It is set to be concretised by the end of 2028.

2. Across all energy-intensive industries, the generalised tendency of the last years has been to get acquainted and progressively introduce the so-called "sustainable fuels", in essence, those that are considered cleaner than traditional fossil fuels, as they emit fewer pollutants to the atmosphere or are sourced from greener origins.

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[60] World Port Sustainability Program, "*Ports: Green Gateways to Europe*". July 2022. https://sustainableworldports.org/wp-content/uploads/PORTS_GREEN_GATEWAYS_TO_EUROPE_FINAL29JUNE.pdf
[61] https://piernext.portdebarcelona.cat/en/environment/ten-ways-to-decarbonize-ports/
[62] Port Economics, Management and Policy, "Coldironing: On-shore Power Supply for Vessels". https://porteconomicsmanagement.org/pemp/contents/part3/green-supply-chain-management-ports/coldironing-on-shore-power-supply-vessels/.
[63] *Ibid*.
[64] https://piernext.portdebarcelona.cat/en/environment/ten-ways-to-decarbonize-ports/
[65] Port of Barcelona, "Nexigen". N/D. https://www.portdebarcelona.cat/es/nexigen.

The maritime sector realises that its decarbonisation process necessarily needs to encompass equally a fuel switching strategy.

In this sense, the greener fuel par excellence in the industry is the liquefied natural gas (LNG), which has experienced one of the strongest uptakes. Even though it is technically a fossil fuel, according to the International Energy Agency (IEA), "natural gas emits 50% less greenhouse gases than coal"[66] as an energy source, and provides significant benefits, as it meets the regulatory requirements already, offers enhanced competitiveness and improves the overall quality of the air[67]. This makes it an attractive middle-ground solution to transition from traditional fossil fuels and less polluting ones, allowing for a smoother uptake, as its infrastructure can further be adapted to introduce bio-LNG or synthetic natural gas[68].

LNG, however, is not the only option. The following chart represents the maritime energy demand and projected fuel mix until 2050:

[66] Koons, Eric (2023). "Is LNG Considered Clean or Green Energy?" https://energytracker.asia/is-lng-clean-energy/.

[67] DNV. "LNG as a Marine Fuel". https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/.

[68] PierNext (2022). "Ten ways ti decarbonise ports". Port of Barcelona. https://piernext.portdebarcelona.cat/en/environment/ten-ways-to-decarbonize-ports/.

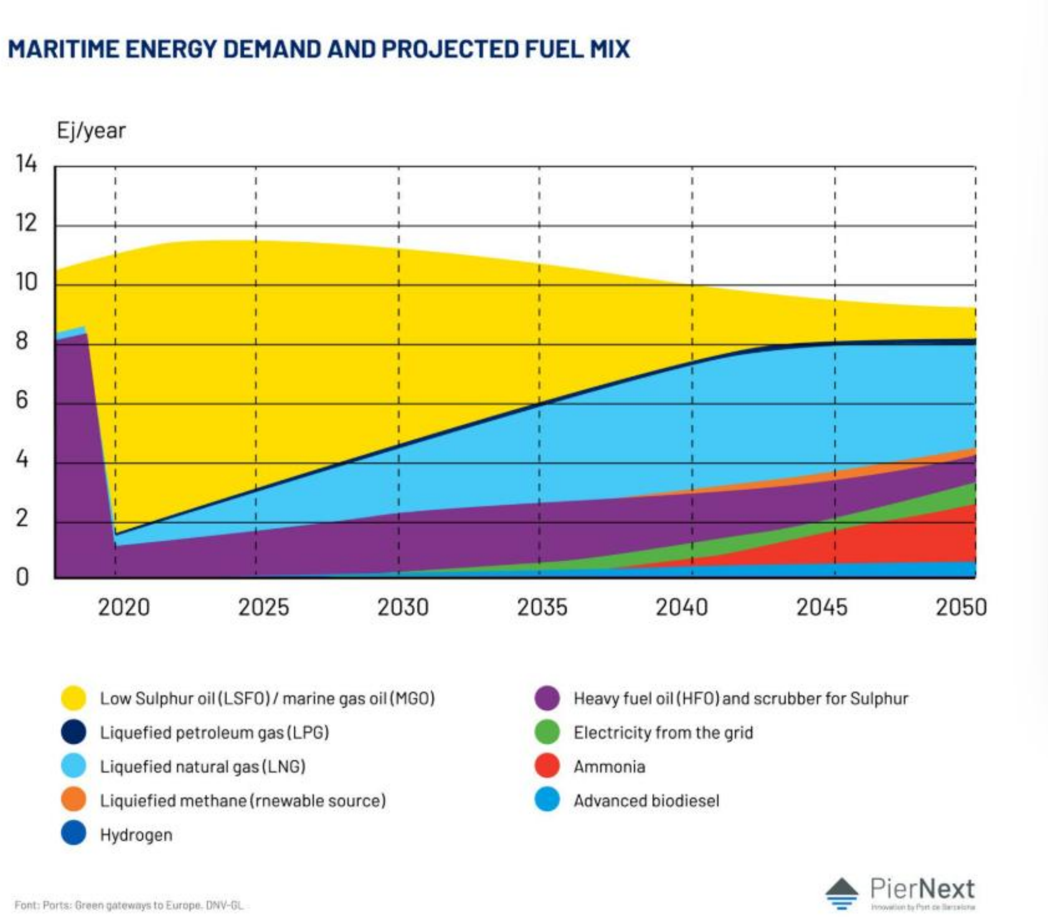

Figure 5- Maritime energy demand and projected fuel mix until 2050. Source: PierNext, by Port of Barcelona.

3. **Electrification of the maritime industry:** electrification is one of the most extended strategies across all sectors in their transition towards decarbonisation. In the case of the maritime industry, electrification, as the European Maritime Safety Agency states, "brings advantages for the sector not only in terms of sustainability, by reducing emissions and energy consumption, but also in design and operations, reducing maintenance and allowing for more flexibility in the powertrain arrangements on board"[69].

4. **Integration of offshore wind**: This transition involves leveraging the proximity of the port and the sea to install offshore wind infrastructure, connecting this energy to the grid. The objective is to ensure that the energy used for port electrification is sourced from renewable origins[70]. If a port generates its own

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[69] EMSA, "Electrification". https://www.emsa.europa.eu/electrification.html.
[70] PierNext (2022). "Ten ways to decarbonise ports". Port of Barcelona. https://piernext.portdebarcelona.cat/en/environment/ten-ways-to-decarbonize-ports/.

electricity or obtains it from a nearby source, it results in overall emission savings and more efficient operations.

5. **Energy system integration:** consists in interconnecting the different energy systems to optimise their potential altogether, which allows for a more efficient use of the renewable energy excess, adjust the offer according to the demands and increasing the energetic autonomy of the port. In other words, it optimises the consumption and production of energy within the port, as it allows to utilise the excess renewable energy, increasing the energetic efficiency. An integrated system like this can allow to manage in a more effective way (to better calibrate) the offer and demand in intermodal terminals, the systems and even the vehicles that operate within them.

6. **Hydrogen as a feedstock and energy vector**: it focuses on the generation and use of green hydrogen, produced through renewable sources, within and nearby the port installations. This energy can be applied across all activities, from feeding the vehicles, the equipment and can even contribute to generate other renewable fuels. Linking the hydrogen network from a port to its outside transportation wider system can contribute positively to the objectives of intermodality, offering a clean alternative to conventional fuels from the source, facilitating a "greener" *first and last mile*[71] connection.

7. **Phase-out of fossil fuelled power plants**: the transition towards sustainability inevitably implies leaving behind that infrastructure that has traditionally allowed the development of activities but that no longer can participate from the new trajectory of ports. Progressively eliminating from the premisses those installations that consume fossil fuels is the only way to liberate space for the assumption of newer solutions.

8. **Carbon capture and storage**: not all industrial processes can be decarbonised completely, but these remaining emissions can be captured and storage to be later utilised as raw materials. It is, therefore, a complementary strategy within the wider transition efforts.

[71] Definition of *first and last mile*:

9. **New regulations**: without regulatory clarity and guidance, a process as complex as the decarbonisation proves difficult to achieve. The establishment of objectives, methodologies and time horizons is, therefore, key to ensuring the success and complete assimilation of sustainability within ports.

10. **A circular and bio-based economy**: the sustainability of ports, although already positive on its own, needs to be integrated with broader sustainability and circular economy trends. This involves adopting newer technologies that can facilitate the transition and regularly updating practices to align with these developments. Intermodality emerges as a key driver of the circular economy, as it promotes maximum efficiency in transportation operations— a crucial aspect of ports and hubs—which in turn positively impacts emission reduction.

All these diverse approaches to sustainability highlight how multifaced the ecological transition in the port realm can take place. They should be taken into account and implemented, to their possible extent, not as individual actions, but altogether to ensure a cleaner, more environmental considerate future horizon for the industry.

3. Intermodality as a Key Strategy.

3.1. Introduction

Transport represents 5% of the EU's Gross Domestic Product (GDP), being critical not only to the European economy, but also to the global supply chain. However, these positive figures come with an associated cost in emissions. In 2021, these emissions represented "around 25% of the EU's total greenhouse gas emissions", which, since then, have increased over the years[72].

In line with this, the prisonisation of the shift from more pollutant transport modes to those with a lesser environmental cost is a key component of the transport sustainable transition. Sustainable development in the transportation dimension implies meeting its evolving needs while aiming for the implementation of the minimal cost of degradation to the environment. In this sense, European transportation policies stipulate that "by 2030, 30% of freight transport over distances greater than 300 km should be carried by means other than road, and by 2050 this rate should exceed 50%" (European Commission, 2011)[73].

In this context, intermodality emerges as a key strategy. As previously defined in **Section 1.3. Defining Intermodality**, it consists in the utilisation of at least 2 modes of transport that are compatible for the same cargo unit, avoiding its exchange between modes, priming efficiency, and therefore, emission savings. In other words, it optimises the cargo flux and allows the shift from the more polluting road transport to other modes with lesser impact, namely waterborne transport or rail, becoming essential for the achievement of global climate goals.

When compared to single-mode traditional transport, particularly, road transport, the combination of several modes has been proven to reduce GHG emissions, minimising "the carbon footprint per unit of cargo transported by utilising more fuel-efficient modes

72 European Commission (2021). "Transport and the Green Deal. Providing Efficient, safe and environmentally friendly transport" https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/transport-and-green-deal_en#:~:text=Documents-,Providing%20efficient%2C%20safe%20and%20environmentally%20friendly%20transport,Delivering%20the%20European%20Green%20Deal.

73 European Commission, "Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions". Press Release. March 2011. https://ec.europa.eu/commission/presscorner/detail/en/ip_11_372.

for long-haul segments" and by grouping cargo into larger interchangeably "packages" for transportation, decreasing "the overall number of trips required, further mitigating emissions and alleviating congestion on roads" [74].

The key word to understand the benefits of intermodality is "efficiency". By targeting the strengths of each transport mode, energy is saved and less resources are employed, translating directly into emission reduction. As Maersk indicates, "the real value of intermodal logistics lies in combining the strengths of each mode to enable reliable, cost-effective, and scalable freight movement."[75]

Rail stands as the highlight mode, being the most fuel-efficient to transport cargo through land and, by freight ton-mile, it can be up to four times more efficient than truck transit[76]. It is also the most efficient mode of transport for passengers[77].

Maritime transport ranks as the second most efficient means of transporting. A new study commissioned by the EEA shows a clear hierarchy of passenger and freight transport modes, in terms of their greenhouse gas emissions. This study revealed that rail and waterborne transport "have the lowest emissions per kilometre and unit transported". Indeed, the EEA points out that "emissions for freight transported by maritime shipping, rail and inland waterway are very low compared with those for freight transported by heavy goods vehicle (HGV)"[78].

In light of the above, leveraging the potential of smoothing the transition between these two strategic modes becomes a focal point for tackling transport emissions, as their efficiency, especially for long-haul distances, could contribute greatly to GHG emissions'

[74] Cornerstone Systems, "Five Ways Intermodal Transport Champions Environmental Sustainability". N/D. Intermodal Transport Champions Environmental Sustainability

[75] Maersk, "Intermodal transport: What is it and how does it work?". June 2025. Intermodal Transport: Types, Use Cases, and FAQs | Maersk

[76] U.S. Department of Energy's primary national laboratory for energy systems (NREL), "Freight Transport". Freight Transport | Transportation and Mobility Research | NREL

[77] European Environmental Agency (2021). "Rail and waterborne – best for low-carbon motorised transport. https://www.eea.europa.eu/en/analysis/publications/rail-and-waterborne-best-for-low-carbon-motorised-transport#:~:text=A%20new%20study%20commissioned%20by,basis%20would%20support%20these%20efforts.

[78] European Environmental Agency (2021). "Rail and waterborne – best for low-carbon motorised transport. https://www.eea.europa.eu/en/analysis/publications/rail-and-waterborne-best-for-low-carbon-motorised-transport#:~:text=A%20new%20study%20commissioned%20by,basis%20would%20support%20these%20efforts.

reduction objectives. Intermodality is not merely a line of action, but a complete re-architecture of traditional cargo distribution.

3.2. Intermodality in the Port Context

In this sense, ports stand out as “crucial hubs” for achieving European modal shift objectives of moving away from road transport and promoting the use of rail or waterborne transport instead. This is because ports very often act as the connection point between several transport modes, being able to leverage this strategic condition to facilitate mode transition.

As in any hub, intermodality implemented in ports translates into the optimisation of traffic flows and the reduction of CO2 emissions. Intermodal transport also promotes the minimisation of congestion, mainly from truck traffic, in ports, leading to reduced congestion and exhaust emissions[79].

Different potential modal combinations involve ports as the main intermodal actors. Maersk identifies the following, specifying that “the right configuration depends on distance, infrastructure access, cargo type, and speed requirements.”[80]

1. “**Ocean + truck:** Combines ocean freight with road transport for final delivery or drayage. Best for shorter inland distances, areas without rail access, and freight with flexible delivery schedules.

2. **Ocean + rail:** Pairs ocean freight with long-haul rail for efficient inland distribution. Offers cost savings for high-volume moves, provided rail infrastructure is accessible.

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[79] Karaś, A. The Role of Intermodal Transport in the Decarbonization of Seaports. November 2024. European Research Studies Journal, XXVII(2), 1014-1021. Available at: The Role of Intermodal Transport in the Decarbonizationof Seaports (3).pdf.

[80] Maersk, “Intermodal transport: What is it and how does it work?”. June 2025. Intermodal Transport: Types, Use Cases, and FAQs | Maersk

3. **Ocean + barge**: Links ocean shipping with inland water transport. Particularly useful in regions with navigable rivers and for heavy or bulk cargo that benefits from barge efficiency."[81].

One of the intermodal modes of transportation and a crucial component of the intermodal transportation system is sea-rail intermodal connection. Although intermodality often involves more than two modes of transport, the sea–rail link is the current and future trend in international cargo transportation, as long-distance cargo transportation—particularly for bulk products—has been considered the most important step toward achieving sustainable transportation[82].

Sea–rail intermodal transportation is the mode "in which goods are transported to coastal ports and wharves by rail and then transported to the destination port by ship, or goods are transported to coastal ports and wharves by ship and then transported to the final destination by rail"[83]. As literature indicates, one of the benefits of opting for this kind of freight movement is that it "only needs "one declaration, one inspection, one release" to complete the whole transportation process"[84], which, on top of enhancing the effectiveness of the movement of the goods, also simplifies traditional time-consuming associated bureaucratic requirements.

In this line, by linking railroads and waterways, the port serves as the backbone of sea-rail intermodal transportation, unifying different forms of transportation and enabling seamless trade. The port is "the link between port operations and landside operations, where port operations are the loading and unloading of goods, and landside operations are the loading and unloading of goods to other modes of transportation."[85]

Ports, given their role as crucial parts of economic systems, often act as the beginning, middle, and end of transportation networks. especially international transportation networks. Intermodality is already being implemented in certain ports

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[81] Maersk, "Intermodal transport: What is it and how does it work?". June 2025. Intermodal Transport: Types, Use Cases, and FAQs | Maersk
[82] Mathisen, T.A.; Hanssen, T.-E.S. The academic literature on intermodal freight transport. *Transp. Res. Procedia* 2014, *3*, 611–620. The Academic Literature on Intermodal Freight Transport - ScienceDirect
[83] Liu, T., & Wang, H. Evaluating the service capacity of port-centric intermodal transshipment hub. *Journal of Marine Science and Engineering, 11*(7), 1403. July 2023. https://doi.org/10.3390/jmse11071403
[84] *Ibid*.
[85] Liu, T., & Wang, H. Evaluating the service capacity of port-centric intermodal transshipment hub. *Journal of Marine Science and Engineering, 11*(7), 1403. July 2023. https://doi.org/10.3390/jmse11071403

worldwide. A concrete "real-life example of a target for modal split" is presented through an agreement involving the Rotterdam Port Authority. As part of the *Maasvlakte 2 initiative*, a condition was set for new terminal owners to cap the maximum modal share of road transport at 45%. This illustrates a direct involvement of a port authority in setting and enforcing policies to promote intermodal transport and reduce road dependency[86].

As highlighted, the role of the port authorities can be key to achieving modal shift. Assuming an “active landlord function”[87], port authorities have the capacity to implement strategies to coordinate the different stakeholders that interact in the port area, streamlining intermodal operations and leveraging their hinterland to increase efficiency and reduce, therein, emissions. Some of the strategies they can implement in this sense are the **usage of incentives, meaning “**coordinating “the operations of freight actors to improve the utilisation of transport chains and their underlying assets. It can involve using a preferential rate structure for customers that provide a minimum volume or meet a reliability level…”[88]; fostering alliances, such as “**vertical integration** (along transport chains), where a maritime shipping company and a terminal operator can agree to coordinate their services, or **horizontal integration** (between competitors), where an equipment or container pool can be established to improve asset utilisation”[89], or promoting “c**ollective actions**; strategies under the port authority leadership, such as setting up public-private partnerships to create a logistics zone...”[90].

In this light, by adopting an active and coordinated role, port authorities can act as pivotal enablers of modal shift. Incentives, alliances, and collective action will help make attractive the optimisation of the efficiency of transport chains to the main players that comprise it.

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[86] Tavasszy, Lóránt A., and Jaco van Meijeren. “*Modal Shift Target for Freight Transport Above 300km: An Assessment”*. Discussion Paper – 17th ACEA SAG Meeting, October 2011. Association des Constructeurs Européens d’Automobiles (ACEA). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.acea.auto/files/SAG_17.pdf.
[87] Notteboom, T., et al, “Port Economics, Management and Policy (1st ed.). January 2022. Routledge. https://doi.org/10.4324/9780429318184.
[88] *Ibid*.
[89] Notteboom, T., et al, “Port Economics, Management and Policy (1st ed.). January 2022. Routledge. https://doi.org/10.4324/9780429318184.
[90] *Ibid*.

3.3. Benefits and Opportunities - How Intermodality Supports Emission Reduction and Efficiency.

In recent years, intermodality has emerged as a key strategy towards the achievement of a cleaner and more sustainable port industry. It establishes itself as a powerful driver, mainly by tackling one key environmental aspect: emissions reduction. Increasingly, the literature and academia defend the evidence that this strategy quantitatively supports the reduction of the operational impact of ports in the environment.

By giving priority to transportation modes with lower pollutant outputs and implementing the most effective mode combinations while accounting for emissions throughout the whole transport chain, intermodality helps reduce harmful emissions.

In 2021 (the most updated complete dataset available), ClimateWatch reflected the following figure regarding global greenhouse gas emissions by sector:

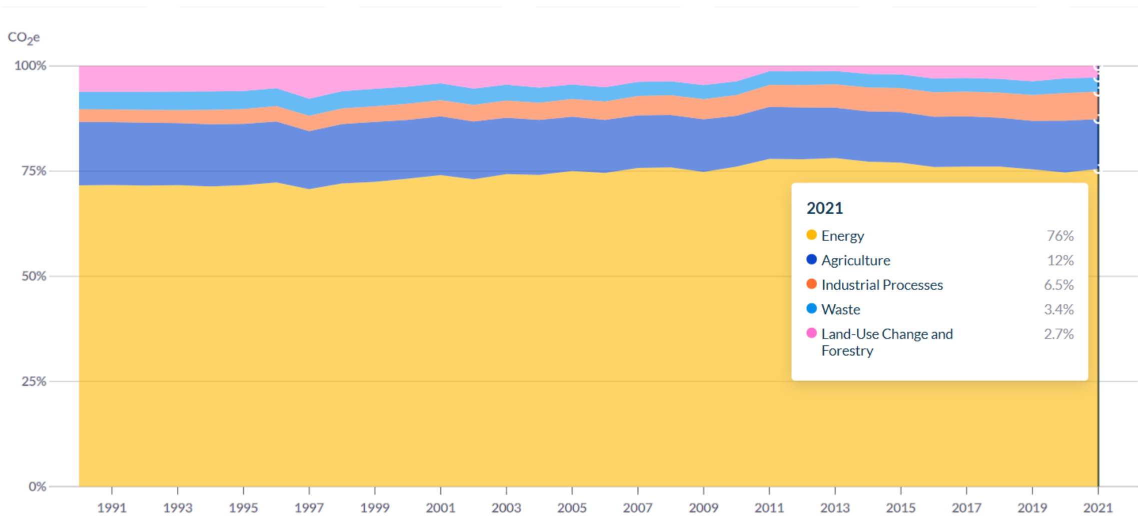

Figure 6 - Global Historical Emissions projected by ClimateWatch, 2021. Source: World | Total including LUCF | Greenhouse Gas (GHG) Emissions | Climate Watch

As evidenced, the predominant sector out of the five is "energy", representing around 76% of total emissions. Within it, it is calculated that transport accounts for around 14%, out of which around a 12% represents road transport while only around 2% is attributed to shipping[91]. The following image demonstrates these numbers graphically:

[91] World Resources Institute "Where Do Emissions Come From? 4 Charts Explain Greenhouse Gas Emissions by Sector". December 2024. https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors.

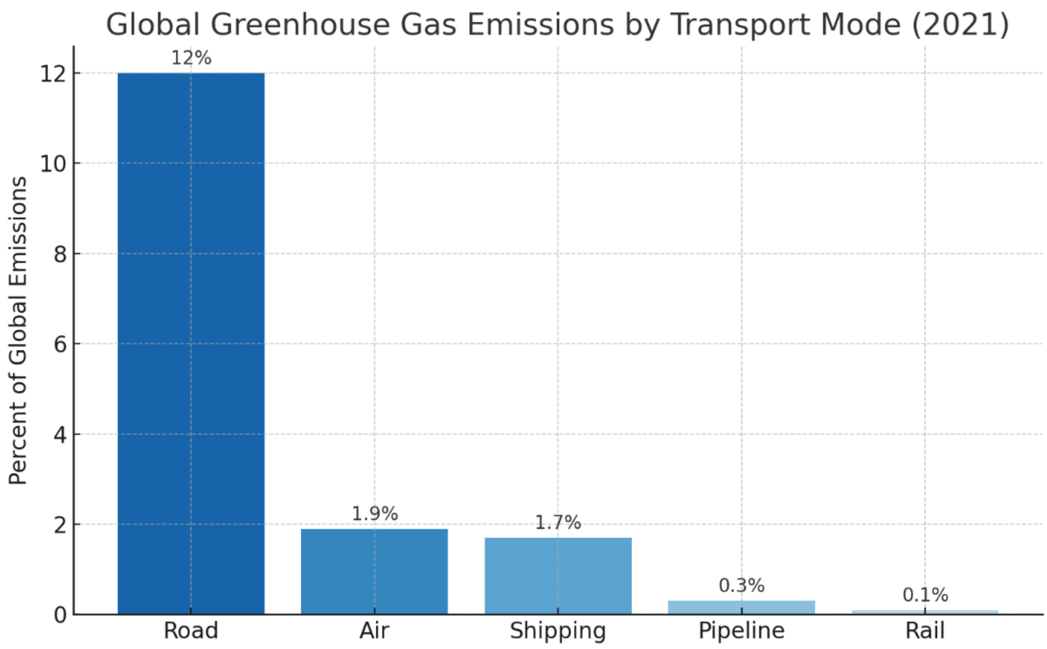

Figure 7- Global GHG emissions by mode. Source: own elaboration with data from World Resources Institute.

However, the Fourth IMO GHG Study 2020[92] has revealed a concerning step back in the reduction of emissions in the maritime sector, which is worth considering when moving forward with the implementation of intermodality. Its key findings in this sense are as follows:

- "The greenhouse gas (GHG) emissions — including carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), expressed in CO2e — of total shipping (international, domestic and fishing) have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase). In 2012, 962 million tonnes were CO2 emissions, while in 2018 this amount grew 9.3% to 1,056 million tonnes of CO2 emissions
- The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018.
- Under a new voyage-based allocation of international shipping, CO2 emissions have also increased over this same period from 701 million tonnes in 2012 to 740 million tonnes in 2018 (5.6% increase), but to a lower growth rate than total shipping emissions, and represent an

[92] International Maritime Organisation (2020). "Fourth IMO GHG Study 2020". Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://greenvoyage2050.imo.org/wp-content/uploads/2021/07/Fourth-IMO-GHG-Study-2020-Full-report-and-annexes_compressed.pdf.

> approximately constant share of global CO_2 emissions over this period (approximately 2%)…CO_2 emissions have increased over the period from 848 million tonnes in 2012 to 919 million tonnes in 2018 (8.4% increase)"[93].

Aware of this panorama, the management of logistic chains from an environmental point of view is progressively becoming more important to the point of shaping current supply processes. The utilisation of an interchangeable type of cargo unit, compatible with different modes of transport and, especially, the maximisation of each of these mode's benefits from an emissions perspective is a promising line of action towards sustainability in the sector.

In this line, the sea-freight mode has been classified as "the most efficient in terms of overall kg*eCO_2 per kilometre"[94]. A recent study developed by the University of Gdańsk and the University of Technology of Poznań, Poland[95], concluded that "intermodal maritime transport, taking into account the weight of the goods transported and the distance, is approximately 68% more efficient than road transport"[96].

To put the benefits of intermodal transport into perspective, the US Environmental Protection Agency determines the following statistics[97]:

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[93] International Maritime Organisation (2020). "Fourth IMO GHG Study 2020". Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://greenvoyage2050.imo.org/wp-content/uploads/2021/07/Fourth-IMO-GHG-Study-2020-Full-report-and-annexes_compressed.pdf.

[94] Bielenia, Małgorzata, Damian Dubisz, and Ernest Czermański. "Methodological Introduction to the Carbon Footprint Evaluation of Intermodal Transport." *Frontiers in Environmental Science*, vol. 11. August 2023, Section Environmental Economics and Management, https://doi.org/10.3389/fenvs.2023.1237763

[95] *Ibid*.

[96] Bielenia, Małgorzata, Damian Dubisz, and Ernest Czermański. "Methodological Introduction to the Carbon Footprint Evaluation of Intermodal Transport." *Frontiers in Environmental Science*, vol. 11. August 2023, Section Environmental Economics and Management, https://doi.org/10.3389/fenvs.2023.1237763

[97] U.S. Environmental Protection Agency, "Intermodal for Shippers". 2019. https://nepis.epa.gov/Exe/ZyNET.exe/P100X04Q.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2016+Thru+2020&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C16thru20%5CTxt%5C00000013%5CP100X04Q.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL/files/2019-07/documents/420f19013.pdf.

- An intermodal train can haul the equivalent of approximately 280 truckloads of freight.
- The relative energy efficiency of rail is estimated at 1.5 to five times that of trucking and the ratio for GHG emissions is similar.
- Railway operations on average emit about 15.07 grams of CO2 per tonne-kilometer compared to truck operations which emit approximately 44.52 grams per tonne-kilometer[98].

3.4. Challenges of Intermodality

Intermodality, as beneficial as it is from a sustainability point of view, does not come without associated challenges. Indeed, the implementation of this strategy faces a series of multifaceted difficulties that threaten its efficiency, hindering the seamless integration of maritime, rail, and road transport networks. Coordination efforts and physical constraints of the port space, including terminal capacity limits and last-mile bottlenecks, destabilise the efficiency of operations and the smooth connectivity of the port with its hinterland[99].

Furthermore, coordination between the different flows of the transport systems and the stakeholders and actors involved requires an extreme level of attention, since any mismatch on vessel arrival times with train schedules and/or truck availability may lead to inefficiencies and disconnections. Lastly, intermodality is also faced with institutional and regulatory obstacles that represent one more barrier to overcome.

A. Infrastructure Limitations and Operational Constraints.

Physical capacity is, naturally, the first factor that must be weighed in when considering effective intermodal implementation. Congested terminals, limited rail capacity and road-access restrictions may result in delays and increased logistic costs that

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[98] The US Environmental Protection Agency's findings have been converted into the European metric system.

[99] Liu, Y., & Wang, H, "Evaluating the service capacity of port-centric intermodal transshipment hubs. Journal of Marine Science and Engineering". June 2023. https://doi.org/10.3390/jmse11071403.

may threaten the viability of the intermodal chain, an obstacle that is particularly true for those ports that are situated in urban areas of high density[100].

In this line, potential bottlenecks derived from the complexity of coordinating the characteristics of each mode require the focus of optimisation and special attention to the loading and admission processes; otherwise, these structural obstacles have the potential of compromising the fluidity of the chains. Strategic investments in infrastructure and terminal capacity are, therefore, of essence to achieve a smooth interchange of transport units. Last-mile connections of the port with other modes, especially rail, must be the priority area for allocating efforts, ensuring the availability of sufficient track access to effectively compete against road transport and, in consequence, reduce emissions in the port area[101].

B. Intermodal Coordination

A second challenge that the effective implementation of intermodality faces derives from its overarching and holistic nature, as it requires the cooperation of many actors, of very diverse nature, that need to work together seamlessly to execute a unified action. Ports function within multi-actor environments where port authorities, rail operators, logistics providers, customs, and shipping lines pursue divergent objectives. This institutional fragmentation leads to conflicting priorities and weak alignment in strategic planning, undermining coordinated intermodal solutions[102].

The main entities and stakeholders that usually take part in the intermodal chain, both private and public, are shown in the consecutive figure:

[100] Karam, A., et al., "Analysis of the barriers to multimodal freight transport and their mitigation strategies". European Transport Research Review, 15(1), 43. November 2023. https://doi.org/10.1186/s12544-023-00614-0.

[101] Ambrosino, D., Asta, V., & Crainic, T. G. (2021). Optimization challenges and literature overview in the intermodal rail-sea terminal. Transportation Research Procedia, 52, 163-170. https://doi.org/10.1016/j.trpro.2021.01.089.

[102] Kringelum, L. B, "Reviewing the challenges of port authority business model innovation". *World Review of Intermodal Transportation Research*, *8*(3), 265-291. January 2019. https://www.researchgate.net/publication/336037803_Reviewing_the_challenges_of_port_authority_business_model_innovation#fullTextFileContent.

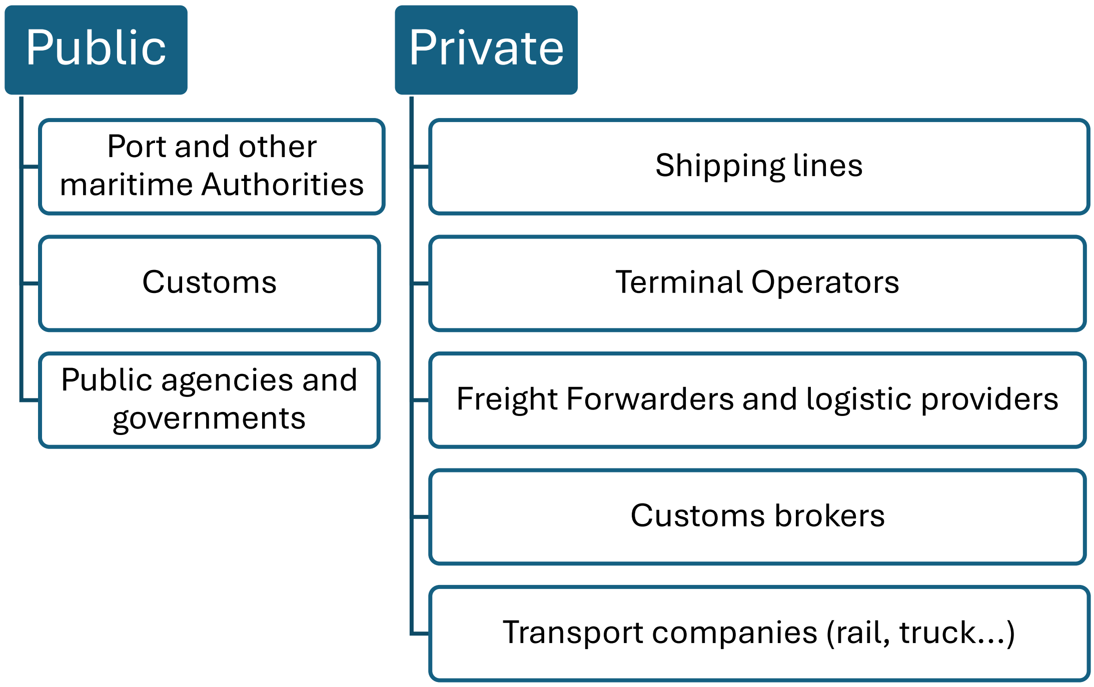

Figure 8- List of Main Public and Private Entities usually involved in the Intermodal Chain.

Apart from the excellent coordination effort required to effectively deploy intermodality, an additional challenge arises: the increased cost. In 2022, a report conducted by the European Court of Auditors concluded that, even though the most pollutant, road transport is often the cheapest and fastest method of delivering cargo, as it is not only more flexible, but it also offers a "door-to-door" journey[103]. The Court presented these figures in the following manner in its report:

[103] European Court of Auditors, "Special Report. Intermodal Freight Transport". 2023. Available at: Special report 08/2023: Intermodal freight transport

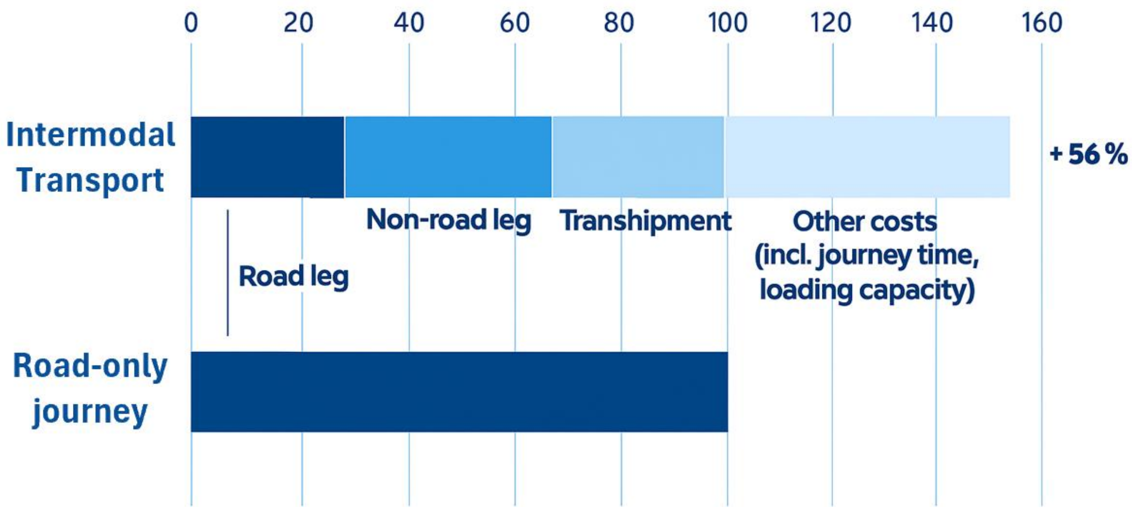

Figure 9- Cost comparison between intermodal and road-only freight transport

In this light, the synchronisation of the different actors involved becomes an essential requirement for ensuring the effective flow of the system, and without which, transportation success is impeded.

C. Policy, Regulatory and Institutional Barriers.

Finally, beyond physical capacity and effort coordination, intermodality in ports may be hampered by complex governance and institutional frameworks. Indeed, regulatory misalignments and discrepancies have the potential to hinder the interoperability of the overall system. An example of such obstacles can be found in the often-different standards and procedures across modes and jurisdictions.

Even though a complicated gap to overcome, these regulatory divergences could be addressed by the standardisation of technological systems across modes. Currently, many port systems are not integrated with hinterland logistics platforms. In this sense, Business Process Management Systems (BPMS) could streamline tasks such as cargo declarations and document management, but their adoption in port processes is still rare (Martín-Navarro, A., et al. (2020)). In this sense, “a wide range of business processes in port operations can be optimised through the adoption of more advanced technologies. Such tools facilitate greater coordination and automation of critical functions, including the preparation of cargo manifests, customs clearance procedures, scheduling management, and the handling of dangerous goods”[104].

[104] Martín-Navarro, A., Sancho, M. P. L., & Medina-Garrido, J. A. (2020). Business process management systems in port processes: a systematic literature review. International Journal of Agile Systems and Management, 13(3), 258-278. https://doi.org/10.1504/IJASM.2020.109245.

4. Case Studies: Intermodality in Action

As seen, theory already backs intermodality as a key sustainable solution; but a strategy is only as strong as the practical result of its implementation. In this line, this section aims at examining three major ports within the European Union, namely the ports of Rotterdam, Barcelona and Hamburg, which, with different characteristics, have assumed intermodality as a differentiating strategy and committed to its implementation.

4.1. Port of Rotterdam: Largest Port in Europe, Leading through Integrated Intermodal Solutions

Port of Rotterdam

1. **Location:** Rotterdam, the Netherlands
2. **Length of the Port Area:** 42 km
3. **Containers annually/ Cargo throughput:** approximately 436 million tonnes of freight a year[105].

[105] Port of Rotterdam, "Facts and Figures". Facts and Figures | Port of Rotterdam

4. Handles primarily: - Liquid Bulk, including crude oil, LNG, and other petroleum products, serving as a critical import centre and refining hub for Northwest Europe. - Dry Bulk: The port handles large quantities of raw materials like iron ore, coal, and agricultural products.
5. Uniqueness: Largest port in Europe.
6. Environmental focus- Pioneering initiatives: - *Maasvlakte 2 initiative.* - *Virtual Energy System.*

Stretching over "40 kilometers in length and 10 kilometers in width," [106] the Port of Rotterdam is the largest port complex in Europe and one of the most important players in the global supply chain. It welcomes around "30,000 oceangoing ships and 130,000 river ships annually"[107], enabling a smooth flow of goods worldwide. As declared by the European Union, "Rotterdam was by far the EU port with the highest activity in Q4 2024, with 98.5 million tonnes of gross weight of goods handled"[108], continuing to lead the EU in port activity. Worldwide, Rotterdam ranks as the world's fifth-largest bulk port and among the top ten cargo handlers[109].

Aware of its dynamic role in global trade, the port continues to grow and modernise, focusing on three main lines of action: improving safety, inclusivity and sustainability[110]. Given its size, its role in the European economy and its compromise with intermodal logistic systems, Rotterdam stands out as an example for efficiency and reduction of ports' environmental impact.

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[106] Sinay, "What is a transshipment hub? Top transshipment ports in the world". May 2025. Available at: https://sinay.ai/en/what-is-a-transshipment-hub-top-transshipment-ports-in-the-world/
[107] *Ibid.*
[108] Eurostat, "Maritime transport of goods at port level - quarterly data". June 2025. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_transport_of_goods_at_port_level_-_quarterly_data.
[109] World Shipping Council, "Top 50 Container Ports". N/D. https://www.worldshipping.org/top-50-ports
[110] Port of Rotterdam, "Welcome to the Port of Rotterdam". N/D. https://www.portofrotterdam.com/en.

Rotterdam's elevated flow of traffic, the multimodal nature of its infrastructure and its strategic interconnection with Europe's hinterland make out of the port the perfect test ground for studying intermodal integration as a sustainable strategy, as it is also a neuralgic point where several modes, namely, sea, inland waterways, rail and road, collide.

The port's climate action is architected around 4 main pillars: 1) increased efficiency and better infrastructure, 2) increased assimilation and production of new energies, such as green hydrogen and other biofuels, 3) implementation of new raw materials and fuel systems and 4) sustainable transport.

In this sense, Rotterdam has set the goal of becoming a frontrunner of the energy transition by accelerating its own CO2 emissions, establishing as a target the reduction of at least 90% carbon emissions in 2030 when compared to 2019 levels[111].

Concerning shipping itself, the port strategy targets the management area, which extends 60km inland from the coast. It sets the objective of reducing emissions by, at least, 20% in 2030, through the progress of various developments. Among these are the "application of shore power (so that berthed ships can switch off their generators and plug in), and bunkering clean fuels (such as LNG, biofuels, and methanol) by shipping". Efficiency increase, however, is at the forefront of these strategies, which aims at optimising the logistics processes and smoothing the flows, opening the space for intermodality to play a key role in the achievement of this goal.

Routescanner's 'Direct Connections'[112] interactive map, also available at Rotterdam's Port website, shows the direct sea, railway and inland shipping connections from and to Rotterdam:

[111] Port of Rotterdam, "The Port of Rotterdam Authority accelerates the reduction of its own carbon emissions" June 2022. http://portofrotterdam.com/en/news-and-press-releases/the-port-of-rotterdam-authority-accelerates-the-reduction-of-its-own-carbon

[112] Route Scanner. Direct Connections. Last accessed 13.09.2025

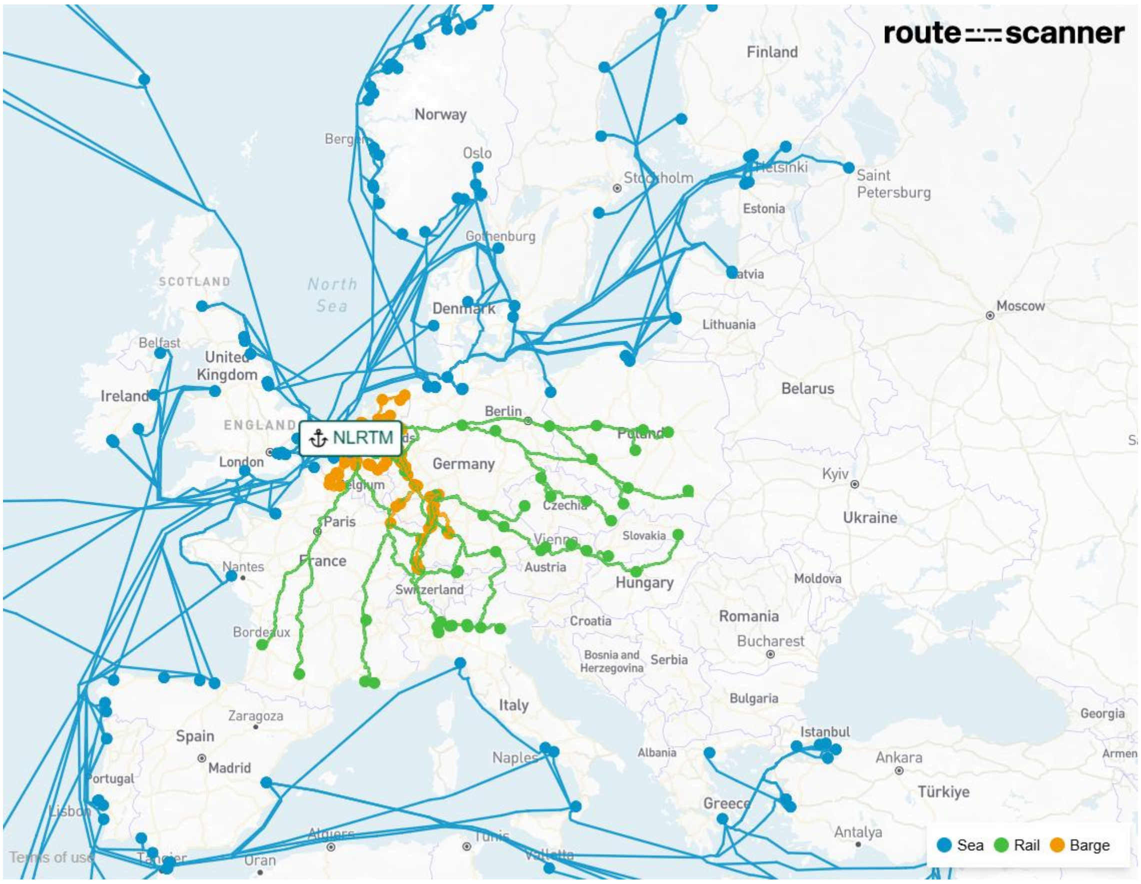

Figure 10- Direct sea, railway and inland shipping connections from and to Rotterdam.

Among its innovative strategies, it is worth highlighting the Maasvlakte 2 initiative, through which new terminal owners now have the possibility to cap the maximum modal share of road transport at 45%, revealing a direct involvement of a port authority in setting and enforcing policies to promote intermodal transport and reduce road dependency[113].

Furthermore, the "Virtual Energy System" project aims to "create a more sustainable, reliable, and competitive energy system by developing a simulation model that visualises and measures sustainable energy solutions within energy clusters"[114]. It is an AI-powered model, fed by qualitative data, which enables stakeholders to see "the potential impact of various strategies, leading to better decision-making. The prototype developed under this project provides real-time insights into energy flows and metrics for

[113] Tavasszy, Lóránt A., and Jaco van Meijeren. "*Modal Shift Target for Freight Transport Above 300km: An Assessment*". Discussion Paper – 17th ACEA SAG Meeting, October 2011. Association des Constructeurs Européens d'Automobiles (ACEA). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.acea.auto/files/SAG_17.pdf.
[114] Port of Rotterdam. Artificial Intelligence in the Port. https://www.portofrotterdam.com/en/port-future/innovation/artificial-intelligence-port.

sustainability, reliability, and competitiveness"[115]. By modeling various situations, the model assists in determining the best course of action to fulfill the port's goal of becoming the most sustainable port globally, which will help to green logistics and industry while enhancing the standard of living.

4.2. Port of Barcelona: Rail and Sea Connectivity for Sustainability at a Cruise Hub.

Port of Barcelona

1. Location: Barcelona, Spain.
2. Length of the Port Area: 23km
3. Containers annually/ Cargo throughput: 3.1 million TEU**.**
4. Handles primarily: Containers, vehicle traffic and touristic cruise ships.
5. Uniqueness: Diversified facet.
6. Environmental focus- Pioneering initiatives: - *Nexigen.* - *Positive Impact Port*

[115] Port of Rotterdam. Artificial Intelligence in the Port. https://www.portofrotterdam.com/en/port-future/innovation/artificial-intelligence-port.

Barcelona's Port stands out as one of the main logistic hubs along the strategic Mediterranean Sea. Its origins trace back to the 10th century, performing a central role as a neuralgic trade centre for the Roman Empire. Today, the port is among the top 10 busiest ports in the European Union. It is the 1st in Spain regarding international traffic[116] and the 3rd in container movement, handling around 3.1 million TEU annually. It is, as well, the 1st cruise port in Europe and the 4th worldwide[117].

The uniqueness of this port, however, relies on its diversified nature. It not only mobilises cargo, but also vehicle traffic and, especially, cruise ships, seamlessly integrating logistics, trade and tourism. Furthermore, its management is focused on making out if it a smart port by betting on technology integration and innovation, pioneering in this sense. Positioned, therefore, at the vanguard of digitalisation, another signature characteristic of Barcelona's port is its commitment to sustainability and the energy transition of the port sector.

In this context, the port is renowned for leading frontrunner initiatives to support the decarbonisation of the industry:

In terms of the energy transition, "*Nexigen*" is its current leading project. It consists of an "ambitious plan to electrify docks in order to supply renewable electricity to ships while they are in port. The €200 million investment has enabled the installation of Onshore Power Supply (OPS) systems, which prevent ferries and cargo ships from having to start their engines and therefore eliminate emissions". It constitutes a key step towards aligning Barcelona's port activities and ultimately contributing to the decarbonisation of the Mediterranean space[118].

Furthermore, Barcelona Port aims to establish itself as a reference for sustainability capacity-building in the sector. In this context, its key project, the only one of these characteristics at an international level, is "*Positive Impact Port***".** Its primary objective is to develop an annual report on sustainability, measuring and monitoring the

[116] Port de Barcelona. Port de Barcelona | Inicio.
[117] Port of Barcelona. Port of barcelona: An Intermodal Hub bridging Morocco and Europe
[118] Port de Barcelona, "Nexigen". Nexigen | Port de Barcelona

advancements and milestones achieved in this area by the region's Port Community. It developed around three main areas[119]:

- Environmental sustainability – reducing emissions, energy and waste management, water consumption, and promoting decarbonisation projects.
- Social sustainability – gender equality, training, workplace wellbeing, risk prevention, environmental awareness.
- Good governance and ethics – existence of sustainability managers in companies, environmental criteria in the hiring of suppliers, internal communication of sustainability policies.

Every year, a survey is shared with the main organisations and stakeholders of the Community, analysing more than "170 indicators"[120], which allowed for data compilation and storage for the further development of capacity-building in sustainability.

The project also elaborates and defines a Strategic Sustainability Plan 2030, which establishes three objectives: foster the protection of the environment, a fair port and an ethical port[121], aligning the port with the Sustainable Development Goals (SGDs) of the United Nations for 2030.

Since the propulsion of this initiative, as reported by Barcelona's Port Authority, "environmental sustainability projects continue to grow among port companies: 63% measure their energy consumption; 52% have an energy management policy; and 68% of companies implement measures to reduce the waste they generate"[122].

Nonetheless, the port of Barcelona stands out from other European Ports for one commitment: its firm stance on intermodality. Indeed, the increase of the intermodal offer within the port is one of its central sustainable strategic goals, aiming to consolidate its position as a European leading hub in this context[123].

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[119] Port de Barcelona, "La iniciativa 'Positive Impact' del Port de Barcelona, finalista de los IAPH 2025 Sustainability Awards". August 2025. La iniciativa 'Positive Impact' del Port de Barcelona, finalista de los IAPH 2025 Sustainability Awards | Port de Barcelona.
[120] *Ibid.*
[121] Port de Barcelona, "La iniciativa 'Positive Impact' del Port de Barcelona, finalista de los IAPH 2025 Sustainability Awards". August 2025. La iniciativa 'Positive Impact' del Port de Barcelona, finalista de los IAPH 2025 Sustainability Awards | Port de Barcelona
[122] *Ibid.*
[123] Port de Barcelona, « Sostenibilidad ». Sostenibilidad | Port de Barcelona

The port integrates several modes of transport, namely maritime, air, road and, as its main focus, rail. Regarding the latter, Barcelona has deployed an extensive network of rail services, being the only port in Spain with connection to the European Gauge Connection[124], enabling direct, border-free rail freight transport with international destinations, becoming the leader in the country in this sense. This network is seamlessly connected to a wide range of locations, both national and international, being this highly rail connectivity its differentiating factor, strengthening its competitiveness in external trade within its hinterland.

The following image reflects Barcelona's wide range of intermodal services and connections:

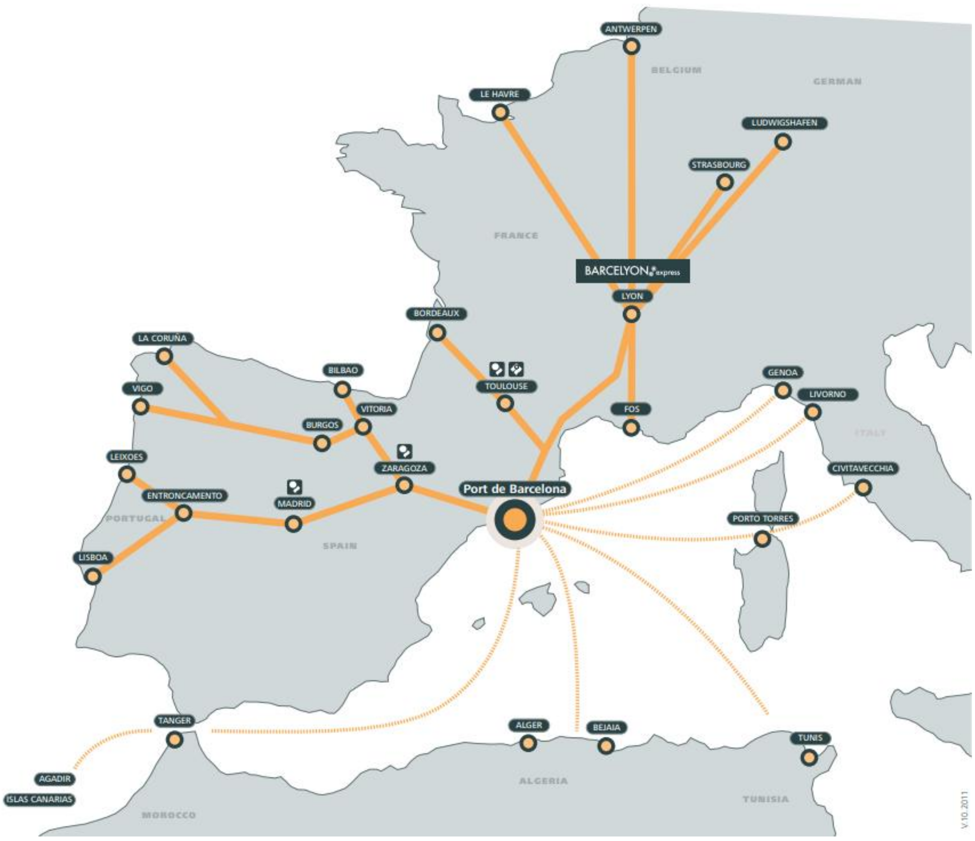

Figure 11- Intermodal Services from the Port of Barcelona[125]

Moreover, several terminal operators within the port count with an integrated railway terminal inside their facilities that further enhances the smooth development of the intermodal chain[126].

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[124] Port de Barcelona, « Intermodality ». Intermodality_WWW
[125] Source: Intermodality_WWW.
[126] Port of Barcelona. Port of barcelona: An Intermodal Hub bridging Morocco and Europe.

The commitment of the Port with intermodality and its strengthening sea-rail pairing came to a peak in March of 2024, when both the National Railway Infrastructure Manager, ADIF, and the Port Authority of Barcelona came together to join efforts in a shared company, "Train Port Barcelona"[127]. Its primary task will be to manage the railway logistics hub comprising the intermodal terminals at Can Tunis and La Llagosta and the future terminals at the port and the railway motorway[128]. This constitutes a historical step to centralise and ensure the coordination of the effective intermodality deployment in the port, overcoming the principal challenge that this implies.

Therefore, it is evident that Barcelona's Port leverages its extensive intermodal offer as a differentiating factor, highly investing in infrastructure and services that ensure a smooth and direct connection of goods from ships to other means of transport.

In essence, Barcelona is an excellent example of not effective deployment of intermodality in a port, but the assimilation of it as a key identitarian factor and the chosen strategy to achieve sustainability.

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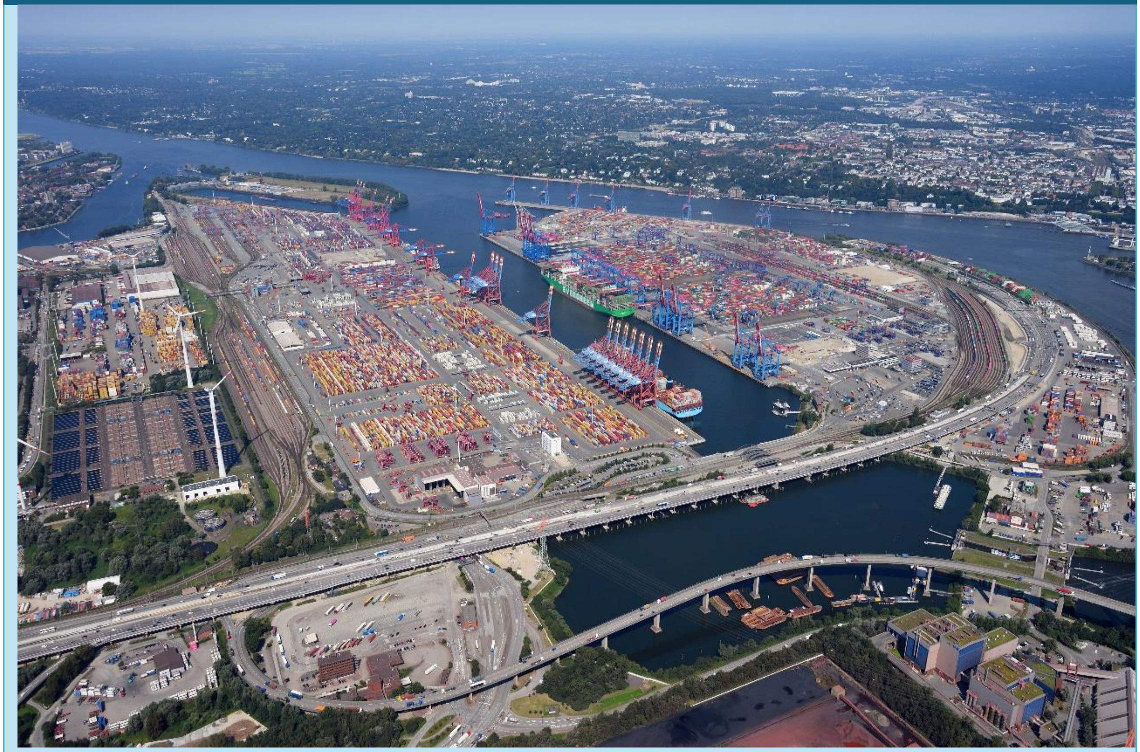
[127] ADIF, "Adif y el Port de Barcelona lanzan la sociedad Train Port Barcelona para impulsar el transporte de mercancías". March 2024. Adif y el Port de Barcelona lanzan la sociedad Train Port Barcelona para impulsar el transporte de mercancías - Adif

[128] *Ibid*.

4.3. Port of Hamburg: Intermodal Innovation for Emission Reductions

Port of Hamburg

7. **Location:** Hamburg, Germany.
8. **Length of the Port Area:** 72 km.
9. **Containers annually/ Cargo throughput:** 46 million tonnes of goods and 2.6 million TEU**.**
10. **Handles primarily:** container cargo, general cargo, bulk goods (such as coal, iron ore, and agricultural products), and vehicles. This diversity of cargo contributes to Hamburg's position as a multipurpose port and as Germany's leading trading Gateway.
11. **Uniqueness:** Europe's largest rail port and the second in the world
12. **Environmental focus- Pioneering initiatives:** - Port Railway: largest port railway network in Europe. Handles over 200 freight daily, a crucial component of the intermodal strategy. - TransPORT Rail IT-System.

The Port of Hamburg, Germany, is the largest seaport in the country and the third in Europe. It is the largest multipurpose and leading port in the country in terms of foreign trade, in great part allowed by its strategic location between the Baltic Sea and the North Sea. However, the uniqueness of this port is being Europe's largest rail port[129].

Its strategy is rooted in 3 main objectives: digitalisation, investment in technology of the handling facilities and, more importantly, efficiency of transport chains and, in particular, rail-sea intermodality.

As the Port reported, "with a volume of 5.2 million TEU, hinterland traffic at the Port of Hamburg moved more goods than in 2023. Transhipment reached a volume of 2.6 million TEU. In terms of tonnage, hinterland transport accounted for 83.1 million tonnes and transhipment for 28.7 million tonnes.

Rail is particularly noteworthy in the modal split, moving 46.2 million tonnes and 2.6 million TEU in 2024. Indeed, rail once again surpassed the 50 percent mark, holding a 50.2 percent share of container transport… Rail also gained ground in the tonnage-based modal split"[130]. These numbers consolidate Hamburg as the largest rail port in Europe, the key to its market leadership.

The Port of Hamburg's prime asset is its exceptional rail links. As the port itself publishes, the railway has "a track network of about 300 kilometres, which efficiently handles around 200 goods trains with over 5,500 railcars daily. To ensure seamless rail traffic all container terminals have cutting-edge, high-performance handling facilities. Multi-purpose and bulk cargo terminals are also connected to the rail network."[131]

Every week, around 2,000 container train connections take place between Hamburg and the European hinterland. In the Czech Republic, Austria, and Hungary, more than 90% of exports are transported by rail to and from the Port of Hamburg. With 200 scheduled weekly connections, Europe's top rail port is also critical to the New Silk Road to China[132].

To put Hamburg's intermodality into true perspective, around half of the container units that arrive at or depart from the port do so by rail, making Hamburg the largest rail

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[129] Hafen Hamburg. The Port of Hamburg | Port of Hamburg
[130] Port of Hamburg, "Porto f Hamburg: Growth in Container Throughput and Rail Transport". February 2025. Port of Hamburg | Port of Hamburg: Growth in container throughput and rail transport
[131] Port of Hamburg, "Europe¡s largest rail port". https://www.hafen-hamburg.de/en/hinterland/rail/-
[132] Port of Hamburg, "Port of Hamburg- Gateway to the World". portofhamburg.com | Hamburg, Your Port!

port in Europe and second in the world[133]. As explained by HHLA logistic network, one of the port's main operator, "In a direct comparison, more goods are transported by rail in the Port of Hamburg than in the ports of Rotterdam and Antwerp combined. This outstanding position underlines the efficiency of Hamburg's rail port."[134]

In its tracks, more than 160 rail companies operate[135], and all terminals count with access to the mode via the Port Railway. This structure is, as explained by the Hamburg Port Authority, "a link between the transhipment companies and the European rail network. Whether the goods are transported from the port to the four corners of the world or vice versa, the Port Railway provides the necessary infrastructure for every rail transport company that wants to access the Port of Hamburg"[136].

Furthermore, these intermodal services are governed by the *TransPORT rail IT-system*, which "settles all train journeys, occupancies and loading processes in the port".

When examining the environmental benefits, the Port of Hamburg's intermodal strategy specifically targets the most environmentally friendly option for its characteristics: the combination of large ships and rail. From an ecological perspective, rail freight transport is particularly advantageous. Compared to trucks, trains emit 110 times less CO2 per tonne-kilometre and require only 1.2 hectares of space per kilometre travelled, compared to 3.6 hectares for road freight transport[137]. Rail is ideal for long distances and the transport of large quantities, thus contributing to more efficient and environmentally friendly logistics chains. Aware of this, the Port's intermodal strategy targets the optimisation of land use and emissions to effectively take a step towards more sustainable logistics, setting an example for other ports to emulate.

The following images, extracted from the Port of Hamburg website's interactive map, reflect the intermodal connections offered, mostly covered by rail. It reflects the vast territory these services encompass, spanning across the German and European Hinterland, but also through the New Silk Route to Asia:

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133 https://hhla.de/en/the-power-of-networks/intermodal-logistics/railway-port-hamburg.
134 *Ibid*.
135 Port of Hamburg, "Europe¡s largest rail port". https://www.hafen-hamburg.de/en/hinterland/rail/-
136 Hamburg Porth Authority, "PORT RAILWAY: FROM THE DOCKS TO THE HEART OF EUROPE". https://www.hamburg-port-authority.de/en/port-railway.
137 Port of Hamburg, "Hamburg Railway Port: Europe's Frontrunner". https://hhla.de/en/the-power-of-networks/intermodal-logistics/railway-port-hamburg.

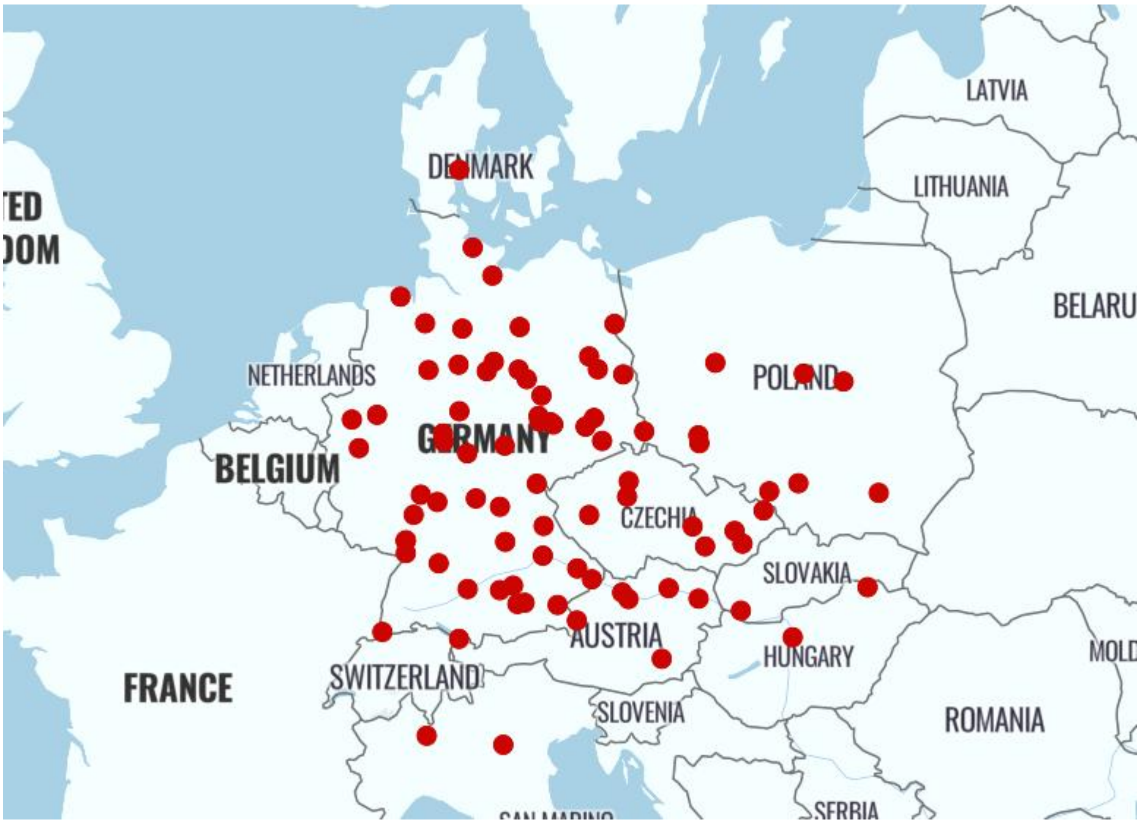

Figure 12- Image of the European Hinterland locations covered by intermodal services from the Port of Hamburg

Figure 13- Global intermodal connections locations offered from the Port of Hamburg

Hamburg's success serves a benchmark example for the industry, showing how a strategic and forward-thinking approach to intermodality can create a more resilient, efficient, and environmentally responsible global supply chain. Hamburg continues to set the standard for port operations.

4.4. Case Studies Conclusions

The study of these three key ports concludes that intermodality is not a mere theoretical solution, but a practical and fundamental strategy of modern ports. This is due to the fact that it not only allows ports to promote sustainability and the achievement of the climate targets set for the industry, but it also serves to differentiate those hubs implementing it as a differentiating factor from others, enhancing their competitiveness and position in the European and even international market.

These three ports, regardless of their different characteristics, have successfully integrated intermodality as a key component of their operations, with the aim to reduce emissions and optimising transport flows both within the port itself and its hinterland.

The following specific conclusions can be, therefore, drawn from the empirical implementation of intermodality:

- **Intermodality has become a well-settled strategy and a pillar of present and future port sustainability.**
  Three of the most relevant ports in Europe, each for diverse motives, utilise intermodality, particularly the maritime-rail connection, stepping away from road transport to reduce their environmental footprint. The Port of Hamburg stands out, as around half of its container traffic is indeed moved by rail. Barcelona, apart from implementing innovative programs such as *Nexigen* for the electrification of docks, intermodality is present in every decision. The direct connection to the European UIC gauge network is the key to efficient and borderless rail transport. Finally, the Port of Rotterdam relies on its vast multimodal infrastructure to build its efficiency strategy directly around the promotion of intermodality.
- **Intermodal efficiency as a competitive advantage.**
  But, as evidenced, intermodality is not merely an environmental decision, but a strong economic competitiveness line of action that help ports implementing it strengthen their position in the market and differentiate themselves.
- **Importance of technological innovation and adequate infrastructure to support the strategy.**
  The case studies highlight that the success of the implementation of intermodality must be accompanied by supporting factors. In Hamburg, *TransPORT Rail IT* is a key component of the reliable intermodal operations within the port, while both

Barcelona and Rotterdam integrated rail terminals are a key infrastructure to ensure the fastest, most efficient manner of transferring gids between these modes. Furthermore, key stakeholder collaboration, such as the one between Barcelona Port and ADIF is crucial not only for the present, but for the future further development of intermodality.

In light of the above, the case studies analysed in this chapter evidence that intermodality is a proven tool for enhancing sustainability within the port industry. This strategy, commencing to settle and expand, is not only demonstrably feasible; it has also produced tangible benefits, both in regard to the environment and the competitiveness of the port. These empirical results provide a useful confirmation of the theoretical hypotheses of this study, demonstrating the importance of intermodality in accomplishing sustainability and efficiency goals in the port industry.

5. Conclusions.

The port sector has historically been a critical nexus in global trade, accompanying human progress and necessities and acting as the main channel for economic growth. For centuries, volume capacity and throughput efficiency were the main concerns. However, the industry is navigating a fundamental paradigm shift in the modern era. Ports are changing from being merely logistical hubs to becoming proactive change agents, prompted by international agreements such as the Kyoto Protocol and growing environmental consciousness worldwide.

In this sense, the present research paper aimed at examining in an informed manner a central premise: that intermodality can effectively promote decarbonisation and sustainability in the port industry. Based in this overarching objective, three hypotheses were formulated, whose study performs the role of guiding the evaluation of intermodality within the context of port sustainability.

The findings of this dissertation, derived from technical and regulatory analysis, as well as the study of practical cases, allow to affirm conclusively the validity of the presented hypothesis:

i. ***To identify and evaluate the degree to which ports are currently integrating sustainable solutions within their infrastructures and operations, highlighting best practices and challenges in their implementation***

The study has demonstrated that the port sector has moved on from simply taking conscience to becoming a frontrunner of the ecological transition in the transport industry. Several milestones highlight this fact, such as the expansion of the "green port" concept, not only as a label to easily identify those ports undertaking the bigger efforts, but as a strategic framework to help guide the implementation of sustainable solutions and set practical precedents and best practices to be emulated by other hubs. Among these, common exercises are the electrification of equipment and digitalisation, the implementation and on-site production of renewable sources to feed the port and, most notably, the optimisation of the operation processes. Case studies emphasise the successful practical adoption of these solutions, often leading to advantageous market placement and enhanced competitiveness of these ports in comparison to others.

However, while leveraging these positive findings, the investigation has also brought out significant challenges that the effective settlement of sustainability and, particularly, intermodality, face and must overcome. The three most notable are: a)

Infrastructure limitations and operational constraints; b) Coordination of the different stakeholders and agents involved and, c) Policy, Regulatory and Institutional Barriers.

Regarding the second hypothesis:

- ***To assess whether intermodality, in combination with other sustainable port strategies, can significantly contribute to the decarbonisation goals set by international organisations and regional bodies, such as the International Maritime Organization (IMO) and the European Union.***

Intermodality, in combination with other sustainability strategies, has been found to be not only a complement, but an essential contributor to decarbonisation objectives. The analysis of the regulatory frameworks, such as the IMO 2023 strategy or the Fit for 55 Package has demonstrated that the industry faces not a voluntary assimilation of sustainability, but a mandatory imperative requirement.

By enabling the modal shift from traditional road transport to, especially, rail, a substantial reduction in emissions per tonne-kilometre transported is achieved. Therefore, while strategies within the port terminal are important, the impact of intermodality extends to the entire supply chain, maximizing the reduction of the total carbon footprint of logistics operations.

Finally, as for the third and main hypothesis:

- ***Ultimately leverage if intermodality effectively serves as a strategic tool for enhancing the sustainability of port operations, having as a result optimised logistic flows, lesser greenhouse gas emissions and overall reduction of the environmental footprint of activities.***

This work demonstrates that intermodality is not simply an efficiency choice, but a **fundamental strategic tool** for sustainability. The case studies of the ports of Rotterdam, Barcelona and, paradigmatically, Hamburg, provided empirical evidence that the optimisation of logistics flows through intermodal integration has a direct and positive effect on the reduction of greenhouse gas emissions.

The Port of Hamburg, which has consolidated its position as the largest rail port in Europe, is a clear example of how a strategic approach to intermodality translates into a measurable reduction in the carbon footprint and an increase in competitiveness and operational resilience. The evidence presented suggests that ports that invest in intermodality will not only be better positioned to meet regulatory demands, but will also gain a competitive advantage by offering faster, more flexible and sustainable supply chains.

In conclusion, this work has proven that intermodality is a strategic and necessary pillar in the ecological transition of the port sector. The findings suggest that a continued focus on intermodal network development, supported by infrastructure investment and actors' collaboration, will be crucial for ports to meet regulatory demands and position themselves as agents of change in the fight against climate change. Future research could focus on the role of emerging technologies, such as artificial intelligence and *blockchain*, in further optimising the coordination of intermodal flows and accelerating decarbonisation.

Bibliography

Books and Book Chapters

- Quinn, J. *All at Sea: The Maritime Lives of the Ancient Phoenicians*. Princeton: Princeton University Press, 2020.
- Levinson, Marc. *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger - Second Edition with a New Chapter by the Author*. Princeton University Press, 2016. https://doi.org/10.2307/j.ctvcszztg.
- Notteboom, T., et al. *Port Economics, Management and Policy*. 1st ed. Routledge, 2022. https://doi.org/10.4324/9780429318184.

Journal Articles & Academic Papers

- Ambrosino, D., Asta, V., & Crainic, T. G. "Optimization challenges and literature overview in the intermodal rail-sea terminal." *Transportation Research Procedia* 52 (2021): 163-170. https://doi.org/10.1016/j.trpro.2021.01.089.
- Bielenia, M., et al. "Methodological Introduction to the Carbon Footprint Evaluation of Intermodal Transport." *Frontiers in Environmental Science* 11 (2023). https://doi.org/10.3389/fenvs.2023.1237763.
- Cullinane, K., & Yang, Y. "Evaluating the Costs of Decarbonising the Shipping Industry: A Review of the Literature." ResearchGate, 2022. https://www.researchgate.net/publication/361905604_Evaluating_the_Costs_of_Decarbonizing_the_Shipping_Industry_A_Review_of_the_Literature.
- Karaś, A. "The Role of Intermodal Transport in the Decarbonization of Seaports." *European Research Studies Journal* XXVII, no. 2 (2024): 1014-1021. https://doi.org/10.35808/ersj/2005.
- Karam, A., et al. "Analysis of the barriers to multimodal freight transport and their mitigation strategies." *European Transport Research Review* 15, no. 1 (2023): 43. https://doi.org/10.1186/s12544-023-00614-0.
- Kringelum, L. B. "Reviewing the challenges of port authority business model innovation." *World Review of Intermodal Transportation Research* 8, no. 3 (2019): 265-291. https://www.researchgate.net/publication/336037803_Reviewing_the_challenges_of_port_authority_business_model_innovation#fullTextFileContent.
- Lagouvardou, S., & Psaraftis, H. "Implications of the EU Emissions Trading System (ETS) on European container routes: A carbon leakage case study."

Research in Transportation Business & Management 45 (2022). https://www.sciencedirect.com/science/article/pii/S2666822X22000107.

- Liu, T., & Wang, H. "Evaluating the service capacity of port-centric intermodal transshipment hub." *Journal of Marine Science and Engineering* 11, no. 7 (2023): 1403. https://doi.org/10.3390/jmse11071403.
- Martín-Navarro, A., Sancho, M. P. L., & Medina-Garrido, J. A. "Business process management systems in port processes: a systematic literature review." *International Journal of Agile Systems and Management* 13, no. 3 (2020): 258-278. https://doi.org/10.1504/IJASM.2020.109245.
- Mathisen, T. A., & Hanssen, T.-E. S. "The academic literature on intermodal freight transport." *Transp. Res. Procedia* 3 (2014): 611–620. https://www.sciencedirect.com/science/article/pii/S221201731400263X.
- Tavasszy, Lóránt A., and Jaco van Meijeren. "Modal Shift Target for Freight Transport Above 300km: An Assessment." Discussion Paper – 17th ACEA SAG Meeting, October 2011. Association des Constructeurs Européens d'Automobiles (ACEA). https://www.acea.auto/files/SAG_17.pdf.

Reports and Documents

- European Court of Auditors. "Special Report. Intermodal Freight Transport." 2023. https://www.eca.europa.eu/en/publications/special-report-08-2023-intermodal-freight-transport.
- European Environment Agency. "EU maritime transport: first environmental impact report acknowledges good progress towards sustainability and confirms that more effort is needed to prepare for rising demand." Noticia, 1 de septiembre de 2021. https://www.eea.europa.eu/highlights/eu-maritime-transport-first-environmental.
- European Environment Agency. "Rail and waterborne – best for low-carbon motorised transport." Noticia, 18 de mayo de 2021. https://www.eea.europa.eu/en/analysis/publications/rail-and-waterborne-best-for-low-carbon-motorised-transport.
- European Commission. "Commission Staff Working Document: Impact Assessment Report Accompanying Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society." SWD(2024) 63 final – Part 3 (Figura 76, p. 99). https://eur-lex.europa.eu/resource.html?uri=cellar:6c154426-c5a6-11ee-95d9-01aa75ed71a1.0001.02/DOC_3&format=PDF.

- European Commission. "Reducing Emissions from the Shipping Sector." Accessed 14 September 2025. https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en.
- European Commission. "Revision of the Energy Taxation Directive." Accessed 14 September 2025. https://taxation-customs.ec.europa.eu/taxation/excise-taxes/revision-energy-taxation-directive_en.
- European Commission. "The European Green Deal." Accessed 14 September 2025. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
- European Commission. "Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions." Comunicado de prensa, marzo de 2011. https://ec.europa.eu/commission/presscorner/detail/en/ip_11_372.
- European Commission. "Decarbonising maritime transport – FuelEU Maritime." Accessed 14 September 2025. https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en.
- European Commission. "European Climate Law." Accessed 14 September 2025. https://climate.ec.europa.eu/eu-action/european-climate-law_en.
- European Commission. "Multimodal and combined transport." Accessed 14 September 2025. https://transport.ec.europa.eu/transport-modes/maritime/multimodal-and-combined-transport_en.
- European Parliament and Council of the European Union. Regulation (EU) 2021/1119 of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R1119.
- European Parliament and Council of the European Union. Regulation (EU) 2023/1804 of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. https://eur-lex.europa.eu/eli/reg/2023/1804/oj/eng.
- European Parliament and Council of the European Union. Regulation (EU) 2023/1805 of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1805.
- FuelsEurope. "Maritime Transport." Accessed 14 September 2025. https://www.fuelseurope.eu/maritime-transport.
- IMO. "2023 IMO Strategy on Reduction of GHG Emissions from Ships." Accessed 14 September 2025. https://www.imo.org/en/ourwork/environment/pages/2023-imo-strategy-on-reduction-of-ghg-emissions-from-ships.aspx.

- IMO. "Climate Action." Accessed 14 September 2025. https://www.imo.org/en/ourwork/environment/pages/decarbonization%20of%20shipping.aspx.
- IMO. "Historic Background." Accessed 14 September 2025. https://www.imo.org/en/about/historyofimo/pages/historicbackground.aspx.
- IMO. "IMO approves net-zero regulations for global shipping." Press release, 2025. https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-approves-netzero-regulations.aspx.
- IMO. "Fourth IMO GHG Study 2020". (2020). Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://greenvoyage2050.imo.org/wp-content/uploads/2021/07/Fourth-IMO-GHG-Study-2020-Full-report-and-annexes_compressed.pdf.
- Kely, C. "The History of Shipping Containers: From Inception to Global Trade Revolution." *National Self Storage*, 2024. https://www.nationalselfstorage.com/blog/history-of-shipping-containers.
- Transport and Environment. "State of European Transport 2024." 2024. https://www.transportenvironment.org/state-of-european-transport/state-of-transport/ships.
- UNCTAD. *UNCTAD Handbook of Statistics 2023*. 2023. https://unctad.org/publication/unctad-handbook-of-statistics-2023.
- UN Trade and Development. "Net-zero by 2050: Achieving shipping decarbonization through industry momentum and the new ambition at IMO." Septiembre 2023. https://unctad.org/publication/net-zero-by-2050-achieving-shipping-decarbonization-through-industry-momentum-and-the-new-ambition-at-imo.
- United Nations. "The Kyoto Protocol." UN Climate Change. Accessed 14 September 2025. https://unfccc.int/kyoto_protocol.
- United Nations. "What is the United Nations Framework Convention on Climate Change?" UN Climate Change. Accessed 18 de marzo de 2023. https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change.
- U.S. Environmental Protection Agency. "Intermodal for Shippers." 2019. https://nepis.epa.gov/Exe/ZyNET.exe/P100X04Q.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2016+Thru+2020&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C16thru20%5CTxt%5C00000013%5CP100X04Q.txt&User=ANONYMOUS&Password=anonymous&SortM

ethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL/files/2019-07/documents/420f19013.pdf.

- U.S. Environmental Protection Agency. "Overview of Greenhouse Gases." Última actualización enero 2025. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

- World Port Sustainability Program. "Ports: Green Gateways to Europe." Julio 2022. https://sustainableworldports.org/wp-content/uploads/PORTS_GREEN_GATEWAYS_TO_EUROPE_FINAL29JUNE.pdf.

- World Resources Institute. "Where Do Emissions Come From? 4 Charts Explain Greenhouse Gas Emissions by Sector." Diciembre 2024. https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors.

Websites and Online Resources

- ADIF. "Adif y el Port de Barcelona lanzan la sociedad Train Port Barcelona para impulsar el transporte de mercancías." Marzo 2024. https://www.adif.es/es_ES/comunicacion/notas_de_prensa/adif-y-el-port-de-barcelona-lanzan-la-sociedad-train-port-barcelona-para-impulsar-el-transporte-de-mercancias-1065.

- APEC Port Services Network. "About GPAS." Accessed 14 September 2025. https://www.apecpsn.org/apsn/GPAS/index.jhtml.

- APEC Port Services Network. "GPAS Indicator system." Accessed 14 September 2025.. https://www.apecpsn.org/apsn/GPASINDICATORSYSTEM.jhtml.

- Cornerstone Systems. "Five Ways Intermodal Transport Champions Environmental Sustainability." Accessed 14 September 2025. https://www.cornerstone-systems.com/blog/five-ways-intermodal-transport-champions-environmental-sustainability.

- DNV. "LNG as a Marine Fuel." Accessed 14 September 2025. https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/.

- DNV. "Ports can be the front-runners of the energy transition if port authorities and industry sectors join forces." Accessed 14 September 2025. https://www.dnv.com/news/ports-can-be-the-front-runners-of-the-energy-transition-if-port-authorities-and-industry-sectors-join-forces-179736/.

- EcoPorts. "EcoPorts. Green your Port, Join EcoPorts." Lastly reviewed: 12 May 2025. https://www.ecoports.com/#:~:text=EcoPorts%20is%20the%20main%20environmental,Organisation%20(ESPO)%20since%202011.
- EcoPorts. "EcoPorts Network." Accessed 14 September 2025. https://www.ecoports.com/network.
- EcoPorts. "Port Environmental Review System (PERS): the only port sector specific environmental management standard." Accessed 14 September 2025. https://www.ecoports.com/pers.
- EcoPorts. "Self Diagnosis Method (SDM): The user-friendly environmental checklist." Accessed 14 September 2025. https://www.ecoports.com/sdm.
- EMSA. "Electrification." Accessed 14 September 2025. https://www.emsa.europa.eu/electrification.html.
- Eurostat. "Maritime transport of goods at port level - quarterly data." June 2025. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_transport_of_goods_at_port_level_-_quarterly_data.
- Green Marine. "Certification Process." Accessed 14 September 2025. https://green-marine.org/certification/certification-process/.
- Green Marine. "Performance Indicators." Accessed 14 September 2025. https://green-marine.org/certification/performance-indicators/.
- Hafen Hamburg. "The Port of Hamburg." Accessed 14 September 2025. https://www.hafen-hamburg.de/en/.
- Hafen Hamburg. "Port of Hamburg: Growth in Container Throughput and Rail Transport." February 2025. https://www.hafen-hamburg.de/en/newsroom/press-releases/port-of-hamburg-growth-in-container-throughput-and-rail-transport-23956.
- Hamburg Port Authority. "PORT RAILWAY: FROM THE DOCKS TO THE HEART OF EUROPE." Accessed 14 September 2025. https://www.hamburg-port-authority.de/en/port-railway.
- HHLA. "The Power of Networks: Intermodal Logistics: Railway Port Hamburg." Accessed 14 September 2025. https://hhla.de/en/the-power-of-networks/intermodal-logistics/railway-port-hamburg.
- Jxx Logistics. "Difference between Intermodal and Multimodal Transport." Accessed 14 September 2025. https://www.jjxlogistics.co.uk/difference-between-intermodal-and-multimodal-transport/.

- Koons, Eric. "Is LNG Considered Clean or Green Energy?" *Energy Tracker Asia*, 2023. https://energytracker.asia/is-lng-clean-energy/.
- Maersk. "Intermodal transport: What is it and how does it work?" June 2025. https://www.maersk.com/logistics-services/intermodal-transport.
- Nexxiot. "Intermodal vs Multimodal Transportation." June 2023. https://nexxiot.com/resources/intermodal-vs-multimodal-transportation/.
- PierNext. "Ten ways to decarbonise ports." *Port of Barcelona*, 2022. https://piernext.portdebarcelona.cat/en/environment/ten-ways-to-decarbonize-ports/.
- Port de Barcelona. "Intermodality." Accessed 14 September 2025. https://www.portdebarcelona.cat/en/intermodality_www.
- Port de Barcelona. "La iniciativa 'Positive Impact' del Port de Barcelona, finalista de los IAPH 2025 Sustainability Awards." August 2025. https://www.portdebarcelona.cat/en/press-room/news/-/asset_publisher/v6sL7yC89P1c/content/la-iniciativa-positive-impact-del-port-de-barcelona-finalista-de-los-iaph-2025-sustainability-awards.
- Port de Barcelona. "Nexigen." Accessed 14 September 2025. https://www.portdebarcelona.cat/es/nexigen.
- Port de Barcelona. "Port de Barcelona | Inicio." Accessed 14 September 2025. https://www.portdebarcelona.cat/en.
- Port de Barcelona. "Sostenibilidad." Accessed 14 September 2025. https://www.portdebarcelona.cat/en/sostenibilidad.
- Port of Hamburg. "Europe's largest rail port." Accessed 14 September 2025. https://www.hafen-hamburg.de/en/hinterland/rail.
- Port of Hamburg. "Port of Hamburg- Gateway to the World." Accessed 14 September 2025. https://www.hafen-hamburg.de/en.
- Port of Rotterdam. Artificial Intelligence in the Port. Accessed 14 September 2025. https://www.portofrotterdam.com/en/port-future/innovation/artificial-intelligence-port.
- Port of Rotterdam. "Facts and Figures." Accessed 14 September 2025. https://www.portofrotterdam.com/en/port-authority/port-in-brief/facts-and-figures.
- Port of Rotterdam. "The Port of Rotterdam Authority accelerates the reduction of its own carbon emissions." Junio 2022. http://portofrotterdam.com/en/news-and-press-releases/the-port-of-rotterdam-authority-accelerates-the-reduction-of-its-own-carbon.

- Port of Rotterdam. "Welcome to the Port of Rotterdam." Accessed 14 September 2025. https://www.portofrotterdam.com/en.
- Port Economics, Management and Policy. "Coldironing: On-shore Power Supply for Vessels." Accessed 14 September 2025. https://porteconomicsmanagement.org/pemp/contents/part3/green-supply-chain-management-ports/coldironing-on-shore-power-supply-vessels/.
- Route Scanner. "Direct Connections." Accessed 14 September 2025.
- Safety4Sea. "IMO MEPC 81 Proposes new Chapter 5 of MARPOL Annex VI." 2024. https://safety4sea.com/imo-mepc-81-proposes-new-chapter-5-of-marpol-annex-vi/.
- Sener. "Decarbonisation of Ports: Strategies and Technologies to Transform the Industry." November 2024. https://www.group.sener/en/insights/decarbonisation-of-ports-strategies-and-technologies/.
- Sinay. "What is a transshipment hub? Top transshipment ports in the world." May 2025. https://sinay.ai/en/what-is-a-transshipment-hub-top-transshipment-ports-in-the-world/.
- Union Civil Protection Knowledge Network. "The Green Ports Concept and PROMPT Project." February 2024. https://civil-protection-knowledge-network.europa.eu/stories/green-ports-concept-and-prompt.
- U.S. Department of Energy's primary national laboratory for energy systems (NREL). "Freight Transport." Accessed 14 September 2025. https://www.nrel.gov/transportation/freight-transport.html.
- World Shipping Council. "Top 50 Container Ports." Accessed 14 September 2025. https://www.worldshipping.org/top-50-ports.

Bibliography

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