

UNIVERSITY OF PIRAEUS



School of Maritime and Industrial Studies
Department of Maritime Studies

“Green Ports: Towards Energy Efficiency and Environmental Sustainability”

KONSTANTIA N. KARAGKOUNI

Ph.D. Dissertation

Submitted to
Department of Maritime Studies
of the University of Piraeus

Piraeus 2026

KONSTANTIA N. KARAGKOUNI

Diploma in Spatial Planning and Development Engineering
MSc Transport Engineer

DOCTORAL DISSERTATION

**GREEN PORTS: TOWARDS ENERGY EFFICIENCY &
ENVIRONMENTAL SUSTAINABILITY**

Date of Defence: 29/07/2026

SUPERVISORY COMMITTEE

PROF. MARIA BOILE
(SUPERVISOR)
Dep. of Maritime Studies –
University of Piraeus

**PROF. EFSTRATIOS
PAPADIMITRIOU**
Dep. of Maritime Studies –
University of Piraeus

**PROF. EMERITUS
CONSTANTINOS CHLOMOUDIS**
Dep. of Maritime Studies –
University of Piraeus

EXAMINATION COMMITTEE

PROF. MARIA BOILE
Dep. of Maritime Studies – University of Piraeus

PROF. EFSTRATIOS PAPADIMITRIOU
Dep. of Maritime Studies – University of Piraeus

**PROF. EMERITUS CONSTANTINOS
CHLOMOUDIS**
Dep. of Maritime Studies – University of Piraeus

PROF. DIMITRA VAGIONA
Dep. of Spatial Planning and Development
Aristotle University of Thessaloniki (AUTH)

**ASSOCIATE PROFESSOR IOANNIS
LAGOUDIS**
Dep. of Maritime Studies – University of Piraeus

**ASSISTANT PROFESSOR ANASTASIA
CHRISTODOULOU**
Dep. of Maritime Studies – University of Piraeus

**ASSISTANT PROFESSOR EVANGELOS
TSIOUMAS**
Dep. of Maritime Studies – University of Piraeus

Acknowledgements

The completion of this dissertation marks the end of a long and rewarding journey that has challenged me both academically and personally. Looking back, I realize that this achievement would not have been possible without the support and encouragement of many people. First and foremost, I would like to express my deepest gratitude to my supervisor, Professor Maria Boile, for her continuous guidance, encouragement, and invaluable support throughout this doctoral journey.

I would also like to sincerely thank the members of my examination committee, Professor Efstratios Papadimitriou, Professor Konstantinos Chlomoudis, for their valuable comments, insightful suggestions, and the time they dedicated to evaluating this work.

Finally, I would like to express my heartfelt gratitude to my family and friends. Their unconditional love, patience, encouragement, and belief in me have been my greatest source of strength throughout this journey. They stood by me during every challenge and celebrated every milestone. Their support and belief in me made this journey possible, and I will always be grateful to have had them by my side.

To everyone who has contributed, directly or indirectly, to this achievement, I extend my sincere appreciation. This dissertation represents not only the completion of a doctoral journey but also the beginning of many new challenges and opportunities ahead.

Copyright Statement ©

The person who prepares this Dissertation bears the entire responsibility for determining the fair use of the material, which is defined based on the following factors: the purpose and character of the use (commercial, non-profit, or educational), the nature of the material it uses (part of the text, tables, figures, images or maps), the percentage and significance of the portion it uses in relation to the whole copyrighted text and the possible consequences of such use on the market or the general value of the text under copyright.

Abstract

The transition of ports towards energy-efficient and low-emission operations has become a strategic priority within international and European transport policy. Among the available decarbonisation pathways in the green transition of ports, electrification has received significant attention and considered as one of the rapidly expanding approaches. Nevertheless, the implementation of this approach represents a complex transition process, influenced by interactions between technological maturity, financial resources, infrastructure readiness, regulatory requirements and operational conditions. Rather than examining port electrification as a collection of individual technologies or static investment decisions, this dissertation reconceptualises this transition as a dynamic system within the broader context of “greening” of ports. By capturing the interactions between technological, economic, infrastructural and regulatory factors over time, the proposed System Dynamics framework supports port authorities and policymakers in evaluating alternative investment pathways, identifying critical constraints and making more informed strategic decisions under conditions of uncertainty.

Against this background, the dissertation aims to address the key research question of how ports can evaluate and prioritise strategies for electrification and energy efficiency under conditions of uncertainty, while facilitating their transition towards environmentally sustainable operations. To address this central research question, the research investigates the challenges and opportunities associated with port electrification, examines how investment allocation and sequencing influence long-term transition pathways, explores how the complexity and uncertainty of these interactions can be represented through a dynamic modelling framework, and identifies the key factors shaping electrification strategies under infrastructure constraints, investment dynamics and system interdependencies.

The research first establishes the problem context through a systematic review of the literature, complemented by an extensive synthesis of international port practices and documented implementation cases, highlighting the principal environmental challenges, observed across ports worldwide. It provides a comprehensive understanding of the literature with an extensive analysis of port case studies and good green practices internationally, establishing an integrated evidence base on the implementation of green port measures across different operational and geographical contexts. The enabling and constraining factors implementing electrification measures are synthesised through a PESTLE analysis and subsequently operationalised within a System Dynamics modelling framework, where they are transformed into endogenous variables, causal feedback structures and stock-and-flow relationships that capture the dynamic evolution of port electrification over time.

The developed model incorporates the principal electrification measures currently implemented in ports, including Shore-Side Electricity (SSE-OPS), electrification of cargo-handling equipment, charging infrastructure for heavy-duty vehicles and electricity grid upgrades. An illustrative application for medium-sized European ports is developed to investigate alternative investment strategies under different funding conditions, implementation priorities and infrastructure constraints over a thirty-year planning horizon. The model is further subjected to structural, behavioural and robustness tests, substantiating the reliability of its internal consistency and its suitability as a strategic decision-support framework. The analysis demonstrates that the effectiveness of port electrification depends

not only on the adoption of individual technologies but also on the dynamic interactions between investment allocation, infrastructure deployment, electricity demand, grid capacity and implementation sequencing. The findings identify electricity infrastructure readiness as a critical factor influencing the pace of electrification, while also demonstrating that investment timing and capital allocation decisions substantially affect long-term transition outcomes. The results further indicate that electrification pathways are characterised by path dependency, highlighting the importance of coordinated planning and timely infrastructure development.

Methodologically, the research establishes a transparent framework for integrating qualitative evidence with quantitative System Dynamics modelling, enabling the representation of feedback mechanisms, delays and resource constraints that are not adequately addressed by existing analytical approaches. From a practical perspective, the proposed framework provides a flexible decision-support tool capable of assisting port authorities and policymakers in prioritising investments, assessing alternative transition pathways and supporting the long-term planning of energy-efficient and environmentally sustainable ports.

Περίληψη

Η μετάβαση προς ενεργειακά αποδοτικές και χαμηλών εκπομπών λιμενικές λειτουργίες έχει καταστεί στρατηγική προτεραιότητα στο πλαίσιο της διεθνούς και ευρωπαϊκής πολιτικής μεταφορών. Μεταξύ των διαθέσιμων μεθόδων απανθρακοποίησης στην πράσινη μετάβαση των λιμένων, ο εξηλεκτρισμός έχει λάβει σημαντική προσοχή και θεωρείται μία από τις ταχύτερα αναπτυσσόμενες προσεγγίσεις. Ωστόσο, η εφαρμογή αυτής της προσέγγισης αποτελεί μια πολύπλοκη διαδικασία, η οποία επηρεάζεται από τις αλληλεπιδράσεις μεταξύ της τεχνολογικής ωριμότητας, των οικονομικών πόρων, της ετοιμότητας των υποδομών, των κανονιστικών απαιτήσεων και των λειτουργικών συνθηκών. Αντί να εξετάζει τον εξηλεκτρισμό των λιμένων ως ένα σύνολο μεμονωμένων τεχνολογιών ή στατικών επενδυτικών αποφάσεων, η παρούσα διατριβή επαναπροσδιορίζει την προσέγγιση αυτή ως ένα δυναμικό σύστημα στο ευρύτερο πλαίσιο της πράσινης μετάβασης των λιμένων. Καταγράφοντας τις αλληλεπιδράσεις μεταξύ υποδομής, τεχνολογικών, οικονομικών, και κανονιστικών παραγόντων στο πέρασμα του χρόνου, το προτεινόμενο πλαίσιο της Δυναμικής των Συστημάτων υποστηρίζει τις λιμενικές αρχές και τους υπεύθυνους χάραξης πολιτικής και λήψης αποφάσεων στην αξιολόγηση εναλλακτικών επενδυτικών διαδρομών, στον εντοπισμό κρίσιμων περιορισμών και στη λήψη πιο τεκμηριωμένων στρατηγικών αποφάσεων υπό συνθήκες αβεβαιότητας.

Στο πλαίσιο αυτό, η διατριβή στοχεύει να εξετάσει το βασικό ερευνητικό ερώτημα σχετικά με τον τρόπο με τον οποίο οι λιμένες μπορούν να αξιολογούν και να ιεραρχούν στρατηγικές για τον εξηλεκτρισμό και την ενεργειακή απόδοση υπό συνθήκες αβεβαιότητας, διευκολύνοντας παράλληλα τη μετάβασή τους προς περιβαλλοντικά βιώσιμες λειτουργίες. Για την αντιμετώπιση αυτού του κεντρικού ερευνητικού ερωτήματος, η έρευνα εξετάζει τις προκλήσεις και τις ευκαιρίες που συνδέονται με τον εξηλεκτρισμό των λιμένων, αναλύει τον τρόπο με τον οποίο η κατανομή και η αλληλουχία των επενδύσεων επηρεάζουν τις μακροπρόθεσμες πορείες μετάβασης, διερευνά πώς η πολυπλοκότητα και η αβεβαιότητα αυτών των αλληλεπιδράσεων μπορούν να αποτυπωθούν μέσω ενός πλαισίου δυναμικής μοντελοποίησης και προσδιορίζει τους βασικούς παράγοντες που διαμορφώνουν τις στρατηγικές εξηλεκτρισμού υπό περιορισμούς υποδομών, δυναμική επενδύσεων και αλληλεξαρτήσεις του συστήματος.

Η έρευνα καθορίζει αρχικά το πλαίσιο του προβλήματος μέσω μιας συστηματικής ανασκόπησης της βιβλιογραφίας, η οποία συμπληρώνεται από μια εκτενή σύνθεση διεθνών λιμενικών πρακτικών και τεκμηριωμένων περιπτώσεων εφαρμογής, επισημαίνοντας τις κύριες περιβαλλοντικές προκλήσεις που παρατηρούνται σε λιμάνια παγκοσμίως. Παρέχει, επίσης, μια ολοκληρωμένη κατανόηση της βιβλιογραφίας με εκτενή ανάλυση διεθνών μελετών περιπτώσεων λιμένων και ορθών «πράσινων» πρακτικών, δημιουργώντας μια ολοκληρωμένη βάση τεκμηρίωσης σχετικά με την εφαρμογή μέτρων «πράσινων» λιμένων σε διαφορετικά επιχειρησιακά και γεωγραφικά πλαίσια. Οι παράγοντες που ευνοούν και οι παράγοντες που περιορίζουν την εφαρμογή μέτρων εξηλεκτρισμού συνθέτονται μέσω μιας ανάλυσης PESTLE και, στη συνέχεια, ενσωματώνονται σε ένα πλαίσιο μοντελοποίησης Συστημικής Δυναμικής, όπου μετατρέπονται σε ενδογενείς μεταβλητές, δομές αιτιώδους ανατροφοδότησης και σχέσεις αποθεμάτων και ροών που αποτυπώνουν τη δυναμική εξέλιξη του εξηλεκτρισμού των λιμένων με την πάροδο του χρόνου.

Το μοντέλο που αναπτύχθηκε ενσωματώνει τα βασικά μέτρα εξηλεκτρισμού λιμενικών λειτουργιών που εφαρμόζονται επί του παρόντος στους λιμένες, συμπεριλαμβανομένης της

παροχής ηλεκτρικού ρεύματος στα πλοία από την ξηρά (SSE-OPS), του ηλεκτρικού εξοπλισμού διακίνησης φορτίων, της υποδομής φόρτισης για βαρέα οχήματα και των αναβαθμίσεων του ηλεκτρικού δικτύου. Αναπτύχθηκε μια ενδεικτική εφαρμογή για μεσαίου μεγέθους ευρωπαϊκούς λιμένες, με σκοπό τη διερεύνηση εναλλακτικών επενδυτικών στρατηγικών υπό διαφορετικές συνθήκες χρηματοδότησης, προτεραιότητες υλοποίησης και περιορισμούς υποδομών, σε ένα χρονικό ορίζοντα σχεδιασμού τριάντα ετών. Το μοντέλο υποβάλλεται περαιτέρω σε δομικές, συμπεριφορικές και δοκιμές ανθεκτικότητας, οι οποίες τεκμηριώνουν την αξιοπιστία της εσωτερικής του συνοχής και την καταλληλότητά του ως πλαισίου στρατηγικής υποστήριξης λήψης αποφάσεων. Η ανάλυση καταδεικνύει ότι η αποτελεσματικότητα της ηλεκτροκίνησης των λιμένων εξαρτάται όχι μόνο από την υιοθέτηση μεμονωμένων τεχνολογιών, αλλά και από τις δυναμικές αλληλεπιδράσεις μεταξύ της κατανομής των επενδύσεων, της ανάπτυξης υποδομών, της ζήτησης ηλεκτρικής ενέργειας, της χωρητικότητας του δικτύου και της αλληλουχίας υλοποίησης. Τα ευρήματα προσδιορίζουν την ετοιμότητα της υποδομής ηλεκτρικής ενέργειας ως κρίσιμο παράγοντα που επηρεάζει τον ρυθμό του εξηλεκτρισμού, ενώ παράλληλα καταδεικνύουν ότι ο χρονισμός των επενδύσεων και οι αποφάσεις κατανομής κεφαλαίων επηρεάζουν ουσιαστικά τα μακροπρόθεσμα αποτελέσματα της μετάβασης. Τα αποτελέσματα υποδεικνύουν επίσης ότι το αποτέλεσμα της επιτυχημένης μετάβασης εξαρτάται από την πορεία υλοποίησης, τονίζοντας τη σημασία του συντονισμένου σχεδιασμού και της έγκαιρης ανάπτυξης υποδομών.

Μεθοδολογικά, η έρευνα δημιουργεί ένα πλαίσιο για την ενσωμάτωση ποιοτικών στοιχείων και ποσοτικών παραμέτρων σε ένα μοντέλο Δυναμικής Συστημάτων επιτρέποντας την απεικόνιση μηχανισμών ανατροφοδότησης, καθυστερήσεων και περιορισμών πόρων που δεν αντιμετωπίζονται επαρκώς από τις υπάρχουσες αναλυτικές προσεγγίσεις. Από πρακτική άποψη, το προτεινόμενο πλαίσιο παρέχει ένα ευέλικτο εργαλείο υποστήριξης λήψης αποφάσεων, ικανό να βοηθήσει τις λιμενικές αρχές και τους υπεύθυνους χάραξης πολιτικής στην ιεράρχηση των επενδύσεων, στην αξιολόγηση εναλλακτικών διαδρομών μετάβασης και στη στήριξη του μακροπρόθεσμου σχεδιασμού ενεργειακά αποδοτικών και περιβαλλοντικά βιώσιμων λιμένων.

Table of Contents

Acknowledgements.....	2
Abstract.....	3
Περίληψη.....	5
Chapter 1: Context and background of port “greening”.....	11
1.1 Introduction to the research context.....	11
1.2 Environmental footprint of port sector	13
1.3 Greening of ports as a strategic response.....	16
1.3.1 Conceptualising “greening” of ports.....	17
1.3.2 Ports as energy and transition hubs	19
1.4 Trends shaping port “greening”	21
Chapter 2: Research motivation, and questions to be addressed	24
2.1 Research motivation.....	24
Chapter 3: Theoretical background.....	28
3.1 Port operations	28
3.2 Port size classification	30
3.3 Environmental aspects and impacts in ports	33
3.3.1 Environmental aspects and impacts definitions under ISO 14001 environmental management standard.....	33
3.3.2 Environmental aspects and impacts in terms of port operations.....	35
3.3.3 Key findings on environmental aspects of port operations Systematic Literature Review (SLR).....	39
.....	40
3.4 Classification of “green” practices in ports: a systematic approach.....	42
3.4.1 Shore Side Electricity – Onshore Power Supply (SSE-OPS)	45
3.4.2 Alternative fuels	47
3.4.3 Alternative Fuel-Powered Port Terminal Equipment	48
3.4.4 Alternative fuel-powered supporting vessels	49
3.4.5 Circular economy.....	50
3.4.6 Waste management.....	51
3.4.7 Other “green” port practices.....	52
3.5 Analytical review of port electrification drivers and barriers using the PESTLE framework.....	54
3.5.1 Political factors influencing port electrification.....	59
3.5.2 Economic factors influencing port electrification.....	60
3.5.3 Social factors influencing port electrification.....	61
3.5.4 Technological factors influencing port electrification.....	61
3.5.5 Legal factors influencing port electrification.....	62
3.5.6 Environmental factors influencing port electrification	63
3.6 Literature-based parameterisation of SFD model constants	64
3.7 Analytical approaches used in port electrification studies	66
3.8 Key Research Gaps	67
Chapter 4: Research design and methodological positioning.....	69

Chapter 5. Methodology	72
5.1 PESTLE analysis	72
5.1.1 Political drivers and barriers.....	72
5.1.2 Economic drivers and barriers.....	73
5.1.3 Social drivers and barriers.....	74
5.1.4 Technological drivers and barriers.....	75
5.1.5 Legal drivers and barriers.....	77
5.1.6 Environmental drivers and barriers	79
5.2 Development of the Causal Loop Diagram (CLD)	80
5.3 Development of the stock-and-flow diagram (SFD)	84
5.3.1 Scenario-based sensitivity analysis of capital allocation priorities	94
5.3.2 Impact of grid capacity constraints on SSE-OPS deployment.....	97
5.3.3 Installed grid capacity across policy scenarios	102
5.4 Main constraints / stress scenarios	103
5.5 Validation and model testing.....	107
5.5.1 Structural adequacy and consistency tests	110
5.5.2 Extreme Condition and Behaviour Tests.....	111
5.5.3 Robustness tests	114
Chapter 6. Illustrative operational application: medium-sized EU ports	115
Chapter 7. Policy recommendations	120
7.1 Policy recommendations for port authorities & policy makers	120
Chapter 8: Conclusions	123
8.1 Integrated insights from the analysis	123
8.2 Original scientific contribution of the Dissertation	124
8.3 Future research paths	127
8.4 Research limitations	128
References.....	130
ANNEX I: Port size classification and benchmarking dataset.....	140
ANNEX II: Association matrix of environmental aspects and impacts.....	169
ANNEX III: Comparative overview of port-related emissions by case	170
ANNEX IV: List of Good Green practices related to ports	242
ANNEX V: The entire list of model's variables and equations	343
ANNEX VI: System Dynamics Model Specification (.mdl file extract).....	347

List of Figures

Figure 1. The strategic role of ports	11
Figure 2. Port environment, stakeholders and interests	13
Figure 3. Port emissions components for developed countries	14
Figure 4. Top 10 environmental priorities of the port sector over the years.....	15

Figure 5. A transition path towards a “decarbonized port”	17
Figure 6. The EU Green Deal	18
Figure 7. Planned investments of Port Managing Bodies by type	20
Figure 8. Energy pillars of the port energy hub.....	20
Figure 9. Schematic overview of port operations.....	28
Figure 10. Port environmental aspects and impacts.....	34
Figure 11. The cause-and-effect relation of environmental aspects and impacts related to the port operations.....	36
Figure 12. Location of cases identified in the context of SLR method	40
Figure 13. The outline of the research process	43
Figure 14. Share of the number of good practices by type of information source	44
Figure 15. Consolidated outcomes of the port electrification analysis.....	56
Figure 16. Type of literature reviewed for the article.....	57
Figure 17. Number of references contributed barriers/drivers of port electrification to each PESTLE pillar.....	58
Figure 18. Port related electrification measures used for the research	69
Figure 19. Methodological framework for analysing port electrification using System Dynamics	70
Figure 20. CLD of port electrification	82
Figure 21. Subset of selected loops for the SFD	85
Figure 22. Stock & Flow diagram of port electrification.....	87
Figure 23. Highlighted in the red box, variables of grid readiness constraints	98
Figure 24.....	98
Figure 24. Key findings from the comparison of unconstrained and grid-constrained SSE-OPS deployment scenarios	101
Figure 26. Extreme conditions test with allocation shares	112

List of Tables

Table 1. Comparative characteristics of selected European ports used for benchmarking medium-sized port conditions (indicative sample)	32
Table 2. Link between port environmental aspects and impacts	38
Table 3. Summary of indicative case studies related to the environmental aspect of emissions to air – numerical data	40
Table 4. Prevalent and other identified groups of “green” practices related to ports	44
Table 5. Model constants and literature justification	64
Table 6. Indicative comparative assessment of analytical approaches used in port electrification and sustainability studies	66
Table 7. Political barriers and drivers.....	72
Table 8. Economic barriers and drivers	73
Table 9. Social barriers and drivers	74
Table 10. Technological barriers and drivers.....	76
Table 11. Legal barriers and driver	78
Table 12. Environmental barriers and drivers.....	79
Table 13. Reinforcing & Balancing Loops derived from CLD.....	83
Table 14. Variables and mathematical formulations of the budget allocation sub-model (baseline scenario).....	88
Table 15. GSV deployment sub-model.....	89
Table 16. SSE-OPS deployment sub-model.....	90
Table 17. Electric cranes deployment sub-model	91
Table 18. Grid capacity upgrade sub-model	93
Table 19. Budget allocation shares applied under each scenario	95
Table 20. Variables of models’ grid readiness constraints.....	97

Table 21. Sterman’s list of validation tests provided for the SFD model.....	108
Table 22. Illustrative parameter configurations for representative medium-sized EU ports.....	116
Table 23. Port profile and classification indicators.....	140
Table 24. Cargo and passenger throughput data	146
Table 25. Data sources and descriptive notes.....	148
Table 26. Policy and Governance Characteristics of Green Port Practices.....	242
Table 27. Operational and Implementation Dimensions of Green Port Practices.....	265
Table 28. Sources of Green Port Practices	332

List of Diagrams

Diagram 1. SSE-OPS infrastructure deployment under various priority strategies on SSE-OPS deployment	96
Diagram 2. SSE-OPS infrastructure deployment under various priority strategies with grid capacity constraints	100
Diagram 3. Evolution of installed grid capacity across policy scenarios	103
Diagram 4. Stress scenario/ low budget for SSE-OPS deployment	104
Diagram 5. Stress scenario/ delayed investment for SSE-OPS deployment.....	105
Diagram 6. Stress scenario/ high CAPEX for SSE-OPS deployment.....	106
Diagram 8. SSE-OPS infrastructure deployment across representative electrification configurations.....	117
Diagram 9. Grid readiness factor across illustrative port configurations.....	118

Chapter 1: Context and background of port “greening”

1.1 Introduction to the research context

Ports are increasingly positioned at the crossroads of three transitions that are unfolding simultaneously: the decarbonisation of transport, the restructuring of energy systems and the reconfiguration of global supply chains (Figure 1). While historically conceptualised as logistics interfaces facilitating cargo flows, contemporary ports operate as complex, multi-layered systems where transport, energy, industrial activity and digital infrastructure interact. This systemic complexity makes ports critical enablers of economic activity and key intervention points for addressing climate change and environmental issues. The environmental dimension of port activity cannot be understood in isolation from the broader port system. Emissions and impacts are generated across interconnected processes, including maritime operations, terminal activities, and hinterland transport. This multifaceted nature of environmental challenges necessitates an alternative approach to conventional port-related emissions, which are typically regarded as discrete or sector-specific phenomena. Ports act as nodes for externalities, where emissions from berthing vessels, cargo handling equipment, and land-based transport accumulate in spatial and temporal terms (ESPO, 2022d)(Alamouch et al., 2021). In this sense, the environmental footprint of ports reflects not only their internal operations, but also their position within the wider context of global transport and energy systems.

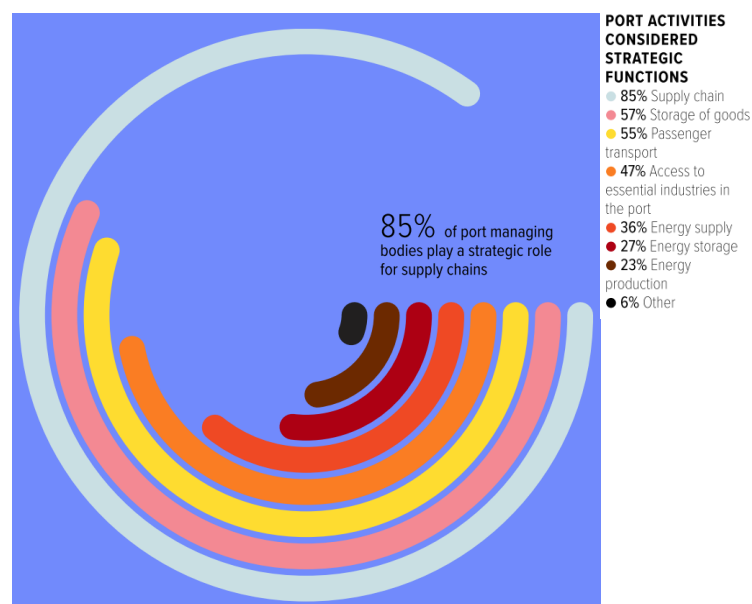


Figure 1. The strategic role of ports (ESPO, 2022d)

At the same time, the scale and intensity of port operations are increasing due to growth in global trade, larger vessels and the concentration of logistics activities. These trends are reinforcing the need for fossil fuel-based infrastructure and operational practices. As recent literature has highlighted, although maritime transport remains relatively energy efficient in terms of tons per kilometer, the absolute emissions associated with port activities are substantial and are projected to grow under business-as-usual scenarios (IMO and IAPH, 2018) (UNCTAD, 2021). This creates a fundamental challenge: ports are expected to increase

capacity and efficiency while reducing their environmental impact. Within this context, the 'greening of ports' has emerged not merely as a recommended goal, but as a necessary transformation of port systems under multiple and often conflicting pressures. However, the concept itself is ambiguous in the literature and is often used as an umbrella term to encompass a wide range of interventions, from minor efficiency improvements to major changes in energy use and infrastructure. Previous studies have identified and categorised many green practices, such as Shore-Side Electricity Onshore Power Supply, alternative fuels, the electrification of equipment, energy management systems, and initiatives for a circular economy. These studies have highlighted the diversity and fragmentation of existing approaches.

The terms sustainability, decarbonisation and “greening” reflect distinct yet interrelated aspects within the port context. This distinction is critical because sustainability provides the broader framework, while decarbonisation focuses on emission reduction targets. In contrast, “greening” of ports is operationalised through concrete infrastructure choices, resource allocation decisions, and the sequencing of investments. The effectiveness of “greening” strategies depends not only on the technical performance of individual measures, but also on how well they are aligned and interact within the broader port’s system. Policy developments at the international and European levels further reinforce the need for such a systemic understanding: the revised IMO strategy on greenhouse gas emissions sets a trajectory towards net-zero emissions in international shipping by 2050, introducing increasing pressure for the deployment of low- and zero-emission technologies (IMO, 2023). In parallel, the European Green Deal and the 'Fit for 55' package establish an integrated policy framework linking climate targets with transport, energy and industrial policies (European Commission, 2020). Initiatives such as FuelEU Maritime and the Alternative Fuels Infrastructure Regulation (AFIR) explicitly require ports to develop infrastructure capable of supporting alternative fuels and onshore power supply, thereby embedding ports within the broader energy transition.

However, despite the strong policy momentum, the transition towards greener ports is not straightforward. Empirical evidence suggests that ports follow different pathways, influenced by local conditions, governance structures, traffic composition and access to financial resources as highlighted in Figure 2. Large port hubs may pursue integrated energy strategies, combining electrification, hydrogen production and renewable energy integration, while smaller ports often adopt more incremental approaches due to financial and technical constraints (European Commission, 2024). This heterogeneity makes one-size-fits-all policy approaches less effective and highlights the need for decision-making that takes into account the specific characteristics of each port. In addition, the implementation of “greening” measures is characterised by inherent interdependencies and potential trade-offs. For example, investments in electrification are closely linked to the availability and capacity of energy infrastructure, while the uptake of alternative fuels depends on developments in both the supply and demand sides. Similarly, measures that improve environmental performance in one area may create new challenges in another, such as increased energy demand or infrastructure requirements. These interrelationships emphasise the importance of viewing port “greening” as a system-level approach rather than a series of isolated interventions.



Figure 2. Port environment, stakeholders and interests (Source: (ESPO, 2024b))

Overall, the “greening” of ports can be understood as an evolving process shaped by the interaction between environmental aspects, technological possibilities, and institutional frameworks, and its complexity lies in the diversity of available solutions and the dynamic conditions under which decisions are made and implemented. Capturing this complexity is essential for developing a more holistic understanding of how ports can navigate the transition towards energy efficiency and environmental sustainability, particularly in a context where expectations and uncertainties continue to increase.

1.2 Environmental footprint of port sector

The environmental footprint of the port sector should not be understood simply as the sum of emissions generated within port boundaries, but rather as the outcome of a broader concentration of transport, logistics, industrial and energy-related activities in strategically important coastal areas (Figure 3). European ports are no longer limited to a narrow transport context. As ESPO notes, ports are increasingly operating as hubs for energy, industry and the blue economy, while simultaneously remaining critical interfaces for maritime mobility, trade and wider economic connectivity. In governance terms, this broader role is now well established: 85% of European port management bodies consider supply chain operations to be a strategic function, while 36% already identify energy supply, 27% energy storage and 23% energy production as strategic functions (ESPO, 2022d). This repositioning has direct environmental implications because it means that the port sector is increasingly exposed not only to the externalities of transport activity, but also to the pressures of system-wide decarbonisation and energy transition.

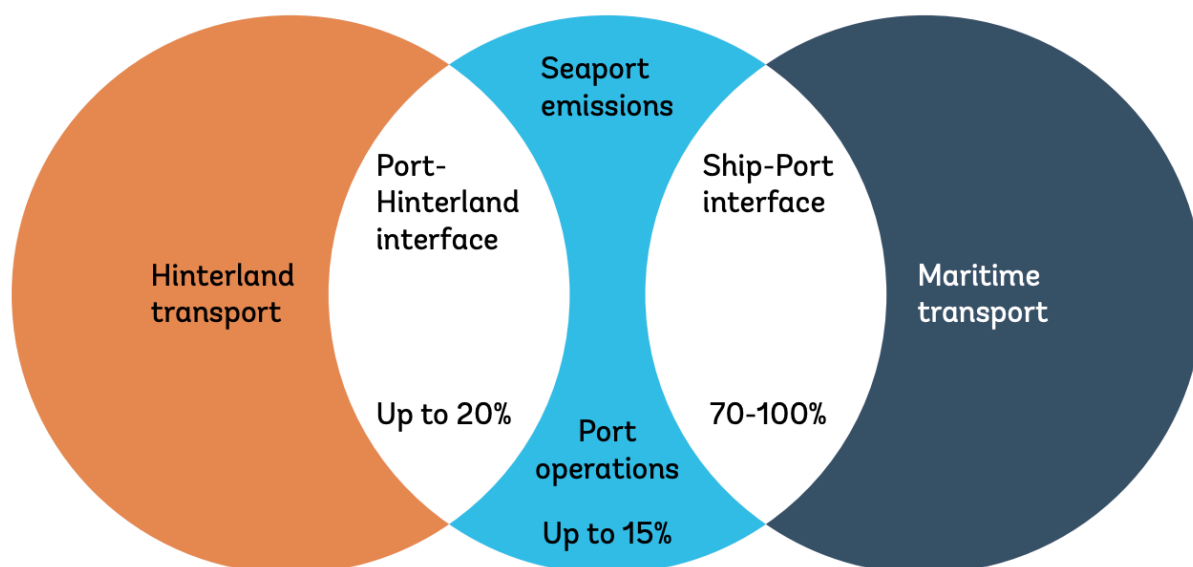


Figure 3. Port emissions components for developed countries (World Bank Group, 2025)

The extent of this environmental challenge becomes evident when considering the role of ports within the broader European freight and transport system. According to the European Commission, freight transport is responsible for over 30% of transport-related CO₂ emissions, and freight demand is expected to grow by around 25% by 2030 and 50% by 2050. At the same time, over 50% of freight in the EU is carried by road, which is important for ports as they are a vital link between maritime flows and inland freight distribution (European Commission, 2023). Even when emissions are not strictly generated within the port, ports are still structurally linked to the carbon intensity of the logistics chains they facilitate (DNV, 2021).

Within the European port sector itself, the latest ESPO evidence shows that environmental pressures are no longer perceived as secondary operational concerns, but as core strategic issues. The 2025 ESPO Environmental Report, based on data from 77 ports in 18 European countries, identifies climate change, air quality, and energy efficiency as the top three environmental priorities for ports as shown in Figure 4 (ESPO, 2025).

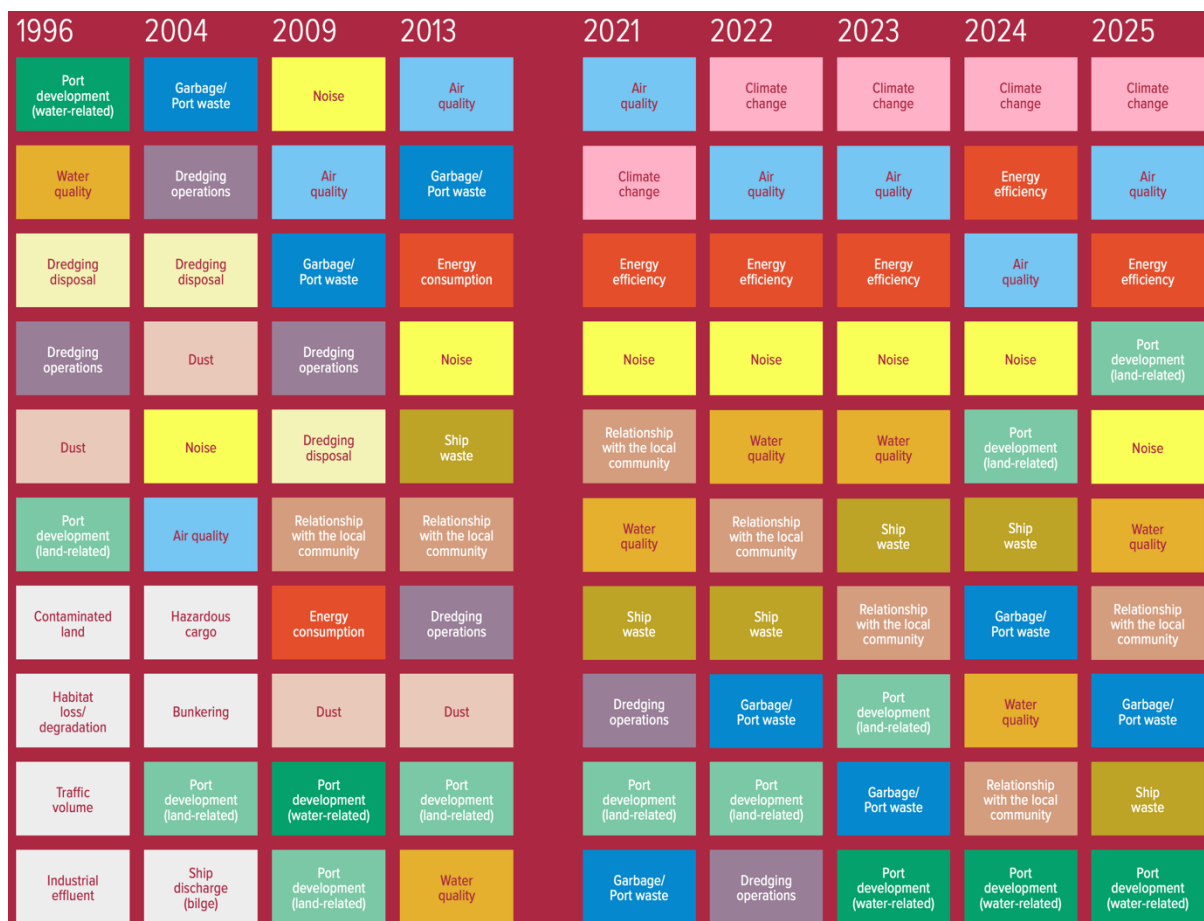


Figure 4. Top 10 environmental priorities of the port sector over the years (Source: ESPO, 2025)

The quantitative trends reported by ESPO further demonstrate the expansion of environmental footprint management over time. Carbon footprint monitoring increased from 48% of ports in 2013 to 78% in 2025, representing the most significant increase among all monitoring indicators. Energy efficiency monitoring rose from 65% to 84% over the same period, while air quality and noise monitoring both reached 69% in 2025. Water quality monitoring stood at 79%, sediment quality at 78%, and port waste monitoring at 87%. Importantly, 36% of ports now include emissions from stakeholders such as terminals and tenants in their carbon accounting, while 37% extend this further to include third-party emissions, such as those from ships. This shows that the environmental footprint of ports is increasingly being treated as a systemic approach rather than as a narrow accounting exercise for port authorities (ESPO, 2022d). In parallel, European ports are shifting their focus from environmental monitoring to setting more explicit targets. ESPO reports that 80% of port authorities have set their own GHG reduction targets, 66% have adopted air emissions reduction targets, and 53% have formal zero-emission targets for port-related activities and operations. However, only 37% report the existence of low-emission zones or berth emission standards. This discrepancy is significant: it suggests that ambition is spreading faster than the implementation of effective operational measures. It also indicates that, while the environmental footprint of the sector is increasingly recognised and quantified, this is not fully matched by uniformly implemented control mechanisms across ports. In this sense, the sector's environmental footprint is not only an environmental issue, but also a governance challenge.

The energy dimension of the port sector adds a further layer of complexity. DNV's analysis of European ports argues that ports can become front runners of the energy transition, but only if electrification, energy integration and supporting infrastructure advance at the required pace. By 2050, the total electricity generating capacity of industrial ports could increase by more than tenfold, while renewable energy could account for at least 70% of total electricity generation, compared with only 5% today. Even more importantly, industrial production in ports could increase by almost 60% and cargo throughput by 30% by 2050, yet electrification and energy efficiency could be more than compensate for this growth in terms of energy use and CO₂ emissions, while the carbon intensity of port-side energy use could almost decrease by 50%. It is important to understand that the impact of the port sector on the environment is changing. This is because of the energy transition, which may reduce local emissions but also increase the need for electricity, the need for grids, and the need for new infrastructure (DNV, 2021). The environmental footprint of the port sector therefore needs to be interpreted in two ways. On the one hand, ports remain areas of significant environmental impact within wider freight, shipping and industrial systems. On the other hand, they are becoming key hubs for the implementation of decarbonisation, electrification and climate adaptation measures. This twofold nature is also evident in governance data. 93% of European port management bodies are publicly owned, 77% define themselves as mission-driven rather than purely profit-driven, and 69% explicitly aim to balance public and private interests (ESPO, 2022d). In practice, this means that the environmental footprint of the port sector is inseparable from its public interest role. Ports are expected to maintain competitiveness, support trade, accommodate growth, and secure energy functions while reducing emissions, adapting infrastructure, and enabling the decarbonisation of shipping and freight. The sector's footprint is therefore not just an environmental issue to be measured, but a transitional pressure that is reshaping the strategic role of ports in Europe (ESPO & HaskoningDHV Nederland, 2022) (MSE International, 2024).

1.3 Greening of ports as a strategic response

Building on the environmental and energy-related pressures identified in the previous section, the “greening” of ports emerges as a strategic response to the need for reducing environmental impacts, while maintaining operational and economic performance. However, this response cannot be understood simply as the implementation of isolated technical measures. Rather, it reflects a broader efforts of port systems as indicated in Figure 5, involving changes in infrastructure, energy use, operational practices and governance structures. In this context, “greening” evolves from a set of environmental management actions into a systemic transition process that redefines the role of ports within transport and energy systems (Notteboom et al., 2021).

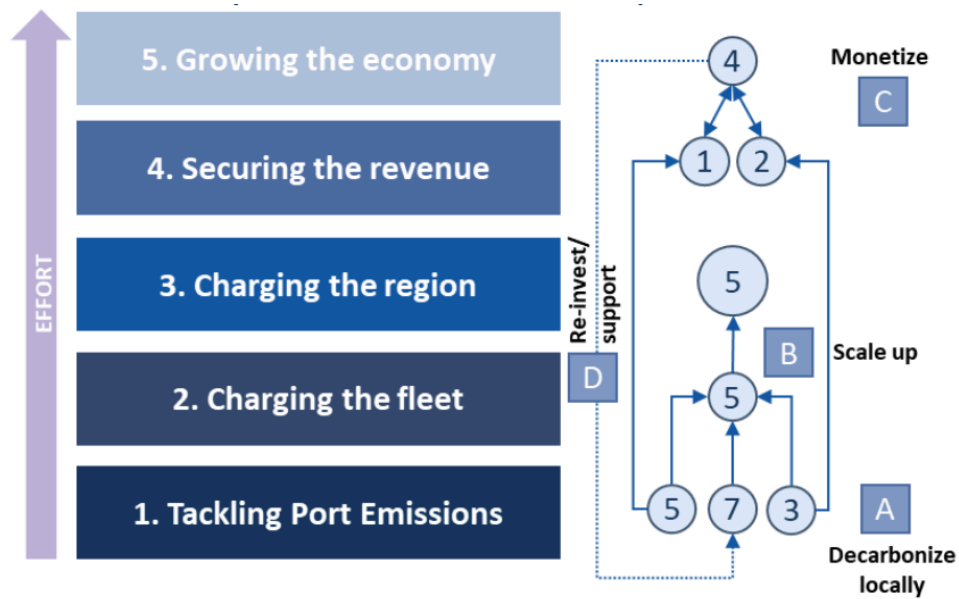


Figure 5. A transition path towards a “decarbonized port” (Source: International Association of Ports and Harbors, 2024)

1.3.1 Conceptualising “greening” of ports

The concept of 'greening ports' is widely used in academic and policy contexts, yet it remains inherently ambiguous. It is often used as an umbrella term to encompass a wide range of initiatives, from minor efficiency improvements to major infrastructural changes. In many cases, “greening” is used similarly to related terms such as 'sustainability' or 'decarbonisation', although there are important differences between them (Acciaro et al., 2014) (ESPO, 2020). Figure 6 further illustrates the scope and multi-dimensional nature of this concept by situating port “greening” within the wider policy architecture of the European Green Deal. Rather than referring to a single set of technical interventions, the concept of “greening” is embedded in a broader transition framework that encompasses climate neutrality, clean energy, a circular economy, sustainable transport and environmental protection. As demonstrated, these policy pillars extend across multiple domains, including energy systems, industrial processes, biodiversity preservation and resource efficiency, all of which are directly or indirectly linked to port activities.

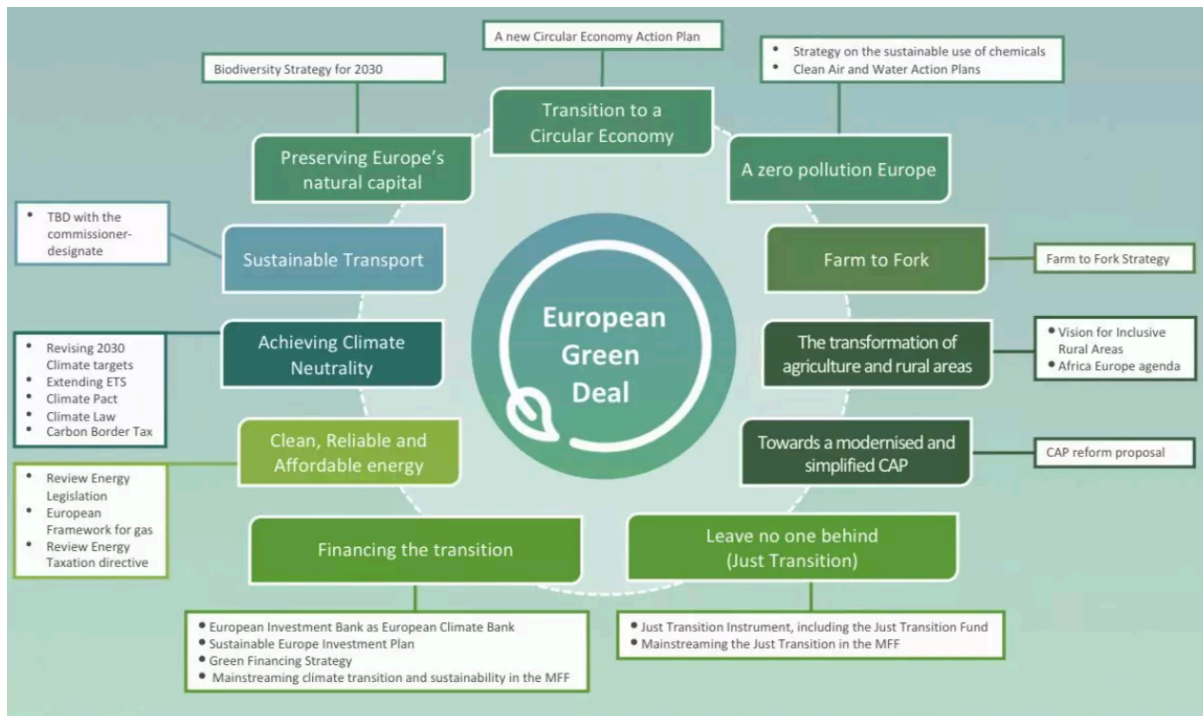


Figure 6. The EU Green Deal (Source: European Commission, 2019)

Sustainability is the broader normative framework that integrates the environmental, economic, and social aspects of development, whereas decarbonisation focuses specifically on reducing greenhouse gas emissions, often through quantified targets and timelines. The “greening” of ports involves translating these broader objectives into practical actions related to infrastructure, energy systems, and operational processes within the port system. Therefore, it is not solely defined by the presence of specific technologies, but by how different interventions are combined and implemented within the port environment (Notteboom & Haralambides, 2023). This distinction is particularly relevant in decision-making contexts, where sustainability and decarbonisation define the direction of change and “greening” defines how this change is operationalised, inherently involving choices regarding investment priorities, technological pathways, and implementation timing. These choices are influenced by the specific characteristics of each port.

Existing definitions of ‘greening a port’ tend to emphasise either environmental performance improvements or the adoption of specific technologies, without fully capturing the systemic nature of the transition and the interactions between different actors and components within the port ecosystem. Therefore, for the purposes of this dissertation, it is necessary to adopt a more explicit and operational definition of port “greening” that reflects its multi-dimensional and system-oriented character:

“The greening of ports can be understood as a transition process involving the planning, investment and implementation of environmentally sustainable practices across port operations and the wider maritime and logistics system, with the aim of progressively reducing environmental impacts and moving towards net-zero emissions over time. This process extends beyond individual measures, requiring the coordinated engagement of multiple port-related stakeholders, including port authorities, terminal operators, shipping companies and energy providers, who collectively shape and implement “greening” strategies within the port ecosystem” (Source: own elaboration)

1.3.2 Ports as energy and transition hubs

One of the most significant aspects of the ongoing transformation of ports is their evolving role within energy systems. Driven by decarbonisation policies, ports are transitioning from conventional fuel supply points to integrated energy hubs, playing an increasingly active role in energy production, management and distribution while supporting the wider energy transition. (DNV, 2025)(DNV, 2025) (Deloitte & ESPO, 2021). In the context of this energy transition landscape, the electrification of port operations, the deployment of SSE-OPS and the anticipated adoption of electrically propelled vessels are collectively driving a significant increase in electricity demand. Simultaneously, the shift towards alternative fuels, such as hydrogen, ammonia and synthetic fuels, introduces new demands for storage, handling and distribution infrastructure within port areas. Consequently, ports are required to accommodate various energy carriers simultaneously, transitioning towards multi-vector energy systems. Figure 7 highlights a clear shift in investment priorities within the port sector towards sustainability and energy transition. The increase from less than 10% in 2018 to nearly 25% in 2023 indicates that decarbonisation is becoming a central strategic focus rather than a peripheral activity (ESPO, 2024a).

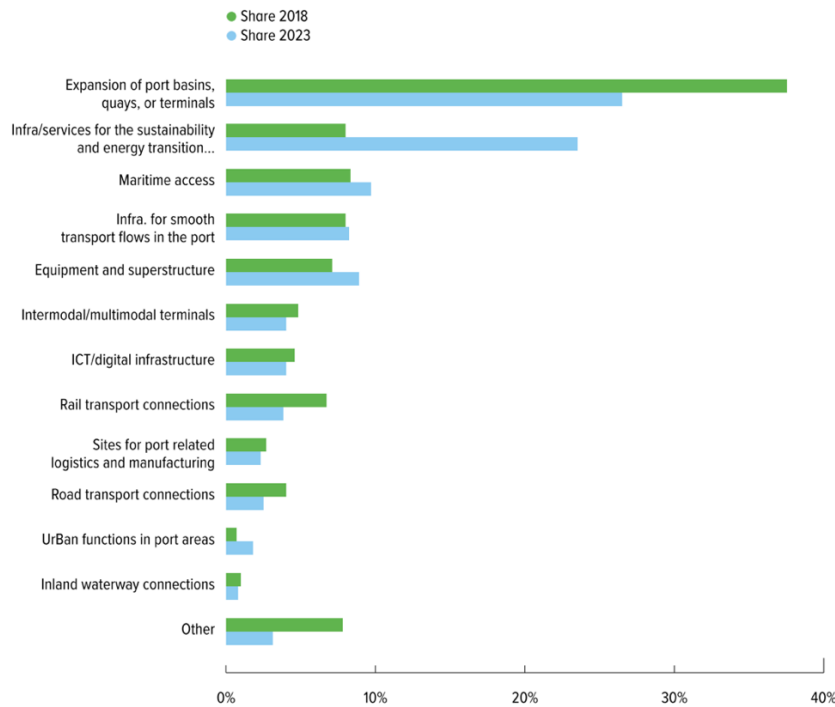


Figure 7. Planned investments of Port Managing Bodies by type (ESPO, 2024a)

In this context as shown in Figure 8, ports are increasingly becoming platforms for the deployment and integration of renewable energy. Their spatial characteristics including large available surfaces (e.g. rooftops, terminals and breakwaters) as well as their proximity to coastal and offshore wind resources and their connectivity to national grids, provide optimal conditions for renewable energy generation (Buonomano et al., 2023).

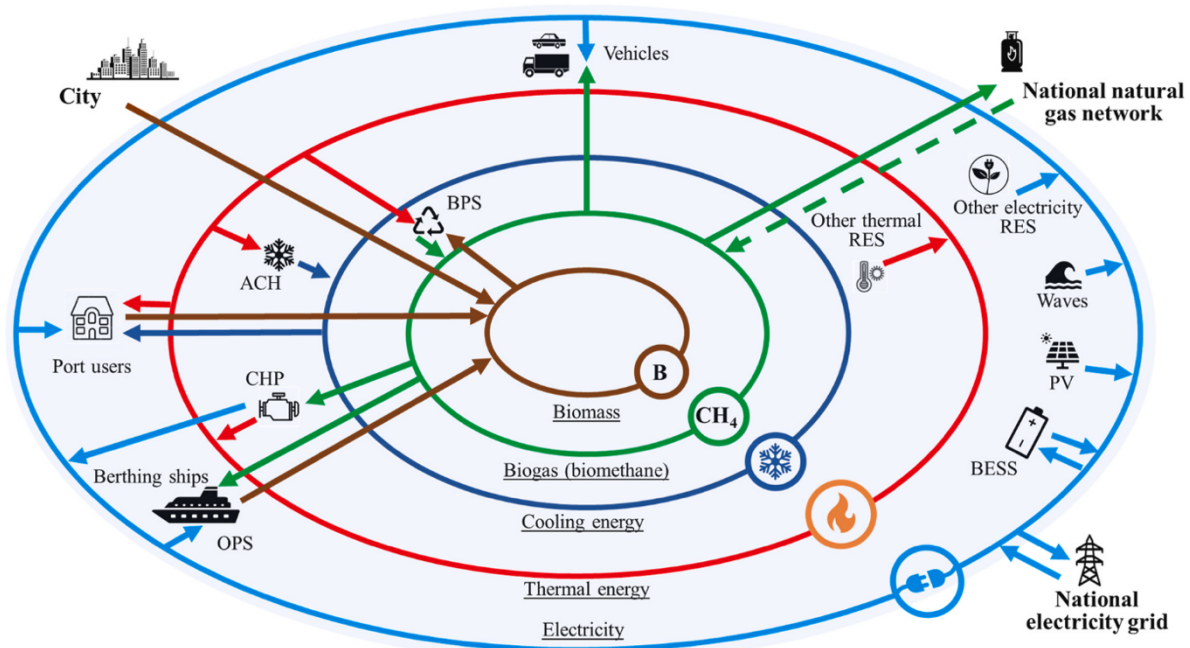


Figure 8. Energy pillars of the port energy hub (Source: Buonomano et al., 2023)

Transforming ports into energy hubs has also significant organisational and governance implications. Integrating energy systems within port environments requires coordination among diverse stakeholders, such as port authorities, terminal operators, shipping companies, energy providers, and regulatory bodies. These stakeholders have different objectives, constraints, and decision-making frameworks, which can lead to misalignment and coordination issues. For instance, investments in SSE-OPS infrastructure depend on port-level decisions and the willingness of shipping companies to retrofit vessels and utilise such systems. Similarly, developing alternative fuel infrastructure depends on supply-side availability and demand-side adoption. Furthermore, this transformation introduces new dependencies that extend beyond the traditional boundaries of the port system, with ports becoming increasingly dependent on external energy systems, particularly with regard to electricity supply, grid capacity and energy pricing. Fluctuations in energy markets, delays in grid expansion and constraints in renewable energy availability can directly affect the feasibility and performance of port “greening” strategies, meaning that the environmental performance of ports becomes tightly coupled with developments in the wider energy system. This reinforces the need for a systemic perspective. From a strategic perspective, the evolving role of ports as energy hubs highlights a fundamental shift in how port performance is evaluated. Beyond traditional metrics such as throughput and efficiency, energy-related indicators, including energy consumption, emissions intensity and energy resilience, are becoming increasingly important. This reflects a broader redefinition of port competitiveness, in which environmental performance and energy integration are key considerations.

Overall, the transformation of ports into energy and transition hubs illustrates the systemic nature of port “greening”, demonstrating that achieving environmental sustainability in ports requires the reconfiguration of energy systems, infrastructure, and stakeholder interactions, not just the adoption of clean technologies. This evolution reinforces the argument that port “greening” should be approached as a complex transition process characterised by interdependencies, uncertainties, and dynamic feedback loops, rather than as a linear sequence of technological upgrades.

1.4 Trends shaping port “greening”

The “greening” of ports is increasingly shaped by a set of interrelated technological and operational trends that reflect the ongoing transformation of port systems towards more efficient and environmentally sustainable modes of operation. These trends are not limited to the adoption of individual technologies but correspond to broader changes in how ports manage information, coordinate stakeholders, automate processes and address energy consumption and greenhouse gas emissions. As identified in recent research on emerging port technologies, these developments can be understood through four main areas of intervention: *i) technologies enhancing educated decision-making, ii) technologies supporting communication and coordination, iii) technologies dealing with the automation of physical processes, and iv) technologies addressing energy management & GHG emissions reduction* (Karagkouni et al., 2025).

A key trend is the increasing use of advanced technologies to support more informed decision-making in port operations. The complexity of port environments, characterised by multiple interacting subsystems and dynamic operational conditions, requires decision-making

processes that go beyond traditional planning approaches. In this context, artificial intelligence, machine learning and data analytics are being used to improve the prediction and optimisation of key operational parameters such as vessel traffic, berth allocation and cargo handling processes. For example, predictive systems analyse sensor data and historical operational patterns to estimate vessel arrival times and optimise scheduling, thereby reducing delays and inefficiencies. This improves operational performance and reduces fuel consumption and emissions by minimising unnecessary waiting times and inefficient movements. Integrating such technologies supports a shift towards data-driven, anticipatory decision-making frameworks where environmental considerations are embedded in operational planning rather than treated as secondary outcomes.

Closely connected to this trend is the increasing emphasis on communication and coordination among port stakeholders. Port operations involve a wide range of actors, including shipping companies, terminal operators, logistics providers, customs authorities and public agencies, each with their own procedures, data requirements and operational priorities. This fragmented environment has traditionally led to inefficiencies, delays and operational bottlenecks, which in turn increase energy consumption and environmental impact. Emerging technologies, such as blockchain-based systems and digital platforms, aim to address these challenges by enabling transparent, real-time information exchange among stakeholders. By providing access to real-time information on cargo status, vessel movements and administrative procedures, these systems facilitate the synchronisation of operations across the transport chain. Improved coordination reduces idle times, unnecessary movements and administrative delays, contributing to more efficient and environmentally friendly port operations. At the same time, the adoption of such technologies highlights the importance of interoperability and standardisation, as effective communication depends on the ability of different systems and actors to exchange and interpret data consistently.

Another important trend is the increasing automation of physical processes within port environments. Automation technologies, including automated cargo handling equipment, autonomous vehicles, and unmanned aerial systems, are progressively transforming port operations. Automated systems can operate in a variety of conditions, delivering consistent performance and reducing reliance on manual processes. For example, automated straddle carriers and rubber-tyred gantry cranes enable more efficient and predictable terminal operations, while autonomous internal transport vehicles facilitate cargo movement within terminals. The use of drones for data collection and environmental monitoring is another emerging application that enables ports to gather real-time information on operational conditions and environmental parameters. From an environmental perspective, automation optimises physical processes by reducing inefficiencies associated with manual operations, such as suboptimal routing, idle times, and inconsistent performance, leading to a more efficient use of equipment and resources and ultimately reducing energy consumption and emissions. However, integrating automated systems introduces new challenges, particularly in coordinating automated and non-automated processes and ensuring proper interface between different subsystems, so achieving the full environmental benefits of automation requires technological deployment and system-level integration and coordination. In parallel, the growing focus on energy management and reducing greenhouse gas emissions represents a key trend in the “greening” of ports. Ports are under increasing pressure to minimise their environmental impact in response to regulatory requirements and broader sustainability strategies. This has led to the development and adoption of technologies that

reduce energy consumption and emissions in port operations. Key examples include the electrification of terminal equipment, shore-to-ship power systems, and alternative fuel sources for port fleets and operations. The electrification of port equipment, such as cranes, vehicles, and handling systems, is widely recognised as an effective way to reduce emissions and improve energy efficiency, as replacing diesel-powered machinery with electric alternatives lowers both direct emissions and fuel consumption, as well as maintenance costs. Similarly, providing Shore-Side Electricity enables vessels to connect to the port's electrical grid while at berth, reducing the need for onboard generators and their associated emissions. At the same time, the use of alternative fuels for port-related vessels and equipment is gaining increasing attention. Efforts to decarbonise port fleets, including tugs, dredgers and support vessels, involve the adoption of cleaner propulsion systems and fuel alternatives. These developments contribute to the reduction of emissions within port areas and support the broader transition towards low- and zero-emission maritime transport. Beyond individual technologies, the growing importance of energy management reflects a broader shift in the role of energy within port systems: energy is now recognised as a critical factor influencing operational efficiency and environmental performance, rather than just a supporting input. Technologies and systems that enable the monitoring, optimisation and management of energy use are therefore becoming increasingly important, including the use of data and digital tools to analyse energy consumption patterns, identify inefficiencies and support more effective energy planning.

These trends demonstrate that the “greening” of ports is driven by the convergence of multiple technological and operational developments. Technologies enhancing decision-making, improving communication, automating processes and managing energy and emissions are not independent solutions, but interconnected components of a broader transformation. Their combined application enables ports to improve operational efficiency, reduce environmental impact and move towards more sustainable modes of operation. At the same time, the interaction between these trends increases the complexity of port systems, reinforcing the need for integrated approaches that can capture the dynamic relationships between different components and support more effective decision-making in the context of port “greening”.

Although the concept of green ports encompasses a broad range of environmental strategies, including alternative fuels, circular economy practices, renewable energy integration, waste management and ecosystem protection, this dissertation focuses on port electrification as the principal analytical perspective through which the green transition of ports is examined. This choice reflects the increasingly central role of electrification in contemporary port decarbonisation policies, as well as its broad applicability across multiple port functions, including Shore-Side Electricity (SSE-OPS), electrified cargo-handling equipment, charging infrastructure and electricity network upgrades. More importantly, electrification represents one of the most systemically significant pathways towards energy-efficient and low-emission port operations, as its successful implementation depends on the interaction of technological, infrastructural, financial and regulatory dimensions rather than on the deployment of individual technologies alone. Consequently, while the broader objective of this dissertation is the greening of ports, electrification constitutes the specific transition pathway through which this objective is investigated.

Chapter 2: Research motivation, and questions to be addressed

2.1 Research motivation

The transition towards “greener” ports is driven by the need to reduce emissions, improve energy efficiency, and support the decarbonisation of maritime transport. Ports are now recognised as critical interfaces where transport, energy, and industrial hubs, placing them at the heart of the energy transition. This expanded role requires ports to accommodate new energy demands, integrate alternative fuels, and adapt their infrastructure accordingly. In this context, electrification and energy efficiency are key pillars of port “greening”, with the deployment of SSE-OPS, the electrification of equipment, and the integration of renewable energy systems expected to significantly reduce emissions, particularly at berth and within port areas. However, these measures introduce new operational and infrastructural requirements, including increased electricity demand, grid capacity constraints, and the need for coordinated investment strategies. At the same time, ports should balance environmental objectives with economic and operational considerations, while responding to evolving policy requirements, technological developments and market conditions. Consequently, decisions related to port electrification involve multiple interdependent trade-offs, and the long-term implications of alternative investment pathways are often difficult to assess using conventional planning approaches.

The central challenge addressed by this dissertation lies in the fact that port electrification cannot be approached as a sequence of independent technological or investment decisions. Instead, it represents a dynamic transition process in which infrastructure development, electricity demand, financial resources, regulatory interventions and operational requirements continuously interact and influence one another over time. Although these interactions are critical to the success of electrification strategies, existing planning approaches provide limited support for understanding their long-term implications and for evaluating alternative investment pathways under conditions of uncertainty.

These decisions are also influenced by policy frameworks and market conditions, creating a complex decision-making environment with multiple options available, but their implications are not always clear. In response to this challenge, this dissertation aims, to advance understanding of the drivers, barriers and implementation challenges associated with port electrification, and to develop a dynamic decision-support framework for strategic port planning. The framework integrates PESTLE analysis with System Dynamics modelling in order to capture the complex interactions, feedback mechanisms, and time delays that influence the adoption of electrification measures within port systems. This supports and enables port’s decision makers to evaluate the alternative investment pathways, the prioritisation and sequencing of electrification interventions, and the assessment of the impact of different policy, economic and technological conditions on transition outcomes over time.

The central research question is therefore defined as follows:

How can ports evaluate and prioritise electrification and energy efficiency strategies in the context of “greening” under uncertainty?

To address this question, the research explores the following:

- ◇ *What are the main challenges and opportunities linked to the implementation of port “greening” measures, particularly those related to electrification and energy efficiency?*
- ◇ *How does the allocation and sequencing of investments influence the evolution of port “greening” over time?*
- ◇ *How can the complexity, uncertainty and dynamic nature of these interactions be represented in a way that supports decision-making?*
- ◇ *What are the factors that shape the electrification strategies in ports, considering infrastructure constraints, investment dynamics and system interdependencies?*

Collectively, these research questions examine port electrification from complementary perspectives. The first identifies the principal implementation challenges and opportunities, the second investigates the influence of investment allocation and sequencing on transition pathways, the third addresses the representation of system complexity through dynamic modelling, while the fourth identifies the key factors governing electrification strategies under infrastructure, financial and operational constraints. Together, they establish the conceptual and methodological basis for the development of the proposed decision-support framework.

The contribution of this dissertation extends beyond the analysis of individual electrification measures by proposing a structured decision-support framework for evaluating port electrification as a dynamic transition process. Rather than examining electrification through isolated technological, environmental or economic assessments, the research integrates qualitative and quantitative approaches to capture the interactions between investment decisions, infrastructure development, electricity demand, policy conditions and operational constraints over time. The dissertation advances the methodological development of port electrification research by combining PESTLE analysis with System Dynamics modelling within a consolidated analytical framework. At the same time, it provides a practical tool capable of supporting port authorities and policymakers in assessing alternative electrification pathways, prioritising investment interventions, exploring policy scenarios and improving strategic planning under conditions of uncertainty.

This dissertation is structured to progressively develop a systemic understanding of port “greening”. It moves from contextual framing and conceptual fundamentals to methodological development, model application, and policy implications.

Chapter 1 provides an overview of the research context by examining the role of ports in the broader transitions of decarbonisation, energy system transformation, and evolving logistics networks, and by analysing the environmental impact of the port sector. It introduces the concept of port “greening” as a strategic response to these challenges, with a particular focus on electrification and energy-related transformations. The chapter also discusses the key trends influencing port “greening” and reviews the relevant policy and legislative framework, establishing the basis for the research objectives and the direction of the study.

Chapter 2 defines the research motivation and formulates the main research questions addressed in the dissertation, outlining the rationale for focusing on electrification and energy

efficiency in ports, and framing the key analytical challenges related to decision-making under complex and evolving system conditions.

Chapter 3 provides the theoretical background to the study and introduces the operational structure of ports. It presents a classification framework for port size to enable comparisons in the analysis and examines environmental aspects and impacts associated with port operations. Drawing on environmental assessment principles and a systematic literature review, the chapter analyses these aspects and develops a structured classification of “green” port practices, with a particular focus on electrification-related measures. It then develops a PESTLE framework to analyse the key drivers and barriers influencing port electrification. Finally, it supports the subsequent modelling work by identifying and justifying key model parameters based on the literature.

Chapter 4 places the research within the wider methodological framework and outlines the research design, explaining the conceptual approach adopted and justifying the use of system dynamics as an appropriate framework for capturing the complexity and interdependencies inherent in port “greening” processes.

Chapter 5 presents the core methodology of the dissertation. It begins with the the PESTLE analysis and proceeds to the development of the causal loop diagram (CLD), which captures the key feedback mechanisms within the system. This is followed by the formulation of the stock-and-flow diagram (SFD), which constitutes the quantitative modelling framework. The chapter also includes scenario-based analyses, examining the impact of capital allocation strategies and grid capacity constraints on electrification pathways. Model validation and robustness testing are conducted to ensure the structural and behavioural reliability of the model.

Chapter 6 demonstrates the application of the modelling framework through an illustrative case focusing on medium-sized European ports. This chapter translates the model insights into practical implications and provides targeted policy recommendations for both port authorities and policymakers, particularly in relation to infrastructure planning, investment sequencing and system-level coordination.

Chapter 7 presents the policy recommendations derived from the findings of the dissertation. Building upon the insights obtained from the System Dynamics analysis, the chapter proposes targeted recommendations for port authorities, national and regional policymakers, and public funding authorities. The recommendations focus on supporting the strategic planning and implementation of port electrification by addressing investment prioritisation, infrastructure development, policy coordination and long-term transition planning.

Chapter 8 concludes the dissertation by synthesising the principal findings and discussing their implications for port electrification and the broader green transition of ports. It highlights the original scientific contribution of the research, outlining its theoretical, methodological, modelling and practical contribution, and identifies potential directions for future research aimed at extending and further validating the proposed decision-support framework.

Overall, the structure of the dissertation reflects a transition from conceptual understanding to analytical modelling and practical application, supporting a comprehensive examination of port “greening” as a dynamic and system-driven process.

Chapter 3: Theoretical background

3.1 Port operations

Port operations refer to the set of activities that take place within the port area and at the ship-shore interface. These activities enable the arrival, servicing and departure of vessels, as well as the handling of cargo and the movement of passengers as indicated in Figure 9. Port operations can be broadly divided into three categories: waterside operations, intra-terminal processes, landside operations and supporting logistics and infrastructure activities (European Commission, 2024).

Seaside operations include the approach and manoeuvring of vessels, pilotage and tug assistance, and the berthing, mooring, unberthing and departure of vessels. During this stage, ports provide key services for vessels, such as bunkering, waste reception and the supply of electricity at berths, either through onboard engines or onshore power systems. Waste management involves the collection and treatment of various waste streams generated by ships, while bunkering processes may vary depending on the type of fuel used. This includes conventional fuels, as well as alternative fuels such as LNG, which require dedicated infrastructure and procedures. Port operations also include dredging activities, which are necessary for maintaining navigation channels and port basins. These activities involve the removal, transport, and disposal of sediment. In parallel, infrastructure development and maintenance activities (e.g. the construction and repair of berths, terminals, and facilities) are essential for operational continuity, but they also generate emissions and waste that affect air, water, and soil quality (Jürgen W. Böse, 2020).

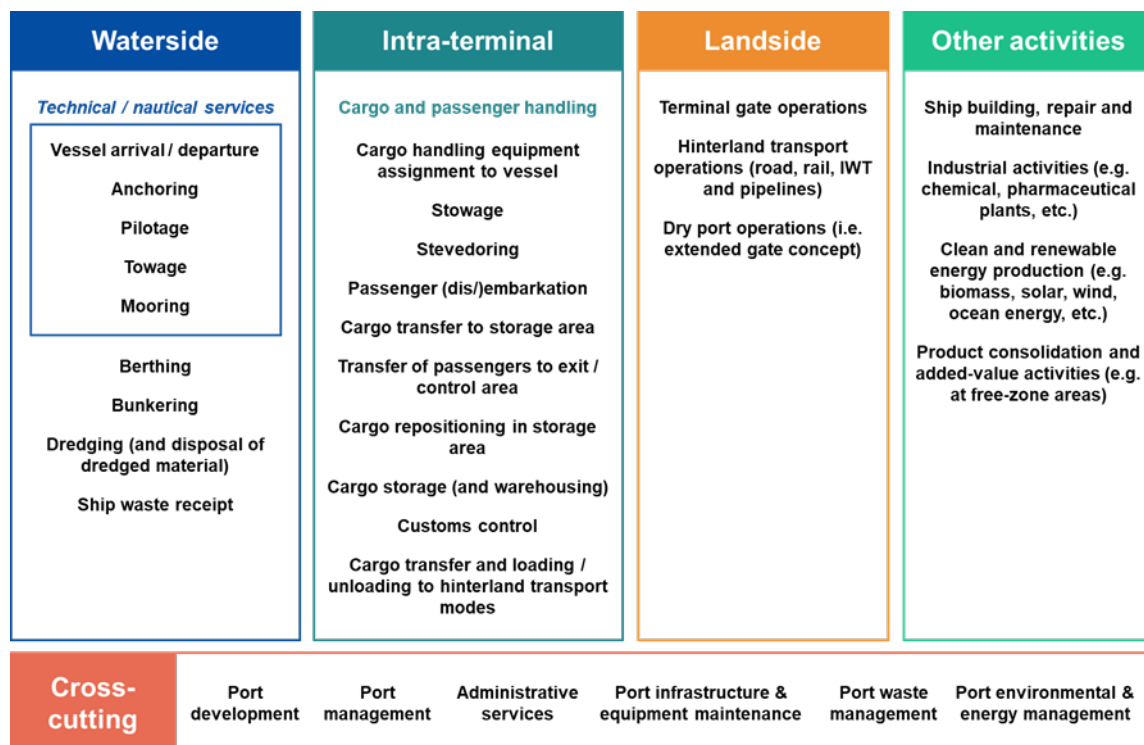


Figure 9. Schematic overview of port operations (Source: European Commission, 2024)

The operations within port area broadly comprise activities related to the terminals located at the port, the intra-terminal connections and the link between the terminals and the port's

hinterland network. Terminals are categorised by the type of cargo and traffic they handle, including container, breakbulk, dry bulk, liquid bulk, Roll-on/Roll-off (RoRo), and passenger terminals. Each terminal type has its own distinct handling systems, equipment, and operational sequences, such as loading and unloading, intra-terminal transport, storage and stacking, and gate processing. Container terminals typically involve vessel-terminal interface operations, intra-terminal transport, storage, and receipt and delivery processes, supported by specialised equipment such as cranes and transport vehicles (Kim & Günther, 2007). Other terminal types, such as bulk or RoRo terminals, rely on different handling systems, depending on cargo characteristics and operational requirements. Passenger terminals incorporate additional processes related to passenger handling and security procedures. Within the broader port system, terminal operations are closely linked with logistics facilities such as warehouses, container freight stations and inland transport interfaces, while gate operations form the main interface with the hinterland and involve inspection, customs and traffic control processes (European Dredging Association, 2021)(Bailey et al., 2004).

Land-side operations refer to the activities and interactions between the port area and inland logistics, industrial and transport systems. Depending on the port's import or export profile and the characteristics of its cargo, the port is connected to a network of nearby logistics facilities, typically located within a radius of 50-100 km. This is especially the case where a metropolitan area is adjacent to the port (Wayne K. Talley, 2018). These facilities emerge due to a scarcity of land, high leasing costs and operational constraints within the port area, while ensuring proximity to the final distribution of cargo. Key logistics facilities include warehouses for storage and last-mile distribution, satellite terminals for transloading, and logistics parks that integrate multiple warehousing and distribution functions (Lun et al., 2010). These facilities are connected to the port by truck, rail or barge, and their operation may generate environmental impacts that are either directly or indirectly linked to port activities.

Apart from the core seaside, intra-terminal, and landside operations described above, port areas also accommodate a wider range of complementary activities, including shipbuilding, repair, and maintenance. In addition, the maintenance and expansion of port infrastructure - such as coastal engineering works, quay and pier upgrades, and flood protection systems - are essential for ensuring safe and efficient operations, as well as for enabling ports to handle increasing cargo volumes and larger vessels (Bailey et al., 2004). Over time, the scope of port activities has expanded significantly, driven by broader developments in maritime transport and global trade, such as the growth in vessel size, the adoption of alternative fuels, and the continuous expansion of international shipping. These trends, combined with technological, economic, and social developments, have transformed ports into complex operational systems that extend beyond traditional cargo handling functions, with modern ports increasingly accommodating industrial and semi-industrial processes. In this context, ports are often considered industrial clusters and strategic energy nodes within the global supply chain, providing value-adding functions across the wider energy ecosystem (Mikael Lind, 2023).

At the same time, ports play a central role in coordinating transport and logistics activities across the value chain. This requires enhanced data exchange and the progressive adoption of digital solutions to support end-to-end visibility and operational efficiency. Consequently, ports are evolving into digital nodes that facilitate more efficient, decarbonised transport systems. Industrial activities associated with port complexes may be located either within the port area itself or in adjacent industrial zones and clusters, as observed in major port hubs

such as Rotterdam and Antwerp. In other cases, industrial facilities operate in close proximity to ports, relying on raw materials handled through port terminals. Typical industrial activities linked to ports include steel production, oil refining, energy production (including biofuels), food processing (such as edible oils), and chemical production and processing (e.g. chlorine, methanol, resins, and fertilisers). In most cases, raw materials are imported through port terminals and then transported to industrial facilities via pipelines, trucks, rail, or barges depending on factors such as distance, volume, commodity type, and infrastructure availability. This concentration of industrial activity in and around ports reflects an advanced stage of port system development.

Looking ahead, the evolution of ports is increasingly shaped by the integration of industrial processes with energy production, particularly in relation to clean and renewable energy. Industrial facilities within ports benefit from logistical advantages such as reduced transport distances and simplified supply chain structures. At the same time, growing concerns related to climate change have led to increased investment in renewable energy generation within port areas. Port stakeholders are actively pursuing solutions to meet their own energy demands while improving environmental performance. Among these, photovoltaic systems have seen widespread adoption, followed by the development of wind energy (both onshore and offshore) and emerging applications of marine energy technologies.

3.2 Port size classification

For the purposes of the methodology developed in this dissertation, it is necessary to classify ports according to size to ensure consistency in modelling assumptions and comparability across cases. Since ports differ substantially in terms of scale, activity profile, infrastructure and traffic intensity, using a common, size-based classification provides an analytical basis for structuring subsequent methodological steps. Port size is determined by a combination of indicators reflecting the scale and complexity of port operations, rather than by a single variable. In this dissertation, categorisation is based on selected parameters including total annual throughput, cargo composition, passenger traffic, spatial extent and proximity to the urban area. Taken together, these variables provide an indicative representation of each port's operational profile and support grouping them into broad size categories. The selection of criteria aimed to capture the physical scale and functional intensity of port activity. Distance from the city centre and total port area indicate the spatial characteristics of the port, while throughput-related indicators reflect the magnitude and composition of port operations. Including containers, RoRo/cars, dry bulk, liquid bulk, total annual throughput and passenger traffic enables the classification to account for different traffic structures and operational profiles rather than relying on a single aggregate measure. Taken together, these variables support a more balanced and representative categorisation of ports by size.

To complement the data extracted from the scientific literature, further information was collected from the official Eurostat database and the ESPO Annual Report, particularly with regard to the annual cargo throughput of European ports by cargo type. Additional information on passenger traffic and the spatial characteristics of each port was obtained primarily from the relevant ports' official websites. All the information collected was subsequently integrated into a structured database, which is presented at the end of this section.

Specifically, an indicative classification of port size was carried out for the ports referenced in the Good “Green” Practices section of this dissertation. The selected sample includes a mix of Core and Comprehensive TEN-T ports appeared also in good “green” practices selection of the research, in order to reflect a range of operational, spatial and infrastructural conditions across European port contexts. Based on the above criteria, ports were grouped into the following indicative size categories: very small, small, medium, large and very large. The dataset clearly illustrates the diversity of European ports included in the analysis, with ports such as Rotterdam and Piraeus classified as very large and large accordingly, due to their extensive spatial footprint, high throughput and complex traffic profile. Rotterdam, for example, stands out due to its exceptionally high total annual throughput and strong bulk and container activity, while Piraeus combines major container and passenger traffic, highlighting its role as a commercial and passenger hub. Similarly, Valencia also appears in the very large category due to its strong container performance and the overall scale of its operations.

In the large port category, Barcelona, Genoa, Venice, Koper, Klaipėda and the Port of London are notable for their high degree of operational diversity. These ports handle substantial cargo volumes and have differentiated traffic structures, including containers, dry bulk, liquid bulk, RoRo flows and, in some cases, significant passenger traffic. This category encompasses ports with considerable operational complexity, albeit on a smaller scale than the largest European hub ports. The medium category includes ports such as Bari, Naples, and Bergen, which are particularly relevant to the logic of this study. These ports combine significant levels of activity with moderate infrastructure and throughput, making them suitable reference points for analysing decarbonisation and electrification challenges under more constrained conditions than major hubs operate under. In contrast, smaller cases such as Aberdeen and Mytilene represent small and very small ports, respectively, illustrating contexts with limited traffic intensity and simpler operational structures.

Table 1. Comparative characteristics of selected European ports used for benchmarking medium-sized port conditions (indicative sample)

Port size	Port	Country	Region	Distance from city center (km)	Port area (km ²)	Containers (annual TEUs)	RO/RO cars (tons)	Dry bulk (tons)	Liquid bulk (tons)	Total annual throughput (million tons)	Passenger traffic (annual)
Large	Port of Livorno	Italy	Europe	3.2	1.85	745,500	467,889	567,000	4,503,000	33.0	2,282,500
Large	Port of Barcelona	Spain	Europe	5.0	7.86	2,033,500	2,562,000	4,013,000	12,862,000	44.0	3,800,000
Medium	Port of Bari	Italy	Europe	4.7	1.15	20,000	1,629,000	3,511,000	29,000	5.1	1,850,000
Medium	Port of Napoli	Italy	Europe	2.3	1.42	532,500	2,384,000	1,104,000	6,507,000	22.0	7,400,000
Large	Port of Venice	Italy	Europe	1.4	20.0	n/a	1,153,000	4,953,846	8,566,470	26.4	2,400,000
Large	Port of Klaipeda	Lithuania	Europe	3.9	5.57	373,260	1,839,000	23,671,000	9,058,000	29.8	280,300
Large	Port of genoa	Italy	Europe	3.5	7.0	1,800,000	6,834,000	923,000	10,231,000	52.0	3,650,000
Large	Port of koper	Slovenia	Europe	1.1	2.8	n/a	617,157	5,933,022	3,323,068	16.0	n/a
Very large	Port of rotterdam	Netherlands	Europe	34.2	48.1	10,000,000	24,000,000	793,761,000	191,986,000	435.0	n/a
Small	Port of aberdeen	Scotland	Europe	1.2	38.8	27,000	n/a	n/a	n/a	4.5	137,300
Medium	Port of bergen	Norway	Europe	0.9	0.15	101,000	101,000	2,155,000	55,582,000	96.0	232,000

*Data refer to 2020, used as a common reference year to ensure comparability across ports for benchmarking purposes (Source: own elaboration)

It should be noted that this classification is used as an analytical simplification for the purposes of this research only, and does not aim to establish a fixed or universal typology of European ports. Rather, it serves as a methodological tool to support the interpretation of the selected cases and the development of the modelling framework. The full list of ports considered in this process is provided in the ANNEX I, while an excerpt of the dataset used for the classification is presented in Table 1.

3.3 Environmental aspects and impacts in ports

3.3.1 Environmental aspects and impacts definitions under ISO 14001 environmental management standard

The ISO 14001 environmental management standard is a widely recognised certification framework used by organisations to formalise, structure and validate environmental management processes. It sets out the requirements, procedures and guidelines that organisations should follow when designing and implementing an environmental management system in a comprehensive and systematic manner. As Kausek (2006) notes, the standard establishes the operational requirements with regard to activities that generate environmental effects (Kausek, 2006). Within this context, a seaport can be considered a complex industrial system comprising a variety of interconnected activities and processes that inevitably have environmental implications, making the concepts of environmental aspects and environmental impacts, as defined within the ISO 14001 framework, particularly relevant to the port sector. These concepts provide a useful basis for structuring environmental analysis across a range of operational environments.

The relationship between the two can therefore be understood as a cause-and-effect relationship: aspects represent the source of environmental pressure, while impacts represent the resulting environmental change. From this perspective, identifying, assessing and prioritising environmental aspects becomes a central component of effective port environmental management.

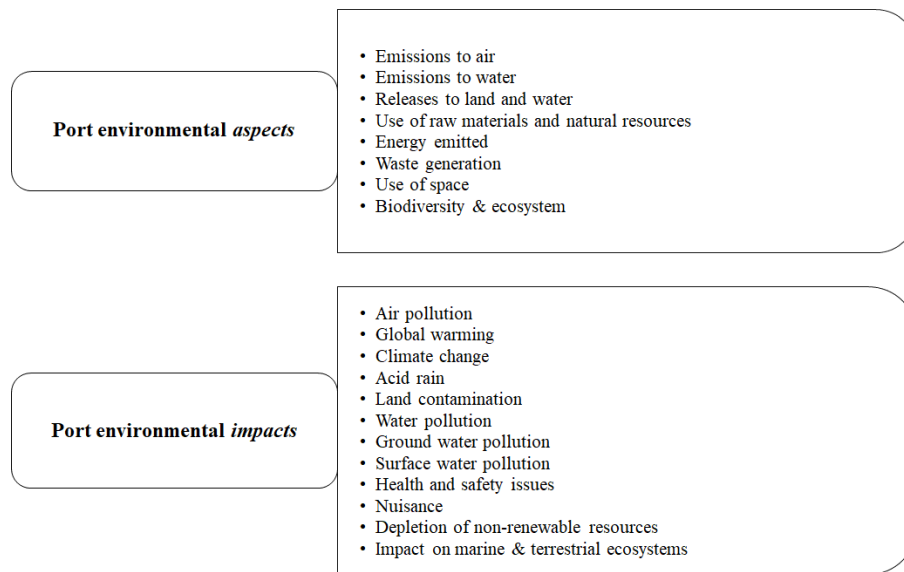


Figure 10. Port environmental aspects and impacts (Source: (Boile et al., 2023))

In the case of ports, identifying environmental aspects and impacts is particularly important given the diversity of activities within port areas and the variation between ports (Figure 10). The nature and significance of these aspects can differ depending on the types and scale of port activities, the extent of industrial and logistics functions, the level of regulatory compliance required for issues such as noise and dust emissions, and stakeholder pressures (ISO, 2015). Consequently, there is no single, fixed list of aspects and impacts that can be considered universally applicable to all ports. The identification of environmental impacts related to ports is widely regarded as a core component of environmental management. Its purpose is to support the quantitative assessment of the most significant environmental aspects associated with a particular port, so that appropriate environmental objectives and targets can be defined to reduce environmental pressures. In parallel, a clear understanding of environmental aspects related to ports also supports the establishment of environmental registers and facilitates awareness of applicable legislation.

Within this process, the identified aspects and impacts should be assessed against a set of criteria such as *severity*, *duration*, *frequency* and *exposure*. In addition, their significance should be considered under different operational conditions as is common practice in risk assessment. These include:

- ◇ Normal operating conditions, which correspond to routine activities and processes
- ◇ Abnormal conditions, which arise during non-routine situations such as maintenance, machinery start-up or shut-down, or temporary operational disruptions
- ◇ Emergency conditions, which relate to unexpected events involving significant hazards and risks such as major spills, fires, explosions, equipment failures, uncontrolled releases of hazardous substances or other severe incidents

Building on the principles established by ISO 14001, the first step in applying an environmental management system is to identify the environmental aspects relevant to the organisation. In this respect, the present dissertation adopts a consolidated list of environmental aspects and impacts developed primarily on the basis of ISO 14001 implementation logic and broader environmental management principles. Individual components is provided within a table in ANNEX II. To enhance its relevance to the port sector, this framework is further informed by definitions and categorisations identified in the literature.

3.3.2 Environmental aspects and impacts in terms of port operations

Building on the rationale used to identify port environmental aspects and impacts, which draws mainly on the principles of the ISO 14001 environmental management standard and a literature review, this section examines the relationship between port activities, environmental aspects and environmental impacts. Typical environmental aspects associated with port activities can be grouped into the following categories: air emissions; discharges to water; leaks or spills affecting soil; noise and vibration; waste generation; consumption of natural resources; and alterations to terrestrial habitats and marine ecosystems.

Environmental aspects can be distinguished into three main groups:

- ◇ those for which the port authority holds direct legal responsibility;
- ◇ those over which the port authority can reasonably exercise influence in its role as landlord (e.g. the activities of tenants and operators);
- ◇ and those considered significant at a local, national or regional level (European Commission, 2024)

The environmental impacts resulting from these aspects include air and water pollution, soil contamination, health and safety risks, habitat disturbance and biodiversity loss, and the depletion of non-renewable resources. Although port activities vary significantly between different ports, environmental impacts can be broadly categorised into four main groups:

- ◇ impacts arising from cargo and passenger handling within the port area;
- ◇ impacts associated with other on-site activities, including industrial operations;
- ◇ impacts generated by vessels calling at the port; and
- ◇ impacts related to hinterland transport systems connecting the port with inland regions

The relationship between environmental aspects and impacts in port operations, across waterside, terminal and landside activities, can be understood as a cause-and-effect relationship. In this context, environmental aspects and impacts are considered in relation to operations within the port area. For this reason, the analysis is organised according to the three main categories of port activity: waterside, intra-terminal and landside operations (Figure 11).

With regard to waterside operations, the emission of CO₂, NO_x and SO_x are of the most important environmental issues, primarily due to the combustion of fossil fuels such as diesel, gasoline and other commonly used marine and operational fuels. In addition, the electricity

consumption associated with waterside activities may indirectly contribute to such emissions depending on the energy source used. Particulate emissions, particularly PM₁₀ and PM_{2.5}, are also closely connected to shipping activity, especially during the approach and berthing of vessels. In the case of shipping, particulate emissions may be further intensified by the use of fuels with a high sulphur content, such as heavy fuel oil (Agrawal et al., 2008). However, the impact of these pollutants on human health depends significantly on the proximity of the emission source to the receptor, meaning that emissions produced at sea are generally less harmful to human populations than those generated within the port area or on land (Miola et al., 2009). Another important aspect of waterside operations is the generation of hazardous waste from ships, which requires dedicated reception facilities and associated port services.

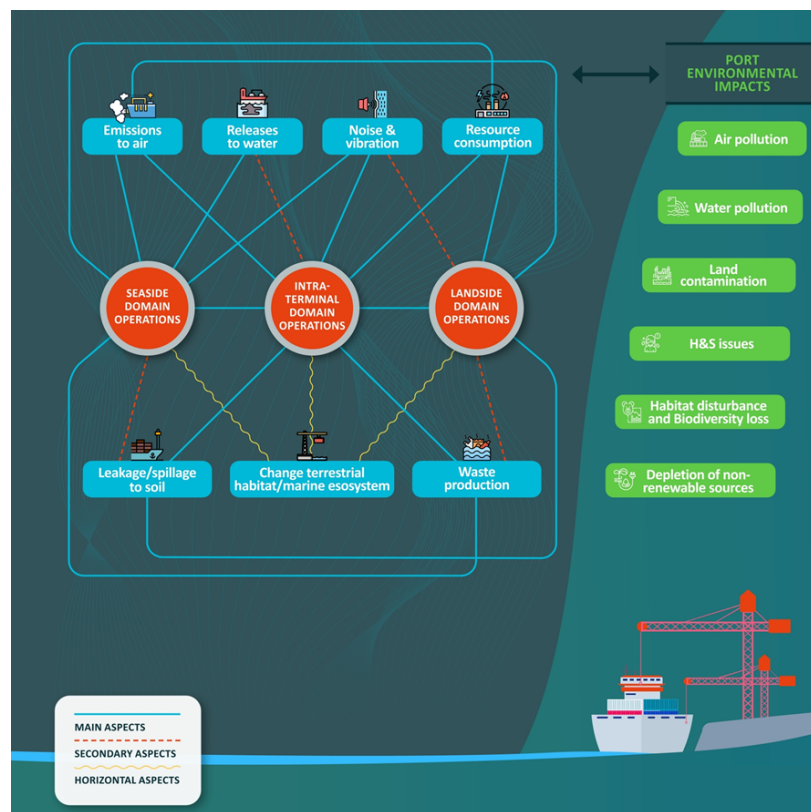


Figure 11. The cause-and-effect relation of environmental aspects and impacts related to the port operations (Source: European Commission, 2024)

Noise, including underwater noise, is strongly associated with waterside activities. Such emissions are mainly generated through engine operation and propeller wake during shipping movements, berthing, mooring, pilotage, and towing (Badino et al., 2012). Dredging activities further contribute to both airborne and underwater noise through the use of machinery to remove sand, sediments, and other seabed materials. Marinas and yachting activities may also disturb aquatic life through similar noise-related pressures. In addition, seabed alterations resulting from dredging, deepening navigation channels, developing manoeuvring basins, and disposing of sediment may significantly affect marine biodiversity by disturbing or removing seabed materials (World Bank Group, 2017). Although port authorities often seek to mitigate such effects, a wide range of shipping and port-related activities, including fishing, mooring, and anchoring, continue to place pressure on marine habitats (Simone Panigada, 2008). Waterside activities are also linked to the introduction of invasive species, particularly through

the discharge of ballast water, while marine leisure activities may facilitate the spread of non-native aquatic organisms (Hewitt et al., 2009; Minchin et al., 2009). Finally, leaks and spills of oil and other hazardous substances, whether during bunkering or as a result of accidents, represent a significant environmental issue with implications for human and aquatic health.

In relation to port development activities at sea, it should be noted that expanding port infrastructure into the marine environment can have significant environmental impacts. In many cases, these developments are also connected to changes on land. Port development can alter marine habitats through coastal hardening, dredging and land reclamation, as well as causing changes to seabed topography and local water currents due to structural interventions and increased vessel traffic. Moreover, construction and dredging works associated with such developments generate additional waste and put further pressure on the environment.

Similar pressures are observed in intra-terminal operations. Within the terminal area, emissions of CO₂, NO_x and SO_x are among the most significant environmental issues, arising either directly from fuel combustion or indirectly from energy use. These emissions are produced by cargo handling equipment, vehicles for transporting goods, locomotives where applicable, personnel transport vehicles and terminal buildings and industrial facilities within the port area (Mousavi et al., 2018). Closely linked to these emissions is the release of particulate matter. Operations involving the loading, unloading and transport of dry bulk materials are particularly important in this regard as they can produce large quantities of suspended particles. Depending on the material being handled and the prevailing meteorological and operational conditions, such processes can generate dust plumes that spread to surrounding areas, degrading local air quality (Artiñano et al., 2007).

Another key environmental aspect of terminal operations is the occurrence of leaks and spills under normal and emergency conditions. Small releases may arise from machinery and vehicles during operation or maintenance, while larger incidents may occur during the handling and transport of liquid products. Terminal operations are also closely associated with energy consumption. Major electricity users include ship-to-shore cranes, forklifts, gantries, port lighting, buildings, industrial facilities, reefer containers and other electrically powered units. Since electricity use is central to terminal activity, improving energy efficiency has become an important issue, driven not only by voluntary action, but also by pressure from industrial stakeholders (Sdoukopoulos et al., 2019). At the same time, vehicles and handling equipment that are not electrified continue to depend on diesel, gasoline, LPG or other fuels, making fuel use another prominent environmental issue. In some cases, this also includes the heating of terminal buildings where natural gas is unavailable.

Terminal activities generate noise on land and underwater due to sound propagating through port structures and surrounding areas. Sources include container loading and unloading, the movement of goods by machinery and vehicles, railway activity and internal traffic (Fredianelli et al., 2021). Port machinery may also create vibrations which can travel through connected structures and amplify overall noise levels, creating a nuisance for nearby populations and fauna in the vicinity of the port.

With regard to landside operations, emissions of CO₂, NO_x, SO_x and particulate matter also represent major environmental aspects, mainly associated with transporting goods to and from

the port. Trucks generally dominate this transport mode, followed by rail and inland waterways to a lesser extent (Olaf Merk, 2015). Even in ports where rail and inland waterway transport are relatively well developed, road transport often still constitutes more than half of hinterland traffic. Ports can influence traffic conditions through gate management, physical layout and capacity planning. However, the broader development of efficient hinterland transport infrastructure usually falls under the responsibility of local, regional and national authorities (Zanne et al., 2021). As in other port domains, using diesel, gasoline and other fuels is therefore a key environmental aspect of landside operations, as is electricity use, particularly for gate systems and industrial or logistics facilities. of port infrastructure and equipment generates hazardous and non-hazardous waste streams, making waste generation another important environmental aspect of landside activity.

Beyond these core operational domains, other port-related activities may also have significant environmental impacts. For example, shipbuilding, ship repair and maintenance activities involve the extensive use of raw materials such as sheet metal and other processing materials. The welding gases used in these activities can affect air quality and pose health and safety risks, while the use of chemicals can lead to leaks, spills and discharges into soil and water. Shipyards often occupy both land and marine spaces, so port development and associated changes to marine and terrestrial habitats are also relevant. Ship hull cleaning, whether performed in dry docks or at sea where permitted, generates significant environmental pressures, including hazardous waste in the form of removed biological material, biocides and toxic paint residues. These require careful management (Song & Cui, 2020). Similarly, industrial facilities located within or near ports can generate additional environmental impacts, including sewer discharges, hazardous waste and odours and volatile organic compounds, depending on the nature of their production processes.

Table 2 provides a structured overview of the correlation between individual port environmental aspects and the environmental impacts that arise from them. It links each aspect with its potential effects on the natural environment and human health. The association matrix of environmental aspects and impacts related to ports can be found in ANNEX II.

Table 2. Link between port environmental aspects and impacts (Boile et al., 2023)

Port environmental aspects	Port environmental impacts
Emissions to air	Air pollution, Acid rain, Global Warming, Climate change, Health and Safety issues, Nuisance, Impact on marine and/or terrestrial ecosystems
Emissions to water	Water pollution, Surface water pollution, Impact on marine and/or terrestrial ecosystems, Biodiversity loss, Land contamination, Ground water pollution
Releases to land & water	Water pollution, Surface water pollution, Impact on marine and/or terrestrial ecosystems, Biodiversity loss, Land contamination, Ground water pollution, Health & safety issues
Use of raw materials and natural resources	Air pollution, Land contamination, Water pollution, Ground water pollution, Surface water pollution, Health and

	Safety issues, Nuisance, Impact on marine and/or terrestrial ecosystems, Biodiversity loss, Depletion of non-renewable resources, Global warming
Energy emitted	Health and Safety issues, Nuisance, Impact on marine and/or terrestrial ecosystems, Biodiversity loss
Waste generation	Land contamination, Health & safety issues, Ground water pollution, Surface water pollution, Water pollution, Air pollution, Nuisance, Impact on marine and/or terrestrial ecosystems, Biodiversity loss
Use of space	Land contamination, Depletion of non-renewable resources, Ground water pollution, Surface water pollution, Water pollution, Air pollution, Nuisance, Health & safety issues, Impact on marine and/or terrestrial ecosystems, Biodiversity loss
Biodiversity & ecosystem	Impact on marine and/or terrestrial ecosystems, Biodiversity loss

3.3.3 Key findings on environmental aspects of port operations Systematic Literature Review (SLR)

The Systematic Literature Review aimed to retrieve numerical data on environmental aspects associated with port operations and highlight key findings from the scientific literature, in support of a thorough evaluation of recent evidence. The review primarily focused on academic, peer-reviewed journal articles, book chapters, conference proceedings published in scientific online sources and conducted in 2022.

The SLR process consisted of three main stages:

- i) Review preparation
- ii) Review implementation
- iii) Reporting of results

During the preparation stage, an appropriate review protocol was developed to guide the search and screening process. A set of relevant keywords and key phrases (“environmental aspects in ports”, “environmental impacts in ports”, “emissions to air OR water OR land OR noise AND ports OR seaports” was defined to support the web-based literature search, with particular emphasis placed on studies published within the last five years. The main scientific databases used for the literature search were Scopus, Google Scholar and Science Direct. The initial search yielded 437 studies. The screening process was followed, and studies were excluded if they did not address the selected topics in sufficient depth or if they presented repetitive or overlapping results. The end result was that 75 studies were deemed relevant and included in the final stage. These studies provided numerical data on emissions to air, noise, and sediment pollution associated with 58 specific ports or terminals worldwide and linked to different port activities. Figure 12 highlights the location of cases identified in the context of SLR method.

Following the initial literature review, a one-page factsheet was prepared for almost every port case included in the reviewed studies, and these factsheets have been compiled in ANNEX III. Table 3 presents an indicative list of numerical results.

Each factsheet in ANNEX III is structured around the following:

- i) General information on the scientific article, including title, authors, and abstract
- ii) The name of the port and country corresponding to the selected case study
- iii) Data on the environmental aspects identified for the seaport, including methodology, environmental aspects, and relevant tables and figures
- iv) Additional port-related data, such as freight and passenger traffic and total port area



Figure 12. Location of cases identified in the context of SLR method (Source: own elaboration)

Table 3. Summary of indicative case studies related to the environmental aspect of emissions to air – numerical data (Source: own elaboration)

Name of Port	Country	Distance from city center	Period of assessment	Methodology	Numerical results	Time period basis of measurements	Specifications on results
Port of Dubrovnic	Croatia	3.5 km	2012-2014	Emissions estimation using numerical modelling	Total air emissions NOx, SO ₂ , PM (tons): 414.7	Annual	Results refer to shipping operation (maneuvering, berthing etc.)
Port of Kotor	Croatia	0.4 km	2012-2015	Emissions estimation using numerical modelling	Total air emissions of NOx, SO ₂ , PM (tons): 306.7	Annual	Results refer to shipping operation (maneuvering, berthing etc.)
Port of Piraeus	Greece	12 km from Athens city center & 2.50 km from Piraeus	2017-2018	Emissions estimation using numerical modelling	Contribution to total air emissions: Passenger ships 46% Cruise ships 6% Containerships 29% Road traffic 5%	Annual	Contribution of ship categories and other port emissions sources

Name of Port	Country	Distance from city center	Period of assessment	Methodology	Numerical results	Time period basis of measurements	Specifications on results
		city center			Ground emissions to air: 320 tons of NOx from cargo handling equipment, 50 tons of NOx from road traffic		Annual air pollutant emissions
Port of Bari	Italy	4.7 km	2019	Emissions estimation using numerical modelling	Total emissions of NOx ($\mu\text{g}/\text{m}^3$): 9.0-12.0	Annual	The highest NOx emissions 9.0-12.0 $\mu\text{g}/\text{m}^3$ are concentrated right over the berths of the port of Bari
Port of Mytilene	Greece	1.3 km	2012	Emissions estimation using numerical modelling	Total emissions of PM10 (Kg): at berth: 25 Kg maneuvering: 15 Kg	Daily	Results refer to 20/08/2012
Port of Busan	South Korea	6.7 km	2017	Emissions estimation using numerical modelling	Container ship maneuver: 51.13% Container ship at berth: 0.57% Container at crane: 35.66% Container trailer: 9.92%	not clarified	Contribution of vessel and equipment activities to total carbon emissions
Port in the Izmit Bay	Turkey	17.2 km	2020	Emissions estimation using numerical modelling	Reduction of emissions: CO2 at berthing & unberthing: 97.51 % CO2 at hoteling: 22.02%	not clarified	Total estimated emissions using Entec calculating methodology

As an overview of the results, it is observed that among the 58 ports and terminals examined, the majority (57%) are located in Europe, followed by Asia (36%), America (5%), while one case concerns ports in Africa. In terms of thematic focus, most of the 75 reviewed studies (88%) address air emissions related to port activities. These emissions are reported at different levels of analysis, including per vessel type calling at a port, per type of emission for a specific terminal, or per terminal activity, covering both seaside and landside operations. Regarding the methodological approaches adopted, emissions are derived from either direct measurements and pollutant data collected at the port (23% of studies), energy consumption records (3%), or predominantly through numerical modelling techniques (75%). Beyond air emissions, additional environmental aspects are addressed to a much lesser extent in the literature, including emissions to water (3%), energy-related aspects and noise emissions (4%), use of raw materials and natural resources (4%), and waste generation (1%).

The ports included in the analysis exhibit significant variation in their characteristics. Differences are observed in terms of annual throughput, with ports ranging from very large to very small, as well as in spatial characteristics such as total port area and distance from the city centre. In several cases, large ports in terms of both size and throughput are located in close proximity to urban areas, while smaller ports tend to be situated further away and have a lower surrounding population. This diversity in port profiles underscores the limitations of direct comparisons, especially when evaluating specific environmental aspects and impacts.

This variability is also reflected in the numerical results reported in the literature, even when similar datasets are examined. For example, the reported values for emissions from container vessels at container terminals differ significantly across studies, mainly due to variations in methodologies, system boundaries, assumptions and measurement conditions. Nevertheless, the analysis reveals some key observations. There is a clear emphasis on air emissions as the dominant environmental aspect studied, growing research interest in port environmental performance in recent years and a strong concentration of studies focusing on European ports compared to other regions.

Overall, the findings of the SLR indicate that, although scientific publications worldwide address environmental aspects related to port operations and, in some cases, examine the same ports, the methodological approaches adopted vary considerably. As a result, the reported environmental aspects and associated results cannot be considered directly comparable, as reflected in the numerical data presented in ANNEX III and summarised in Table 3.

3.4 Classification of “green” practices in ports: a systematic approach

The aim of this section is to examine the sustainability initiatives and “green” practices currently being discussed within the port industry, as well as those already implemented or planned by ports to align with their environmental sustainability objectives. In this context, these practices are being systematised and a structured classification scheme is being developed based on their scope. Emerging trends and potential gaps in implementation are also being identified. To support the categorisation of “green” port-related practices, a structured methodological approach is adopted, including defining categories based on the type of “green” initiatives and technologies applied, and establishing specific criteria such as scale of impact, technology type, and stakeholder engagement level. In parallel, data are collected from multiple sources focusing on ports that have implemented or plan to implement such practices. This is followed by an analysis process aimed at refining the categorisation and documentation.

This classification provides a clear, structured framework that improves understanding of the range of existing “green” activities and their positioning within a broader context. It also provides a structured framework for port authorities and relevant stakeholders to make more informed decisions about selecting and prioritising “green” practices based on environmental objectives and strategic priorities. To ensure the inclusion of a representative body of literature, a comprehensive set of keywords and search phrases was defined and aligned with the research objectives as indicated in Figure 13. The keywords were used for both the scientific literature review and broader web-based research conducted through platforms such as Google Scholar and general web search engines, enabling access to academic publications, reports, conference proceedings, government and industry documents, and professional and sector-specific databases.

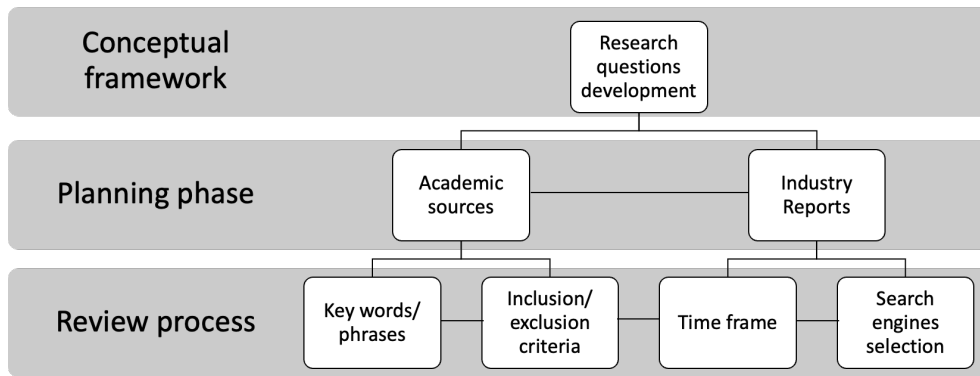


Figure 13. The outline of the research process (Source: own elaboration)

A review combining academic and industry sources was undertaken to identify documented cases of “green” practice implementation in ports, with the aim of providing insight on how “green” port-related actions can be categorised systematically, and whether there are observable trends and gaps in efforts to enhance the environmental performance of port operations. The review process followed a structured approach, as outlined in the research design, comprising a planning phase during which relevant data and information on “green” initiatives in ports were collected, analysed and systematised, with particular emphasis placed on recent developments, trends and priorities associated with ports' transition towards carbon neutrality and zero-emission operations. This initial, broad review enabled key issues frequently addressed in academic and industry literature to be identified.

Subsequently, the review was refined using targeted keywords and phrases to identify specific cases of “green” practice implementation in the port sector. To ensure a representative set of studies was included, a comprehensive list of keywords was defined in line with the research objectives. These keywords were used for both the scientific literature review and broader web-based searches conducted through Google Scholar and general search engines, enabling access to a wide range of sources including academic publications, reports, conference proceedings, government and industry documents, sector-specific databases, trade journals and professional association websites. The keywords used included, among others: 'cold ironing', 'onshore power supply', 'shore side electricity', 'alternative fuels in ports', 'hydrogen in ports' or 'hydrogen production in seaports', 'LNG in seaports', 'bunkering alternative fuels in seaports', 'electricity in ports' or 'electrified vessels and machinery', 'digital solutions in seaports', “green” policies in seaports', 'smart grids in seaports', 'decarbonisation in seaports', 'electric trucks in seaports', 'circular economy in ports', 'waste management in seaports', and 'application of solar and wind farms in seaports'.

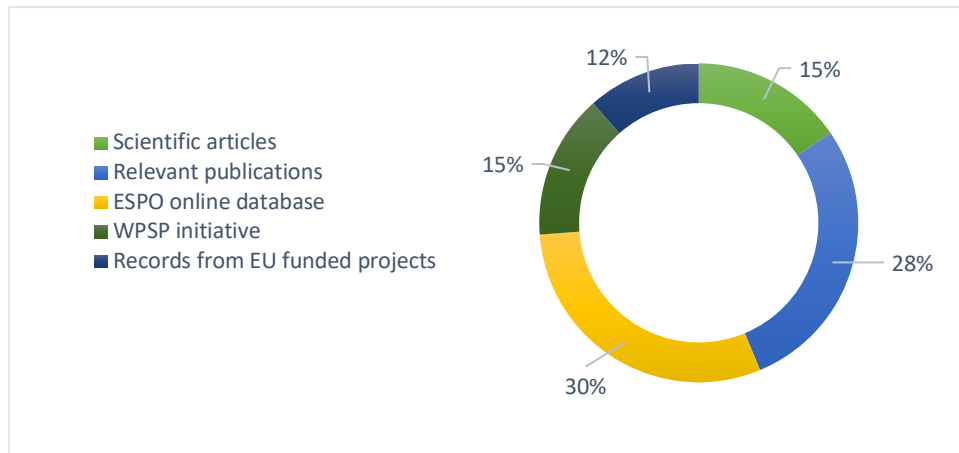


Figure 14. Share of the number of good practices by type of information source

As part of the review process, specific inclusion and exclusion criteria were applied, and studies were selected if they provided relevant information on the implementation of “green” practices. This included aspects related to the benefits, critical factors and challenges associated with specific port cases. Priority was given to studies published within the last ten years, particularly those published within the last three years. In this context, 60 scientific articles were identified as the most relevant sources of concrete cases of “green” practice implementation, along with their associated outcomes. The sources were then organised by publication type as shown in Figure 14.

Overall, 380 records of “green” port practices were identified, derived from academic and industry sources. It should be noted that several publications include multiple practices and/or refer to more than one port case, contributing to the scope of the analysed dataset.

Table 4. Prevalent and other identified groups of “green” practices related to ports (Source: (Karagkouni & Boile, 2024))

“Green” Port Practices		Short Description of “green” Port Practices Content
Prevalent groups of “green” practices	Shore Side Electricity–Onshore Power Supply (SSE–OPS)	Implementation/commercialisation/knowledge transfer of SSE–OPS in ports, exploring the different characteristics and capacities of the systems, business models, and network planning, and cooperation for implementation/scale-up of the infrastructure
	Alternative fuels	Production/bunkering/charging (vessels, trucks) /transport network–corridor–supply chain planning of alternative fuels Alternative fuel supporting vessels and port terminal equipment
	Circular economy	Recycling and efficient (re)use of resources such as sediments from dredging operations, sea-storm water, and rain
	Waste management	Reduction, reception, recovery and use, management/treatment of plastic, water, heat, and raw material

Other “green” practices	Pollution prevention and response	Vessel emissions’ capturing/water pollution prevention
	Renewable energy	Production/provision/conversion/use of wind, solar, and geothermal energy
	Energy efficiency	Infrastructure (terminal area, buildings)/equipment/energy systems
	Operational efficiency	Automation, 5G, IoT and AI, port call optimisation, port traffic management, port environmental conditions forecasting, and eco-driving
	Carbon management	Capture, storage, transport, monitoring, utilisation, and reporting
	Environmental quality monitoring	Air emissions, odour nuisances, water quality, and acoustic characterisations
	Award/certification/incentive schemes	Environmental awareness/environment, energy, integrated management/discounts, and priority handling
	“green” policy and planning	Modal split, carbon-neutrality, zero-emission operations, and climate change adaptation
	Biodiversity protection	Port (re)development planning, port land uses, protection infrastructure, marine species management, and planting

From a conceptual and descriptive perspective, the results of the case studies are classified into 13 broad categories of “green” port practices, as illustrated in Table 4. Specifically, it summarises “green” port practices, emphasising those most commonly discussed in publications: Shore Side Electricity Onshore Power Supply, alternative fuels, the circular economy and waste management. Other “green” port practices include biodiversity protection, renewable energy production initiatives, “green” port policies and strategies, environmental quality monitoring, carbon management and pollution prevention and response measures. Continuous monitoring of energy consumption in seaports is essential for controlling escalating energy costs and growing fuel consumption. Therefore, several “green” practices related to energy efficiency are documented. Additionally, to optimise operational efficiency, port authorities and port-related stakeholders are implementing digital tools and automation solutions. The entire list of good “green” practices identified for this dissertation, is presented in ANNEX IV.

3.4.1 Shore Side Electricity – Onshore Power Supply (SSE-OPS)

A significant share of the “green” port practices identified in the literature focuses on the economic and operational evaluation of Shore-Side Electricity Onshore Power Supply (SSE–OPS) systems, either in the context of specific port applications or through the investigation of pathways that support the wider adoption of cold ironing infrastructure. In this context, several key parameters are typically considered when assessing the feasibility and performance of SSE–OPS systems, including: (i) the number and type of vessels calling at the port; (ii) the cost of electricity production and distribution; (iii) vessel arrival patterns; and (iv) the existing or potential integration of renewable energy sources within the port area. Within scientific studies, these parameters are often estimated and used as inputs in modelling approaches. The deployment of SSE-OPS in European ports is supported by regulatory and technical guidance frameworks, such as those developed by EMSA for port authorities (EMSA, 2022). The literature extensively discusses the regulatory context and technical requirements

associated with such systems, covering key planning and operational dimensions (Mutarraf et al., 2021) (Zhang et al., 2022). SSE-OPS is typically conceptualised as part of a broader integrated energy system within the port, often combined with complementary components such as microgrids, renewable energy installations, smart grids and virtual power plant applications (Iris & Lam, 2019). These systems aim to optimise the balance between energy supply and demand efficiently. However, the scale and configuration of such integrated systems varies significantly between ports, depending on factors such as available resources, energy demand and the characteristics of the vessels served (Kinnon et al., 2021).

In the case of smart grid integration, the electricity supplied to vessels may originate from multiple sources, including local renewable energy installations (e.g. wind and solar), national grids, or hybrid configurations. Smart grids incorporate advanced technologies such as sensors, smart metering, real-time monitoring and control systems, energy storage and communication infrastructure. Despite their potential, the implementation of microgrid systems in ports faces several technical challenges, with battery sizing being one of the most critical and frequently discussed issues (Tao et al., 2014) (Mutarraf et al., 2020). Although this topic has been widely explored in literature, there are still gaps in practical implementation. The integration of Energy Storage Systems (ESS) enables ports to optimise energy demand management by dynamically allocating energy from different sources, including storage units, renewable energy and conventional grids. The ability to store excess energy for later use allows ports to better manage demand fluctuations and achieve cost efficiencies in operational planning. From an environmental perspective, previous studies consistently highlight the significant benefits of SSE-OPS implementation when electricity is sourced from renewable energy. In port areas, estimated emission reductions are 65–82% for CO₂, 75–97% for SO₂, 75–90% for NO_x, and more than 95% for particulate matter. However, these benefits depend heavily on the energy mix used (Karapidakis et al., 2022) (Bakar et al., 2022).

The economic dimension of SSE-OPS remains a critical consideration, with investment costs varying considerably depending on the stakeholder and scale of application. For shipowners, retrofit costs may range from USD 300,000 to 1–2 million per vessel, while for port authorities, costs for shore-side infrastructure may range from USD 300,000 to 4 million per berth. Overall investment levels can reach several million, depending on technical specifications, with the payback period typically ranging between four and six years and being closely linked to vessel type and usage patterns (Abdaoui, 2021). The economic attractiveness of SSE-OPS systems differs across regions; they tend to be more viable in Northern European and North American ports, where electricity costs are lower and environmental regulations are stricter (ESPO, 2025). In contrast, higher energy costs in regions such as Southern Europe can act as a barrier to investment in such infrastructure. Despite the recognised benefits, several barriers to the wider adoption of SSE-OPS remain, which can be summarised as follows:

- i) High capital costs and a relatively low return on investment make implementation challenging, and the effectiveness of SSE-OPS depends on the proportion of vessels equipped to use the technology. Limited vessel compatibility reduces the potential benefits (Mutarraf et al., 2020) (Karapidakis et al., 2022).
- ii) Long payback periods create financial uncertainty, particularly in the absence of public subsidies or financial incentives (Bakar et al., 2022).

iii) Low adoption rates globally reflect a coordination problem between ports and shipping companies: ports are reluctant to invest without sufficient vessel demand, while shipowners are hesitant to retrofit vessels without adequate port infrastructure. Strategic deployment typically requires targeting terminals with high traffic and long berthing durations, followed by gradual scaling up (EMSA, 2022) (Mutarraf et al., 2020).

iv) Technical standardisation challenges persist, particularly regarding voltage and frequency compatibility, with differences between 50 Hz and 60 Hz systems across regions and vessels hindering interoperability and slowing down widespread implementation (Iris & Lam, 2019) (Rahman & Khan, 2020).

3.4.2 Alternative fuels

As part of their broader efforts to achieve carbon neutrality targets, ports and port-related stakeholders are increasingly investigating their capability to produce, integrate and utilise alternative fuels within their operations. Within this context, “green” practices in ports are largely associated with producing alternative fuels and providing bunkering or charging infrastructure for vessels and land-based transport, such as trucks. They are also associated with exploring new configurations in transport networks and supply chain structures. Fuels such as electricity, liquefied natural gas (LNG), hydrogen, ammonia, methanol and fuel cells are commonly classified within the broader category of alternative fuels.

This analysis highlights the particular emphasis placed on developing and deploying “green” hydrogen solutions, including their production, transportation and storage, especially in major European port hubs such as Amsterdam, Barcelona, Rotterdam, North Sea Port, Gothenburg and Antwerp (World Port Sustainability Program, 2023) (ESPO, 2022b) (ESPO, 2023). These ports aim to establish hydrogen hubs within their infrastructure, develop dedicated production and storage facilities for hydrogen, collaborate with other ports to facilitate its transport and design integrated supply chains. As ports progressively transition away from fossil fuel dependency, hydrogen is identified as a versatile energy carrier with multiple applications, including: (i) direct substitution of heavy fuel oil in terminal operations and engines; (ii) enabling bunkering services and supporting sustainable cargo transport to the hinterland; and (iii) serving as a feedstock for the production of synthetic fuels applicable to different transport modes.

With respect to production pathways, hydrogen in port environments is typically generated using non-fossil energy sources, such as hydroelectricity, solar power and wind power, or through water electrolysis processes. This is done in order to minimise or eliminate the emission of air pollutants. In such cases, the only by-products of “green” hydrogen production are heat and water. In parallel, the analysis identifies the expansion of LNG-related infrastructure, including the development of LNG bunkering terminals in ports such as Barcelona, Marseille and Bilbao. Additionally, the Port of Klaipėda is developing a floating LNG import terminal designed to supply LNG into the gas transmission system. Further developments include the production of ammonia from natural gas, combined with carbon capture and storage (CCS), in northern Norway (Port Strategy, 2023) (World Port Sustainability Program, 2019a). This ammonia is planned to be transported to Rotterdam under a memorandum of understanding (ESPO, 2021d). The complexity of hydrogen systems

in port environments varies significantly depending on several factors, including the chosen production method (e.g. “green” hydrogen from renewable sources), the intended application (e.g. use in fuel cell vehicles) and the structural characteristics of each port (Joubi et al., 2022). For example, a techno-economic assessment was conducted in the Port of Trieste which examined hydrogen production under two scenarios: one addressing demand for hydrogen in steel production activities within the port and the other considering simultaneous supply to both steelworks and a hydrogen refuelling station. The results indicated that the cost of producing hydrogen in these scenarios was approximately €7.50/kg H₂. The proposed system configuration included photovoltaic (PV) installations, a grid connection, an energy management system, electrolyzers, low-pressure compressors and hydrogen storage infrastructure (Masip Macía et al., 2021) (Pivetta et al., 2022). Additional large-scale projects further demonstrate the evolving role of ports as energy hubs. In the Port of Wilhelmshaven, for example, a 70 MW electrolysis facility is under development to integrate offshore wind energy with hydrogen production on a large scale (ESPO, 2022c). The aim is to support decarbonisation across industrial sectors such as chemicals, steel and transport. Similarly, in the Port of Bilbao, an investment of €67 million is being allocated to an e-fuel production plant with a capacity of 8,000 litres per day. This will enable large-scale storage and utilisation of renewable energy (ESPO, 2021c). In the Port of Shoreham, meanwhile, “green” hydrogen and renewable electricity generated from solar and onshore wind installations are being used to power heavy-duty forklifts and trucks. This has led to annual CO₂ emission reductions of up to 45,000 tonnes, as well as reducing noise pollution (Notteboom & Haralambides, 2023).

Technologically, the market is increasingly offering scalable, replicable electrofuel production systems that combine “green” hydrogen (produced from renewable electricity and water) with captured biogenic carbon dioxide to generate electrofuels such as e-methanol, enabling the production of fuels with the potential to achieve carbon neutrality and further supporting the decarbonisation of port-related operations and transport systems.

3.4.3 Alternative Fuel-Powered Port Terminal Equipment

The electrification of terminal equipment is widely recognised as a key practice for reducing emissions, decreasing fuel consumption and lowering maintenance costs in port terminals. This transition can be achieved by retrofitting existing diesel-powered machinery or replacing it entirely with electric systems. Typical equipment subject to electrification includes forklifts, straddle carriers, prime movers, lift trucks, terminal tractors, rubber-tyred gantry cranes (RTGs) and mobile harbour cranes (MHCs) (Port Technology International, 2023). Adopting electric propulsion systems for such equipment is an energy-efficient and economically viable way to mitigate emissions from cargo handling operations in ports. It is important to note, however, that the environmental performance of fully electric equipment is directly linked to the source of electricity. Such systems can be considered emission-free only when powered by electricity generated from renewable energy sources. Electric container handling equipment, typically equipped with lithium-ion batteries, offers multiple charging configurations and can be adapted to meet the specific operational and technical requirements of individual terminals. In cases where full electrification is not feasible, hybrid diesel-electric systems provide a transitional solution. Although they do not entirely eliminate emissions, they significantly reduce exhaust pollutants and greenhouse gas emissions compared to conventional diesel-powered equipment.

In addition to electrification, alternative energy carriers such as hydrogen, ammonia and methanol are emerging as potential solutions for powering terminal equipment. However, these technologies are currently less mature and less widely deployed in port environments. There are also existing applications of dual-fuel engines, particularly in trucks and terminal equipment operating on diesel and LNG. For heavy-duty machinery or equipment with extended operating cycles, low- and zero-carbon fuels such as hydrogen are expected to become more widely used in the near future, either through fuel cell technologies or combustion engines. Battery-based solutions are also considered complementary options. The market already offers advanced solutions such as electric container handlers with integrated lithium-ion batteries and flexible charging options, and hybrid configurations combining battery systems with hydrogen fuel cells are being developed to address high power demand and intensive operational cycles. In such cases, electricity and hydrogen are expected to operate in a complementary manner to provide integrated energy solutions for energy-intensive port activities (Port Technology International, 2021). One of the key advantages of hydrogen compared to purely electric solutions is that it can supply energy without requiring extensive high-capacity charging infrastructure, which is particularly important in scenarios where the energy demand of a fleet exceeds the capacity of the local electricity grid.

The ongoing global transition towards electrically powered terminal equipment offers clear environmental advantages, primarily by reducing local emissions and noise levels. Electrification also helps to minimise the environmental impact of port operations on surrounding communities and ecosystems. Compared to diesel-powered equipment, electric alternatives can significantly reduce carbon emissions. For instance, Guangzhou Container Terminal has reported emission reductions of over 50% following the adoption of electric equipment. Such developments suggest that wider deployment of energy-efficient terminal technologies will lead to substantial reductions in CO₂ emissions in the near future. To achieve zero-emission port operations, major ports with high activity levels are increasingly adopting integrated solutions (Margherita Bruno, 2023). These solutions combine low- and zero-emission fuels with advanced technologies. The Vancouver Fraser Port Authority is a good example of this. There, initiatives are underway to test a combination of battery-electric terminal tractors, hydrogen-powered cranes, and the use of 100% renewable diesel in locomotives. The aim is to completely eliminate emissions associated with port activities (Margherita Bruno, 2022).

3.4.4 Alternative fuel-powered supporting vessels

The transition towards “greener” port operations has placed significant emphasis on decarbonising port fleets, including tugboats, dredgers and other support vessels. Port operators are increasingly participating in initiatives to either replace or retrofit existing vessels with cleaner propulsion technologies. A variety of alternative propulsion systems have been developed for such vessels, including diesel-electric and diesel-hydraulic configurations as an alternative to conventional diesel-mechanical propulsion. Other systems are based on liquefied natural gas (LNG), dual-fuel technologies and fully electric propulsion powered by batteries. The selection of an appropriate propulsion system during the design of a vessel is primarily determined by its ability to deliver the required power to achieve the expected maximum service speed; however, in the case of tugboats, the maximum bollard pull is an additional critical parameter that influences the overall propulsion system requirements.

Traditionally, robust diesel engines have been preferred as the main source of propulsion power; nevertheless, marine diesel engines operate most efficiently within a load range of approximately 70% to 85% of their nominal capacity, which is suitable for many vessel types but may not be optimal for tugboats, short-distance vessels, or those operating under low-load conditions, as reliance on conventional diesel engines in such cases may lead to inefficiencies (Ozsoysal, 2021) (Johnathan Cookson, 2023).

Under these operational constraints, the adoption of alternative solutions is particularly relevant. The use of non-fossil fuels with lower consumption profiles, as well as hybrid propulsion systems that combine diesel engines with alternative energy sources, such as electricity, is being increasingly explored. Hybrid electric–diesel vessels, in particular, have attracted growing interest in recent years; for instance, the introduction of two diesel-electric hybrid firefighting vessels at the Port of Hamburg illustrates the practical application of such technologies. Despite these developments, the overall use of electricity-based propulsion systems and alternative fuels in support vessels remains relatively limited, although a growing number of projects are currently being implemented, indicating a gradual transition. These initiatives include fully electric passenger vessels and ferries equipped with battery systems for short-distance operations, as well as hybrid propulsion systems combining batteries with diesel or gas engines for longer routes. In specific cases, significant progress has already been made: nearly half of the support fleet at the Port of Algeciras has been replaced with hybrid or fully electric vessels, supported by the necessary charging infrastructure, and a fully emission-free workboat powered exclusively by batteries has been deployed in the Port of Bergen. This vessel performs a wide range of port-related activities, including maintenance of port infrastructure, towing operations, personnel transport, emergency response and oil spill management (ESPO, 2021a).

3.4.5 Circular economy

In line with the principles of the circular economy, port stakeholders are increasingly promoting the design and utilisation of products incorporating secondary materials. This enables waste streams to be reused as inputs for new processes, aiming to reduce resource consumption and minimise waste generation within port operations. A characteristic example is provided by the Port of Nakskov, where circular economy principles have been applied to essential port equipment: the red navigation beacons (ESPO, 2021f). Due to prolonged exposure to sunlight, these beacons gradually deteriorate and require replacement. Instead of discarding them, the Port has implemented a process involving grinding and repainting, allowing them to be reused and extending their lifecycle. Similarly, the Port of Taipei demonstrates the economic and environmental benefits of circular practices by using recycled materials in infrastructure development, specifically in the construction of port fencing. This has resulted in cost savings of approximately TWD 560 million (USD 17.5 million), while reducing the consumption of natural resources (Fu-Tian Wei, 2020).

On a larger scale, major European port hubs, including the ports of Rotterdam and Antwerp, have developed strategic initiatives aimed at establishing themselves as centres of the circular economy. Initiatives such as the 'Upcycle Factory Project' in Rotterdam and the '88-hectare NextGen District' in Antwerp demonstrate a systematic effort to integrate circular economy concepts into port development (Kovačič Lukman et al., 2022) (ESPO, 2021b). Leading ports such as Antwerp, Rotterdam, Amsterdam and Hamburg are moving in a similar direction,

focusing on gradually phasing out fossil fuels, increasing the use of renewable energy, improving energy efficiency and enhancing waste management practices. However, smaller ports often face significant challenges in adopting circular economy models due to limited resources and difficulties in aligning port expansion strategies with urban planning frameworks. Within the context of implementing a circular economy in ports, dredging operations are a critical activity, particularly in coastal environments. The concept of 'building with nature', which is being adopted more and more in dredging practices, is closely aligned with the principles of a circular economy by enabling the management of sediments in a way that is compatible with local ecosystems (EcoShape, n.d.). Depending on the type of dredging operation (capital, maintenance or remedial) and the level of contamination of the dredged material, these materials can be reused as secondary resources in construction activities within the port. For instance, in the Port of Sevilla, a 275-metre section of infrastructure was developed using around 62,000 cubic metres of sand recovered from the maintenance dredging of the navigation channel (Mańkowska et al., 2020) (Port Authority of Seville, 2022).

Despite these advancements, there are still several challenges to implementing circular economy strategies in port environments. These include internal resistance to organisational change, which is often linked to a lack of awareness among employees; insufficient traceability of materials used in port-related activities; a lack of coordination and information exchange between stakeholders; and uncertainties relating to return flows and increased transportation costs. Such challenges have been observed in the case of the Port of Szczecin, for example, highlighting the complexity of transitioning from linear to circular operational models (Gurning & Tangkau, 2022) (IMO, n.d.).

3.4.6 Waste management

Waste management is a key part of “green” practices in ports. It involves reducing, collecting, receiving, recovering, treating and handling different types of waste, such as plastics, materials, wastewater and hazardous substances (IMO, n.d.). This waste is produced by port and maritime activities. Within this context, port authorities, waste management companies and shipping firms are working together to improve waste management systems, promote recycling and produce alternative fuels from waste. As well as setting up port reception facilities as required by the MARPOL convention, ports are moving towards more advanced waste treatment solutions. These solutions cover a wider range of waste types and use different processing techniques. Several practical initiatives illustrate the application of such practices: in Spanish ports, including Algeciras, Valencia, and Barcelona, targeted campaigns have been implemented to limit the use of single-use plastic bottles among port personnel (ESPO, 2021g). These initiatives are supported by the installation of water dispensers within port areas, which facilitate the reduction of plastic consumption at source. Similarly, the Port of Barcelona has introduced a system involving the installation of 30 water dispensers, which has resulted in the avoidance of approximately 118,680 plastic bottles annually. The long-term objective of such measures is to reduce waste generation and potentially eliminate the need for recycling or reuse processes for specific waste streams (ESPO, 2022a).

In parallel, other ports are developing more technologically advanced approaches. The North Sea Port is investing in advanced chemical recycling technologies to treat plastic waste generated within the port area. The corresponding recycling facility is expected to process around 55,000 tonnes of mixed plastic waste per year - equivalent to the annual plastic

packaging waste produced by approximately 1.7 million EU citizens. In a different initiative, the Port of Vigo is developing an integrated waste management system that primarily focuses on waste generated by fishing activities, such as plastic packaging, polystyrene containers, discarded fishing gear and marine litter (Ramos Velasco et al., 2022). From an implementation perspective, “green” practices related to waste reception, treatment and processing often have relatively short deployment timelines of typically zero to two years, according to port authorities and waste management operators. Innovative approaches that utilise waste streams such as slop oil, solvents, solid waste and fats as inputs for alternative fuel production or the development of new port infrastructure are associated with moderate implementation costs generally estimated at between €20,000 and €50,000 (Regulation (EU) 2023/1805 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport, and Amending 2009/16/EC, 2023). Such waste valorisation practices are also considered to have relatively high transferability potential across different ports provided the necessary resources and operational conditions are available.

3.4.7 Other “green” port practices

3.4.7.1 “Green” policy and planning

The transition towards “greener” port development is increasingly being addressed through the formulation of comprehensive policy frameworks and strategic planning processes. Such approaches typically incorporate objectives related to modal shift, carbon neutrality, zero-emission operations and climate change adaptation. Ports articulate their commitments and strategic direction through official documents, including port strategies, master plans and dedicated policy frameworks. Among the most frequently addressed priorities are carbon neutrality, emission reduction targets and climate-related risks, alongside considerations such as ocean acidification and flood risk management. For example, Flinders Port Holdings in Australia has developed a climate change adaptation strategy that identifies environmental risks and opportunities, while the Port of Baku has outlined a climate strategy and action plan for developing a “green” port and logistics hub that aligns with international standards. Similarly, the Port of Helsinki promotes stakeholder engagement through incentive schemes that support its carbon neutrality objectives (World Port Sustainability Program, 2021a).

3.4.7.2 Environmental quality monitoring and pollution prevention

Environmental monitoring systems are increasingly recognised as critical tools for improving environmental performance in ports, typically focusing on monitoring air emissions, water quality, noise levels and odour nuisance through the deployment of smart sensors and digital platforms. In parallel, emerging technologies such as drones and autonomous robotic systems are being utilised to enhance pollution detection, prevention and response capabilities. For example, real-time monitoring systems have been implemented in the Ghent–Terneuzen Canal to enable continuous assessment of air and water quality, facilitating the timely identification and mitigation of environmental risks (ESPO, 2021i).

3.4.7.3 Carbon Management

The stricter environmental regulations and the increasing cost of carbon emissions have driven growing interest in carbon management practices within the port sector, including carbon capture, storage, transport, utilisation, monitoring and reporting. The rise in carbon

pricing, particularly in Europe, has further intensified attention on such practices. However, despite their potential, Carbon Capture, Utilisation and Storage (CCUS) technologies have not yet matured into economically viable solutions, limiting their widespread adoption. As a result, although recognised as a promising pathway for reducing carbon emissions in ports, these technologies remain at an early stage of implementation (World Port Sustainability Program, 2020b).

3.4.7.4 Renewable energy and energy efficiency

Renewable energy production has emerged as a key pillar of the “green” transition in ports, with installations such as offshore wind farms and solar parks contributing significantly to reducing emissions and supporting cleaner port operations. In certain cases, renewable energy initiatives extend beyond port boundaries to support local communities. For example, Solomon Ports has allocated funding to community-based renewable energy projects aimed at reducing greenhouse gas emissions, and at the Port of Hirtshals, wind turbines have enabled electricity generation levels that sometimes exceed consumption by up to 50% (World Port Sustainability Program, 2021b). Similarly, large-scale solar projects such as the 60 MW solar farm in the North Sea Port supply energy to thousands of households while achieving notable reductions in CO₂ emissions (ESPO, 2021e) (Luo et al., 2023).

3.4.7.5 Biodiversity protection

The environmental pressures associated with port operations have highlighted the importance of biodiversity protection measures. these initiatives aim to mitigate impacts on local ecosystems and preserve both marine and terrestrial habitats. typical actions include the restoration of degraded ecosystems, replanting of sensitive vegetation such as seagrass, enhancement of habitat conditions for wildlife, and awareness-raising activities related to ecosystem conservation. in addition, measures such as CO₂ sequestration contribute to broader environmental objectives. several ports, particularly in Spain, are actively investing in projects and studies focused on ecological restoration. for instance, restoration works at the port of Tarifa aim to maintain both the structural integrity of port infrastructure and the surrounding ecosystem (World Port Sustainability Program, 2016) (World Port Sustainability Program, 2019b).

3.4.7.6 Operational efficiency

Digitalisation and automation have become key enablers for improving operational efficiency and environmental performance in ports. Technologies such as 5G, Internet of Things (IoT), and Artificial Intelligence (AI) are increasingly applied to optimise port calls, manage traffic flows, and enhance decision-making processes. Systems such as the dynamic under keel clearance system enable more efficient use of port capacity and support optimisation of dredging activities (World Port Sustainability Program, 2020a) (World Port Sustainability Program, 2020c). Digital platforms, such as PortXchange, facilitate real-time coordination among port stakeholders, including shipping lines, terminals, and port authorities. The adoption of such technologies contributes not only to cost reduction but also to lower energy consumption and improved sustainability outcomes. however, barriers remain, including high implementation costs, limited technical expertise, regulatory constraints, and the need for stakeholder coordination. Addressing these challenges requires investment in skills

development, knowledge sharing, and collaboration with technology providers (Surucu-Balci et al., 2024).

3.4.7.7 Awards, certifications and incentives

To further promote sustainable practices, ports are increasingly participating in certification and incentive schemes designed to recognise environmental performance. Such schemes reward ports for actions including reducing emissions, improving energy efficiency and managing waste effectively. Certification programmes such as Ecoports provide formal recognition of compliance with high environmental management standards. Incentives may include financial benefits, regulatory support or enhanced public visibility, thereby encouraging ports to adopt innovative technologies and strengthen their environmental performance.

3.5 Analytical review of port electrification drivers and barriers using the PESTLE framework

Ports have gradually transitioned from being conventional trade and logistics hubs to becoming key players in the global sustainability efforts. They are playing an increasingly important role in supporting climate mitigation and energy transition objectives. Regardless of their size, ports are adopting more and more “green” initiatives to reduce emissions, improve operational efficiency and align with net-zero targets (ESPO Secretariat, 2024). Within this context, electrification has become a vital part of the solution, helping to optimise operations and improve environmental performance. It facilitates the shift from fossil-based energy systems to cleaner alternatives by providing shore-to-ship electricity (SSE-OPS), electrified cargo handling equipment, and supporting vessels and port vehicles. This is in response to evolving regulatory requirements and technological developments (European Parliamentary Research Service, 2021) (ESPO, 2024b) (EMSA, 2023) (Frederic Godemel, 2023). Port electrification also involves introducing hybrid and fully electric propulsion systems for port fleets and developing charging infrastructure for electric trucks and other vehicles accessing port areas. These developments are increasingly complemented by renewable energy-based microgrid systems, strengthening the role of ports as integral components of broader energy transition infrastructures. In parallel, ports are evolving into hubs of industrial symbiosis, integrating renewable energy technologies such as wind turbines, solar panels, and hydrogen electrolyzers, while also contributing to grid stability and enhancing local energy resilience (European Commission, 2024).

Thus, although several alternative decarbonisation pathways, including hydrogen, methanol, ammonia and hybrid energy systems, are being explored within the maritime sector, the present dissertation focuses specifically on electrification. This choice reflects the objective of the research rather than an assumption that electrification represents the optimal solution for all ports. Electrification was selected because it comprises a diverse portfolio of measures with different levels of technological maturity, investment requirements and infrastructure implications, making it particularly suitable for investigating the dynamic interactions, investment trade-offs and implementation pathways addressed through the proposed System Dynamics framework.

However, the implementation of electrification technologies in ports is constrained by several factors, including high initial investment costs, limitations in existing infrastructure, and the relatively low maturity of certain technologies (DNV, 2020). Despite these challenges, the potential environmental and economic benefits remain significant. Existing studies indicate that adopting shore-side electricity could reduce global port-related emissions by almost 10%, with considerably higher local impacts: 57% in Kaohsiung Port (Taiwan) and 2% in the United Kingdom (Zis et al., 2014) (C. C. Chang & Wang, 2012). In cruise shipping, electrification has achieved average emission reductions of 29.3%, with peak reductions of 99.5% in Norway, 84.9% in France, and 85.3% in Brazil (Hall, 2010). Similarly, electrifying port equipment has demonstrated notable benefits: rubber-tyred gantry (RTG) cranes achieving 67% emission reductions and hybrid straddle carriers showing 27.1% improvements in fuel efficiency and reductions in carbon emissions exceeding 66% (Huang et al., 2023). These findings highlight the substantial environmental gains already achieved through initial electrification applications.

The European policy framework plays a crucial role in accelerating the transition to a more sustainable future. Regulatory instruments such as the Alternative Fuels Infrastructure Regulation (AFIR) (Regulation (EU) 2023/1804) and the FuelEU Maritime Regulation (Regulation (EU) 2023/1805) establish binding requirements for the deployment of shore-side electricity systems and alternative fuel infrastructure in ports. These initiatives are supported by financial mechanisms such as the Connecting Europe Facility (CEF) and are aligned with the broader objectives of the European Green Deal, which aims to reduce greenhouse gas emissions by 55% by 2030 and achieve climate neutrality by 2050 (ESPO Secretariat, 2024) (European Commission, 2025). Consequently, port electrification is now seen as an immediate requirement embedded within the regulatory and environmental obligations of European ports, rather than a future-oriented objective. A growing number of ports have already implemented various electrification technologies, generating initial outcomes that provide valuable practical insights. These early applications demonstrate significant benefits, such as reductions in emissions and improvements in energy efficiency, as well as ongoing challenges, including high capital costs, technical complexities and resistance among stakeholders. The systematic evaluation of these experiences helps to identify key drivers that facilitate adoption and clarify the barriers that may hinder wider implementation of electrification solutions across the port sector.

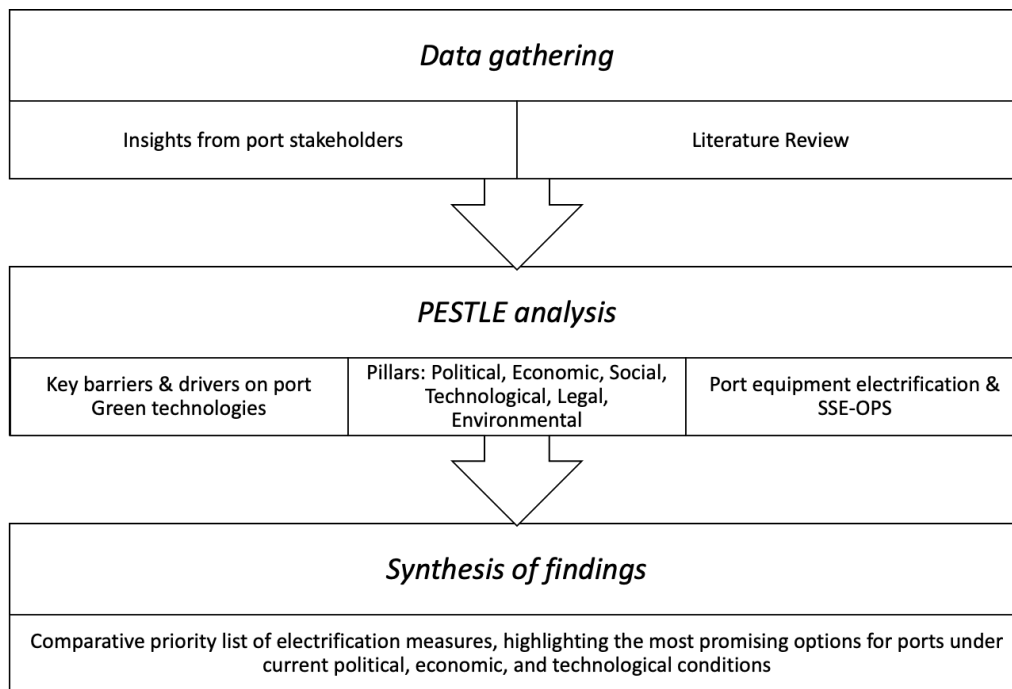


Figure 15. Consolidated outcomes of the port electrification analysis (Source: (Karagkouni & Boile, 2025))

In order to systematically capture and analyse these factors, the present dissertation adopts the PESTLE framework, which enables a structured examination across six key dimensions: Political, Economic, Social, Technological, Legal and Environmental. Within this context, the literature review in this section aims to identify and summarise the main factors influencing the adoption of electrification measures in ports, focusing particularly on Shore-Side Electricity Onshore Power Supply (SSE-OPS), as well as the electrification of port equipment and operations. The review as indicated in Figure 15 involves a systematic collection and analysis of existing studies, considering both the technical characteristics of electrification solutions and the broader contextual factors influencing their implementation. Particular attention is given to interpreting findings through the PESTLE framework, enabling categorisation of evidence across the six analytical dimensions. This approach provides a more comprehensive understanding of port electrification as a process influenced by regulatory, economic and strategic considerations, not just a technological transition. Emphasis is placed on extracting insights from documented implementations and empirical findings to identify recurring patterns, enabling conditions and constraints, which facilitates the identification of common trends across different port contexts while acknowledging variability in implementation conditions and outcomes.

The literature review draws on over 60 peer-reviewed academic articles, 25 technical reports from technology providers and NGOs, and 12 EU legislative texts (Figure 16). Among these, the EU-commissioned “Greening of EU Ports” study (European Commission, 2024), plays a central role. It offers valuable data through a mix of interviews with 12 port stakeholders, seven in-depth interviews with legal experts, a survey of 96 port representatives, and a desk review of 380 good practice cases. This extensive evidence base provides insights into real-world implementation challenges, legal ambiguities, and institutional dynamics relevant to electrification.

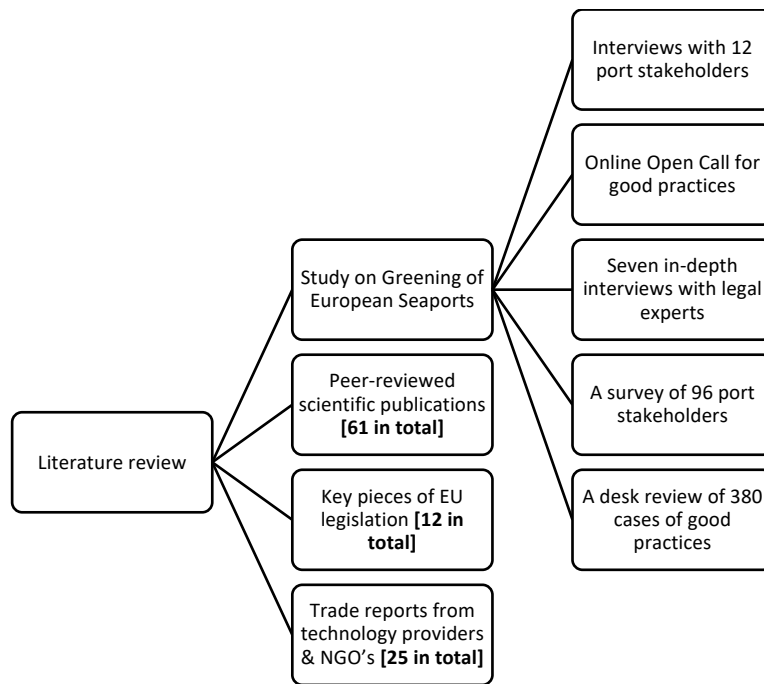


Figure 16. Type of literature reviewed for the article (Source: (Karagkouni & Boile, 2025))

Electrification has emerged as a pivotal element in the transformation of port operations, fundamentally reshaping equipment, fleets and supporting infrastructures. When combined with electricity generated from renewable energy sources (RES), this transition enables the gradual replacement of fossil fuels, reduces the overall carbon footprint and supports alignment with evolving regulatory and policy frameworks (MSE International, 2024). Within this context, the deployment of shore-side electricity (SSE) constitutes a key intervention, enabling vessels to connect to the onshore electricity grid while at berth and eliminating the need for auxiliary engine operation. Its implementation has been formalised within the European regulatory framework and is mandated under the Alternative Fuels Infrastructure Regulation (AFIR) and the FuelEU Maritime Regulation for TEN-T Core Ports by 2030 (Gundersen et al., n.d.). Financial support mechanisms such as the Connecting Europe Facility (CEF) have also accelerated its adoption (T. Chen et al., 2025). As electrification technologies become increasingly integrated into global port practices, both academic literature and port case studies consistently emphasise their contribution to sustainability goals and operational innovation (DNV, 2020) (Meng et al., 2023) (Port Strategy, 2025). The electrification measures examined, represent the primary categories of interventions driven by technological advancements and policy objectives. These categories demonstrate a convergence of academic research, regulatory frameworks, and industry practices, indicating areas where implementation is already occurring and where future actions are anticipated to generate the most significant impact.

In particular, the electrification of Ground Support Vehicles (GSVs), including cargo-handling equipment such as forklifts and stackers, as well as other terminal machinery and port-owned vessels, has been extensively examined as a core component of port electrification (H. Chen et al., 2023) (Sadiq et al., 2021). The transition from conventional propulsion systems to electric alternatives is widely recognised as a critical step towards reducing emissions and improving operational efficiency (Zis et al., 2014) (Chang & Wang, 2012) (Hall, 2010). Similarly, the electrification of cranes, such as rubber-tyred gantry (RTG) cranes, stacking

cranes and ship-to-shore gantry cranes, has received significant attention due to its potential to reduce fuel consumption and maintenance costs, and to contribute to environmental performance targets (T. Chen et al., 2025) (Oslo Havn, 2021). Retrofitting existing equipment is widely discussed in the literature as a cost-effective alternative to full replacement strategies (ESPO and Royal HaskoningDHV, 2022). However, such approaches often present technical challenges, particularly regarding compatibility and integration with existing systems (Port Technology International, 2024). In parallel, the development of charging infrastructure for electric trucks highlights the increasing importance of decarbonising hinterland connections (Rahman & Khan, 2020) (Port of Los Angeles, 2024). The electrification of auxiliary port vessels, including support vessels and tugboats, is another relevant area of investigation. Hybrid-electric, fully electric and alternative fuel-based propulsion systems offer considerable potential for reducing emissions and noise levels (Fadiga et al., 2024).

The PESTLE framework is widely recognised as an effective analytical tool for supporting strategic decision-making in complex systems influenced by external factors, such as ports (Münter, 2024). It enables the structured identification, prioritisation and assessment of the factors influencing port electrification, while ensuring alignment with broader sustainability objectives. In this research, the PESTLE framework has been adopted due to its ability to capture the multidimensional nature of the challenges and opportunities associated with port electrification, as well as its consistency with current academic and industry practices. In dynamic environments characterised by evolving regulatory requirements, financial limitations and rapid technological developments, PESTLE provides a structured basis for deriving insights to support strategic planning and policy development. The framework's relevance is further supported by its application in recent port-related studies: for instance, Praharsi et al. (2021) combined PESTLE analysis with the Balanced Scorecard approach and Smart Port concepts to address inefficiencies, environmental pressures, and technological gaps in port systems (Praharsi et al., 2021). Similarly, Tsvetkova et al. (2024) applied PESTLE within a technology roadmap to identify the main drivers facilitating the adoption of cleaner propulsion systems, and Christodoulou and Cullinane (2019) employed a combined SWOT/PESTLE framework to analyse the deployment of energy management systems in Northern European ports (Tsvetkova et al., 2024) (Christodoulou & Cullinane, 2019).



Figure 17. Number of references contributed barriers/drivers of port electrification to each PESTLE pillar

The distribution of literature supporting the identification of drivers and barriers across the PESTLE dimensions highlights the relative importance of each pillar. The economic dimension is the most prominent, with 22 references reflecting a strong focus on investment requirements, funding availability and cost–benefit considerations as indicated in Figure 17. Technological factors follow with 19 references emphasising issues related to infrastructure readiness and technological innovation. Social aspects are represented by 16 references primarily relating to workforce skills, public perception and stakeholder acceptance. Both the legal and environmental dimensions are supported by 13 references each indicating the importance of regulatory compliance and sustainability requirements. Finally, political factors are reflected in 12 references relating to governance structures and policy frameworks. This distribution illustrates the inherently multidimensional nature of port electrification and confirms the value of the PESTLE framework as an organising structure for such analysis.

3.5.1 Political factors influencing port electrification

Political factors play a pivotal role in shaping the trajectory of port electrification, acting as both enabling mechanisms and potential constraints. On the one hand, government support schemes, including subsidies, grants and tax incentives, mitigate the substantial initial costs of adopting electrified technologies such as ground support vehicles, electric cranes and supporting vessels (Frederic Godemel, 2023). Within the European Union, funding programmes have facilitated the development of renewable energy projects, particularly shore-side electricity installations, reducing reliance on conventional fossil fuels. Additionally, the Energy Taxation Directive (ETD) (Directive 2003/96/EC) permits member states to exempt electricity supplied to berthed vessels from taxation, promoting the adoption of SSE-OPS systems as a cleaner alternative to onboard diesel-based power generation (European Commission, 2021). Regulatory frameworks also play a central role in accelerating electrification. The Alternative Fuels Infrastructure Regulation (AFIR) introduces mandatory requirements for the installation of shore-side electricity systems in TEN-T Core Ports by 2030. In parallel, stricter emission standards for heavy-duty vehicles have created additional incentives for the development of charging infrastructure for electric trucks (Regulation (EU) 2019/1242). Political support also facilitates collaboration among ports, public authorities and industry stakeholders, contributing to the standardisation of solutions and the scaling up of electrification initiatives. Broader policy commitments, such as the European Green Deal, further reinforce long-term investments in electrification technologies (Wang et al., 2021).

However, the implementation process continues to be affected by several political barriers. Resistance from established actors, including organisations and shipping companies that are reluctant to adopt disruptive technological changes, can slow down progress. In addition, uncertainties within regulatory frameworks, particularly with regard to the allocation of responsibilities for infrastructure ownership and operational costs, create additional challenges (ESPO, 2024a) (Transport & Environment, 2023). Bureaucratic complexity is another constraint, as large-scale projects, such as shore power installations, often require approvals from multiple authorities, which leads to extended implementation timelines (Rahman & Khan, 2020). Differences in national regulatory regimes further complicate deployment, necessitating adaptation to varying standards across jurisdictions (Jack Simpson, 2024). Despite these challenges, aligning political support with economic and technological strategies remains critical for advancing the transition towards sustainable port operations.

3.5.2 Economic factors influencing port electrification

The electrification of port operations offers significant benefits in terms of operational efficiency, environmental performance and long-term economic value creation. A critical factor in facilitating this transition is access to financial support mechanisms from both public and private sources, including funding schemes and partnerships between public authorities and original equipment manufacturers (OEMs). These mitigate the high initial investment costs associated with electrification technologies (European Commission, 2024) (Bakar et al., 2022b) (Karapidakis et al., 2022). Furthermore, strategic collaboration between terminal operators and OEMs improves technical compatibility and cost efficiency in deploying such systems (ABB, 2023). From an operational perspective, electric cargo-handling equipment has a lower total cost of ownership than conventional diesel-powered alternatives, resulting in reduced operating expenses over time. Additionally, ports that invest in infrastructure to support electric trucks can offer incentives such as reduced parking fees, thereby increasing their attractiveness and operational competitiveness. At the same time, European funding instruments, including the Connecting Europe Facility (CEF), improve the financial feasibility of SSE-OPS installations (European Commission, 2024).

Another important economic advantage of electrification is reduced dependence on fossil fuels, which decreases exposure to fuel price volatility and enhances long-term cost predictability (MSE International, 2024) (ESPO and Royal HaskoningDHV, 2022) (Karapidakis et al., 2022) (Nnachi et al., 2013). Ports that integrate renewable energy sources (RES) into their electrification strategies, either through shore power systems or electrified equipment, can strengthen their energy resilience and limit the impact of price fluctuations further (Electric Power Research Institute, 2009). In parallel, electrification initiatives can increase productivity and create new employment opportunities, particularly when new infrastructure is developed and deployed (Schenk et al., 2020). Retrofitting existing equipment is an economically attractive option as it is generally more cost-effective than full replacement, requiring fewer extensive changes to infrastructure and workforce training despite the technical challenges involved (Martínez-Moya et al., 2024). However, despite these advantages, several economic barriers continue to constrain the widespread adoption of port electrification, one of the most significant of which is the high initial capital investment required for acquiring new equipment, retrofitting existing machinery, developing charging infrastructure and installing SSE-OPS systems, particularly for smaller ports with limited access to financial resources (Electric Power Research Institute, 2009) (Port Technology, 2011) (Muratori & Borlaug, 2021). For example, electric cranes involve substantially higher acquisition costs than their diesel-powered counterparts.

Furthermore, the uncertainty surrounding the return on investment (ROI), which is driven by rapidly evolving technologies, fluctuating energy prices and uncertain future utilisation levels, makes port authorities cautious about committing to large-scale electrification projects (European Commission, 2024). Operational electricity costs, particularly in grid-based SSE systems, can also introduce variability in expected savings, which further complicates investment decisions (Wang et al., 2021) (Bakar et al., 2022) (Colarossi & Principi, 2020). In some cases, such as the Port of Kiel, these economic challenges have been partially addressed through measures such as tax exemptions and the procurement of electricity through stock market mechanisms, achieving cost parity with conventional bunkering practices; nevertheless, these approaches still require substantial initial investment. Finally,

the electrification of port-related road transport, particularly truck fleets, is also limited by the availability of fast-charging infrastructure, vehicle range concerns, and the relatively high cost of electric vehicles (Sharifi et al., 2024).

3.5.3 Social factors influencing port electrification

The social dimension is a key factor in the adoption of port electrification initiatives, acting as both a facilitator and a potential obstacle. Growing societal expectations for cleaner, more sustainable port operations put significant pressure on port authorities to implement electrification measures. Technologies such as electric cranes, shore-side electricity (SSE-OPS) and electrified ground support vehicles improve air quality by reducing diesel emissions, enhancing public health and improving working conditions for port employees (Damman & Steen, 2021). These improvements strengthen the relationship between ports and local communities, reinforcing the social license to operate, particularly when noise and air pollution are mitigated effectively through electrification solutions such as shore-side electricity. In addition, growing environmental awareness among clients and consumers increases expectations for sustainable logistics practices, enhancing the reputation of ports that adopt electrification as modern, environmentally responsible hubs.

Another important social benefit relates to workforce development. The implementation of electrification projects is often accompanied by targeted training programmes to support personnel in upskilling for the operation and maintenance of advanced technological systems (O'Brien et al., n.d.). This strengthens internal technical capacity, enhances safety conditions and reduces dependence on external expertise, while supporting local employment. In certain cases, the social impacts of port-related emissions can be quantified; for instance, in the Port of Piraeus, the external costs associated with health impacts were estimated at around €25 million per year, with 61% of this total attributed to particulate matter (Chatzinikolaou et al., 2015). However, despite these benefits, social barriers continue to affect the pace of electrification adoption, with resistance to change among established stakeholders, including major shipping companies and port operators, stemming from the financial and operational implications of transitioning from existing systems (Mańkowska et al., 2020) (Le et al., 2023). The adaptation of vessels and infrastructure to accommodate technologies such as SSE-OPS requires alignment with evolving technical standards, introducing additional logistical and economic challenges. In response, ports are increasingly adopting incentive mechanisms, such as differentiated port fees, to encourage uptake, while also promoting closer collaboration with shipping companies to ensure technical compatibility and effective operational coordination (Williamsson et al., 2022) (European Commission, 2024).

3.5.4 Technological factors influencing port electrification

The technological dimension is a fundamental factor in the implementation of port electrification, acting as both a key enabler and a source of constraints. Recent advancements in energy storage systems, charging infrastructure and automation technologies have greatly facilitated the deployment of electrification solutions. Innovations such as ultra-fast charging systems, battery swapping technologies and wireless charging solutions reduce operational downtime and improve the efficiency of ground support vehicles (GSVs) and electric cranes (CleanTechnica, 2024). In parallel, technological progress in hybrid systems and battery performance has made it more feasible to retrofit existing equipment, enabling older

machinery to remain in operation while achieving substantial reductions in emissions (APM Terminals, 2023) (Martínez-Moya et al., 2024). With regard to port vessels, integrating advanced battery technologies and hybrid propulsion systems - combining electric power with diesel or liquefied natural gas (LNG) engines - enables flexible and efficient operational performance (T. Chen et al., 2025). Fully electric systems are increasingly being used for low-demand operations, whereas hybrid configurations are more suitable for energy-intensive applications, such as tugs and dredgers. Similarly, electric cranes increase productivity while reducing reliance on fossil fuels and maintaining scalability across ports of different sizes (ABB, 2023).

The integration of renewable energy sources, such as solar and wind power, into shore power systems can further improve the environmental performance of ports by enabling the supply of electricity with near-zero emissions (Rahman & Khan, 2020) (Colarossi & Principi, 2020) (Piccoli et al., 2021). In addition, smart grid technologies and advanced energy management systems are crucial for balancing energy demand, especially with regard to charging infrastructure for electric trucks (CleanTechnica, 2024). However, despite these technological advancements, several challenges remain, one of the most significant of which is the lack of standardisation across equipment types and manufacturers, which limits interoperability between systems (APM Terminals, 2023) (Kempower, 2024) (Malmö, n.d.). Variations in battery specifications, charging technologies and power requirements for equipment such as GSVs and cranes also complicate integration efforts. Battery management is also a critical challenge, as inappropriate charging practices can significantly reduce battery lifespan, and addressing this issue requires the development of targeted training programmes to ensure the proper handling and maintenance of batteries, which are one of the most costly components of electrified equipment (Kalmar, 2021).

Furthermore, integrating renewable energy into shore power systems introduces additional complexity. Advanced grid management solutions, hybrid system configurations and robust energy storage technologies are required to ensure a reliable and stable electricity supply. Grid capacity limitations during peak demand periods are another significant constraint. For instance, the Port of Kiel invested €1.5 million in a high-voltage substation to address capacity requirements, while the Port of Hamburg explored using mobile energy barges as an alternative solution (European Commission, 2024)(Abu Bakar et al., 2023). The electrification of external truck fleets also necessitates the development of high-capacity charging infrastructure, which can put additional pressure on existing grid systems (Williamsson et al., 2022). Moreover, the weight of batteries has been identified as a factor that influences the performance and energy consumption of equipment.

Overall, while technological developments provide substantial opportunities for decarbonising port operations, overcoming the aforementioned constraints requires coordinated investment, the establishment of international standards and enhanced collaboration among stakeholders to ensure scalability and effective implementation.

3.5.5 Legal factors influencing port electrification

A key enabling factor is the European Union's strong regulatory emphasis on reducing emissions, as reflected in a series of policy instruments and legislative frameworks (European Commission, 2019) (European Commission, 2020) (European Commission, 2021). Port

operations are subject to specific environmental regulations, such as Directive (EU) 2016/802, which addresses the sulphur content of marine fuels and promotes the adoption of cleaner alternatives, and Directive (EU) 2016/2284, which establishes national emission reduction commitments through air pollution control programmes. These regulatory instruments require Member States to develop national emission inventories and introduce measures that support sustainability in port-related activities. In addition, emission standards extend to port fleets and associated equipment: Regulation (EU) 2019/1242 sets CO₂ emission performance standards for heavy-duty vehicles, directly affecting port authorities operating such equipment. More recent legislative developments, including Regulation (EU) 2023/1805 on renewable and low-carbon fuels and Regulation (EU) 2023/1804, which mandates the implementation of shore-to-ship electricity supply systems (SSE-OPS) by 2030, further strengthen the legal requirements for electrification.

These frameworks oblige ports to reduce emissions, thereby encouraging the electrification of cranes, vehicles and supporting infrastructure, and provide a supportive legal environment by ensuring compliance with health and safety standards. Furthermore, adjustments to national legislation, such as exempting ports from classification as energy suppliers when providing electricity, improve the business case for shore power and facilitate the integration of renewable energy sources. Additional provisions, including tax exemptions under initiatives such as the proposed revision of the Energy Taxation Directive (ETD), aim to reduce the cost disparity between electricity supplied through OPS and conventional marine fuels. Despite these enabling conditions, significant legal barriers persist, such as uncertainties regarding ownership and operational responsibility for key infrastructure, particularly grid connections, which may delay or hinder project implementation (ESPO and Royal HaskoningDHV, 2022). Complex and time-consuming permitting procedures also constrain the deployment of large-scale investments, including charging infrastructure projects (Rahman & Khan, 2020). For instance, in Germany, the deployment of SSE-OPS systems was initially hindered by regulations that classified operators as energy companies, thereby imposing disproportionate administrative and regulatory requirements; subsequent legal reforms, however, aligned SSE-OPS with electric vehicle charging infrastructure, removing licensing barriers and facilitating faster implementation. Additional legal challenges arise from integrating renewable energy sources into SSE-OPS systems, particularly with regard to grid balancing requirements and ensuring an uninterrupted energy supply. Furthermore, deploying electrification technologies, such as electric cranes and charging hubs, may require renegotiating contracts with logistics operators or energy providers (Sugihara et al., 2024) (Ahmed M. Ismail a, 2024).

Addressing existing legal uncertainties and achieving greater alignment of regulatory frameworks across countries are essential prerequisites for enabling the widespread deployment of electrification technologies in port environments.

3.5.6 Environmental factors influencing port electrification

The environmental dimension is a key driver for the adoption of port electrification, primarily due to its ability to significantly reduce harmful emissions, including greenhouse gases (GHGs), sulphur oxides (SO₂), nitrogen oxides (NO_x) and particulate matter. Implementing electric-powered cranes, ground support vehicles (GSVs) and shore-side electricity–onshore power supply (SSE-OPS) systems substantially improve air quality, positively impacting public

health in nearby urban areas (Piccoli et al., 2021) (Probiez & Śladowski, 2014) (Krämer & Czermański, 2020) (German-Galkin & Tarnapowicz, 2020) (Kiliç et al., 2020). In particular, shore power systems play a critical role in reducing emissions and mitigating noise pollution by enabling vessels to shut down auxiliary engines while berthed. Additional environmental benefits are derived from reduced dependence on fossil fuels and the use of energy recovery systems, which enhance the overall sustainability performance of port operations.

However, despite these advantages, several environmental challenges remain. The production, use and disposal of batteries required for electrified equipment and vessels involves resource-intensive processes with environmental implications, and the sustainable management of battery waste remains a complex issue requiring further attention. Moreover, integrating renewable energy sources (RES) into shore power systems introduces additional challenges, particularly due to the variability of energy generation, affecting the reliability and consistency of supply (Rahman & Khan, 2020). Infrastructure-related interventions, such as retrofitting activities and the development of charging hubs, may temporarily or permanently impact local ecosystems, primarily due to land use requirements during construction phases. While port electrification offers substantial environmental benefits, effective implementation depends on addressing the lifecycle impacts of batteries and integrating renewable energy systems to ensure environmental gains are achieved without generating new adverse effects (Karapidakis et al., 2022).

3.6 Literature-based parameterisation of SFD model constants

The constant variables incorporated into the model are derived from values reported in scientific and industry literature, reflecting the typical ranges observed in port electrification projects. The selected values correspond to those of a medium-sized European port, ensuring consistency throughout the modelling process. Table 5 presents the main constants used, along with their definitions and the sources of supporting literature. Where multiple values were identified, mid-range values were selected to strike a balance between realism and applicability.

Table 5. Model constants and literature justification

Variable	Value	Unit	Description	Literature justification
New funding approvals	10,000,000	euros/year	Annual approved funding (e.g. grants, co-financing) supporting port investments	EU funding instruments such as CEF and Green Deal related programmes indicate multi-million annual funding allocations for port decarbonisation projects (CINEA, 2026)
CAPEX per GSV	150,000	euros/vehicle	Investment cost for electric ground support vehicles	the investment cost for electric ground support vehicles is reported in the literature within a range depending on equipment type (e.g. terminal

Variable	Value	Unit	Description	Literature justification
max GSV capacity	60	Vehicles	Maximum number of GSV supported by port	tractors, forklifts) (Kalmar, 2026) (Hyster, 2026) Medium-sized ports typically operate fleets ranging from a few tens up to approximately 100 cargo-handling vehicles, depending on throughput and terminal configuration (Marius Bucur, 2019)
CAPEX per berth (OPS)	6,000,000	euros/berth	Cost of full OPS installation per berth	The cost of SSE-OPS installations varies significantly depending on voltage level, grid upgrades, and infrastructure complexity (Abu Bakar et al., 2023) (ESPO, 2024a)
max OPS capacity	12	berths	maximum number of berths equipped with OPS	Ports typically prioritise electrification of high-traffic berths rather than full deployment. Studies and industry reports show that a subset of total berths (commonly 5–15) is equipped with OPS in medium-sized ports (DNV, 2024)
CAPEX per charger	150,000	euros/charger	Cost of installing one charging unit	Charging infrastructure costs vary depending on power level (fast vs ultra-fast). Heavy-duty charging units suitable for trucks typically range between €50,000 and €200,000 (Joint charging, 2025)
max charging unit capacity	40	Chargers	maximum number of chargers supported by port	Charging infrastructure deployment is constrained by grid capacity and operational demand (ESPO & HaskoningDHV Nederland, 2022)
CAPEX per crane	3,000,000	euros/crane	cost of electric crane (RTG, STS etc.)	Electric cranes (RTGs, STS, etc.) involve high capital costs depending on automation and capacity (“Port Reform Toolkit,” 2025)
max cranes capacity	12	cranes	maximum number of electric cranes in port	Medium-sized container terminals typically operate between 6 and 15 cranes

Variable	Value	Unit	Description	Literature justification
max grid capacity	80	MW	maximum electrical capacity supported by port	depending on throughput and layout (Gharehgozli et al., 2023) Port electrification scenarios indicate that medium-sized ports require electrical capacities in the range of tens of megawatts, depending on electrification intensity (ESPO & HaskoningDHV Nederland, 2022)
CAPEX per MW grid	1,000,000	euros/MW	cost of grid expansion per MW	Grid expansion costs vary depending on infrastructure complexity. The selected value reflects a mid-range assumption (ESPO & HaskoningDHV Nederland, 2022)

3.7 Analytical approaches used in port electrification studies

The analytical approaches adopted in the existing port electrification literature influence not only the type of insights generated, but also the aspects of the transition process that effectively examined. Different methodologies emphasise different dimensions of the problem, ranging from economic feasibility and environmental performance to technology assessment. Consequently, an examination of the dominant analytical approaches provides a useful basis for identifying methodological limitations and areas that remain insufficiently addressed. Table 6 presents a comparative overview of the principal approaches employed in the literature, highlighting their respective strengths and limitations in the context of port electrification planning and decision-making.

Table 6. Indicative comparative assessment of analytical approaches used in port electrification and sustainability studies (Source: own elaboration)

Analytical approach	Representative studies	Typical application	Limitations
Technical control modelling	Mutarraf et al. (2021)	Seaport microgrid operation and mobile OPS control	Limited to technical power management; no strategic planning or transition analysis
Optimization modelling	Zhang et al. (2022)	Joint OPS–microgrid scheduling	Short-term operational focus; no long-term system dynamics
Literature review	Iris & Lam (2019)	Synthesis of port energy efficiency strategies and technologies	Descriptive; no quantitative assessment or decision-support capability
Techno-economic analysis	Abu Bakar et al. (2022); Abdaoui et al. (2021)	Evaluation of port decarbonisation and electrification options	Static analysis; limited representation of feedback effects, behavioural

Analytical approach	Representative studies	Typical application	Limitations
Feasibility study / engineering assessment	Karapidakis et al. (2022)	under different operational conditions Assessment of shore-side electricity (OPS) implementation requirements, energy demand and emission reduction potential at Heraklion Port	responses and long-term transition dynamics Port-specific case study; static calculations; no dynamic simulation of investment decisions, infrastructure deployment or stakeholder interactions
Engineering simulation/ demand analysis/ power system simulation	Muratori et al. (2022); Rahman et al. (2020)	Assessment of charging requirements, charging profiles and grid impacts of heavy-duty electric vehicle deployment/ assessment of shore-side electricity (cold ironing) impacts on grid performance and power quality	Technology-focused analysis; does not model investment decision-making, stakeholder interactions or transition dynamics over time/ engineering-oriented case analysis; focuses on technical performance and power quality rather than adoption dynamics, investment behaviour or policy effects

As illustrated in Table 6, the analytical approaches most frequently employed in the port electrification and sustainability literature provide valuable insights into specific technological, environmental and economic dimensions of the transition process. However, the majority of these approaches remain predominantly static in nature, focusing on the assessment of individual measures, technologies or predefined scenarios. As a result, their ability to capture feedback mechanisms, infrastructure dependencies, resource allocation trade-offs, implementation delays and the cumulative effects of interconnected decisions remains limited. Furthermore, existing studies rarely examine how electrification measures interact within the broader port system or how alternative investment strategies influence transition outcomes over time. These observations provide the foundation for the research gaps identified in the following section.

3.8 Key Research Gaps

Despite the increasing attention given to port sustainability and the growing number of available “greening” measures, the existing literature presents several limitations in the way the transition is analysed. First, most studies focus on individual technologies or measures, such as electrification, SSE-OPS or alternative fuels, examining their technical, environmental or economic performance in isolation. This approach does not capture how these measures interact within the port system, nor how their combined implementation influences overall outcomes. Secondly, the majority of existing analyses adopt static or case-specific approaches, but port “greening” is a dynamic process influenced by feedback mechanisms, delays, and path dependencies. For instance, investments in electrification can reduce emissions, but they can also increase electricity demand, potentially creating new constraints

related to grid capacity and infrastructure costs, and such dynamic interactions are rarely incorporated into current analytical frameworks. Thirdly, research on investment decision-making in the context of port “greening” is limited. While the costs and benefits of individual measures are often discussed, the literature provides limited guidance regarding the prioritisation and sequencing of electrification investments, despite the fact that ports operate under financial constraints and must allocate resources across multiple competing interventions with different implementation requirements, time frames and expected outcomes. Fourthly, the role of energy systems within ports has not been fully integrated into existing studies, despite the fact that electrification and alternative fuels are widely examined. However, their implications for energy demand, infrastructure requirements and system integration are often considered separately, which limits our understanding of ports as emerging energy hubs.

Finally, the significant differences in size, infrastructure, traffic composition and access to energy systems between ports limits the applicability of generalised solutions, highlighting the need for approaches that can capture system behaviour under varying conditions. These gaps indicate the need for analytical approaches that move beyond isolated, static assessments and capture the interactions, constraints and evolution of port systems over time.

Addressing these limitations requires an analytical perspective capable of linking the external drivers and barriers of port electrification with the organisational, operational and strategic factors that shape transition outcomes over time. Existing approaches provide valuable insights into specific aspects of electrification, yet they offer limited understanding of how these factors interact, reinforce or constrain one another throughout the transition process. This highlights the need for research that examines port electrification as a dynamic and interconnected system rather than as a series of isolated technological interventions. Furthermore, the identified gaps highlight the need for approaches that support a more integrated evaluation of electrification strategies, considering not only technological feasibility and environmental performance but also investment priorities, implementation constraints and long-term transition pathways. By addressing these issues, research can contribute to a more comprehensive understanding of how ports navigate electrification challenges and make strategic decisions under evolving economic, regulatory and operational conditions

Chapter 4: Research design and methodological positioning

The objective of this dissertation is to develop a structured decision-support tool based on System Dynamics that enables the analysis, prioritisation and strategic sequencing of port electrification measures under conditions of uncertainty, infrastructure constraints and interdependent system behaviour. It has been designed to address a practical decision-making challenge faced by ports during the transition towards low-emission operations. Beyond improving the understanding of how electrification measures evolve over time, the framework is intended to support port authorities and other stakeholders in decision making process to evaluate alternative transition pathways, exploring policy and investment scenarios, and assessing the long-term implications of electrification strategies on energy efficiency, environmental sustainability and operational performance. The proposed framework enables the exploration and comparison of alternative electrification pathways, supporting the assessment of investment timing, intervention sequencing and policy effectiveness within a dynamic system context. In this respect, the model operates not only as an analytical tool for understanding system behaviour, but also as a strategic planning tool capable of supporting evidence-based decision-making under uncertainty.

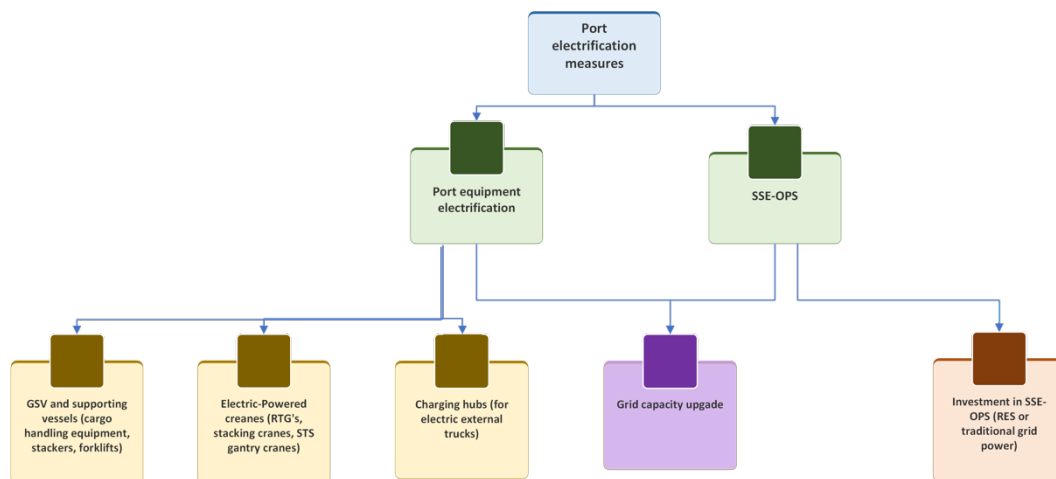


Figure 18. Port related electrification measures used for the research (Source: own elaboration)

The primary research focus pertains to the transition of ports towards energy-efficient and low-emission operational practices, with specific attention being directed towards electrification measures such as Shore-Side Electricity Onshore Power Supply (SSE-OPS), the establishment of charging infrastructure for trucks, grid capacity upgrade and the integration of electric port equipment (Figure 18). The research adopts a holistic approach, examining electrification not as a static process but as a dynamic process shaped by economic viability, infrastructure readiness, and operational constraints. The port system is the established level of analysis, with its governance and influence being overseen by the relevant port authorities and associated stakeholders. The analytical perspective adopted is forward-looking and medium- to long-term period of 30 years, reflecting the strategic planning horizons typically associated with port infrastructure investments. Consistent with established system dynamics practice, the model is intended to enhance understanding of dynamic behaviour and policy

sensitivity, rather than to produce exact numerical forecasts dedicated to specific port case. Consequently, the model is utilised to explore alternative pathways, identify potential failure modes and assess the robustness of electrification strategies under varying hypotheses.

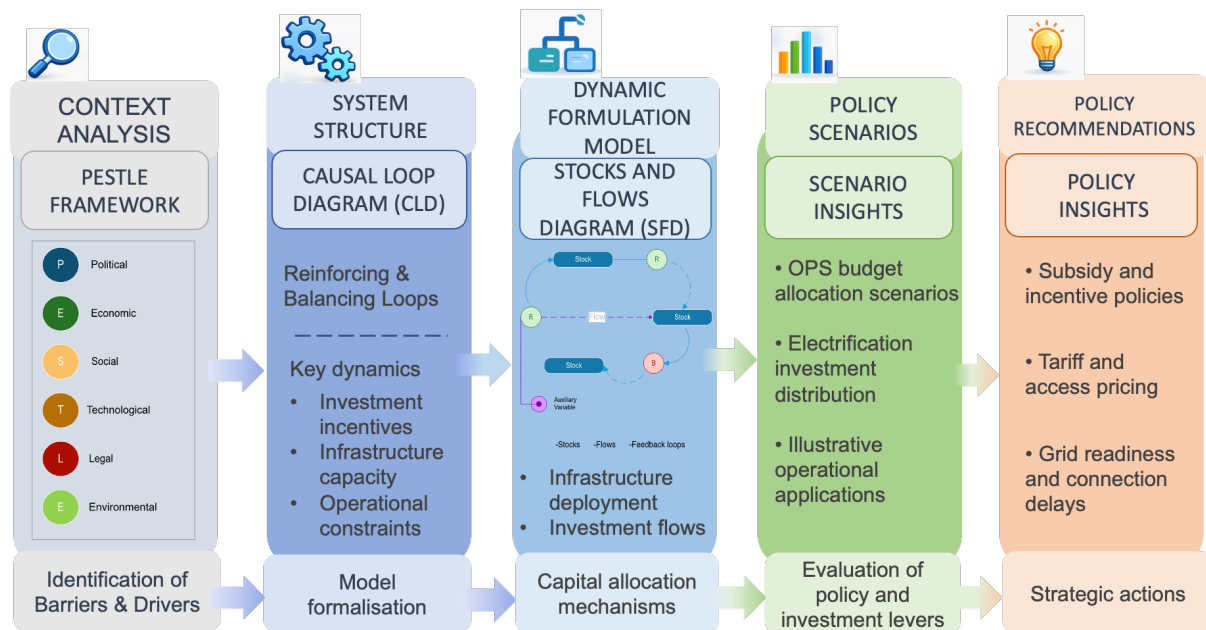


Figure 19. Methodological framework for analysing port electrification using System Dynamics (Source: own elaboration)

The methodological novelty of this dissertation is reflected in the systematic integration of PESTLE analysis with System Dynamics modelling for the analysis of port electrification as can be seen in Figure 19. PESTLE analysis is utilised as a structured analytical framework for the identification, categorisation and documentation of the political, economic, social, technological, legal and environmental drivers and barriers that affect electrification initiatives in ports. This step provides an explicit and traceable evidence base that informs the definition of model boundaries and the selection of variables. System dynamics modelling is subsequently deployed to operationalise selected PESTLE factors by translating them into endogenous variables and causal relationships. Rather than treating drivers and barriers solely as exogenous contextual conditions, the model internalises those factors that directly influence investment decisions, infrastructure deployment, utilisation levels, and economic viability. This enables the representation of feedback mechanisms, time delays, and stock–flow accumulation processes that govern the dynamic evolution of port electrification over time. The integration of the two methods enables a consistent correlation between external contextual pressures and internal system behaviour. PESTLE analysis is a comprehensive and transparent approach to identifying influencing factors, while System Dynamics provides the formal structure required to analyse their interactions and long-term effects. This combined approach supports the exploration of policy sensitivity, investment timing, and structural risks such as under-utilisation or delayed returns, which cannot be adequately captured through static or purely comparative assessment methods. The System Dynamics model developed in this dissertation is conceptual in nature. The objective of the model is to illustrate the key mechanisms and interactions that influence the adoption of electrification measures in ports, rather than reproducing or predicting the behaviour of a specific port case. The purpose of the model is therefore twofold: firstly, it is explanatory and exploratory in nature, with a focus on

understanding structural dynamics, feedback effects, and policy sensitivity; secondly, it is not intended to provide precise numerical forecasts.

The model boundaries are defined in such a way as to include variables that are directly related to investment decisions, infrastructure deployment and economic viability. In contrast, factors that are highly uncertain or largely outside the control of port authorities, such as long-term energy market evolution or macroeconomic trends, are treated as exogenous and have not included in the core model. This boundary choice aligns with established system dynamics practice and promotes analytical clarity and transparency. A deliberate level of model's abstraction is adopted in order to capture the dominant dynamics of port electrification while avoiding unnecessary detail that could impede the clarity of system behaviour. It has also been intentionally designed to be extendable and adaptable. The elements used in the model are grounded in the existing literature, documented policy frameworks, and prior empirical studies, and are further informed by expert judgement in the model's validation process. The implications of these assumptions are examined through sensitivity and scenario analysis.

Chapter 5. Methodology

5.1 PESTLE analysis

5.1.1 Political drivers and barriers

Political factors create barriers and enable progress in port electrification initiatives as highlighted in Table 7. A key barrier is the limited willingness of shipowners to adopt a Shore Side Electricity - Onshore Power Supply (SSE-OPS) due to concerns over operational disruption, vessel compatibility and retrofitting costs. This usually restricts the effectiveness of electrifying ports. Ports adopting electrification also face increased exposure to fluctuations in energy policies and electricity tariffs, introducing financial uncertainty that complicates long-term investment planning. Political instability and weak policy enforcement at national level, in some regions, further discourage investment, while inconsistent incentives and funding mechanisms across Member States create discrepancies that limit the potential for widespread implementation. Additional risks related to the reliability, maintenance, retraining of the workforce and operational disruption associated with the transition to less mature electrification technologies also hinder stakeholders from advancing such investments.

Several political drivers are facilitating electrification efforts. Investments in eco-friendly ground support vehicles, electric-powered cranes and electric support vessels can attract government subsidies and tax incentives, reducing initial capital costs. Tax exemptions on electricity supplied to berthed vessels under the Energy Taxation Directive lower operational costs, making SSE-OPS more financially attractive. Stricter emissions standards for heavy-duty vehicles encourage ports to develop charging infrastructure, thereby aligning regulatory compliance with “green” infrastructure expansion. Strategic collaborations with neighbouring ports facilitate the sharing of best practices and harmonised approaches, thereby reducing individual risks and promoting regional adoption. Furthermore, legislative opportunities that allow ports to sell energy without being classified as energy companies strengthen the business case for electrification by enabling revenue generation while supporting the provision of “green” energy.

Table 7. Political barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
Ship-owners' limited willingness to adopt OPS (ESPO, 2021h)	▲ ¹	SSE-OPS
Exposure to shifts in energy policy or tariffs (ESPO, 2024)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS ²
Political instability & weak enforcement (Jack Simpson, 2024)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Inconsistent incentives & funding mechanisms	▲	SSE-OPS
Risks from immature technologies (DNV, 2021)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Subsidies/tax incentives for eco-friendly GSV, cranes, vessels (Frederic Godemel, 2023)	●	GSV, vessels, cranes
Electricity tax exemptions for berthed vessels (European Commission, 2021)	●	SSE-OPS
Stricter CO ₂ standards for heavy-duty vehicles	●	GSV, charging hubs
Strategic collaboration with neighboring ports	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Legal reform enabling ports to sell energy (European Commission, 2024)	●	SSE-OPS

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; SSE-OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

5.1.2 Economic drivers and barriers

A primary economic barrier is the high initial investment cost of procuring electric equipment and port-owned vessels, a challenge further increased by the financial demands of establishing supporting infrastructure, such as charging and fueling stations as indicates Table 8. The complexity and cost of developing this infrastructure is intensified in urban port areas, where land availability is limited and additional logistical and financial constraints are present. Grid upgrades necessary to support electrification introduce further significant costs, while investments in SSE-OPS systems often require considerable upfront capital with uncertain returns, creating hesitation among stakeholders. Reliance on grid electricity also exposes ports to potential fluctuations in energy prices, leading to concerns about higher operating costs over time. The challenges are further complicated by the high costs of electricity storage and reduced operational flexibility compared to conventional fuel storage. This raises concerns about the reliability of the electricity supply, particularly under variable demand conditions. Despite these barriers, there are several economic incentives that could encourage the implementation of electrification measures within ports. Access to a variety of public and private financing options, such as support from public agencies and partnerships with original equipment manufacturers, could reduce the financial burden of investing in electrified ground support vehicles. The total cost of ownership for battery-electric cargo-handling equipment is shown to be lower than that of diesel-fuelled alternatives over time, which enhances the economic feasibility of electrification. Operational advantages also emerge, as electric trucks may benefit from exemptions from parking fees and full access to truck park facilities, giving ports a competitive advantage. The availability of European Union funding specifically targeting the adoption of shore-side electricity further strengthens the economic case for electrification. In the longer term, implementing electrification measures will lead to cost savings for shipping companies and ports, particularly in anticipation of future regulatory frameworks that may impose emissions-related fees. This provides further financial incentive to transition to “greener” practices.

Table 8. Economic barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
High initial investment cost of electric equipment and port-owned vessels, incl. charging/fueling stations ((Electric Power Research Institute, 2010) ((Port Technology, 2011)	▲ ¹	GSV, vessels, cranes
Establishing charging/fueling infrastructure is complex and costly; limited land in urban ports (Muratori & Borlaug, 2021)	▲	charging hubs ²
Grid upgrades add significant cost (Rahman & Khan, 2020)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Uncertain ROI for SSE-OPS (European Commission, 2024)	▲	OPS
Higher operating costs due to grid electricity price fluctuations (Pesquera, 2024)	▲	GSV, vessels, cranes, retrofits, charging hubs, OPS

High storage costs and reduced flexibility compared to gas/oil (DNV, 2020))	▲	GSV, vessels, cranes, retrofits, charging hubs, OPS
Public-private financing incl. OEM partnerships supports GSV investment (Karapidakis et al., 2022)	●	GSV
Lower TCO for BE-CHE vs diesel (Sharifi et al., 2024)	●	GSV, cranes, retrofits
Electric trucks exempt from parking fees; full truck park access (Sharifi et al., 2024)	●	hubs
EU funding for SSE-OPS adoption (European Commission, 2024)	●	vessels, SSE-OPS
Long-run cost savings for shipping companies and ports under emissions fees (Mjelde et al., 2019)	●	SSE-OPS
Purchasing SSE-OPS electricity on stock market reduces costs to bunkering level (MSE International, 2024)	●	SSE-OPS
Resilience against energy price volatility with res-based SSE-OPS	●	SSE-OPS
Electrification boosts economic output and employment (Schenk et al., 2020)	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

5.1.3 Social drivers and barriers

Social factors significantly impact the progress and efficiency of port electrification efforts by influencing stakeholder perspectives, workforce preparedness, and societal support for sustainable practices as depicted in Table 9. A significant obstacle is the reluctance of stakeholders to embrace new practices and technologies, reflecting their concerns about operational disruptions, unfamiliar procedures, and the perceived risks of transitioning from conventional to electrified systems. A lack of awareness of the broad benefits of shore-side electricity and electrification measures hinders acceptance further, as stakeholders may not recognise their contributions to operational efficiency, emissions reduction and public health improvement. Additionally, many ports face a skills gap, with the current workforce lacking expertise in managing and maintaining electrified systems. This creates operational hesitations and training needs. The deployment of electric truck fleets introduces the need to establish new relationships with utilities, charging providers and permitting agencies, adding complexity to the transition process.

In the context of climate change and societal pressures to reduce emissions, there is strong support for the adoption of port electrification. Electrification measures contribute directly to improved public health by reducing emissions and lowering exposure to harmful pollutants. This decreases the external costs associated with healthcare and enhances the quality of life in port communities. These measures also improve working conditions for port and terminal staff by reducing noise and air pollution, thereby contributing to healthier and safer workplaces. The transition to electrification offers opportunities for workforce development and upskilling, enabling staff to acquire expertise in managing advanced equipment and systems. This can enhance operational resilience and improve the quality of employment.

Table 9. Social barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
--------	------	-------------------

Resistance from stakeholders reluctant to adopt sustainable practices (Mańkowska et al., 2020)	▲ ¹	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS ²
Lack of awareness of SSE-OPS benefits (Le et al., 2023)	▲	SSE-OPS
Lack of workforce expertise in latest port electrification measures (APM Terminals, 2023)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Deployment of electric truck fleets requires new relations with utilities, charging providers & permitting agencies (Sugihara et al., 2024)	▲	charging hubs
Societal pressures & climate awareness drive port transitions (Bjerkan & Ryghaug, 2021)	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Electrification improves public health, reduces external costs (Chatzinikolaou et al., 2015)	●	SSE-OPS
Improved working environment for port & terminal staff	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Workforce development & upskilling opportunities (O'brien et al., n.d.)	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Reduced worker exposure to diesel emissions, better air quality (Meng et al., 2023)	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Strategic partnerships enhance retrofitting actions (ESPO and Royal HaskoningDHV, 2022)	●	retrofits
Charging trucks during mandatory rest periods improves efficiency (Mjelde et al., 2019)	●	charging hubs

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

There are further benefits to be gained from the strategic potential to enhance retrofitting actions through partnerships, facilitating smoother transitions to electrified operations by leveraging shared knowledge and resources. Operational efficiencies are also supported as carriers can optimise productivity by charging electric trucks during mandatory driver rest periods, reducing downtime and improving logistics performance. It is important to address stakeholder concerns, promote awareness and invest in workforce development to overcome barriers while leveraging societal demand for cleaner operations to drive the electrification of port environments.

5.1.4 Technological drivers and barriers

A primary technological barrier involves the challenges associated with the large-scale implementation of electrified Ground Support Vehicles (GSV) across terminals, including constraints related to automated equipment operating on predefined tracks, highlighted in Table 10. The deployment of battery-powered equipment leads to an increased demand on local electricity grids. In scenarios where insufficient investments are made in grid resilience, electrification can pose risks of power outages and operational disruptions during peak loads. Moreover, the absence of standardisation among equipment manufacturers with regard to battery sizes and charging systems gives rise to compatibility issues, which complicate procurement, maintenance, and interoperability across different systems within the port.

The increased weight of batteries in equipment leads to higher energy consumption and environmental concerns related to battery manufacturing and disposal. Battery management complexity also poses a barrier, as improper charging can significantly reduce battery lifespan, requiring technical expertise to maintain optimal operation. The deployment of high-capacity charging stations for electric trucks necessitates advanced grid integration to manage increased loads and ensure compatibility across diverse vehicle types. Meanwhile, implementing SES-OPS systems requires advanced grid management, energy storage solutions, and hybrid systems to maintain a stable power supply. Additional compatibility challenges arise with ships requiring specific converters, and the integration of on-demand renewable energy sources with shore-side operations demands advanced load-balancing technologies. Retrofitting existing terminals with shore-side infrastructure is notably more complex than designing it for new terminals, and limited space in many ports further constrains the installation of necessary electrification infrastructure.

Table 10. Technological barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
Difficulties scaling electrified GSV across terminal; automated mobile equipment on fixed tracks	▲ ¹	GSV, retrofits ²
Battery-powered equipment raises grid demand; risk of outages without grid resiliency (Frederic Godemel, 2023)	▲	GSV, cranes, retrofits
Lack of standardisation in batteries/charging solutions (APM Terminals, 2023)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
Batteries add weight → higher energy use + environmental impact from manufacture/disposal (Rahman & Khan, 2020)	▲	GSV, cranes, retrofits
Complex battery management; improper charging shortens lifespan (Kalmar, 2021)	▲	GSV
High-capacity truck charging stations require advanced grid integration (Transport & Environment, 2023)	▲	charging hubs
Compatibility issues with ships; need for converters (Le et al., 2023)	▲	SSE-OPS
Balancing intermittent RES supply with SSE-OPS demand adds technical complexity (Bakar et al., 2022b)	▲	SSE-OPS
Retrofitting SSE-OPS into established terminals more complex than in new builds	▲	retrofits, SSE-OPS
Grid capacity limits during peak demand (Rahman & Khan, 2020)	▲	SSE-OPS
Lack of available space for SSE-OPS installation (Malmö, n.d.)	▲	SSE-OPS
Ultra-fast chargers, battery swapping, wireless charging reduce downtime (CleanTechnica, 2024)	●	GSV, cranes, charging hubs
Integrating new units of same tech reduces training/infrastructure needs (Martínez-Moya et al., 2024)	●	retrofits
Battery-electric CHE more accessible than other zero-emission options (APM Terminals, 2023)	●	GSV
Hybrid storage/battery-electric GSV improve routing and reduce downtime (Neugebauer et al., 2025)	●	GSV
Battery-electric equipment quieter, low vibration, no emissions (Neugebauer et al., 2025)	●	GSV, vessels, cranes, retrofits
Electric cranes more efficient than conventional (ABB, 2023)	●	cranes
Scalability of electric RTGs for both small and large ports (European Commission, 2024)	●	cranes
Fast-charging & smart energy management reduce downtime for trucks (CleanTechnica, 2024)	●	charging hubs

Technical standards ensure applicability & future-proofing for OPS	●	SSE-OPS
SSE-OPS advances allow coordinated berthing to ease peak electricity demand	●	SSE-OPS
Simpler integration for traditional grid-OPS via standard connections	●	SSE-OPS

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

It is evident that despite these barriers, technological advancements are playing a pivotal role in the advancement of port electrification. Innovations such as ultra-fast chargers, battery swapping stations, and wireless power supply systems have been shown to reduce equipment downtime and enhance operational efficiency during the charging process. The integration of standardised technology units into terminals has been demonstrated to minimise the necessity for additional infrastructure adjustments and workforce retraining, thereby reducing the complexity and cost of implementation. Battery-electric cargo-handling equipment is frequently more accessible to terminal operators in comparison to hydrogen-based alternatives, thereby supporting its adoption. Hybrid energy storage systems and optimised battery-electric GSV use enable efficient routing and reduced downtime. Furthermore, battery-electric equipment offers operational advantages, including quieter operation, lower vibration levels, and zero on-site emissions, thus improving environmental and working conditions within ports. Electric-powered cranes have emerged as a significant advancement in the field of container handling, offering enhanced efficiency and capacity. The scalability of electric rubber-tired gantry cranes, which can adapt to varying port sizes, has contributed to their broader adoption. The development of fast-charging solutions and smart energy management systems has optimised power utilisation and reduced downtime, thereby facilitating efficient fleet management for electric trucks. The establishment of technical standards and clear power requirements has been demonstrated to ensure the future-proofing of investments in SSE-OPS and enhance system interoperability. The advancement of SSE-OPS has also been shown to allow for the coordination of berthing patterns to reduce peak electricity demands. In contrast, traditional grid-connected SSE-OPS have been found to benefit from simpler integration using standardised connections, reducing technical complexity during implementation.

5.1.5 Legal drivers and barriers

Several legal barriers hinder progress, beginning with the need for ports to renegotiate existing contracts with logistics partners and energy providers to accommodate electrified equipment and systems, presented in Table 10. This often introduces delays and legal complexity, especially in large or long-term concession agreements. Uncertainties over who is responsible for owning, operating, and maintaining SSE-OPS infrastructure have a negative effect on planning, while the frequent changes in environmental regulations create uncertainty that discourages long-term investment. In addition, regulatory frameworks often fail to provide clarity on the integration of renewable energy sources into shore power systems, further deterring electrification efforts. A significant legal impediment concerns the extensive and bureaucratic character of the approval procedures for the deployment of operations infrastructure. These processes frequently encompass multiple governmental and environmental authorities, resulting in delayed implementation and increased project costs.

Similarly, ports may encounter legal challenges if classified as energy providers, necessitating amendments to national legislation to permit the direct sale of electricity. Current proposals, for instance the Alternative Fuels Infrastructure Regulation (AFIR), still do not comprehensively address critical technical aspects such as grid connectivity, capacity, power reserve, and frequency conversion. These elements are essential to the full deployment of SSE-OPS. The regulatory gaps thus introduced create additional risk, particularly in the design phase of electrification projects.

Table 11. Legal barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
Ports may need to renegotiate contracts with logistics partners/energy providers for electric cranes (Sugihara et al., 2024)	▲ ¹	cranes ²
Unclear responsibility for SSE-OPS ownership and regulation (ESPO and Royal HaskoningDHV, 2022)	▲	SSE-OPS
Ambiguities/changes in environmental regulations hinder long-term SSE-OPS investment (ESPO and Royal HaskoningDHV, 2022)	▲	SSE-OPS
Lengthy approval processes and bureaucracy delay SSE-OPS deployment	▲	SSE-OPS
Regulatory issues from ports being classified as energy sellers → require legal amendments (European Commission, 2024)	▲	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
AFIR proposal does not cover grid connectivity, capacity, reserve & conversion issues for SSE-OPS (Neugebauer et al., 2025)	▲	SSE-OPS
Lack of clear guidelines for integrating res into shore power (MSE International, 2024)	▲	SSE-OPS
Greener GSV adoption ensures compliance with strict regulations, reducing fines risk (European Commission, 2024)	●	GSV
AFIR (EU 2023/1804) mandates SSE-OPS in TEN-T ports by 2030	●	SSE-OPS
FuelEU maritime regulation (EU 2023/1805) requires ships to use SSE-OPS at berth	●	SSE-OPS
Stricter emissions standards for heavy-duty vehicles incentivise truck charging infrastructure (Regulation (EU) 2019/1242, 2019)	●	charging hubs
Potential tax exemptions for shore power	●	SSE-OPS
Strict air quality regulations (regulation EU 2019/1242; directive EU 2016/2284) reinforce need for clean equipment and SSE-OPS	●	cranes, SSE-OPS

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

Despite the aforementioned constraints, legal frameworks also provide powerful incentives. Ports that proactively adopt electrified equipment and infrastructure are better positioned to comply with increasingly strict environmental regulations, reducing their exposure to fines and enhancing their legal compliance profile. Binding legislation, such as the AFIR Regulation (EU 2023/1804), mandates the establishment of shore power facilities in all ten-tonne maritime ports by 2030, directly compelling investment in SSE-OPS infrastructure. In a similar context, the FuelEU Maritime Regulation (EU 2023/1805) mandates that berthed vessels connect to shore power, thereby creating a direct demand for functional systems. Legislative incentives

are further reinforced by regulations that enforce stricter emissions standards for heavy-duty vehicles, which, indirectly, encourage the development of port charging infrastructure to remain compliant. Tax exemptions for shore power, where permitted by legislation, also contribute to the financial viability of electrification. On a broader scale, binding targets set by overarching air quality and environmental directives promote proactive adaptation by port authorities.

5.1.6 Environmental drivers and barriers

A significant impediment to the adoption of SSE-OPS and other electrification measures is the limited environmental benefit they offer if not primarily powered by renewable energy sources (Table 12). When electricity is sourced from fossil fuel-based grids, the upstream emissions may offset the local environmental gains. Furthermore, the life cycle impact of batteries, particularly their production and disposal, raises concerns regarding sustainability. The manufacturing of batteries requires resource-intensive processes, and their disposal poses risks of chemical leakage and material waste.

Table 12. Environmental barriers and drivers (Source: own elaboration)

Factor	Type	Affected Measures
SSE-OPS has limited environmental benefits if powered mainly by fossil-based grids	▲ ¹	SSE-OPS
Environmental impacts of batteries during manufacture and disposal	▲	retrofits ²
Electrification measures improve air quality and public health (Frederic Godemel, 2023)	●	GSV, vessels, cranes, retrofits, charging hubs, SSE-OPS
GSV adoption reduces emissions and noise while improving efficiency (Piccoli et al., 2021)	●	GSV
Electric cranes produce zero on-site emissions, lowering carbon footprint and energy consumption	●	cranes
RTG cranes with active front-end systems optimise efficiency and reduce emissions (European Commission, 2024)	●	cranes
Electric trucks & charging hubs cut greenhouse gas and pollutant emissions	●	hubs
SSE-OPS reduces port carbon footprint, dust, noise; near-zero emissions if powered by RES	●	SSE-OPS

¹ ▲ barriers, ● drivers; ² Abbreviations: GSV = ground support vehicles; vessels = port service vessels; cranes = electric-powered cranes; retrofits = electrification retrofitting; hubs = charging hubs; OPS = Shore-Side Electricity Onshore Power Supply (SSE-OPS)

Despite these concerns, the environmental advantages of electrification in ports are extensive and documented. Electrification measures, including the deployment of ground support vehicles (GSVs), electric-powered crane equipment, trucks and shore-side electrical operations infrastructure, have been demonstrated to result directly in substantial reductions in air pollutants, greenhouse gas emissions, noise and dust levels in and around ports. It is evident that these reductions have a beneficial effect on both local environmental quality and public health, thereby supporting broader sustainability goals. The adoption of electric GSVs, in particular, has been shown to have a significant impact on operational emissions and acoustic pollution, while also improving energy efficiency and productivity. Electric cranes

have been demonstrated to offer zero on-site emissions, which has been shown to reduce a port's overall carbon footprint and help meet national and international climate targets.

Electric-powered rubber-tyred gantry (RTG) cranes, in particular when combined with active front-end systems, further enhance environmental performance by improving energy conversion efficiency and minimising losses during operation. The introduction of electric trucks and the establishment of charging hubs contribute significantly to lowering transport-related emissions, particularly in hinterland connections, while also reducing reliance on fossil fuels. Electricity supplied from the shore plays a pivotal role in the reduction of emissions from vessels that are berthed, with the greatest benefit being realised when the vessels are powered by renewable sources. The implementation of this electricity results in quantifiable decreases in various air pollutants, including carbon dioxide, nitrogen oxides, sulphur oxides, and particulate matter.

5.2 Development of the Causal Loop Diagram (CLD)

System dynamics was employed to analyse the dynamic interactions that shape the implementation of electrification measures in ports, with the aim of developing a strategic simulation model capable of capturing the long-term effects of alternative policy and investment pathways. The modelling process followed a structured transition from the qualitative insights derived from the PESTLE framework to the formulation of explicit causal feedback structures. The PESTLE analysis generated a broad set of political, economic, social, technological, legal and environmental factors influencing port electrification. In the course of this transition process, the drivers and barriers identified through the PESTLE analysis were translated into model variables according to their influence on investment decisions, infrastructure deployment, utilisation dynamics and economic viability. The variables were subsequently linked through causal relationships and organised into reinforcing and balancing feedback loops, forming the basis of the causal loop diagram. These causal structures were then used to inform the development of the stock-and-flow model. This step was necessary to ensure that the model adequately reflected the complex interactions, time delays and systemic constraints observed in real-world electrification processes, while also enabling a transparent representation of cause/effect relationships among key variables and the feedback mechanisms governing system behaviour. For the modelling process, Vensim PLE (free version) was used in order to ensure accessibility and enable other researchers to replicate and apply the modelling framework. Although Vensim PLE provides a wide range of modelling capabilities, only the functions necessary for the purposes of this research were utilised.

The drivers and barriers identified through the PESTLE analysis constituted the core analytical input for the development of the system dynamics model (Figure 20), and in particular for the specification of variables included in the causal loop diagram. The transition from PESTLE analysis to the CLD therefore represented the first operationalisation step of the modelling process, whereby qualitative evidence from the literature was transformed into interconnected endogenous variables capable of generating system behaviour. Each factor was operationalised within the system dynamics framework and represented according to its functional role in the system. This formulation allowed the identified drivers and barriers to influence system behaviour through explicitly defined causal links and feedback structures, ensuring that external conditions were incorporated as endogenous elements of the model

rather than treated as static contextual descriptive factors. The factors captured through this process included, among others, high capital expenditure requirements, energy price volatility, regulatory uncertainty, stakeholder resistance, technological immaturity and constraints related to supporting infrastructure. The resulting causal loop diagrams therefore provided the conceptual foundation for the subsequent quantitative modelling stage, in which only the dominant feedback structures capable of being parameterised with sufficient analytical consistency were selected for stock-and-flow modelling.

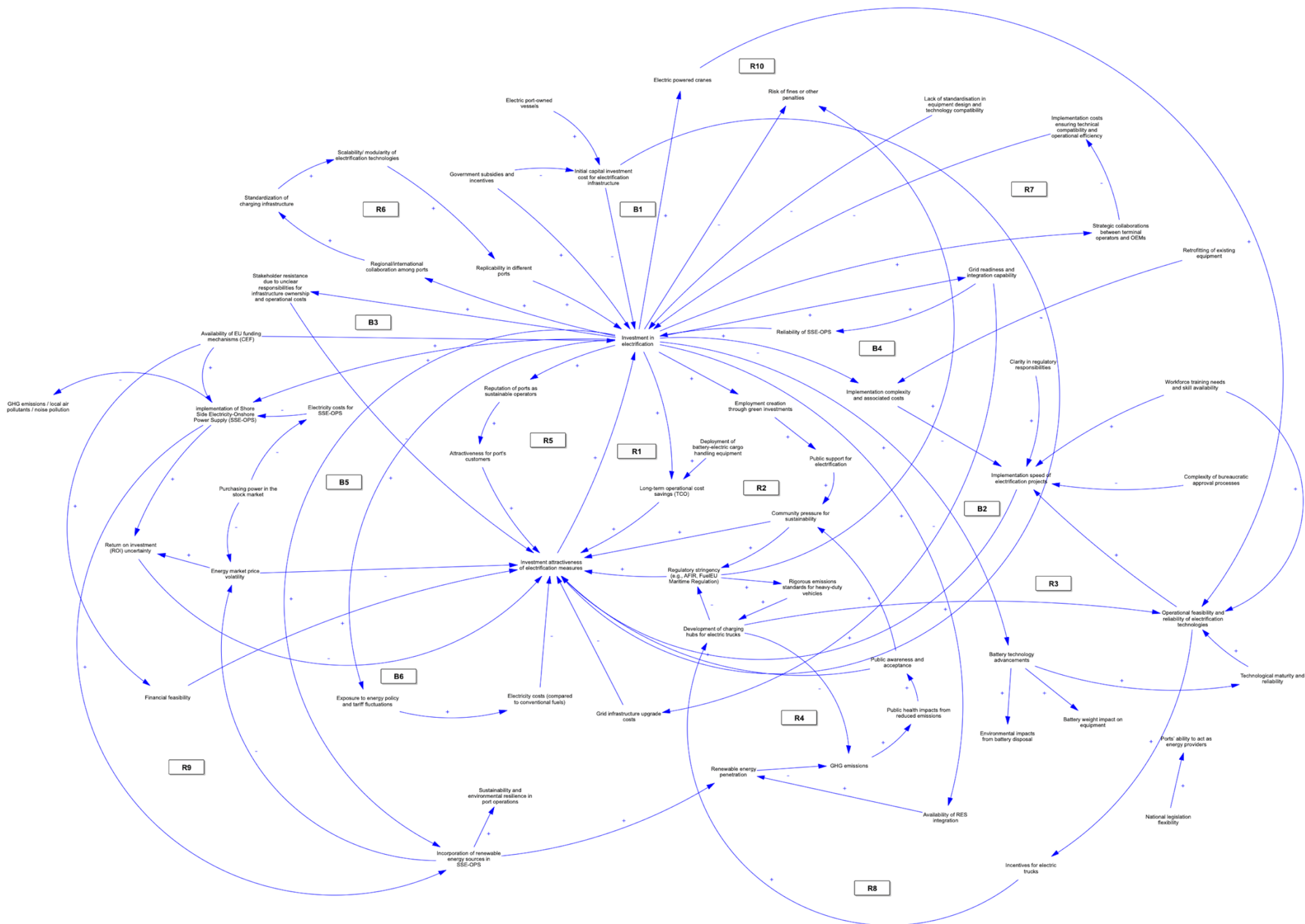


Figure 20. CLD of port electrification (Source: own elaboration)

Table 13. Reinforcing & Balancing Loops derived from CLD (Source: own elaboration)

Loop ID	Type	Loop Name	Key Variables
R1	Reinforcing	Economic viability loop	Investment → Operational cost savings → Investment attractiveness → Investment
R2	Reinforcing	Public support / employment loop	Investment → Employment creation → Public support → Community pressure → Regulatory stringency → Investment
R3	Reinforcing	Technology maturity loop	Investment → Battery tech advancements → Maturity → Feasibility → Implementation speed → Investment attractiveness → Investment
R4	Reinforcing	Environmental & health improvement loop	Investment → RES integration → Emissions → Health → Public awareness → Investment
R5	Reinforcing	Competitiveness & reputation loop	Investment → Sustainable port reputation → Port attractiveness → Investment attractiveness → Investment
R6	Reinforcing	Replication & standardization loop	Investment → Replicability → Collaboration → Standardization → Modularity → Investment
B1	Balancing	Capital cost constraint loop	Investment → Initial capital cost → Investment Attractiveness → Investment
B2	Balancing	Implementation complexity loop	Investment → Complexity → Implementation speed → Investment attractiveness → Investment
B3	Balancing	Stakeholder resistance loop	Investment → Resistance → Investment attractiveness → Investment
B4	Balancing	Grid infrastructure cost loop	Investment → Grid readiness → Upgrade costs → Investment attractiveness → Investment
B5	Balancing	ROI & SSE–OPS deployment	Investment → SSE–OPS → ROI uncertainty → Investment attractiveness → Investment
R7	Reinforcing	Strategic collaboration & implementation efficiency loop	Implementation costs ensuring technical compatibility and operational efficiency → Strategic collaborations between terminal operators and OEMs → Investment in electrification
B6	Balancing	Energy policy risk and investment attractiveness loop	Investment in electrification → Exposure to energy policy and tariff fluctuations → Electricity costs (compared to conventional fuels) → Investment attractiveness of electrification measures --> Investment in electrification
R8	Reinforcing	Charging infrastructure and electric truck incentives loop	Development of charging hubs for electric trucks --> Operational feasibility and reliability of electrification technologies --> Incentives for electric trucks
R9	Reinforcing	SSE-OPS renewable integration and electricity cost stability loop	Investment in electrification → implementation of Shore Side Electricity-Onshore Power Supply (SSE-OPS)→ Incorporation of renewable energy sources in SSE-OPS → Energy market price volatility → Investment attractiveness of electrification measures → Investment in electrification

R10	Reinforcing	Operational capacity loop	Investment in electrification → Electric powered cranes → Operational feasibility and reliability of electrification technologies → Implementation speed of electrification projects --> Investment attractiveness of electrification measures → Investment in electrification
-----	-------------	---------------------------	---

As summarised in the Table 13, the CLD is structured around a set of feedback loops, each representing a distinct dynamic mechanism influencing the implementation and diffusion of port electrification measures. The table provides a systematic overview of these mechanisms, distinguishing between reinforcing and balancing feedback structures that shape system behaviour over time. Reinforcing loops capture processes that amplify change, while balancing loops represent constraining forces that counteract growth or slow system evolution. For instance, loop R1, referred to as the economic viability loop, illustrates how initial investments in electrification lead to reductions in operational costs. These cost savings improve the perceived attractiveness of electrification projects, thereby stimulating additional investment and further reinforcing adoption. Similarly, loop R3, the technology maturity loop, describes how increased deployment contributes to learning effects, performance improvements, and greater technological reliability, which in turn enhance feasibility and accelerate implementation.

In contrast, balancing mechanisms highlight limiting conditions within the system. Loop B1, the capital cost constraint loop, captures the effect of high upfront investment requirements on decision-making, particularly in contexts characterised by budgetary constraints or uncertain returns. Loop B4, the grid infrastructure cost loop, reflects how limitations in grid capacity and the need for costly upgrades act as structural barriers that hinder further development of electrification measures. Additional feedback structures were incorporated to represent more specific dynamics associated with particular interventions. Loop R8 addresses the interaction between charging infrastructure availability and incentives for electric truck adoption, while loop R9 captures the reinforcing effects arising from the integration of renewable energy sources into SSE-OPS systems.

Together, these loops ensure that the causal structure reflects both general system behaviour and measure-specific dynamics. The resulting configuration of feedback loops establishes a coherent dynamic foundation, which subsequently informs the development of the stock-and-flow structure of the model. In this way, the causal loop diagram serves as a transparent and traceable intermediary between the qualitative identification of drivers and barriers and the quantitative representation of system evolution over time.

5.3 Development of the stock-and-flow diagram (SFD)

The causal loop diagrams identified sixteen feedback loops representing the principal dynamic mechanisms influencing port electrification. Since the objective of the quantitative model was to capture the dominant system behaviour rather than reproduce every conceptual relationship, a structured selection process was undertaken to determine which loops would be selected in the stock-and-flow model. This step followed the initial identification of all

potential feedback structures and aimed to ensure analytical focus of the model. The selection was guided by two main criteria. First, the relative importance of the parameters involved in each feedback loop, as reflected in the dissertation's research objectives and the findings of the PESTLE analysis, was assessed. Second, the modelling complexity associated with representing each loop quantitatively was taken into account. Several feedback loops, including those related to stakeholder resistance, public support, and replication effects, were recognised as conceptually important; however, they posed significant challenges in terms of quantification and data availability. The explicit representation of these dynamics would have substantially increased the structural and computational complexity of the model, without achieving an adequate level of explanatory power. For this reason, such loops were treated as exogenous assumptions or considered for potential inclusion in future model extensions.

Following these criteria, have been prioritised feedback loops that captured variables repeatedly identified as critical drivers or barriers across the political, economic, technological and legal dimensions. This ensured that the most influential dynamics shaping port electrification were explicitly represented in the model structure. The systematic assessment of data availability and modelling feasibility indicated six feedback loops that were ultimately selected to inform the development of the stock-and-flow (SFD) model, with their underlying relationships translated into the corresponding quantitative model components. These comprised R1 (economic viability), R3 (technology maturity), R8 (charging infrastructure and electric truck incentives), B1 (capital cost constraint), B4 (grid infrastructure cost), and B5 (return on investment and SSE-OPS deployment). This subset (Figure 21) was considered sufficient to capture the dominant reinforcing and balancing dynamics governing the evolution of port electrification, while preserving an appropriate level of model simplicity and interpretability. It should be noted that the transition from causal loop diagrams to stock-and-flow modelling does not imply a direct translation of each identified feedback loop into a corresponding stock, inflow or outflow. In System Dynamics, the purpose of the quantitative model is to represent the fundamental accumulations and decision processes that generate the observed behaviour of the system. Therefore, the stock-and-flow structure was developed to capture the dominant dynamics of port electrification and the interactions most relevant to the research objectives. The adequacy of the model is assessed by its ability to represent the behaviour and evolution of the system in a plausible and analytically meaningful manner, rather than by the extent to which individual causal loops are replicated within the quantitative structure.

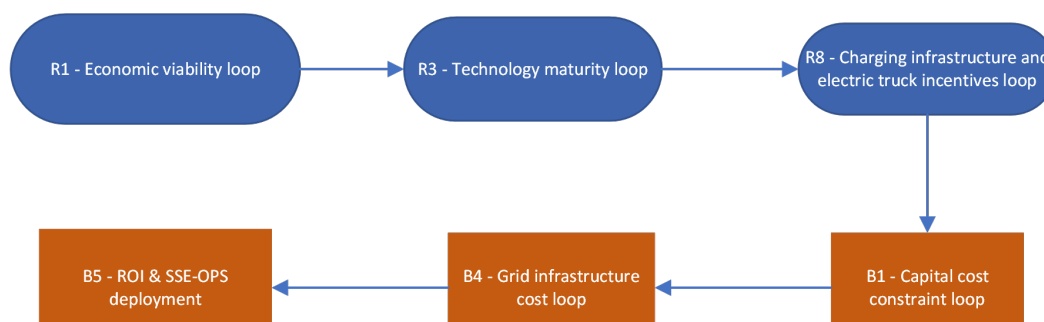


Figure 21. Subset of selected loops for the SFD (Source: own elaboration)

Following the establishment of the fundamental feedback mechanisms, the subsequent methodological stage incorporated the construction of a stock-and-flow diagram, (Figure 22) with the initial emphasis placed on the financial decision-making structure governing the implementation of electrification measures. The modelling effort focused on representing the inflow of available capital and its allocation across the different electrification actions, capturing budget availability as the primary stock through which investment decisions are determined. The initial stock-and-flow structure is thus characterised by the accumulation of available capital, which is increased through new funding approvals and reduced through annual capital allocation. This formulation reflects the role of funding as both a constraining and enabling resource, translating policy support, public funding schemes and investment decisions into a concrete system capacity for implementation. The **allocation of capital** was modelled as an explicit decision process, whereby the **available budget** is distributed across a selected range of electrification measures, including SSE-OPS, charging infrastructure, grid upgrades, electric cranes and ground support vehicles. In this structure, **total annual spending** emerges as a central flow, linking the availability of capital to the pace of infrastructure deployment. **Allocation shares** were introduced to represent prioritisation choices among competing electrification measures, allowing the model to capture trade-offs in investment sequencing and resource distribution. The inclusion of **allocation time** further reflects delays associated with planning, procurement and administrative processes, ensuring that financial decisions do not translate instantaneously into physical deployment. The initial loop establishes a core reinforcing-balancing interaction between funding availability, investment allocation and infrastructure development, thereby providing the financial backbone of the stock-and-flow model.

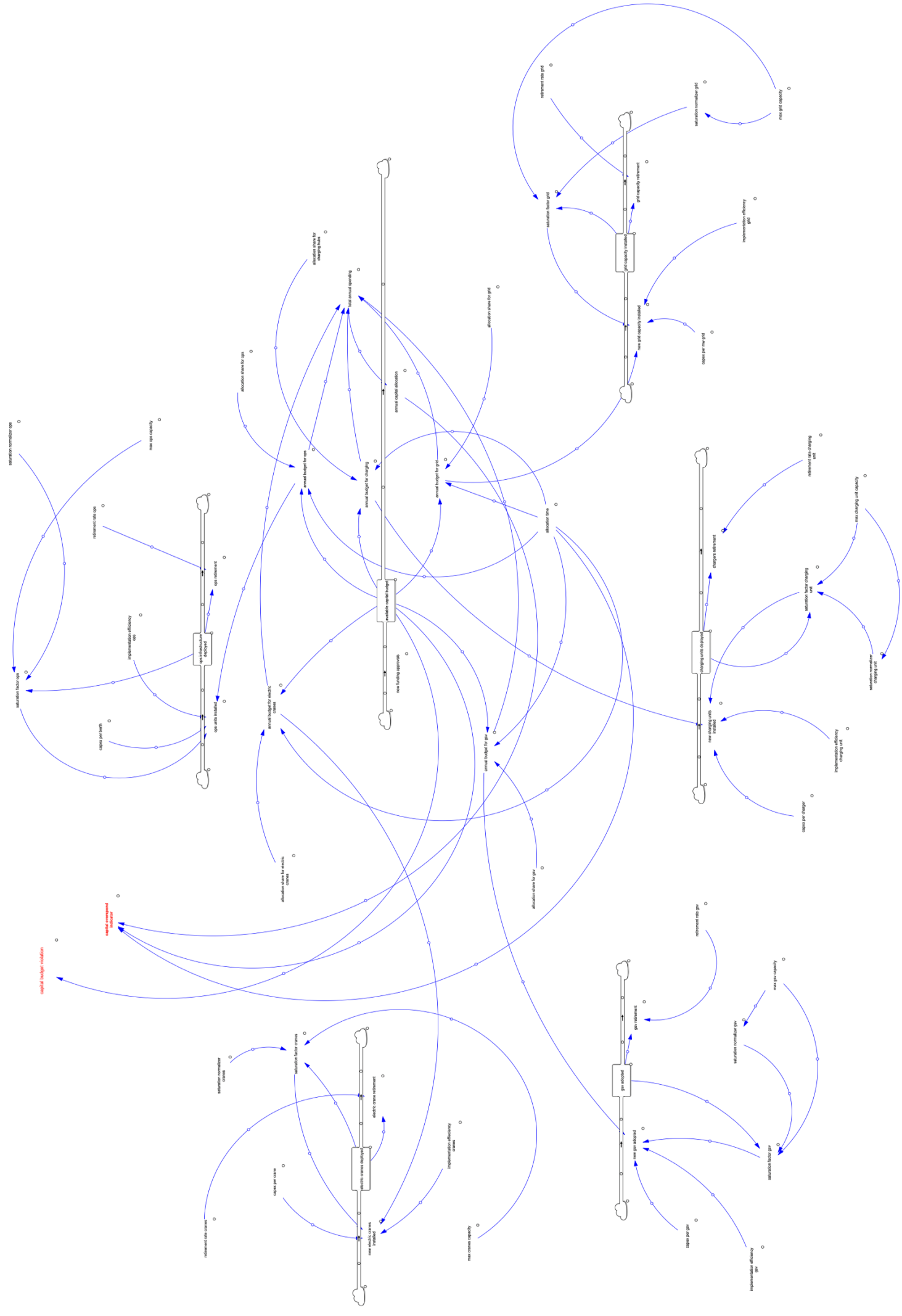


Figure 22. Stock & Flow diagram of port electrification (Source: own elaboration)

Table 14. Variables and mathematical formulations of the budget allocation sub-model (baseline scenario)
(Source: own elaboration)

Variable name	Equation	Type	Units
New funding approvals	10000000	Constant	euros/year
Available capital budget	INTEG (new funding approvals - annual capital allocation , 60e6)	Level	euros
Total annual spending	annual budget for ops + annual budget for charging + annual budget for grid + annual budget for GSV + annual budget for electric cranes	Auxiliary	euros/year
Annual capital allocation	total annual spending	Auxiliary	euros/year
Allocation share for GSV	0.175	Constant	Dmnl
Annual budget for GSV	(available capital budget * allocation share for GSV)/ allocation time	Auxiliary	euros/year
Allocation time	1	Constant	year
Allocation share for SSE-OPS	0.4	Constant	Dmnl
Annual budget for SSE-OPS	(available capital budget * allocation share for SSE-OPS)/ allocation time	Level	euros/year
Allocation share for charging hubs	0.125	Constant	Dmnl
Annual budget for charging hubs	(available capital budget * allocation share for charging hubs)/ allocation time	Auxiliary	euros/year
Allocation share for electric cranes	0.2	Constant	Dmnl
Annual budget for electric cranes	(available capital budget * allocation share for electric cranes)/ allocation time	Auxiliary	euros/year
Allocation share for grid	0.1	Constant	Dmnl
Annual budget for grid	(available capital budget * allocation share for grid)/ allocation time	Auxiliary	euros/year

Table 14 presents the variables and mathematical formulations that constitute the budget allocation subsystem in a port for electrification of their operations¹. This subsystem can be regarded as the financial decision-making structure that guides investment decisions in port electrification measures. The subsystem formalises the accumulation, allocation, and translation of approved funding into annual investment flows across competing electrification options. The fundamental element under consideration is the available capital budget, which is defined as a level variable that accumulates newly approved funding and is reduced by annual capital allocation. This formulation captures the dynamic evolution of the port's investable capital stock over time, reflecting both inflows from funding approvals (e.g. grants or co-financing schemes) and outflows associated with realised investments. The initial value of this stock signifies previously approved but unallocated capital. The annual capital allocation

¹ The entire list of the model's variables and equations can be found in ANNEX V

is defined as equal to total annual spending, ensuring accounting consistency between planned expenditure and the depletion of available capital. The total annual spending is modelled as the sum of annual budgets assigned to each electrification measure, including SSE-OPS, charging hubs, grid upgrades, Ground Support Vehicles (GSV), and electric cranes. This formulation explicitly links strategic budget allocation decisions to the aggregate financial outflow from the investment budget.

The distribution of budget across various electrification measures is governed by a set of allocation shares, expressed as dimensionless constants. Each allocation share represents the proportion of the available capital budget that has been allocated to a specific investment category. These parameters enable the model to represent strategic prioritisation and trade-offs among competing electrification pathways, while maintaining transparency regarding the assumptions upon which decisions are made. The collective allocation of shares determines the distribution of financial resources across SSE-OPS, charging infrastructure, electric cranes, grid upgrades, and GSV investments. The annual budget assigned to each electrification measure is formulated as a function of the available capital budget, the corresponding allocation share, and an allocation time parameter. The allocation time period is indicative of delays associated with the planning, procurement, and administrative processes. This results in the prevention of immediate conversion of capital availability into effective annual spending. This structure introduces realistic temporal smoothing between financial approval and expenditure. All monetary flows are expressed in euros per year, while stock variables are expressed in euros, thereby ensuring dimensional consistency throughout the subsystem. The sub-model's structuring of budget dynamics in this manner provides a coherent and internally consistent representation of how financial resources constrain, enable, and sequence investments in electrification. This financial foundation subsequently connects to the technology-specific stock-and-flow structures, enabling budgetary decisions to disseminate throughout the broader system dynamics model and exert influence on the pace and scale of port electrification over time.

Table 15. GSV deployment sub-model (Source: own elaboration)

Variable name	Equation	Type	Units
gsv adopted	(new gsv adopted-gsv retirement)	Level	vehicles
new gsv adopted	(annual budget for gsv/capex per gsv)*implementation efficiency gsv*saturation factor gsv	Auxiliary	vehicles/year
gsv retirement	gsv adopted*retirement rate gsv	Auxiliary	vehicles/year
capex per gsv	150000	Constant	euros/vehicles
implementation efficiency gsv	0.8	Constant	Dmnl
max gsv capacity	60	Constant	vehicles
retirement rate gsv	0.05	Constant	1/year
saturation factor gsv	$\text{MAX}(0, \text{MIN}(1, (\text{max gsv capacity} - \text{gsv adopted}) / \text{saturation normalizer gsv}))$	Auxiliary	Dmnl
saturation normalizer gsv	max gsv capacity	Auxiliary	vehicles

The variables and equations presented in Table 15 describe the stock-and-flow structure determining the adoption and retirement of electric GSV within the port system. The sub-model captures the dynamic balance between investment in fleet expansion and gradual fleet retirement, while explicitly accounting for financial constraints, implementation challenges, and physical capacity limits. The core state variable of the sub-model is GSV adopted, defined as a stock variable representing the cumulative number of electric GSV that have been deployed and remain operational at the port at any given point in time. It is evident that the stock is subject to an increase as a result of the inflow of new GSVs, and a corresponding decrease due to the outflow of GSVs from retirement. This phenomenon is indicative of the net evolution of the electric GSV fleet. The inflow new GSV adopted is formulated as a function of the annual budget allocated to GSV investments, the unit capital cost per vehicle, and two moderating factors: implementation efficiency GSV and saturation factor GSV. The ratio of the annual GSV budget to the capex per GSV is indicative of the potential number of vehicles, given the financial resources available. The implementation efficiency parameter is a measure of real-world frictions, such as procurement delays, administrative constraints, and technical bottlenecks, that prevent full conversion of budget into installed vehicles. The saturation factor introduces a non-linear constraint that progressively reduces the adoption rate as the system approaches its maximum feasible fleet size.

All variables are dimensionally consistent, with stocks expressed in vehicles, flows in vehicles per year, and financial parameters expressed in euros per vehicle. The sub-model under consideration succeeds in capturing the interaction between budget availability, implementation constraints, fleet replacement and capacity limits. It provides a realistic representation of the dynamics governing electric GSV adoption within the broader port electrification system.

Table 16. SSE-OPS deployment sub-model (Source: own elaboration)

Variable name	Equation	Type	Units
ops units installed	(annual budget for ops/capex per berth) * implementation efficiency ops * saturation factor ops	Auxiliary	berths/year
ops infrastructure deployed	ops units installed - ops retirement	Level	berths
ops retirement	ops infrastructure deployed * retirement rate ops	Auxiliary	berths/year
saturation factor ops	MAX(0,MIN(1,(max ops capacity-ops infrastructure deployed)/saturation normalizer ops))	Auxiliary	Dmnl
capex per berth	6000000	Constant	euros/berths
implementation efficiency ops	0.9	Constant	Dmnl
retirement rate ops	0.05	Constant	1/year
max ops capacity	12	Constant	berths
saturation normalizer ops	5	Constant	berths

The variables presented in Table 16 define the stock-and-flow structure governing the deployment, saturation, and retirement of Shore Side Electricity – Onshore Power Supply (SSE-OPS) infrastructure within the port. The sub-model demonstrates how financial allocation, implementation capacity, infrastructure limits, and asset deterioration collectively influence the long-term evolution of SSE-OPS installations. The primary stock variable is SSE-OPS infrastructure deployed, which represents the total number of OPS-equipped berths that are operational in the port at any given moment. This stock increases through the inflow ops units installed and decreases through the outflow OPS retirement, thereby capturing both infrastructure expansion and gradual decommissioning processes. The inflow SSE-OPS units installed translate the annual budget for SSE-OPS into physical installations by dividing the available expenditure by the CAPEX per berth, which reflects the investment required to equip a single berth with SSE-OPS infrastructure. The potential installation rate is moderated by the implementation efficiency SSE-OPS, a dimensionless parameter that captures real-world constraints such as permitting delays, procurement bottlenecks, grid connection issues, and coordination with terminal operations. Consequently, only a small percentage of the theoretically affordable SSE-OPS units is realised each year.

The outflow SSE-OPS retirement is modelled as a function that is proportional to the existing SSE-OPS stock, using the retirement rate SSE-OPS. This formulation represents the gradual retirement of SSE-OPS units due to factors such as ageing, physical deterioration, technological obsolescence, or replacement cycles. This ensures that infrastructure dynamics reflect long-term asset lifecycles rather than inevitable accumulation. The capacity constraints are explicitly incorporated through the maximum operations capacity (max ops capacity), which defines the upper bound on the number of SSE-OPS-equipped berths that the port can realistically support. The aforementioned limit is indicative of physical space availability, electrical grid capacity, berth configuration, and operational requirements. The saturation factor operations are formulated as a bounded, dimensionless function of the remaining installation potential relative to a saturation normalizer operation. This configuration guarantees a seamless and progressive decrease in installation rates as the system approaches saturation, thereby averting sudden interruptions and preserving numerical stability within the simulation. All variables are defined with consistent units, with stocks expressed in berths, flows in berths per year, and financial parameters in euros per berth. The OPS subsystem is designed to encompass the dynamic interaction between investment decisions, implementation constraints, infrastructure ageing, and system capacity limits. The model provides a transparent and internally consistent representation of how SSE-OPS deployment evolves over time and how financial and technical constraints shape the pace and scale of shore-side electrification in ports.

Table 17. Electric cranes deployment sub-model (Source: own elaboration)

Variable name	Equation	Type	Units
new electric cranes installed	(annual budget for electric cranes / capex per crane) * implementation efficiency cranes * saturation factor cranes	Auxiliary	cranes/year
electric cranes deployed	new electric cranes installed – electric crane retirement	Level	cranes

Variable name	Equation	Type	Units
electric crane retirement	electric cranes deployed * retirement rate cranes	Auxiliary	cranes/year
retirement rate cranes	0.03	Constant	1/year
capex per crane	3,000,000	Constant	euros/crane
saturation normalizer cranes	12	Constant	cranes
saturation factor cranes	MAX (0, MIN(1, (max cranes capacity – electric cranes deployed) / saturation normalizer cranes))	Auxiliary	Dmnl
implementation efficiency cranes	0.8	Constant	Dmnl
max cranes capacity	12	Constant	cranes

The electric crane module formalises the deployment of electrified cargo-handling equipment by representing crane installation as a budget-constrained and capacity-limited process. The concept of the electric crane variable, as highlighted in Table 17, captures the cumulative operational stock, evolving as the difference between annual additions and retirements. This configuration enables the model to reflect both infrastructure growth and gradual reduction due to ageing or replacement. The installation flow is derived from the annual financial resources allocated to electric cranes and the corresponding unit investment cost. This financial driver is moderated by two control mechanisms. Firstly, the implementation efficiency parameter captures the degree to which allocated funds materialise into operational assets, accounting for factors related to constraints. Secondly, the saturation factor introduces a decreasing response as installed capacity approaches the port's feasible upper limit, representing spatial, operational and organisational constraints specific to crane deployment.

The dynamics of this process are represented through a retirement mechanism that is proportional in nature, thereby directly linking the removal of cranes to the existing stock. This formulation ensures that the system remains dynamically balanced over long simulation horizons and avoids unrealistically persistent accumulation. The incorporation of capacity constraints is achieved through the implementation of an explicit maximum threshold, designated as the maximum crane capacity. The saturation normalizer functions to regulate the transition from expansion to saturation, ensuring a smooth and consistent progression. The integration of these components ensures a gradual reduction in installations, thereby avoiding sudden interruptions and facilitating the capture of realistic infrastructure scaling behaviour. The sub-model combines investment decisions, implementation performance and physical limits into a coherent dynamic representation, thereby enabling the assessment of how alternative funding levels and efficiency assumptions shape both the speed and extent of electric crane uptake within the port system.

Table 18. Grid capacity upgrade sub-model (Source: own elaboration)

Variable name	Equation	Type	Units
grid capacity installed	INTEG (new grid capacity installed – grid capacity retirement, 20)	Level	MW
new grid capacity installed	(annual budget for grid / capex per MW grid) × implementation efficiency grid × saturation factor grid	Auxiliary	MW/year
grid capacity retirement	grid capacity installed × retirement rate grid	Auxiliary	MW/year
saturation factor grid	MAX (0, MIN(1, (max grid capacity – grid capacity installed) / saturation normalizer grid))	Auxiliary	Dmnl
retirement rate grid	0	Constant	1/year
saturation normalizer grid	max grid capacity	Auxiliary	MW
max grid capacity	80	Constant	MW
implementation efficiency grid	0.3	Constant	Dmnl
capex per MW grid	1,000,000	Constant	euros/MW

The grid subsystem is intended to illustrate the evolution of the port's electrical infrastructure as a dynamic process driven by investment decisions and constrained by physical and technical limits (Table 18). The fundamental element of the sub-model is the installed grid capacity, which represents the cumulative level of electrical power available at the port at any given moment. This stock is increased through the installation of new grid capacity and, in principle, decreased through the retirement of existing infrastructure. However, the latter is set to zero in the baseline configuration to focus the analysis on expansion dynamics during the examined period. The flow of new grid capacity installed is indicative of the annual rate at which additional electrical power is added to the port's network. The flow is determined by the investment budget allocated to grid upgrades, the capital cost per MW, and the implementation efficiency of grid projects. It is evident that financial resources are translated into physical increases in electrical capacity. However, it must be acknowledged that not all planned investments are fully realised due to procedural, technical, or organisational frictions. As installed capacity grows, further expansion is progressively constrained through the introduction of a saturation factor. This dimensionless variable functions to reduce the rate of grid expansion as the installed capacity approaches the maximum grid capacity that the port can support. The saturation mechanism is indicative of physical space limitations, network integration constraints, and technical thresholds that become increasingly binding as the electrical system approaches its upper operational limit. The saturation normalizer establishes the scale over which these effects manifest, thereby ensuring a smooth and gradual transition from rapid expansion to capacity saturation.

The maximum grid capacity establishes an explicit upper bound for grid development within the model and represents the combined effect of technical, spatial, and network-related constraints. In combination with the saturation factor, this ensures that grid expansion follows a realistic path rather than showing unlimited growth. The implementation efficiency parameter

further moderates this process by capturing the share of allocated investment capital that is effectively converted into installed electrical capacity, accounting for delays in permitting, procurement, construction, and system integration. In conclusion, the capital expenditure per megawatt ultimately establishes a direct correlation between financial investment and tangible infrastructure outcomes. By defining the cost of constructing and connecting one additional megawatt of electrical capacity, this parameter governs the scale of grid expansion achievable under different investment scenarios. The grid subsystem model is a comprehensive representation of the interplay between financial resources, implementation performance, and physical constraints. It offers a structured depiction of the evolution of grid readiness as a foundational catalyst for port electrification.

Also, the capital overspend indicator and the capital budget violation variables are introduced as internal consistency and realism checks within the financial structure of the model. The capital overspend indicator is a financial metric used to measure scenarios in which the annual capital allocation exceeds the level of investment that can be supported by the available capital budget within a given allocation period. By comparing annual capital allocation with the effective spending capacity derived from the available budget and the allocation time, these variable signals when planned investments exceed financial feasibility. The system operates not as a mechanical constraint, but rather as a diagnostic indicator, facilitating the identification of overspending conditions during simulation runs. It is important to note that the capital budget violation variable serves a crucial function in the overall financial management of the system, acting as a mechanism for verifying the system's financial equilibrium. It is a system that tracks instances where the available capital budget becomes negative, thereby indicating that cumulative investment commitments have exceeded the port's approved and accessible financial resources. This variable does not directly modify investment flows; rather, it serves to identify financially unfeasible scenarios and emphasise instances in which investment strategies are not aligned with budgetary constraints. The combined effect of these two variables is to enhance the transparency and credibility of the model by means of explicit monitoring of financial consistency. The primary function of these models is to assess the viability of electrification pathways within the bounds of feasible investment. Additionally, they facilitate the interpretation of simulation outcomes by differentiating between technically feasible dynamics and financially unviable model behaviors. Finally, this methodological progression - from literature evidence, to PESTLE analysis, to causal feedback structures, and finally to stock-and-flow modelling - ensured that the quantitative model remained conceptually grounded while preserving analytical clarity and practical applicability.

5.3.1 Scenario-based sensitivity analysis of capital allocation priorities

This section explores the sensitivity of key electrification outcomes to alternative capital allocation priorities. The analysis is implemented through a set of discrete policy scenarios, in which the total available investment budget remains constant, while allocation shares across electrification measures vary. This methodological approach facilitates the identification of outcomes that are responsive to prioritisation choices and those that remain insensitive under the tested conditions. It should also be noted that the variable “OPS deployment” is used as the primary reference variable to enable consistent comparison across the entire analysis.

The relationships among variables follow the same structural logic across the remaining stocks, ensuring consistency and comparability in the model structure.

The results reveal a clear and consistent pattern: each electrification measure responds primarily to changes in its own allocated budget share, while remaining largely insensitive to the redistribution of capital among other measures. This behaviour has been observed across a range of outputs, including SSE-OPS infrastructure deployed and GSV adoption. It has been noted that several scenarios produce overlapping pathways despite substantially different internal budget compositions. In order to assess the sensitivity of SSE-OPS deployment to alternative investment strategies, a set of capital allocation scenarios was developed. In all scenarios, the total annual investment budget was maintained at a constant level, while the allocation shares across a range of electrification measures were systematically varied. These measures included SSE-OPS, grid upgrades, electric cranes, charging hubs and ground support vehicles (GSV). This approach enables the isolation of strategic prioritisation effects, as opposed to budget-scale effects, on the SSE-OPS deployment process.

Table 19. Budget allocation shares applied under each scenario (Source: own elaboration)

Scenario	SSE-OPS	Grid	Electric cranes	Charging hubs	GSV
Baseline_scenario_main	0.40	0.10	0.20	0.125	0.175
ops_priority	0.60	0.10	0.10	0.10	0.10
grid_priority	0.30	0.35	0.10	0.10	0.15
gsv_priority	0.20	0.10	0.15	0.20	0.35
charging_hubs_priority	0.20	0.20	0.15	0.35	0.10
electric_cranes_priority	0.25	0.15	0.40	0.10	0.10

**In red colour, highlighted the highest values in each scenario*

Table 19 summarises the allocation shares applied under each scenario. The *Baseline scenario* reflects a reference configuration in which SSE-OPS receives the largest share of capital (0.40), followed by electric cranes (0.20), GSV (0.175), charging hubs (0.125), and grid upgrades (0.10). All alternative scenarios deviate from this configuration by increasing the allocation share of a single measure, while correspondingly reducing the shares allocated to others.

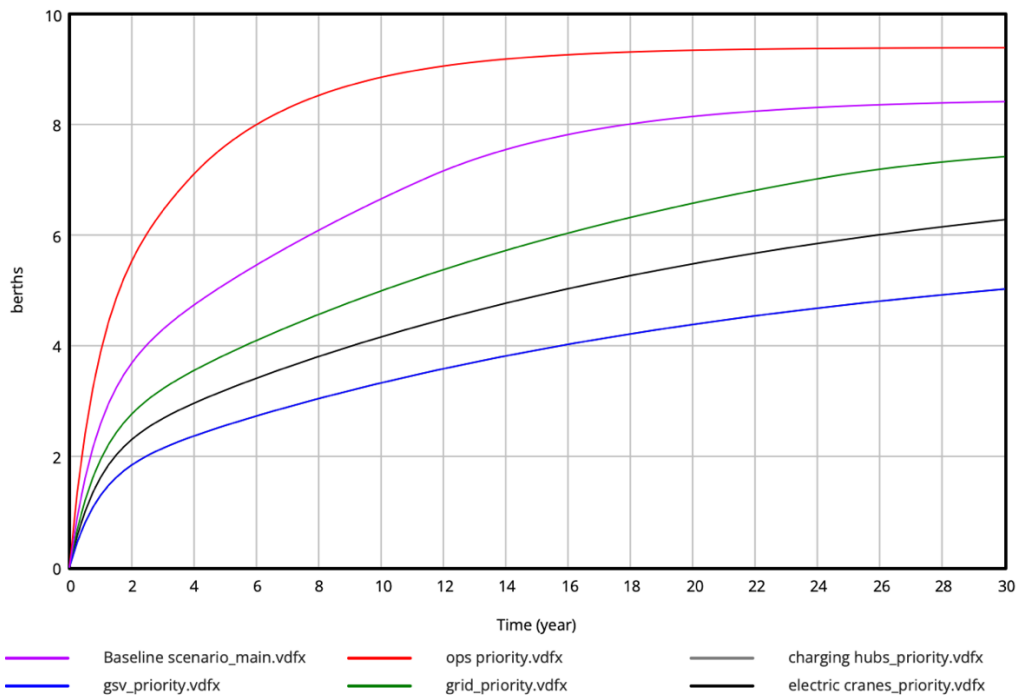


Diagram 1. SSE-OPS infrastructure deployment under various priority strategies on SSE-OPS deployment
(Source: own elaboration)

The Ops_priority scenario in Diagram 1, in which the SSE-OPS allocation share is increased to 0.60, produces the fastest and most significant SSE-OPS deployment pathway among all scenarios examined. As demonstrated in the SSE-OPS deployment diagram, this scenario demonstrates a rapid initial growth phase and attains saturation at a substantially earlier point in time than the other scenarios, reaching high deployment levels within the initial decade of the simulation horizon. This behaviour is indicative of the direct effect of sustained prioritisation of SSE-OPS investment under a fixed total capital budget, and illustrates the reinforcing dynamics associated with early infrastructure scale-up. The baseline scenario, with an SSE-OPS allocation share of 0.40, follows a similar but less accelerated trend, achieving lower deployment levels at any given point in time compared to the ops_priority case. Scenarios involving the assignment of moderate SSE-OPS shares, specifically grid_priority at 0.30, result in intermediate SSE-OPS deployment pathways. In scenarios where the SSE-OPS allocation shares are lower – specifically gsv_priority and charging_hubs_priority, both at 0.20 – the deployment of SSE-OPS throughout the simulation period is both slow and persistent. The near-identical observations made in these two cases are directly influenced by the equal distribution of SSE-OPS budget shares, as well as the comparable temporal progression of grid readiness. In a similar manner, the electric_cranes_priority scenario, with an SSE-OPS allocation share of 0.25, produces an intermediate deployment profile, consistently positioned between the low-OPS and moderate-OPS scenarios.

The results demonstrate that SSE-OPS deployment in the model responds primarily to the SSE-OPS allocation share, which determines the level of investment available for installation, which conditions the extent to which this investment can be realised in practice. It is evident that reallocations of capital towards alternative electrification measures – such as grid upgrades, electric cranes, charging hubs, or ground support vehicles – exert no influence on

SSE-OPS deployment, unless they either directly modify the SSE-OPS budget or modify grid capacity sufficiently to relax installation constraints. The systematic structuring and partial categorisation of deployment strategies across scenarios thus reflect the model's causal clarity and internal consistency, thereby confirming that each electrification measure responds primarily to its own policy lever rather than to indirect or unintended spillover effects.

5.3.2 Impact of grid capacity constraints on SSE-OPS deployment

The introduction of grid readiness constraints constitutes a deliberate conceptual and methodological shift in the modelling framework, transforming the analysis from a purely budget-driven representation of port electrification into also an infrastructure-constrained policy model (Figure 19). In the baseline formulation, SSE-OPS deployment responds exclusively to financial allocation decisions, operating under the assumption that electricity supply capacity can always accommodate the pace of infrastructure expansion. Assuming this to be true, it can be concluded that capital availability is the sole binding driver of deployment outcomes. The introduction of grid readiness constraints represents a deliberate extension of the baseline scenario analysis, with the aim of shifting from a representation of electrification investments that is purely budget-driven to a formulation that is more physically grounded and explicitly accounts for electricity supply limitations. The initial set of allocation scenarios illustrated how different capital allocation strategies affect the deployment pathway of SSE-OPS infrastructure in the absence of power constraints. However, the constrained model (Figure 24) enables the assessment of whether and under which conditions grid capacity becomes a binding factor for SSE-OPS deployment. Table 20 highlights the added variables related to grid readiness.

Table 20. Variables of models' grid readiness constraints (Source: own elaboration)

Variable name	Equation	Type	Units
Grid headroom for ops	$\text{MAX}(0, \text{grid capacity installed} - \text{nonops port load})$	Auxiliary	MW
NonOPS port load	15	Constant	MW
SSE-OPS power requirement per berth	2	Constant	MW /berths
SSE-OPS power required	$\text{ops infrastructure deployed} * \text{ops power requirement per berth}$	Auxiliary	MW
small number mw	0.001	Constant.	Dmnl
Grid readiness factor ops	$\text{MAX}(0, \text{MIN}(1, \text{grid headroom for ops} / (\text{ops power required} + \text{small number mw})))$	Auxiliary	Dmnl

The variable SSE-OPS power required is defined as the total electrical demand associated with the deployed SSE-OPS infrastructure at any given moment. The parameter “SSE-OPS power requirement per berth” was assigned a value of 2 MW, representing an indicative average electricity demand for OPS-equipped berths in medium-sized European ports. The selected value does not correspond to a specific vessel category, but rather reflects an aggregated representation of typical power requirements associated with a mix of vessel types, including feeder container vessels, Ro-Ro/Ro-Pax ferries and general cargo vessels. This modelling choice was considered appropriate given the conceptual and strategic nature of the model, which aims to capture the system-level implications of OPS deployment rather than the operational characteristics of individual ship categories. The calculation of the SSE-OPS infrastructure is performed by multiplying the number of installed berths by a constant parameter, which is indicative of the SSE-OPS power requirement per berth. This parameter is indicative of a generalised assumption concerning the mean peak electrical load necessary to supply a single SSE-OPS-equipped berth, thus serving as a quantifiable metric for conducting sensitivity testing. The model ensures dimensional consistency between physical assets and energy system constraints by directly linking infrastructure deployment to power demand. To account for electricity demand unrelated to SSE-OPS, the variable non-OPS port load is introduced as an exogenous component of total port electricity consumption. This variable signifies the background demand from associated port activities, including terminal operations, buildings, and auxiliary equipment. In the current model configuration, this variable is treated as a constant. This simplifying assumption enables the analysis to concentrate on SSE-OPS–grid interactions without the necessity for a fully endogenous port load sub-model.

The availability of electricity for SSE-OPS is determined by the variable grid headroom for SSE-OPS, which is defined as the difference between the total installed grid capacity and the non-OPS port load. This formulation serves to isolate the part of grid capacity that is considered to be available for allocation to SSE-OPS operations. A key principle of this approach is the non-negativity constraint, which ensures that the headroom of the grid cannot take negative values. This is due to the physical impossibility of supplying power beyond the installed capacity. The adequacy of the grid relative to SSE-OPS demand is expressed through the grid readiness factor for SSE-OPS, a dimensionless variable bounded between zero and one. This factor is computed as the ratio of grid headroom to SSE-OPS power requirements, with an upper bound of one and a lower bound of zero. A small constant term is included in the formula to ensure the integrity of the calculation, preventing division by zero during the initial simulation periods when SSE-OPS deployment may be minimal. In instances where grid headroom exceeds SSE-OPS power requirements, the grid readiness factor is equivalent to one. This finding indicates that electricity supply does not constrain SSE-OPS deployment. Conversely, when SSE-OPS power demand approaches or exceeds available grid headroom, the factor decreases below unity, progressively limiting further SSE-OPS installations.

This formulation introduces a feedback mechanism whereby SSE-OPS deployment increases power demand, which in turn reduces grid headroom and may constrain subsequent SSE-OPS expansion unless additional grid capacity is installed. It is evident that the model under consideration captures the co-evolution of SSE-OPS infrastructure and grid capacity in a physically consistent manner, without imposing hard exogenous limits. Consequently, grid readiness functions as a conditional constraint, which is activated only when electricity supply becomes inadequate relative to demand.

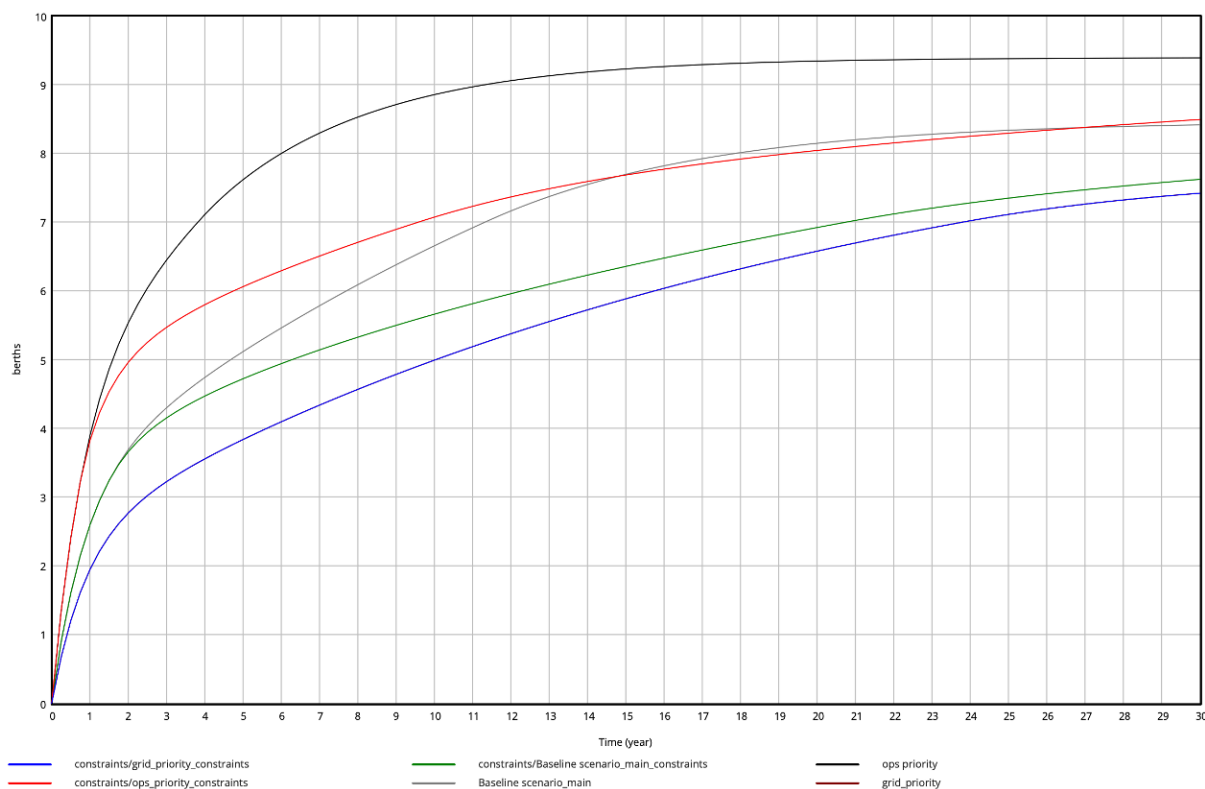


Diagram 2. SSE-OPS infrastructure deployment under various priority strategies with grid capacity constraints (Source: own elaboration)

A particularly informative outcome emerges when comparing the SSE-OPS deployment before and after the introduction of grid readiness constraints as indicated in Diagram 2. In this particular case, the SSE-OPS deployment path under the constrained formulation coincides precisely with the unconstrained deployment path. This equivalence signifies that, within the grid-priority scenario, grid capacity does not act as a binding constraint on SSE-OPS deployment at any point during the simulation horizon.

From a causal perspective, this result can be explained by the simultaneous interaction of two structural conditions embedded in the grid-priority allocation strategy. Firstly, a relatively high allocation share to grid investments leads to a rapid and early increase in installed grid capacity. Secondly, the allocation share to SSE-OPS remains moderate, resulting in a comparatively slower growth of OPS-related electricity demand. Consequently, throughout the simulation period, the available grid headroom allocated to SSE-OPS consistently exceeds the power requirements implied by the installed SSE-OPS infrastructure. It is evident from the data that grid headroom for SSE-OPS remains significantly larger than SSE-OPS power requirements. This has the consequence of ensuring that the grid readiness factor remains equal to one for the entire duration of the simulation. Consequently, the SSE-OPS installation flow remains uninterrupted by grid availability, and the constrained and unconstrained formulations of SSE-OPS deployment yield equivalent results. It is important to note that this

does not imply that the constraint mechanism is inactive or incorrectly specified. Instead, it demonstrates that the constraint is present but non-binding under this specific allocation strategy.

The contrast with other scenarios further reinforces this interpretation. In the OPS-priority scenario, a high allocation share to SSE-OPS, combined with comparatively lower grid investment, results in SSE-OPS power requirements growing at a rate that exceeds that of grid capacity. In this case, the grid readiness factor falls below this value, activating the constraint and leading to a visible difference between constrained and unconstrained SSE-OPS deployment trajectories. In a similar manner, in the baseline scenario, where investments in the grid and SSE-OPS evolve with greater symmetry, the constraint becomes partially binding, resulting in a more modest but nevertheless noticeable deceleration in SSE-OPS deployment once grid headroom becomes constrained.

The grid-priority scenario therefore represents a qualitatively distinct case in which early and sufficient grid reinforcement effectively prevents the emergence of electricity supply bottlenecks. This result underscores a significant policy-relevant insight: grid-related constraints in the model operate conditionally rather than mechanically. It should be noted that these systems do not automatically suppress SSE-OPS deployment; rather, they do so only when the electricity supply becomes insufficient relative to demand. It is evident that strategies prioritise grid reinforcement have the potential to proactively eliminate infrastructure bottlenecks and facilitate uninterrupted SSE-OPS deployment, even in the absence of an escalation in total investment budgets. From a modelling perspective, this outcome serves to strengthen the internal validity of the system dynamics framework. The equivalence between constrained and unconstrained trajectories in the grid-priority scenario should therefore be interpreted not as a limitation of the model, but as evidence that the model correctly distinguishes between binding and non-binding constraints depending on the underlying policy configuration.

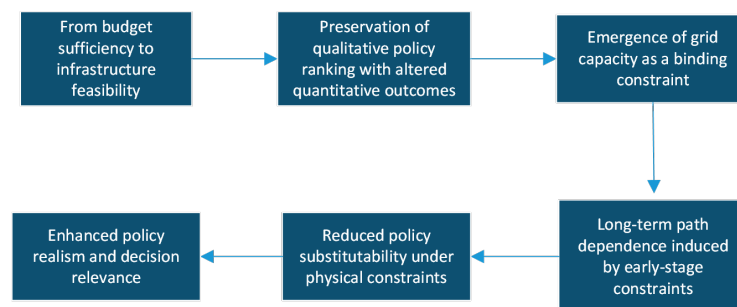


Figure 25. Key findings from the comparison of unconstrained and grid-constrained SSE-OPS deployment scenarios (Source: own elaboration)

The comparison between Diagram 1 & 2 demonstrates a clear transition from a budget-driven representation of electrification to an infrastructure-constrained deployment mechanism as indicated in Figure 24. The unconstrained model directly correlates capital allocation shares with SSE-OPS deployment. In contrast, the constrained model demonstrates that budget availability alone is inadequate when electricity supply limitations are explicitly represented. It seeks to demonstrate the capacity for the preservation of qualitative policy ranking with

modified quantitative outcomes. Across both graphs, the relative ranking of policy scenarios remains consistent, with the SSE-OPS priority scenario exhibiting the fastest and highest deployment path, followed by the baseline and lower-priority cases. However, the introduction of grid constraints systematically reduces the magnitude of deployment across all non-OPS-prioritised scenarios, indicating that physical constraints mitigate the effectiveness of well-funded policies. In the constrained model, several scenarios that performed adequately in the unconstrained case exhibit slower growth and lower long-term deployment levels. This discrepancy suggests that grid capacity becomes an active and binding constraint, particularly in scenarios where SSE-OPS expansion is not aligned with sufficient grid reinforcement.

The analysis of the constrained model reveals that, although deployment strategies tend to stabilise in subsequent years, they do not fully adjust to the initial constraints imposed. This phenomenon, known as long-term path dependence, is characterised by the tendency for strategies to evolve over time, despite the presence of initial restrictions. The initial constraints imposed by grid readiness have resulted in the persistent existence of gaps in the cumulative SSE-OPS deployment. This finding demonstrates that infrastructure bottlenecks in the early stages can generate long-term path dependence, which cannot be fully offset by subsequent investment. In the unconstrained formulation, reallocating capital away from SSE-OPS primarily affects deployment through reduced OPS-specific budgets. Conversely, the constrained model demonstrates that reallocations towards alternative electrification measures can indirectly suppress SSE-OPS deployment by intensifying competition for restricted grid capacity. This underscores the notion that policy measures are no longer autonomous when physical constraints are introduced. Also, the findings demonstrate that effective electrification strategies necessitate a coordinated sequence of SSE-OPS investments and grid upgrades. Policies that prioritise SSE-OPS without parallel grid reinforcement yield diminishing returns, thus underscoring the importance of integrated infrastructure planning as opposed to isolated budget optimisation.

5.3.3 Installed grid capacity across policy scenarios

Diagram 3 presents the evolution of installed grid capacity (MW) under three policy configurations: the baseline scenario, SSE-OPS_priority and the grid_priority scenario. Instead of demonstrating discrepancies in absolute capacity levels, the figure reveals pivotal causal dynamics associated with the timing and structural role of grid investments within the port electrification system. From the early years of the simulation, the grid priority scenario exhibits a faster and more significant increase in installed capacity. This observation is indicative of not only elevated investment levels, but more significantly, a temporal shift in infrastructure development. Earlier grid expansion has been demonstrated to facilitate faster capital absorption and generate electricity capacity earlier, thereby supporting downstream electrified infrastructures such as SSE-OPS and charging systems. The result highlights that, within the model, the timing of grid investments is as critical as their final magnitude.

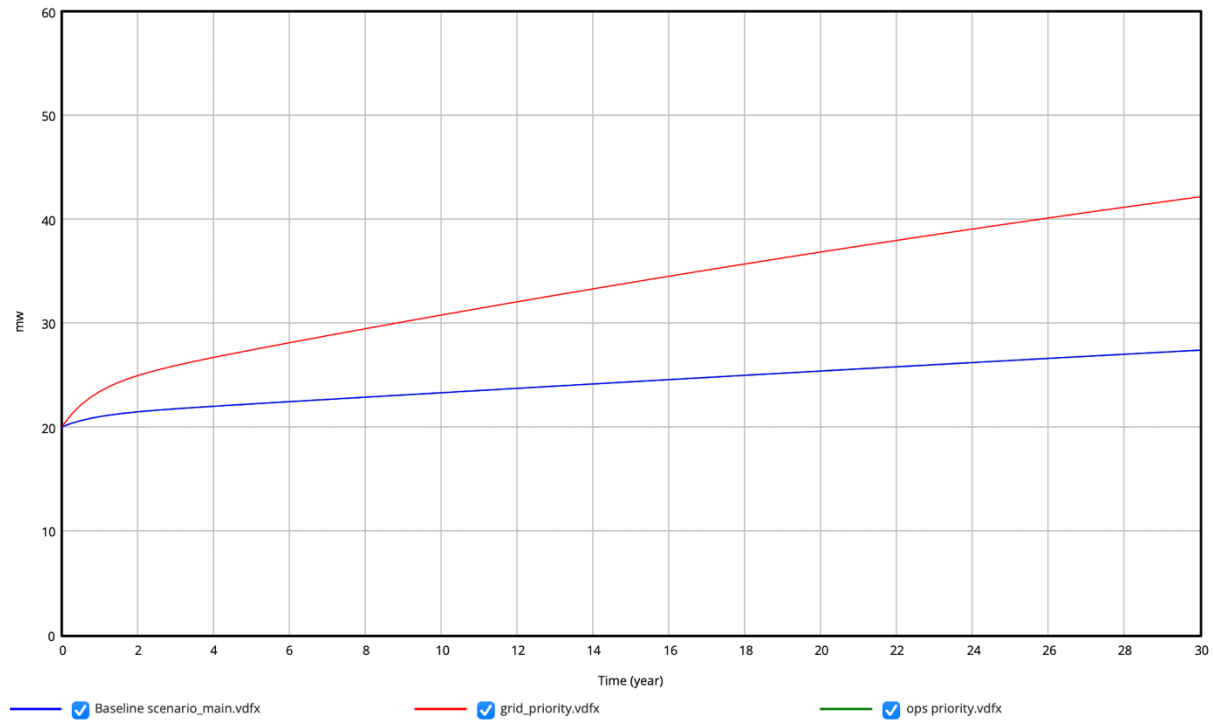


Diagram 3. Evolution of installed grid capacity across policy scenarios (Source: own elaboration)

The persistent gap between these curves indicates that grid prioritisation does not only accelerate convergence towards a shared long-term outcome. Instead, the system is structurally relocated to a higher energy capacity mode. The almost parallel evolution of the curves indicates a persistent difference in the system's physical capability, thereby reinforcing the conceptualisation of the grid as an active enabler rather than a neutral background infrastructure.

5.4 Main constraints / stress scenarios

In contrast to the allocation scenarios, in which the total available capital is assumed to be constant, and the analysis focuses on the distribution of this capital across various electrification measures, the financial stress scenarios examine the resilience of the system under conditions of financial pressure. The emphasis shifts from how investment is allocated to whether the system remains economically viable when funding availability, timing, or cost assumptions deteriorate. The purpose of these scenarios is twofold: firstly, to identify the conditions under which financial constraints become binding, and secondly, to explore the thresholds at which the electrification pathway is delayed, distorted, or no longer sustainable.

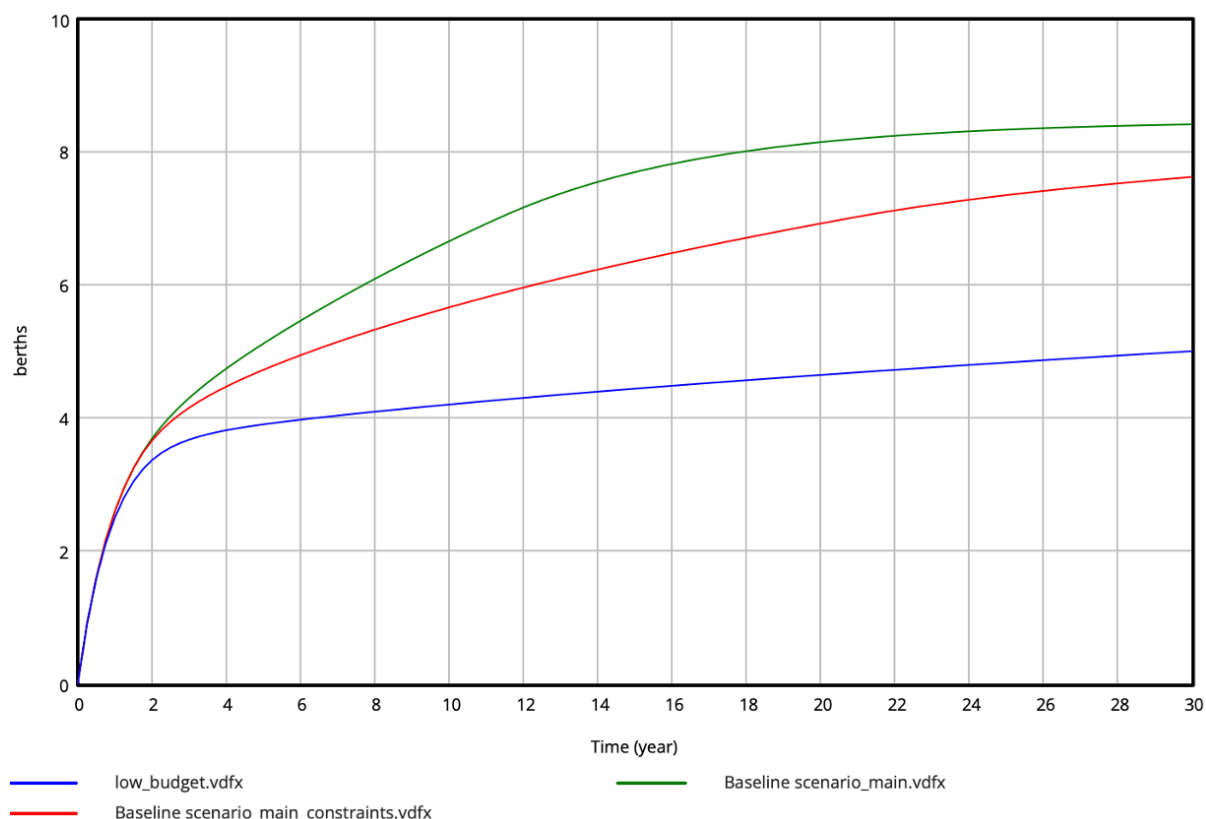


Diagram 4. Stress scenario/ low budget for SSE-OPS deployment (Source: own elaboration)

Diagram 4 presents the evolution of SSE-OPS infrastructure deployment under three stress scenarios: the baseline scenario without financial constraints, the baseline scenario with active financial constraints, and a low funding stress scenario with half of the initial given budget (baseline scenario). By isolating these three pathways, the figure highlights the pivotal role of capital availability and budgetary constraints in influencing the deployment dynamics of SSE-OPS. In the unconstrained baseline scenario, SSE-OPS infrastructure demonstrates the most rapid growth curve and reaches the highest long-term deployment level. This represents the upper-bound development pathway, in which investment flows are assumed to be fully available and immediately translated into infrastructure deployment, subject only to technical and saturation-related constraints. When technical constraints are introduced while maintaining the same policy allocation structure (baseline with constraints), SSE-OPS deployment exhibits a growth pattern that is analogous, yet consistently lower, throughout the simulation horizon. The discrepancy between the constrained and unconstrained baseline scenarios reflects the impact of limited grid readiness.

It is important to note that this difference becomes evident at an early stage and continues over time, suggesting that financial constraints act as a fundamental limitation rather than as a short-term impediment. Despite the ongoing expansion of SSE-OPS, it is evident that this growth is occurring at a decelerated rate, resulting in a shift towards a lower equilibrium level. The low funding stress scenario demonstrates the most significant deviation. In such cases,

the reduced approval rate of new funding significantly limits the deployment of SSE-OPS infrastructure. In contrast to the constrained baseline, the low funding scenario does not merely delay deployment but fundamentally alters the long-term outcome, resulting in a substantially lower installed SSE-OPS capacity by the end of the simulation period. This behaviour demonstrates that insufficient capital inflows cannot be compensated for by longer time horizons or internal system adjustments.

Taken together, the three trajectories illustrate a clear hierarchy of financial robustness. While SSE-OPS deployment remains feasible under moderate financial discipline, sustained reductions in available funding lead to persistent underperformance and lower system outcomes. The results confirm that SSE-OPS is not only sensitive to policy prioritisation but also highly dependent on the magnitude and continuity of investment flows. Consequently, financial constraints act as a binding condition for SSE-OPS expansion, transforming policy ambition into achievable outcomes only when adequate funding is ensured.

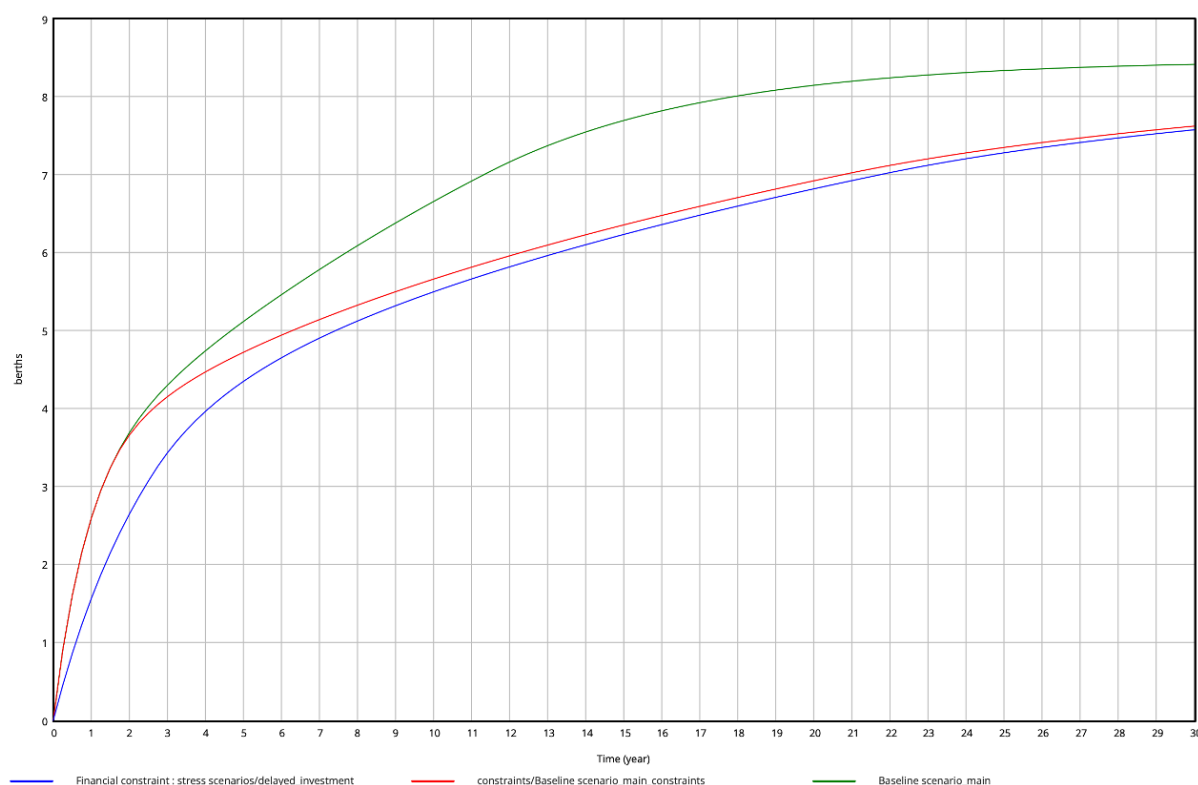


Diagram 5. Stress scenario/ delayed investment for SSE-OPS deployment (Source: own elaboration)

The delayed investment scenario in Diagram 5 explores the sensitivity of SSE-OPS deployment to the temporal distribution of capital from 1 to 2 years, while maintaining constant total funding. The results indicate a significant deviation from the initial scenario during the early and mid-phases of the simulation, followed by a gradual alignment in the subsequent years. This dynamic pattern is indicative of the interaction between budget availability, system capacity constraints, and saturation effects embedded in the model structure. During the preliminary stage of the transition, OPS deployment functions at a significantly lower capacity than its maximum capacity, and the rate of installation is primarily determined by the timing of capital availability. In this phase, the decision to delay investment has a direct impact on deployment, resulting in a significantly slower accumulation of SSE-OPS infrastructure

compared to the baseline scenario. The model demonstrates a notable temporal sensitivity, indicating that delayed funding results in diminished deployment prospects during the period when the system exhibits the greatest responsiveness to investment.

As the simulation progresses, the system approaches its physical and operational saturation limits. The saturation factor has been demonstrated to reduce marginal installation rates across all scenarios, thereby diminishing the ability of additional or delayed capital to generate proportional increases in deployed SSE-OPS capacity. Consequently, the deployment strategies under delayed and baseline investment models exhibit increased similarity over time, despite the persistent difference in cumulative infrastructure levels. This behaviour does not imply that delayed investment is neutral in its long-term impact. Instead, it emphasises that the initial costs of delayed funding are predominantly experienced during the pivotal expansion phase of the transition, when early deployment generates the most significant systemic returns. This observation in later stages of development indicates structural saturation rather than recovery, suggesting that delayed investment is unable to fully mitigate the consequences of earlier deployment. The results of the study demonstrate the significance of the timing of investments in determining the trajectory of electrification, particularly in the initial stages of SSE-OPS diffusion.

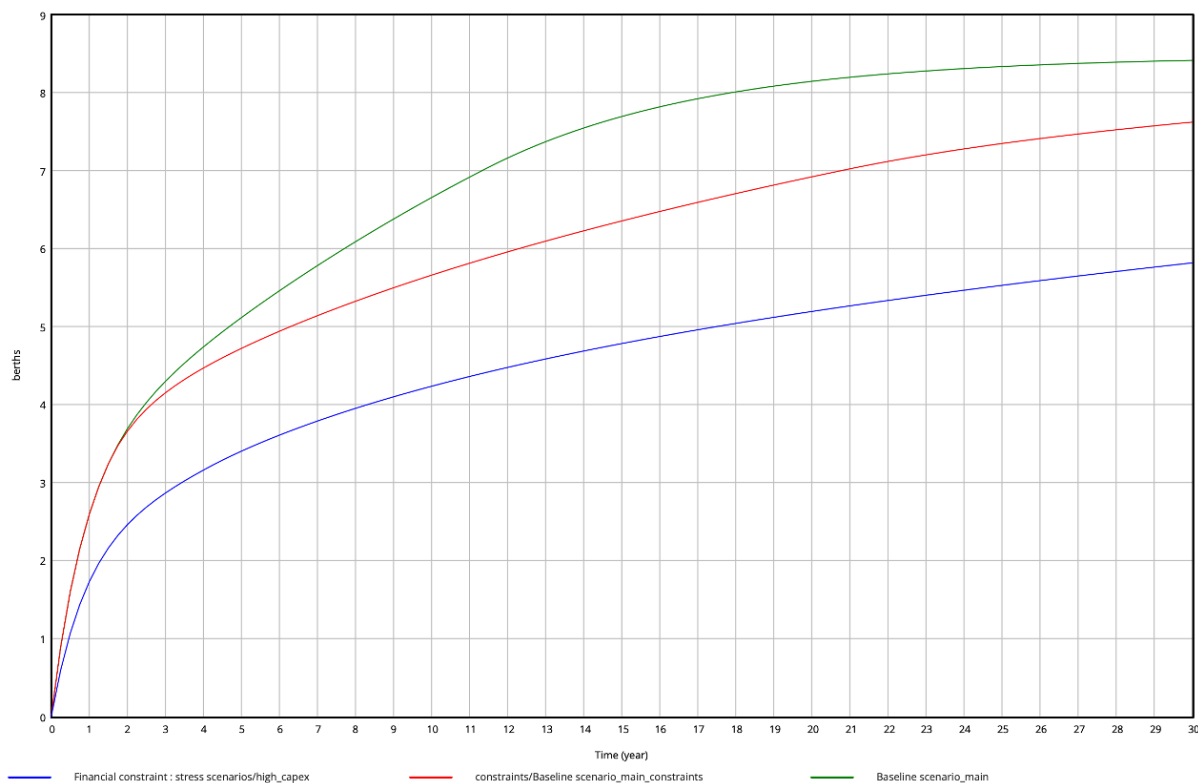


Diagram 6. Stress scenario/ high CAPEX for SSE-OPS deployment (Source: own elaboration)

Diagram 6 presents the evolution of SSE-OPS infrastructure deployed under the high CAPEX stress scenario, compared against the baseline configuration without financial stress and the baseline with infrastructure constraints enabled. In this scenario, the total available investment budget, allocation shares, and sequencing of investments remain unchanged, while the capital expenditure per unit of SSE-OPS infrastructure is increased from 6M to 9M euros. The scenario therefore isolates the effect of cost escalation on deployment outcomes,

independently of policy prioritisation or grid availability. The results indicate a systematic shift of the SSE-OPS deployment trajectory under the high CAPEX scenario across the entire simulation horizon. In comparison with the baseline, a reduced number of SSE-OPS berths are installed at each point in time, and the final level of deployment achieved by the end of the period is substantially lower. This behaviour is indicative of the direct physical impact of increased costs, whereby a given annual investment budget necessitates a reduction in the number of physical units that can be delivered per year, even in circumstances where institutional capacity, implementation efficiency, and grid readiness are sufficient. It is important to note that, in contrast to the scenario of delayed investment, the discrepancy between the high CAPEX trajectory and the baseline does not decrease over time. Delayed funding primarily impacts the deployment timeline, resulting in early-stage variation followed by partial alignment once investment flows return to normal levels. In contrast, the high CAPEX scenario leads to a persistent structural deficit. This finding suggests that cost inflation exerts long-term implications on the scale of electrification that can be achieved, extending beyond the immediate impact on its pace. The comparison with the constrained baseline further demonstrates that financial stress and infrastructure constraints operate through distinct yet reinforcing mechanisms. The constraints associated with the grid primarily impact the feasibility of deployment at particular points in time, while elevated CAPEX has a detrimental effect on the system's effective investment productivity over the entire duration.

From a policy perspective, this scenario demonstrates that electrification pathways are highly sensitive to unit cost assumptions, and that maintaining cost discipline is as critical as securing sufficient funding volumes or prioritising enabling infrastructure. The findings suggest that measures aimed at reducing CAPEX (such as standardisation, modular design, learning effects, or coordinated procurement) can be as impactful as additional public funding in determining the ultimate extent of SSE-OPS deployment. Overall, the scenario highlights that financial viability constitutes a structural boundary of the transition, beyond which policy ambition cannot be realised without parallel improvements in cost efficiency.

5.5 Validation and model testing

The validation of models in System Dynamics does not aim to promote accuracy in forecasting. It is concerned with the assessment of the internal consistency of the model structure, its behaviour, and its policy responses. In addition, it is concerned with the relevance of the model to real-world mechanisms, and with the alignment of the model with those mechanisms. As Sterman (2000) emphasised, validation is an iterative and multi-dimensional process, focusing on the credibility of causal assumptions, the coherence of dynamic behaviour, and the robustness of insights derived from scenario analysis. In this research, validation is conducted in accordance with established System Dynamics practice, incorporating structural tests, extreme condition tests, behavioural assessment, policy sensitivity analysis, and robustness checks. In contrast to the conventional approach of regarding validation as a distinct or exclusively technical undertaking, these tests are seamlessly integrated with the scenario analysis in the previous section.

The objective of the validation process is to verify the three fundamental elements of the model as illustrated in Table 21. Firstly, the representation of port electrification measures, capital allocation mechanisms, and infrastructural constraints is structurally adequate for addressing

the research questions. Secondly, the resulting dynamic behaviour is qualitatively reasonable, free from diagnostic inaccuracies, and consistent with established infrastructure diffusion patterns. Thirdly, that the model responds to policy and financial interventions in a transparent and causally coherent manner, supporting its use as a decision-support tool rather than a predictive instrument. The subsequent sections provide a comprehensive overview of the principal validation and robustness tests employed on the model. These tests are categorised into the following groups: i) structural adequacy and consistency checks, ii) extreme condition and behavioral tests, iii) policy and sensitivity-oriented validation, and iv) robustness and plausibility assessments. The combination of these tests provides confidence in the model's adequacy for its intended purpose and in the relevance to policy of the insights derived from the scenario analysis.

It should also be noted that sensitivity-oriented tests were performed by varying key parameters governing infrastructure deployment, investment allocation and implementation constraints in order to examine whether the dominant behavioural patterns of the model remained consistent. The objective of these tests was not to identify optimal parameter values, but to evaluate the robustness of the principal conclusions under alternative yet plausible assumptions. These tests complement the structural, behavioural and extreme-condition validation procedures previously described, providing additional evidence that the principal model behaviour arises from the underlying system structure rather than from specific parameter values or individual scenario settings. Consequently, confidence in the model is established through the combined application of structural validation, behavioural validation and sensitivity-oriented robustness assessment, consistent with established System Dynamics modelling practice.

Table 21. Sterman's list of validation tests provided for the SFD model (Source: Adapted from Sterman (2000); own elaboration)

Test		Purpose of test	Tools and procedures (applied in this model)
STRUCTURAL TESTS	1. Boundary Adequacy	Whether the model boundary includes all important concepts endogenous to the problem.	The model boundary explicitly includes SSE-OPS, charging hubs, electric cranes, GSVs, grid upgrades, financial budgets, capacity constraints, and saturation mechanisms. External drivers (policy priorities, funding mechanisms) are treated as exogenous. Boundary adequacy was assessed through iterative refinement of causal loop and stock–flow diagrams.
	2. Structure Assessment	Whether the model structure is consistent with relevant descriptive knowledge of the system.	Stock–flow structures represent deployment, retirement, budget allocation, and capacity constraints consistent with infrastructure investment processes. Causal links reflect known dependencies (e.g. grid readiness constraining SSE-OPS deployment). Structure was reviewed against literature

EXTREME CONDITIONS TESTS	3. Dimensional Consistency	Whether each equation is dimensionally consistent without hidden parameters.	on port electrification and infrastructure planning. All equations were checked using Vensim's unit consistency checks. Units such as MW, berths, euros/year, and dimensionless factors (e.g. readiness and saturation factors) are consistently defined across the model.
	4. Parameter Assessment	Whether parameter values are realistic and have real-world counterparts.	Parameters such as CAPEX per berth, grid upgrade capacity, implementation efficiency, and retirement rates were derived from literature, project reports, and conceptual judgment. Sensitivity testing confirmed plausible parameter ranges.
	5. Extreme Conditions	Whether equations behave plausibly under extreme input values.	Zero-input tests (allocation = 0) result in zero installations. Maximum-input tests (allocation = 100%) produce rapid early growth followed by saturation, without unrealistic explosions or negative stocks. Simulations were run with time steps of 0.25 and 0.125 years. Qualitative behaviour and scenario rankings remained unchanged, indicating numerical stability.
	6. Integration Error	Whether results are sensitive to time step or numerical integration.	Infrastructure stocks exhibit gradual growth towards saturation, slowing as saturation and constraints emerge. Retirement leads to gradual stabilisation rather than collapse. Behaviour is consistent with infrastructure adoption theory.
	7. Behavior Reproduction	Whether the model reproduces plausible qualitative behaviour patterns.	No negative stocks and infinite growth were observed across scenarios. Constraint mechanisms prevent unrealistic acceleration of installations.
	8. Behavior Anomaly	Whether implausible behaviours arise when structures or assumptions change.	Model behaviour aligns with documented electrification trajectories in European ports (e.g. phased SSE-OPS deployment, grid-led sequencing), indicating consistency with the broader family of infrastructure transition systems.
BEHAVIOUR TESTS	9. Family Member	Whether the model behaviour is consistent with similar systems.	Conditional activation of grid constraints revealed non-obvious interactions
	10. Surprise Behavior	Whether the model generates	

ROBUSTNESS TESTS		unexpected but interpretable behaviour.	between allocation priorities and readiness, highlighting sequencing effects rather than mechanical policy impacts. These behaviours are interpretable and policy-relevant.
	11. Sensitivity Analysis	Whether conclusions are sensitive to numerical, behavioural, or policy assumptions.	Parameter sensitivity tests (implementation efficiency, CAPEX, allocation shares) show moderate sensitivity affecting timing and speed but not qualitative outcomes. Policy sensitivity tests confirm correct directional effects of policy levers.
	12. System Improvement	Whether modelling improves understanding of the system.	The modelling process clarified how financial, physical, and policy constraints interact over time, supporting more informed decision-making on sequencing and prioritisation of port electrification investments.

5.5.1 Structural adequacy and consistency tests

◇ *Boundary Adequacy*

Structural adequacy and consistency tests assess whether the model includes the appropriate system boundaries, causal structures, parameters, and dimensional coherence required to address the research questions. In accordance with System Dynamics (Sterman, 2000), the emphasis of these tests is on the internal logic of the model rather than its numerical calibration. This ensures that the behaviour of the model arises endogenously from its structure. The model's boundaries were strategically defined to include key electrification measures that are directly relevant to port decarbonisation decisions and policy design. These include SSE-OPS provision, grid upgrades, electric cranes, charging hubs, and ground support vehicles (GSVs), together with the associated capital allocation mechanisms, infrastructural constraints, and retirement dynamics. This boundary choice ensures that all variables required to explain differences in electrification pathways across scenarios are endogenously represented. At the same time, the exclusion of non-central processes avoids unnecessary complexity and reduces the risk of overfitting, making the model suitable for strategic, rather than operational, analysis.

◇ *Structure Assessment*

The causal structure of the model reflects established infrastructure dynamics and capital investment. For each electrification measure, deployment is governed by a stock-and-flow structure in which installation flows are driven by allocated capital budgets, investment efficiency parameters, and saturation effects, while retirement flows capture ageing and decommissioning of infrastructure. The allocation of capital is modelled through the application

of explicit allocation shares to a fixed total investment budget. This ensures that the prioritisation of one measure necessarily implies reduced funding for others. This creates endogenous trade-offs and crowding-out effects, which are central to the research questions. The introduction of infrastructural readiness mechanisms, most notably the grid readiness constraint for SSE-OPS deployment, further establishes causal dependencies between measures, allowing enabling and bottleneck effects to emerge dynamically rather than being imposed exogenously. A thorough review of all feedback loops was conducted to ascertain their causal plausibility and correct polarity. No feedback loop was introduced explicitly for the purpose of shaping outcomes; all loops are consistent with identifiable real-world mechanisms.

◇ *Dimensional Consistency*

Dimensional consistency was systematically verified across all equations by utilising the unit-checking functionality of the modelling environment. It is evident that all stocks, flows, auxiliaries and constants were assigned explicit physical or monetary units, including berths, megawatts, euros and dimensionless ratios. A particular focus was placed on the interfaces between financial and physical subsystems, including the conversion of capital budgets into infrastructure deployment rates and the translation of installed SSE-OPS berths into electrical power requirements. The introduction of constraints related to the grid necessitated explicit alignment between infrastructure units (berths) and electrical capacity (MW). This issue was addressed through the incorporation of an SSE-OPS power requirement per berth parameter, thereby ensuring that all power-related constraints operate on a consistent physical basis. Minor numerical mechanisms (e.g. small constants to prevent division by zero) were introduced solely for numerical stability and do not affect model logic.

◇ *Parameter Assessment*

The parameter values were selected to reflect realistic orders of value rather than precise calibration. The capital expenditure per unit, implementation efficiency factors, retirement rates, and maximum capacity values were informed by a combination of available literature, engineering knowledge, and prior port electrification studies. In circumstances where empirical uncertainty remains, parameters were deliberately established as transparent and subsequently explored through sensitivity and scenario analysis. It is important to note that no parameter was adjusted with the specific intention of reproducing a particular outcome or path. However, the model was designed in such a way that qualitative behaviour - for example, delayed take-off under constraints, and proximity to capacity limits - emerges robustly across a wide range of parameter values that are likely to occur in reality.

5.5.2 Extreme Condition and Behaviour Tests

The objective of extreme condition and behaviour tests is to ascertain whether the model responds in a logically consistent and robust manner when subjected to boundary or stress conditions. In accordance with Sterman (2000), the objective of these tests is not to reproduce empirical data, but rather to ascertain the validity of the model's predictions when key inputs or constraints are subjected to extreme conditions. In the present research, such evaluations

are of particular pertinence in view of the policy-oriented character of the model and its emphasis on long-term infrastructure investment decisions under conditions of uncertainty.

◇ **Extreme Conditions**

In the present model, extreme conditions were explored by subjecting core policy and capacity variables to boundary values. Specifically, zero-input tests were conducted by setting allocation shares for electrification measures to zero and by imposing zero effective capacity for selected infrastructure components. In such circumstances, the model accurately generates zero installation flows and stable stock levels, thereby confirming that infrastructure deployment does not occur in the absence of financial resources or physical capacity. The investigation revealed no occurrence of negative stocks or unreliable dynamics.

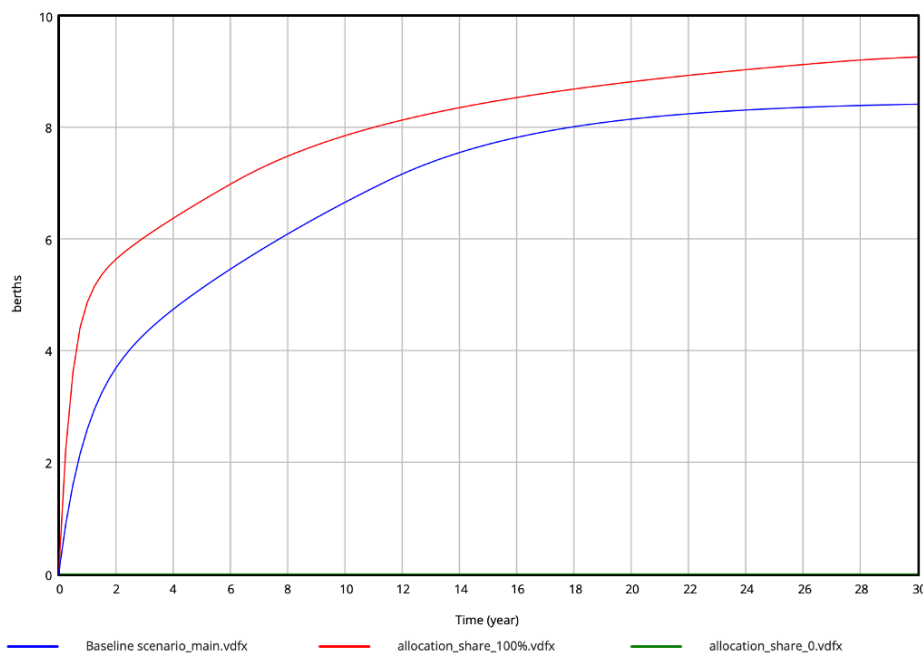


Figure 26. Extreme conditions test with allocation shares

In contrast, maximum-input tests were conducted by allocating the total available funding to specific electrification measures and by reducing CAPEX parameters to very low values. In such cases, the model generates rapid initial growth in infrastructure deployment, followed by a gradual slowdown as saturation factors and capacity constraints become binding. It is important to note that deployment pathways remain constrained and approach saturation levels in a bounded manner, without manifesting exponential growth, numerical instability, or negative values. This behaviour is indicative of the intended logic of the model, namely that reinforcing investment dynamics is balanced by physical, financial and operational constraints.

◇ **Integration Error**

In order to evaluate integration error, the model was simulated using alternative time step value of 0.125 years, in comparison to the baseline time step 0.25 years. Across all tested configurations, the qualitative behaviour of key state variables – such as the deployed SSE-OPS infrastructure and grid capacity installed – remained unchanged. The relative ordering of

scenarios, the shape of growth paths, and the timing of saturation effects were all preserved. Minor quantitative variations in intermediate values were observed, as anticipated when numerical resolution is varied, yet these did not impact the overall interpretation of results or the conclusions derived from scenario comparisons. The absence of periodic fluctuations, numerical instability, or sudden changes in system dynamics suggests that the model is numerically stable and that its behaviour remains unaffected by reasonable variations in the simulation time step.

◇ ***Behaviour Reproduction***

In scenarios where baseline conditions are held constant, and where the adoption of infrastructure is constrained, the model reproduces qualitative behaviour that is consistent with established system dynamics representations of infrastructure adoption. Infrastructure stocks demonstrate a tendency towards smooth, monotonic growth with diminishing marginal returns over time. Concurrently, installation flows reach a peak at an early stage and subsequently decline as saturation increases and retirement flows become more significant. The implementation of grid readiness constraints gives rise to behaviourally significant dynamics, encompassing the delayed initiation of SSE-OPS deployment in the presence of inadequate grid capacity, followed by subsequent acceleration upon the completion of grid enhancements. The emergence of these patterns is an endogenous process, arising from the interaction between investment allocation, physical constraints, and feedback loops. They do not result from external assumptions.

◇ ***Behaviour Anomaly Tests***

The experimental scenarios did not reveal any unusual behaviour. It is evident that all infrastructure stocks remain non-negative, installation flows do not exhibit numerical instability or fluctuations, and no variable displays discontinuous behaviour. Financial stress scenarios have been shown to activate overspend and budget violation indicators without resulting in system instability. This finding suggests that financial constraint mechanisms function as diagnostic signals rather than absolute boundaries.

◇ ***Family Member***

The family member test is a method of assessing the consistency of the behaviour generated by the model with that of other models or real-world systems addressing similar structural problems. In the context of this research, the test assesses whether the simulated dynamics of port electrification align with established patterns observed in infrastructure transition systems and documented port decarbonisation pathways. The model displays behavioural characteristics that are consistent with the broader family of port and energy infrastructure transition systems. In particular, the simulated deployment trajectories of SSE-OPS infrastructure follow a phased adoption pattern, characterised by rapid early growth driven by initial investments, followed by a gradual deceleration as physical capacity limits, saturation effects, and complementary infrastructure constraints become binding. This phenomenon is evidenced by empirical evidence from European ports, where SSE-OPS deployment is typically a gradual process and is closely associated with prior or parallel investments in grid reinforcement.

◇ *Surprise Behavior*

The surprise behaviour test evaluates whether the model generates unexpected outcomes that are nonetheless capable of interpretation and consistent with the underlying structure of the system. Such behaviours are not generally regarded as indicative of flaws in modelling; rather, they frequently offer valuable insights into non-obvious interactions and feedback mechanisms embedded in complex systems. In this model, a significant instance of surprise behaviour emerges from the conditional activation of grid constraints. The introduction of the grid readiness mechanism does not result in uniform restrictions on SSE-OPS deployment across all policy scenarios. In contrast, the constraint becomes binding only under specific combinations of allocation priorities and sequencing choices. In scenarios where grid-priority is implemented, SSE-OPS deployment remains effectively unconstrained. However, in scenarios where OPS-priority or baseline is implemented, grid limitations temporarily slow deployment until sufficient capacity is installed.

This outcome is not immediately apparent *ex ante*, as one might intuitively expect grid constraints to affect SSE-OPS deployment uniformly once introduced. However, the model demonstrates that policy sequencing and budget allocation interact in a non-linear manner, producing qualitatively different outcomes depending on the timing and balance of investments. It is important to note that these behaviours can be fully attributed to the causal structure of the model, and do not stem from non-systematic assumptions or numerical errors.

5.5.3 Robustness tests

◇ *System Improvement*

Through the explicit representation of feedback structures, budget allocation mechanisms, infrastructure saturation effects, and conditional constraints such as grid readiness, the model revealed dynamic interactions that are not immediately apparent in conventional planning or techno-economic assessments. The modelling process revealed that electrification outcomes are not solely determined by the magnitude of investment; rather, they are critically influenced by the sequencing and coordination of investments across complementary infrastructure layers. This is especially evident in the context of SSE-OPS deployment and grid capacity upgrades. The introduction of financial stress scenarios further demonstrated how the system responds under adverse conditions, distinguishing between short-term delays and long-term structural impacts. The findings indicated that the reduction or delay in funding primarily affects the timing of SSE-OPS deployment, while higher capital costs can result in persistent underperformance relative to baseline curves. These insights underscore the system's capacity for partial recovery under specific constraints, and highlight the conditions under which electrification pathways become economically unsustainable.

Chapter 6. Illustrative operational application: medium-sized EU ports

While the system dynamics model developed in this dissertation is designed as a generic decision-support tool for port electrification planning, it is useful to demonstrate how the model can be operationally applied in a realistic planning context. For this purpose, an illustrative application is presented using parameter configurations that approximate the structural characteristics of medium-sized European ports implementing Shore-Side Electricity - Onshore Power Supply infrastructure programmes. The objective of this section is not to reproduce the conditions of a specific port in detail. Rather, the model is parameterised using representative values derived from recent European SSE-OPS investment initiatives to demonstrate how port authorities could use the model to explore electrification strategies with different infrastructure and financial configurations. This illustrative parameterisation serves as a bridge between the conceptual modelling framework developed in previous chapters and the practical decision-making environment faced by port authorities.

Two representative configurations are examined: i) port of Aberdeen, ii) port of Bilbao. These configurations reflect alternative investment structures observed in contemporary SSE-OPS deployment programmes in medium-sized ports. These ports provide a realistic context in which interactions between investment capacity, electricity infrastructure and electrification deployment can be explored without the complexity associated with major international hub ports. The first configuration represents a relatively compact SSE-OPS investment programme that focuses primarily on berth electrification and dedicated investment in grid reinforcement is not included in the electrification programme. This may reflect either a planning assumption that the existing electricity infrastructure is already sufficient, or a situation in which grid upgrades were not explicitly incorporated into the initial investment strategy. The second configuration illustrates a larger-scale electrification programme, in which substantial investment in grid reinforcement and electrical infrastructure expansion accompanies SSE-OPS deployment. These configurations demonstrate how differences in investment magnitude, allocation priorities and infrastructure characteristics influence the dynamics of electrification deployment within the model.

It is important to note that the purpose of this section is not predictive. The results should not be interpreted as forecasts for specific ports. Instead, the illustrative application demonstrates how the proposed modelling framework can examine the dynamic behaviour of port electrification systems under different assumptions and conditions. Although the numerical values employed in the illustrative application are derived from two representative ports, the structure of the model is intentionally generic. Consequently, the framework can be adapted to other ports by modifying parameter values, infrastructure characteristics and local policy conditions while preserving the underlying causal structure and feedback mechanisms.

Beyond illustrating system behaviour, this application shows the framework's practical value as a strategic decision support tool. It enables the exploration of alternative electrification pathways, the assessment of investment timing and prioritisation, and the identification of potential bottlenecks, delays and unintended consequences that may emerge during implementation. While it is conceptual in nature, the case study shows the framework's

potential to support evidence-based planning and long-term decision-making for medium-sized European ports pursuing electrification strategies.

Table 22. Illustrative parameter configurations for representative medium-sized EU ports

Item	Representative configuration 1 (incremental SSE-OPS rollout)	Representative configuration 2 (system-wide SSE-OPS transformation)
Total project investment (SSE-OPS)	€5.3 million	€50 million + €28 million for grid upgrade
Number of electrified berths / connection points	8 berths	11 berths
Implied unit capex (for modelling reference)	~€0.66 million per berth	~€4.5 million per berth
Allocation time (capital absorption / implementation cycle)	1 years	3 years

The parameters presented in Table 22 define the two representative electrification configurations that are used to illustrate the application of the model. These configurations are similar in scale and structure to SSE-OPS investment programmes observed in medium-sized European ports. The parameters include the total investment dedicated to OPS-related infrastructure, the number of berths or connection points targeted by the programme and the time required for capital absorption and project implementation. The first configuration represents a compact SSE-OPS deployment programme characterised by a total investment of around €5.3 million to support the electrification of eight berths within a relatively short implementation period of one year. In this configuration derived from the port of Aberdeen, no dedicated investment is allocated to grid reinforcement within the model structure. This may reflect a planning assumption that the existing electricity infrastructure is sufficient to support SSE-OPS deployment, or that grid upgrades were not incorporated into the initial investment strategy.

The second configuration represents a substantially larger electrification programme, with a total investment amount in the range of €78–91 million targeting eleven SSE-OPS connection points. Within this configuration, approximately €50 million are allocated to the installation of SSE-OPS infrastructure, while an additional €28 million are dedicated to electricity grid reinforcement. The grid upgrade is assumed to increase the installed grid capacity by approximately 30 MW over an implementation period of three years, ensuring that sufficient electrical capacity is available to support the expanded SSE-OPS infrastructure. These values are derived from investment data and infrastructure scope in the Port of Bilbao, providing a basis for modelling the impact of investment magnitude, infrastructure scope, and implementation timing on electrification deployment pathways within the system dynamics framework.

Diagram 8 presents the evolution of SSE-OPS infrastructure deployment across the baseline scenario and the two representative electrification configurations. It illustrates the influence of

differences in investment scale, capital allocation structure and implementation timing on the pace and final level of SSE-OPS deployment within the modelled port system.

The configuration associated with the larger electrification programme (Configuration 2) exhibits the fastest infrastructure expansion. In this scenario, substantial investment and dedicated resource allocation to SSE-OPS installations enable rapid deployment during the early years of the simulation. Consequently, SSE-OPS infrastructure reaches maximum capacity of around eleven electrified berths within the first five years. The deployment curve therefore displays gradual growth towards saturation typically observed in infrastructure diffusion processes: rapid initial expansion followed by stabilisation as the system approaches its structural capacity limits. In contrast, the smaller investment configuration (Configuration 1) produces a more moderate electrification trajectory. Although SSE-OPS installations increase rapidly during the programme's early stages, the lower investment budget restricts the rate at which additional berths can be electrified. Consequently, SSE-OPS deployment stabilises at a lower capacity of around seven electrified berths. This reflects the structural constraint imposed by the limited capital available for infrastructure installation.

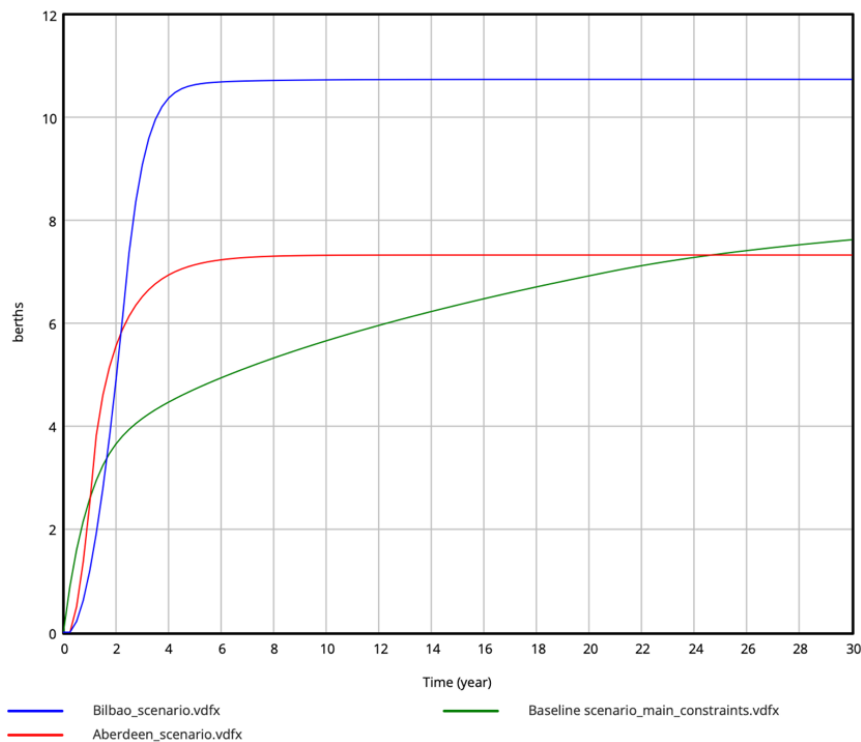


Diagram 7. SSE-OPS infrastructure deployment across representative electrification configurations (Source: own elaboration)

Compared to the two dedicated electrification configurations, the baseline scenario exhibits a significantly slower deployment pathway. In this scenario, available investment resources are distributed across various electrification measures as part of the wider port decarbonisation strategy. Consequently, the annual capital available for SSE-OPS deployment is reduced, resulting in gradual infrastructure accumulation over the simulation horizon. While SSE-OPS deployment continues to increase steadily over time, the system takes much longer to reach saturation than in the other configurations.

Diagram 9 shows how the grid readiness factor evolves across the examined electrification configurations. This indicator, as already described, reflects the extent to which the available electricity infrastructure can support the power demand generated by the deployment of SSE-OPS. A value of one indicates full grid adequacy, meaning the available electrical capacity is sufficient to support SSE-OPS operations without constraints. Values below one suggests that electricity availability could limit SSE-OPS deployment.

The results reveal clear differences between the configurations examined. In Configuration 2 (Bilbao scenario), which is associated with the large-scale electrification programme, the grid readiness factor remains equal to one throughout the entire simulation horizon. This behaviour suggests that the electricity infrastructure consistently provides sufficient support for SSE-OPS deployment, primarily due to the parallel investment in grid reinforcement incorporated in the electrification programme. Approximately €28 million is allocated to grid upgrades in this configuration, enabling an additional 30 MW of electrical capacity to be installed over a three-year implementation period. Consequently, electricity availability does not become a limiting factor at any point during the simulation, enabling SSE-OPS deployment to proceed without energy supply limitations.

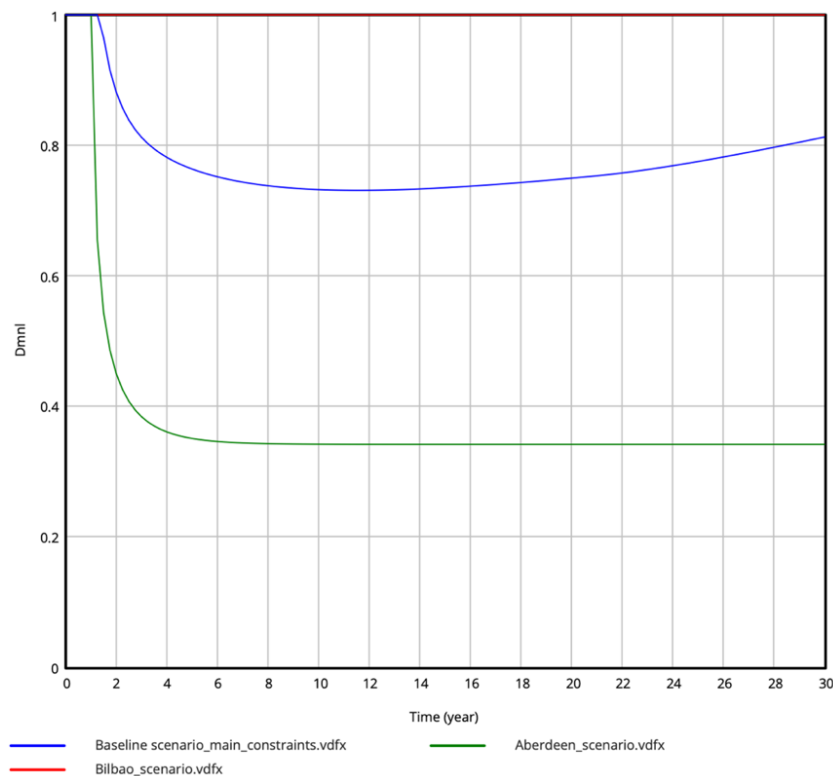


Diagram 8. Grid readiness factor across illustrative port configurations (Source: own elaboration)

In contrast, the baseline scenario exhibits a temporary decline in grid readiness as SSE-OPS deployment increases. While the system initially has full grid adequacy, the readiness factor falls rapidly during the early years of the simulation as SSE-OPS installations expand more quickly than grid capacity upgrades. The indicator falls to around 0.79 by the fourth year and

reaches a minimum value of approximately 0.73 after around ten years. This temporary reduction indicates that electricity infrastructure becomes a moderate constraint during the expansion phase of SSE-OPS deployment. However, as additional grid capacity is gradually installed and SSE-OPS infrastructure growth slows due to saturation effects, the readiness factor begins to recover, stabilising at around 0.81 by the end of the simulation period.

The configuration representing the smaller electrification programme (Configuration 1 - Aberdeen scenario) demonstrates a significantly stronger grid constraint. In this scenario, no dedicated investment in grid reinforcement is included within the electrification programme. As SSE-OPS infrastructure begins to expand, electricity demand increases while grid capacity remains unchanged. Consequently, the grid readiness factor declines sharply from its initial value of one to approximately 0.45 within the first two years of the simulation. The indicator continues to decrease and stabilises at approximately 0.34 after the fourth year, remaining at this level throughout the remainder of the simulation horizon. This value indicates that only around one-third of the required electricity readiness is available to fully support SSE-OPS deployment, suggesting that electricity infrastructure becomes a persistent structural limitation in this configuration.

Overall, the comparison highlights the critical importance of aligning SSE-OPS deployment strategies with electricity infrastructure planning. Configurations that include parallel investment in grid reinforcement ensure full electricity readiness and enable rapid infrastructure deployment. In contrast, electrification strategies that do not incorporate sufficient grid upgrades risk creating structural electricity constraints that can significantly hinder the scale and efficiency of SSE-OPS expansion. These findings demonstrate how the proposed modelling framework can reveal the dynamic interactions between infrastructure investment sequencing and electricity supply adequacy in port electrification strategies. Although the illustrative application is based on representative medium-sized European ports, the underlying model structure captures the fundamental mechanisms governing port electrification, including investment dynamics, infrastructure deployment, electricity demand and grid capacity interactions. These mechanisms are common to the majority of port electrification initiatives, making the framework applicable beyond the illustrative case. Where a more detailed representation is required, the model can be refined through the adjustment of parameter values or the incorporation of additional variables to reflect port-specific characteristics, while preserving the underlying dynamic structure.

Chapter 7. Policy recommendations

The policy recommendations presented in this chapter are informed by both the findings of the PESTLE analysis and the insights generated through the System Dynamics modelling framework developed in this dissertation. The research examined port electrification as a complex transition, characterised by interdependencies between technological development, infrastructure provision, regulatory frameworks, financial constraints and energy system capabilities. This perspective enabled the identification of key factors influencing the transition process and the relationships through which they affect implementation outcomes. By capturing feedback structures, delays and interactions among system components, the modelling framework provides a basis for understanding the broader implications of decisions within the port electrification system. Consequently, the recommendations presented in this chapter are grounded in the systemic understanding developed through the analysis rather than being derived solely from theoretical considerations or individual case studies. They aim to translate this understanding into practical guidance that can support informed decision-making and long-term planning in the context of port electrification.

7.1 Policy recommendations for port authorities & policy makers

The findings of this dissertation indicate that the successful implementation of port electrification measures requires coordinated action across multiple governance and decision-making levels. Although port authorities play a central role in planning, prioritising and implementing electrification investments, the pace and effectiveness of the transition are also influenced by broader regulatory frameworks, public funding mechanisms, and regional development priorities. Consequently, the policy recommendations derived from this research are organised into three complementary categories addressing: (i) port authorities and port operators; (ii) national and regional policymakers; and (iii) policymakers and public funding authorities. Together, these recommendations aim to support the development of coherent electrification strategies, remove implementation barriers and strengthen the long-term transition towards energy-efficient, environmentally sustainable port operations.

◇ **Proactively align electrification deployment with electricity infrastructure planning (Port-level planning)**

Port-authorities

The model results indicate that electrification measures should be planned as components of a broader energy transition strategy within the port system, rather than as isolated infrastructure projects. Measures such as SSE-OPS, charging hubs, electric cargo-handling equipment and electric support vehicles generate additional electricity demand, which may progressively exceed available grid capacity if electricity infrastructure planning is not integrated from the early stages of implementation. The simulations demonstrate that scenarios combining electrification deployment with parallel grid reinforcement result in more stable deployment pathways and prevent infrastructure bottlenecks from emerging, which would slow down implementation. This finding suggests that port authorities should incorporate electricity demand projections, grid adequacy assessments and infrastructure expansion requirements directly into port electrification master plans. Integrated planning is particularly important for medium-sized ports, where rapid electrification programmes could

lead to a significant increase in electricity demand within a relatively short timeframe. Consequently, electrification strategies should not only evaluate the deployment targets of individual technologies, but also the wider energy infrastructure system's ability to support long-term operational requirements.

◇ **Prioritise sequencing of electrification investments**

Port-authorities

The results further demonstrate that the timing and sequencing of investments significantly influence electrification pathways and the performance of infrastructure over time. The simulations show that temporary electricity constraints emerge when electrification measures expand faster than the supporting grid infrastructure, reducing grid readiness and slowing the pace of deployment. By contrast, scenarios in which grid reinforcement is implemented before or in parallel with electrification measures exhibit more stable and uninterrupted deployment paths. This highlights the fact that investment sequencing is not just a financial or administrative issue, but also a structural factor that affects the overall feasibility of port electrification strategies. Therefore, port authorities should prioritise early investment in enabling infrastructure, including grid upgrades, substations and energy management systems, before scaling up the deployment of electricity-intensive technologies. For example, large-scale SSE-OPS deployment without adequate electricity infrastructure could create operational bottlenecks, even when there are sufficient financial resources for installation. Sequencing strategies should therefore be designed to ensure that infrastructure readiness evolves alongside electrification demand, thereby reducing the risk of delayed deployment and underutilised assets and additional retrofit costs.

◇ **Strengthen coordination between port electrification plans and electricity system planning (System-level coordination)**

National / Regional policy makers

The analysis indicates that port electrification is closely interconnected with the wider electricity infrastructure system and cannot be effectively implemented through isolated, port-level decisions alone. Port authorities typically do not control electricity transmission and distribution planning, and electricity system operators may not fully account for future port electrification demand within their infrastructure expansion strategies. This creates a structural coordination challenge, particularly in regions where multiple ports are pursuing decarbonisation and electrification targets simultaneously. The model results demonstrate that, when infrastructure expansion does not keep pace with growing demand from electrified port operations, electricity availability can become an endogenous constraint within the electrification process. Policy frameworks should therefore strengthen coordination mechanisms between port authorities, electricity system operators, regulators, and public authorities responsible for energy infrastructure planning. Integrated planning procedures could improve alignment between port development plans and grid expansion strategies, ensuring that electricity infrastructure evolves proactively rather than reactively. This is particularly relevant for medium-sized ports, where electrification programmes can rapidly increase local electricity demand and place additional pressure on regional energy systems.

◇ **Develop funding instruments for integrated electrification programmes (Integrated financing mechanisms)**

Finally, the findings demonstrate that the effectiveness of port electrification strategies depends on the coordinated development of supporting infrastructure, as well as the adoption of individual technologies. However, existing funding mechanisms often treat electrification measures and electricity infrastructure upgrades as separate investment categories, creating fragmentation in implementation processes. The simulations show that electrification pathways combining investments in electrified equipment, SSE-OPS systems, charging infrastructure, and grid reinforcement achieve significantly higher levels of grid readiness and more stable deployment trajectories than scenarios focused on isolated technology deployment. This suggests that public funding instruments should promote integrated electrification programmes that recognise the systemic nature of port decarbonisation, rather than supporting technology-specific schemes. Financial support mechanisms should therefore enable ports to combine investments in grid upgrades, substations, renewable integration, energy storage systems, and electrified operational equipment within a single, coordinated programme. Supporting integrated investment packages could reduce infrastructure bottlenecks, improve capital efficiency, accelerate deployment rates, and increase the long-term effectiveness of decarbonisation investments.

Chapter 8: Conclusions

8.1 Integrated insights from the analysis

The process of 'greening' in the context of ports necessitates an understanding of the broader transformation of energy and transport systems. The integration of ports into a transition that extends beyond the scope of reducing emissions from specific activities is pivotal. This transition encompasses the reconfiguration of energy production, distribution, and consumption across interconnected infrastructures. In this evolving context, ports function simultaneously as energy consumers, facilitators of maritime decarbonisation, and emerging hubs within broader energy systems. This repositioning of ports fundamentally transforms the nature of environmental responsibility. The process of 'greening' is no longer an incremental improvement process; rather, it is a structural transition that reshapes operational, infrastructural, and governance logics. The present dissertation offers an analysis that confirms the environmental impact of ports is indicative of this wider systemic role. Emissions associated with port activity are not limited to administrative boundaries, but arise from the aggregation of multiple processes, including vessels at berth, cargo handling operations and hinterland transport flows. Therefore, the challenge of reducing emissions cannot be addressed through isolated interventions. Instead, it requires coordinated strategies that operate across different layers of the port system. Within this context, "green" measures - such as shore-side electricity, electrification of equipment, alternative fuels and energy management systems - represent critical mechanisms for facilitating change. However, their effectiveness depends less on their individual technical performance and more on how they are integrated within the broader system.

The PESTLE analysis conducted in this dissertation offers a structured understanding of the conditions under which such integration occurs. It demonstrates that port "greening" is shaped by a set of interacting drivers and barriers that extend beyond purely technical considerations. Regulatory pressure and policy alignment create a strong political and legal incentive for electrification and emission reduction, while economic factors introduce constraints related to capital intensity, cost uncertainty and return on investment. Technological readiness, particularly in relation to grid capacity and infrastructure compatibility, determines the feasibility of implementation. Social and institutional dimensions influence coordination among stakeholders, while environmental considerations both motivate action and introduce additional system requirements. Importantly, these factors do not operate independently; their interaction creates a complex decision-making environment in which trade-offs are unavoidable and outcomes are uncertain. This complexity highlights a fundamental limitation in conventional approaches to port "greening", since much of the existing literature evaluates "green" measures in isolation, focusing on their technical characteristics or cost-effectiveness. Such approaches, while useful, are inherently limited because they do not capture how measures interact within a dynamic system.

The findings of the model demonstrate that electrification pathways are governed by three interrelated dimensions: investment allocation, infrastructure adequacy and timing of implementation. Each of these dimensions exerts a distinct influence on system behaviour, but it is their interaction that ultimately determines the outcomes observed. The scenario-based analysis demonstrates that, under constant total funding, the allocation of capital across

electrification measures acts as a primary policy lever. Increasing the share of investment allocated to a specific measure leads to a corresponding acceleration in its deployment. However, this effect remains largely measure-specific, confirming that prioritisation decisions directly shape infrastructure trajectories. This finding, however, is only valid under the assumption that infrastructure constraints are non-binding. Once electricity capacity limitations are introduced into the model, the dynamics of the system change significantly. Grid capacity emerges as an endogenous constraint that can either enable or limit electrification, depending on how it evolves relative to demand. Importantly, this constraint is not constant. It becomes binding only under specific configurations of investment and demand, highlighting the conditional nature of infrastructure limitations.

A fundamental conclusion that emerges from this analysis is the pivotal role of sequencing. The timing of investments in enabling infrastructure, particularly grid upgrades, relative to the deployment of electrification measures has a considerable impact on system performance. Scenarios in which electrification expands at a faster rate than supporting infrastructure result in temporary but significant constraints. Even when these constraints are mitigated in subsequent stages, their effects persist through lower cumulative deployment levels. This suggests that electrification pathways are path-dependent: early-stage conditions influence long-term outcomes in ways that are not fully reversible. The analysis of financial stress scenarios further reinforces the structural nature of these dynamics. Reductions in funding availability, delays in investment and increases in capital costs each produce effects on electrification trajectories that are distinct but systematic. Reduced funding leads to lower levels of infrastructure deployment, rather than simple delays. Delayed investment primarily affects the early expansion phase, where the system is most responsive to capital inputs, resulting in lasting differences in cumulative outcomes. Increased capital expenditure reduces the effective productivity of investment, constraining the scale of deployment achievable within a given budget. Collectively, these findings demonstrate that financial conditions are not external parameters, but integral components of the system that shape its evolution.

Taken together, the results of this dissertation show that port electrification cannot be understood as a linear or solely technical transition; rather, it is a co-evolutionary process, in which financial, infrastructural and institutional elements interact dynamically over time. Therefore, the effectiveness of “greening” strategies depends not only on the adoption of specific measures, but also on the alignment between these elements. Policies that focus on individual interventions, without addressing this alignment, risk underperforming, even when supported by substantial investment. From a broader perspective, the dissertation contributes to a more detailed understanding of port “greening” as a systemic transformation, highlighting that the transition towards energy-efficient and low-emission port operations is constrained by structural conditions that must be explicitly considered in planning and decision-making. By making these conditions visible, the system dynamics approach provides a basis for more informed and robust strategy design.

8.2 Original scientific contribution of the Dissertation

The integrated approach of this dissertation offers four original contributions to the research domain. Firstly, it contributes to the theoretical understanding of port electrification by

conceptualising it as a dynamic socio-technical transition process characterised by feedback effects, infrastructure dependencies, investment constraints and interactions between policy, technology and operational performance. This perspective extends beyond the conventional assessment of individual technologies and emphasises the systemic nature of the transition process. Secondly, the dissertation introduces a methodological contribution through the systematic integration of PESTLE analysis and System Dynamics modelling. The proposed approach establishes a transparent and traceable process through which qualitative drivers and barriers are translated into endogenous system variables and causal relationships, thereby linking qualitative sustainability assessment with dynamic quantitative analysis. Thirdly, the framework enables the evaluation of alternative electrification pathways, the prioritisation and sequencing of investments, and the assessment of policy sensitivity under different future conditions, providing decision support. The model enables decision-makers to explore the influence of different combinations on infrastructure deployment, utilisation levels, economic viability and environmental outcomes over time. In doing so, it supports scenario exploration, policy experimentation, and the identification of robust investment strategies in the face of uncertainty. Fourthly, the framework provides a practical contribution for port authorities and other port-related stakeholders. By capturing the interactions between electrification measures, infrastructure readiness and investment dynamics, the model supports strategic planning processes and enables a more thorough evaluation of potential risks, bottlenecks and unexpected outcomes related to the shift towards energy-efficient, environmentally sustainable port operations. These contributions position the framework as both a research tool for analysing the dynamics of port electrification and a strategic planning framework capable of supporting long-term decision-making regarding the design, timing and implementation of electrification strategies.

The original contribution of this dissertation can be further categorized in the following theoretical and methodological contributions:

◇ ***Re-conceptualisation of port electrification as a dynamic transition process***

This dissertation contributes to the literature by conceptualising port electrification as a dynamic system-level transition rather than a linear technology adoption process. The proposed perspective recognises that electrification outcomes emerge from the continuous interaction between technological, economic, infrastructure and governance-related factors, which co-evolve over time and influence the pace and direction of the transition.

◇ ***Identification of the key mechanisms shaping electrification pathways***

The research demonstrates that electrification pathways are not only determined by the selection of technologies, but are significantly influenced by the interaction between investment allocation decisions, infrastructure adequacy, and implementation timing. The findings emphasise the importance of considering these interdependencies when designing long-term port electrification strategies.

◇ ***Integration of PESTLE analysis with System Dynamics modelling***

A key methodological contribution is the development of a structured framework that integrates PESTLE-derived drivers and barriers with System Dynamics and stock-and-flow modelling. This approach enables the representation of feedback mechanisms, delays, resource

constraints and temporal dynamics that are often overlooked by conventional static assessment methods.

◇ ***Incorporation of electricity infrastructure constraints***

The dissertation introduces grid capacity as an endogenous system constraint whose influence evolves over time according to the interaction between infrastructure deployment and electricity demand growth. This contribution extends existing electrification studies by explicitly representing how electricity supply limitations can affect the feasibility and pace of electrification investments.

◇ ***Demonstration of path dependency in port electrification***

The analysis shows that electrification pathways are path-dependent, meaning that early investment decisions and initial infrastructure conditions can generate long-term effects that influence future development options. This finding highlights the importance of strategic planning and sequencing when implementing electrification measures in ports.

◇ ***Representation of financial conditions as structural drivers of transition***

The proposed framework demonstrates that financial conditions, including funding availability, capital allocation decisions, investment delays and capital cost variations, should be viewed as structural components of the electrification system rather than as external background parameters. By incorporating these factors into the model structure, the dissertation provides a more realistic representation of how investment conditions shape transition outcomes over time.

It can also be categorized in the following practical/modelling contributions:

◇ ***Development of a policy-relevant decision-support framework***

The dissertation develops a decision-support tool that enables port authorities and policymakers to analyse alternative electrification pathways under different infrastructure, financial and implementation conditions. The framework supports a more comprehensive understanding of how strategic choices influence long-term transition outcomes.

◇ ***Identification of capital allocation as a strategic decision variable***

The findings demonstrate that the allocation of available financial resources across competing electrification measures can significantly influence both the pace and direction of the transition. This highlights the importance of investment prioritisation as a key policy and management lever for port electrification planning.

◇ ***Support for coordinated infrastructure planning***

The analysis shows that successful electrification strategies require coordinated investment between end-use electrification measures and supporting electricity infrastructure. In particular, the results emphasise the importance of aligning investments in OPS, charging infrastructure and electric equipment with the timely development of grid capacity.

◇ ***Guidance on investment sequencing and implementation timing***

The model highlights the importance of sequencing electrification interventions appropriately. The findings indicate that delays in enabling infrastructure may constrain the effectiveness of downstream investments, leading to lower cumulative electrification outcomes and reduced overall system performance.

◇ ***Improved understanding of infrastructure bottlenecks***

The framework enables decision-makers to identify the conditions under which infrastructure constraints become critical barriers to electrification deployment. This supports more targeted planning, allowing infrastructure investments to be prioritised according to their potential impact on future system development.

◇ ***Enhanced support for strategic planning and governance***

By making visible the structural relationships, constraints and trade-offs that influence electrification outcomes, the framework provides a stronger evidence base for long-term planning and policy development. This contributes to more informed decision-making and supports the design of robust and adaptive port “greening” strategies.

Overall, the proposed framework differs from existing approaches to port electrification and decarbonisation in three important ways. Firstly, it analyses electrification measures as interconnected components of a broader port transition system, rather than as isolated technological interventions. Secondly, it explicitly considers feedback mechanisms, delays, infrastructure constraints, and investment interactions that evolve over time and influence future system behaviour. Thirdly, it considers factors such as grid capacity, infrastructure readiness and financial conditions to be endogenous elements of the transition process, rather than fixed external assumptions. Consequently, the framework enables the exploration of long-term electrification pathways and strategic investment decisions in uncertain conditions, which goes beyond the capabilities of conventional static assessment approaches.

8.3 Future research paths

Further research could also expand the scenario framework utilised by the model incorporating a more extensive and diversified set of uncertainty dimensions. Beyond the variables already examined, subsequent analyses could explicitly account for fluctuations in energy prices, volatility in electricity markets, evolving carbon pricing mechanisms, and shifts in regulatory frameworks at both European and international levels. Additionally, technological uncertainty, such as the rate of cost reductions in electrification technologies, advancements in grid management, or the maturity of alternative energy carriers, could be incorporated to better reflect the dynamic conditions under which ports operate. Market-related factors, including

changes in shipping demand, fleet composition, and the adoption rate of low- and zero-emission vessels, could further enrich the analysis. An extension in this direction would facilitate the framework's progression from relatively controlled policy scenarios to a more realistic representation of the external environment, characterised by the interaction and evolution of multiple uncertainties over time. Significantly, this approach would enable the exploration of resilience-oriented questions, such as the robustness of different electrification strategies under adverse or rapidly changing conditions. This would considerably enhance the value of the model as a decision-support tool, allowing port authorities and policymakers to compare alternative strategies and assess their performance under uncertainty, as well as to identify pathways that remain effective across a range of plausible futures.

It is therefore proposed that the modelling framework be extended to include a broader range of “greening” measures beyond electrification, thereby allowing for a more holistic examination of port transition pathways. While the present study focuses on electrification as a central pillar, future work could integrate additional dimensions such as alternative fuels, energy storage systems, circular economy practices, and digital optimisation strategies. The inclusion of alternative fuels would enable the exploration of hybrid transition pathways, where electrification coexists with hydrogen, biofuels or other energy carriers, each with distinct infrastructure and investment implications. Similarly, the explicit representation of energy storage could provide insights into how ports manage intermittency, balance demand peaks and improve overall energy system flexibility. The integration of circular economy practices, including waste valorisation and resource efficiency measures, would further broaden the analytical scope by linking environmental performance with material flows and operational processes. Concurrently, digitalisation and optimisation tools – such as smart energy management systems, demand-side management and predictive maintenance – could be incorporated as mechanisms that enhance system efficiency and influence investment effectiveness. The integration of these elements within a unified modelling framework would enable the examination of interactions, complementarities and potential trade-offs between different “greening” strategies.

The aforementioned extension would contribute to a more comprehensive representation of port “greening” as a multi-dimensional and co-evolving transition process. Furthermore, it would serve to reinforce the central insight of this dissertation, namely that the effectiveness of “greening” strategies does not depend solely on the adoption of individual technologies, but rather on the dynamic alignment between technological options, infrastructure systems, financial conditions and institutional arrangements over time.

8.4 Research limitations

Despite its contribution as a System Dynamics-based decision support framework for analysing alternative port electrification pathways, the following considerations should be viewed primarily as consequences of the modelling approach adopted rather than as inherent limitations of the proposed framework. They reflect deliberate modelling choices made to preserve the strategic focus, transparency, and tractability of the model, and should therefore be taken into account when interpreting the results. First, the model was intentionally designed to provide a strategic representation of the interactions among major electrification measures rather than a detailed engineering or operational simulation. The causal loop diagram

therefore served as the conceptual foundation for the development of the stock-and-flow structure rather than being transferred into the quantitative model on a one-to-one basis. As a result, conceptually mechanisms, such as learning effects, public support, stakeholder resistance, technology diffusion, and broader socio-economic interactions, were not explicitly incorporated into the quantitative model, as they fell beyond the scope and objectives of the present research. Second, the model focuses primarily on infrastructure deployment dynamics and investment allocation rather than on operational performance. Variables describing infrastructure utilisation, electricity consumption, emissions reduction, operational costs, revenues, or return on investment were not explicitly represented. Consequently, the framework should be interpreted as a strategic investment planning tool rather than as a comprehensive techno-economic or environmental assessment model. Third, several modelling assumptions were introduced to maintain model transparency and tractability. Parameters related to implementation efficiency, retirement rates, saturation effects, and investment allocation were selected to represent typical medium-sized European port conditions. Although these assumptions allow the model to explore alternative investment pathways consistently, future applications would benefit from calibration using port-specific operational and financial data.

Finally, the illustrative application presented in this dissertation should not be interpreted as a predictive model for a particular port. Instead, it demonstrates the applicability of the proposed modelling framework under representative conditions. Overall, these considerations do not affect the main contribution of this research, namely the development of a transparent System Dynamics framework capable of supporting strategic decision-making for port electrification by capturing the dynamic interactions between infrastructure investment, implementation constraints, and long-term infrastructure development.

References

- ABB. (2023). *Container cranes with automation from ABB to position Colombo for transshipment ambitions*. <https://new.abb.com/news/detail/110060/container-cranes-with-automation-from-abb-to-position-colombo-for-transshipment-ambitions>
- Abdaoui, A. (2021). Feasibility study of cold ironing from renewable sources in the Nordic region: case study : Port of Kapellskär in Stockholm. *World Maritime University Dissertations*.
https://commons.wmu.se/cgi/viewcontent.cgi?article=2667&context=all_dissertations
- Abu Bakar, N. N., Bazmohammadi, N., Vasquez, J. C., & Guerrero, J. M. (2023). Electrification of onshore power systems in maritime transportation towards decarbonization of ports: A review of the cold ironing technology. In *Renewable and Sustainable Energy Reviews* (Vol. 178).
<https://doi.org/10.1016/j.rser.2023.113243>
- Acciaro, M., Ghiara, H., & Cusano, M. I. (2014). Energy management in seaports: A new role for port authorities. *Energy Policy*, 71, 4–12.
<https://doi.org/10.1016/j.enpol.2014.04.013>
- Agrawal, H., Welch, W. A., Miller, J. W., & Cocker, D. R. (2008). Emission measurements from a crude oil tanker at sea. *Environmental Science & Technology*, 42(19), 7098–7103. <https://doi.org/10.1021/es703102y>
- Ahmed M. Ismail a, b, F. B. b, A. I. "Olçer b, A. S. A. b. (2024). Integrating ports into green shipping corridors: Drivers, challenges, and pathways to implementation. *Research in Transportation Business and Management*, 51.
<https://doi.org/10.1016/j.rtbm.2023.101064>
- Alamoush, A. S., Ballini, F., & Ölçer, A. I. (2021). Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs). In *Journal of Shipping and Trade* (Vol. 6, Number 1).
<https://doi.org/10.1186/s41072-021-00101-6>
- APM Terminals, D. W. (2023). *Reaching a tipping point in Battery-Electric Container Handling Equipment*.
- Artiñano, B., Gómez-Moreno, F. J., Pujadas, M., Moreno, N., Alastuey, A., Querol, X., Martín, F., Guerra, A., Luaces, J. A., & Basora, J. (2007). Measurement of particulate concentrations produced during bulk material handling at the Tarragona harbor. *Atmospheric Environment*, 41(30), 6344–6355.
<https://doi.org/10.1016/j.atmosenv.2006.12.020>
- Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2012). Noise Emitted from Ships: Impact Inside and Outside the Vessels. *Procedia - Social and Behavioral Sciences*, 48, 868–879. <https://doi.org/10.1016/j.sbspro.2012.06.1064>
- Bailey, D., Plenys, T., Solomon, G. M., Campbell, T. R., Feuer, G. R., Masters, J., & Tonkonogy, B. (2004). Harboring pollution. *Strategies to Clean Up U.S. Ports*. *Natural Resources Defense Council*, (August), 85.
- Bakar, N. N. A., Guerrero, J. M., Vasquez, J. C., Bazmohammadi, N., Othman, M., Rasmussen, B. D., & Al-Turki, Y. A. (2022a). Optimal Configuration and Sizing of Seaport Microgrids including Renewable Energy and Cold Ironing—The Port of Aalborg Case Study. In *Energies* (Vol. 15, Number 2).
<https://doi.org/10.3390/en15020431>
- Bjerkkan, K. Y., & Ryghaug, M. (2021). Diverging pathways to port sustainability: How social processes shape and direct transition work. *Technological Forecasting and Social Change*, 166, 120595. <https://doi.org/10.1016/J.TECHFORE.2021.120595>
- Boile, M., Theofanis, S., Sdoukopoulos, E., & Karagkouni, K. (2023). *The environmental implications of seaports: a comprehensive literature review*.

- Buonomano, A., Del Papa, G., Giuzio, G. F., Palombo, A., & Russo, G. (2023). Future pathways for decarbonization and energy efficiency of ports: Modelling and optimization as sustainable energy hubs. *Journal of Cleaner Production*, 420, 138389. <https://doi.org/10.1016/J.JCLEPRO.2023.138389>
- Chang, C. C., & Wang, C. M. (2012). Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. *Transportation Research Part D: Transport and Environment*, 17(3), 185–189. <https://doi.org/10.1016/J.TRD.2011.11.006>
- Chatzinikolaou, S. D., Oikonomou, S. D., & Ventikos, N. P. (2015). Health externalities of ship air pollution at port - Piraeus port case study. *Transportation Research Part D: Transport and Environment*, 40, 155–165. <https://doi.org/10.1016/j.trd.2015.08.010>
- Chen, H., Chen, S., Wang, D., & Shen, M. (2023). Business credit network characteristics and impact on green economy efficiency: Evidence from the Greater Bay Area around Hangzhou Bay of China. *PLoS ONE*, 18(4 April). <https://doi.org/10.1371/journal.pone.0284019>
- Chen, T., Wu, L., Wang, S., Jia, S., & Liu, W. (2025). Tugboat electrification planning for container ports. *Transportation Research Part D: Transport and Environment*, 139. <https://doi.org/10.1016/j.trd.2024.104565>
- Christodoulou, A., & Cullinane, K. (2019). Identifying the main opportunities and challenges from the implementation of a port energy management system: A SWOT/PESTLE analysis. *Sustainability (Switzerland)*, 11(21). <https://doi.org/10.3390/su11216046>
- CINEA. (2026). *Connecting Europe Facility*. https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en
- CleanTechnica. (2024). *A Rational Approach For Installing Heavy-Duty Electric Truck Charging Hubs - CleanTechnica*. <https://cleantechnica.com/2024/03/23/a-rational-approach-for-installing-heavy-duty-electric-truck-charging-hubs/>
- Colarossi, D., & Principi, P. (2020). Technical analysis and economic evaluation of a complex shore-to-ship power supply system. *Applied Thermal Engineering*, 181, 115988. <https://doi.org/10.1016/j.applthermaleng.2020.115988>
- Damman, S., & Steen, M. (2021). A socio-technical perspective on the scope for ports to enable energy transition. *Transportation Research Part D: Transport and Environment*, 91(January), 102691. <https://doi.org/10.1016/j.trd.2020.102691>
- Deloitte, & ESPO. (2021). *Europe's ports at the crossroads of transitions A Deloitte and ESPO Study*. (June).
- DNV. (2020). *Ports: green gateways to Europe*. <https://www.dnv.com/publications/ports-green-gateways-to-europe-179372/>
- DNV. (2021). *Ports can be the front runners of the energy transition , if port authorities and industry sectors join forces*. (July 2020), 2–7.
- DNV. (2024). *Status for onshore power supply in selected EU ports*. www.dnv.com
- DNV. (2025). *ENERGY-EFFICIENCY MEASURES AND TECHNOLOGIES Key solutions and strategies for Maritime's decarbonization journey FOREWORD*.
- EcoShape. (n.d.). *Building with Nature Indonesia - EcoShape*. Retrieved October 30, 2023, from <https://www.ecoshape.org/en/pilots/building-with-nature-indonesia/>
- Electric Power Research Institute. (2009). *Electric Ship to Shore Cranes: Costs and Benefits*. <http://tonto.eia.doe.gov/oog/info/wohdp/diesel.asp>
- Electric Power Research Institute. (2010). *Electric Cable Reel Rubber-Tired Gantry Cranes: Costs and Benefits*. <http://www.arb.ca.gov/ports/cargo/idle/presentations/091609present.pdf>
- EMSA. (2022). *EMSA Guidance on SSE to Port Authorities and Administrations* (Number June).
- EMSA. (2023). *Ship Safety Standards - Shore-Side Electricity (SSE)*. <https://emsa.europa.eu/csn-menu/items.html?cid=14&id=4799>

- ESPO. (2020). *ESPO 's Roadmap to implement the European Green Deal objectives in ports*. (February). [https://www.espo.be/media/ESPO Green Deal position paper Green Deal-FINAL.pdf](https://www.espo.be/media/ESPO%20Green%20Deal%20position%20paper%20Green%20Deal-FINAL.pdf) (Accessed 20.02.2020)
- ESPO. (2021a). *Battery-run workboat for the Port of Bergen*. <https://www.espo.be/index.php/practices/battery-run-workboat-for-the-port-of-bergen>
- ESPO. (2021b). *Circular economy at the Port of Amsterdam*. <https://www.espo.be/practices/circular-economy>
- ESPO. (2021c). *Green hydrogen production plant in the Port of Bilbao*. <https://www.espo.be/practices/green-hydrogen-production-plant-in-the-port-of-bil>
- ESPO. (2021d). *Methanol produced from non-recyclable waste at the Port of Amsterdam*. <https://www.espo.be/practices/methanol-produced-from-non-recyclable-waste-at-the>
- ESPO. (2021e). *Port of Hirtshals: Commercial and Sustainable Energy Production*. <https://www.espo.be/practices/port-of-hirtshals-commercial-and-sustainable-energ>
- ESPO. (2021f). *Port of Nakskov: Applying Circular Economy Principles to Navigational Equipment*. <https://www.espo.be/practices/port-of-nakskov-applying-circular-economy-principi>
- ESPO. (2021g). *Port of Valencia gets rid of plastic bottles*. <https://www.espo.be/practices/port-of-valencia-gets-rid-of-plastic-bottles>
- ESPO. (2021h). *Position of the European Sea Ports Organisation in contribution to the Public Consultation accompanying the Impact Assessment for the revision of the TEN-T Regulation (EU)1315/2013* (Number April).
- ESPO. (2021i). *Water quality monitoring at the Ghent-Terneuzen Sea Canal*. <https://www.espo.be/practices/water-quality-monitoring-at-the-ghent-terneuzen-se>
- ESPO. (2022a). *Chemical recycling of plastic waste at North Sea Port*. <https://www.espo.be/practices/chemical-recycling-of-plastic-waste-at-north-sea-p>
- ESPO. (2022b). *Hydrogen network for North Sea Port*. <https://www.espo.be/practices/hydrogen-network-for-north-sea-port>
- ESPO. (2022c). *Hydrogen production at Wilhelmshaven*. <https://www.espo.be/practices/hydrogen-production-at-wilhelmshaven>
- ESPO. (2022d). *Trends in EU Ports Governance 2022. European Sea Ports Organization*.
- ESPO. (2023). *Hydrogen production at the Port of Rotterdam*. <https://www.espo.be/practices/hydrogen-production-at-the-port-of-rotterdam>
- ESPO. (2024a). *PORT INVESTMENTS STUDY: The Investment Pipeline and Challenges of European Ports*. https://www.espo.be/media/ESP-3217_InvestmentStudyReport2024_LR.pdf
- ESPO. (2024b). *Priorities of the European Sea Ports Organisation for 2024-2029*.
- ESPO. (2025). *ESPO Environmental Report 2025*. www.ecoslc.eu.
- ESPO & HaskoningDHV Nederland. (2022). *The new energy landscape Impact on and implications for European ports*.
- ESPO and Royal HaskoningDHV. (2022). *ESPO: Green Guide & Shore Power Metadata Impact on and implications for European ports*. <https://www.espo.be/media/The%20new%20energy%20landscape.pdf>
- ESPO Secretariat. (2024). *ESPO Environmental Report 2024*. www.ecoslc.eu.
- European Commission. (2021). *New approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future*.
- European Commission. (2019). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
- European Commission. (2020). *Sustainable and Smart Mobility Strategy-putting European transport on track for the future*.
- European Commission. (2021). *Revision Energy Taxation Directive*. https://taxation-customs.ec.europa.eu/taxation/excise-taxes/revision-energy-taxation-directive_en

- European Commission. (2023). *Green Deal: Greening freight for more economic gain with less environmental impact*.
- European Commission. (2024). *Greening of European Sea Ports-Final report*.
- European Commission. (2025). *Connecting Europe Facility - European Commission*. https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/connecting-europe-facility_en
- European Dredging Association. (2021). *About dredging*. European-Dredging.Eu. <https://european-dredging.eu/Dredging>
- European Parliamentary Research Service. (2021). *Sustainable and smart mobility strategy*.
- Fadiga, A., Ferreira, L. M. D. F., & Bigotte, J. F. (2024). Decarbonising maritime ports: A systematic review of the literature and insights for new research opportunities. *Journal of Cleaner Production*, 452. <https://doi.org/10.1016/j.jclepro.2024.142209>
- Frederic Godemel. (2023). *How electrification can decarbonize ports*. <https://blog.se.com/infrastructure-and-grid/transportation/2023/10/10/how-electrification-can-decarbonize-ports/>
- Fredianelli, L., Bolognese, M., Fidecaro, F., & Licitra, G. (2021). Classification of Noise Sources for Port Area Noise Mapping. *Environments 2021*, Vol. 8, 8(2), 1–16. <https://doi.org/10.3390/environments8020012>
- Fu-Tian Wei. (2020). *Port of Taipei – Eco-resilient Future*. World Port Sustainability Program. <https://sustainableworldports.org/project/port-of-taipei-eco-resilient-future/>
- German-Galkin, S., & Tarnapowicz, D. (2020). Energy optimization of the ‘shore to ship’ system— a universal power system for ships at berth in a port. *Sensors (Switzerland)*, 20(14), 1–21. <https://doi.org/10.3390/s20143815>
- Gharehgozli, A., Zaerpour, N., & Li, K. (2023). Optimizing the number of deployed yard cranes in a container terminal. *INFOR*, 61(1), 86–103. <https://doi.org/10.1080/03155986.2022.2106713>
- Gundersen, O., Longva, S. T., Sekkesaeter, Ø., Gill, A., Endresen, H. Ø., Hustad, H., Hermundsgård, H., Lande, P., Kvålsvold, J., & Sverud, T. (n.d.). *FUELEU MARITIME Requirements, compliance strategies, and commercial impacts*.
- Gurning, R. O. S., & Tangkau, D. I. (2022). The Analysis of the Conceptual Framework of Green Port Implementation in Indonesia Using Circular Economy: The Case Study of Benoa Public and Fishing Terminals. *Sustainability (Switzerland)*, 14(10). <https://doi.org/10.3390/su14106083>
- Hall, W. J. (2010). Assessment of CO2 and priority pollutant reduction by installation of shoreside power. *Resources, Conservation and Recycling*, 54(7), 462–467. <https://doi.org/10.1016/j.resconrec.2009.10.002>
- Hewitt, C. L., Gollasch, S., & Minchin, D. (2009). *The Vessel as a Vector-Biofouling, Ballast Water and Sediments*.
- Huang, W., Yu, M., Li, H., & Tai, N. (2023). *Energy Management of Integrated Energy System in Large Ports*.
- Hyster. (2026). *Zero-emissions electric lift trucks providing 7-9 tonnes of lift capacity*. <https://www.hyster.com/en-sg/asia-pacific/4-wheel-electric-forklift-trucks/J7.0-9.0XNL/>
- IMO. (n.d.). *International Convention for the Prevention of Pollution from Ships (MARPOL)*. Retrieved October 30, 2023, from [https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-\(MARPOL\).aspx](https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx)
- IMO. (2023). *IMO Strategy on reduction of GHG emissions from ships*. <https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf>
- IMO and IAPH. (2018). Port Emissions Toolkit, Guide No.2, Development of port emissions reduction strategies. *GEF-UNDP-IMO GloMEEP Project*.

- International Association of Ports and Harbors. (2024). *Study on Investment Requirements of Developing Countries for Port Decarbonisation and Adaptation to Climate Change*.
- Iris, Ç., & Lam, J. S. L. (2019). A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renewable and Sustainable Energy Reviews*, 112, 170–182. <https://doi.org/10.1016/J.RSER.2019.04.069>
- ISO. (2015). *ISO 14001 - Introduction to ISO 14001:2015*.
- Jack Simpson. (2024). Port infrastructure delays threaten UK's transition to net zero, industry says. *The Guardian*. <https://www.theguardian.com/environment/article/2024/jul/02/port-infrastructure-delays-threaten-uks-transition-to-net-zero-industry-says>
- Johnathan Cookson. (2023). Tianjin Port transformed by Huawei autonomous driving software. *Port Technology International*.
- Joint charging. (2025). *Electric Truck Charging Trends in 2025: The Rise and Future of DC EV Chargers*. <https://jointcharging.com/electric-truck-charging-trends-in-2025-the-rise-and-future-of-dc-ev-chargers/>
- Joubi, A., Akimoto, Y., & Okajima, K. (2022). A Production and Delivery Model of Hydrogen from Solar Thermal Energy in the United Arab Emirates. *Energies*, 15(11). <https://doi.org/10.3390/en15114000>
- Jürgen W. Böse. (2020). Handbook of Terminal Planning. In J. W. Böse (Ed.), *Springer* (Vol. 49). Springer International Publishing. <https://doi.org/10.1007/978-3-030-39990-0>
- Kalmar. (2021). *Five steps towards sustainable cargo handling*. https://www.kalmarglobal.com/news--insights/articles/2021/20210708_five-steps-towards-sustainable-cargo-handling/
- Kalmar. (2026). *Light Electric Forklift*. <https://www.kalmarglobal.com/equipment/forklift-trucks/light-electric-forklift-5-9-ton/>
- Karagkouni, K., & Boile, M. (2024). Classification of Green Practices Implemented in Ports: The Application of Green Technologies, Tools, and Strategies. *Journal of Marine Science and Engineering*, 12(4). <https://doi.org/10.3390/jmse12040571>
- Karagkouni, K., & Boile, M. (2025). Electrification in Ports: Barriers, Drivers and Evaluation through PESTLE Analysis. *Journal of Sustainability Research*, 7(4). <https://doi.org/10.20900/jsr20250075>
- Karagkouni, K., Theofanis, S., Boile, M., & Sdoukopoulos, E. (2025). Transitioning Towards Green Port Operations: A State-of-Practice Approach on Emerging “Green” Technologies. *TRAconference 2024. Lecture Notes in Mobility*. Springer, Part F383, 205–212. https://doi.org/10.1007/978-3-031-89444-2_29/TABLES/1
- Karapidakis, E., Nikolaidis, E., Moraitakis, G., Georgakis, F., & Papadakis, M. (2022). Cold ironing feasibility study at the Heraklion Port. *Journal of Physics: Conference Series*, 2339(1), 8–10. <https://doi.org/10.1088/1742-6596/2339/1/012016>
- Kausek, Joe. (2007). *Environmental management quick and easy : creating an effective ISO 14001 EMS in half the time*. ASQ Quality Press.
- Kempower. (2024). *Port electrification - The challenges and opportunities of an electrified port industry*. <https://kempower.com/port-electrification-challenges-and-opportunities/>
- Kiliç, A., Yolcu, M., Kiliç, F., & Bilgili, L. (2020). Assessment of ship emissions through cold ironing method for Iskenderun Port of Turkey. *Environmental Research and Technology*, 3(4), 193–201. <https://doi.org/10.35208/ert.794595>
- Kim, K. H., & Günther, H. O. (2007). Container terminals and terminal operations. In *Container Terminals and Cargo Systems: Design, Operations Management, and Logistics Control Issues*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-49550-5_1

- Kinnon, M. Mac, Razeghi, G., & Samuelson, S. (2021). The role of fuel cells in port microgrids to support sustainable goods movement. *Renewable and Sustainable Energy Reviews*, 147(April), 111226. <https://doi.org/10.1016/j.rser.2021.111226>
- Kovačič Lukman, R., Brglez, K., & Krajnc, D. (2022). A Conceptual Model for Measuring a Circular Economy of Seaports: A Case Study on Antwerp and Koper Ports. *Sustainability (Switzerland)*, 14(6). <https://doi.org/10.3390/su14063467>
- Krämer, I., & Czernański, E. (2020). Onshore power one option to reduce air emissions in ports. *Sustainability Management Forum | NachhaltigkeitsManagementForum*, 28(1–2), 13–20. <https://doi.org/10.1007/s00550-020-00497-y>
- Le, T. T., Nguyen, H. P., Rudzki, K., Rowiński, L., Bui, V. D., Truong, T. H., Le, H. C., & Pham, N. D. K. (2023). Management Strategy for Seaports Aspiring to Green Logistical Goals of IMO: Technology and Policy Solutions. *Polish Maritime Research*, 30(2), 165–187. <https://doi.org/10.2478/pomr-2023-0031>
- Lun, Y. H. V., Lai, K. H., & Cheng, T. C. E. (2010). Shipping and logistics management. In *Shipping and Logistics Management*. <https://doi.org/10.1007/978-1-84882-997-8>
- Luo, J., Xie, Y., Hou, M. Z., Xiong, Y., Wu, X., Lüddecke, C. T., & Huang, L. (2023). Advances in subsea carbon dioxide utilization and storage. *Energy Reviews*, 2(1), 100016. <https://doi.org/10.1016/j.enrev.2023.100016>
- Malmö, S. (n.d.). *WORLD MARITIME UNIVERSITY FEASIBILITY STUDY OF COLD IRONING FROM RENEWABLE SOURCES IN THE NORDIC REGION Case Study: Port of Kapellskär in Stockholm By*.
- Mańkowska, M., Kotowska, I., & Pluciński, M. (2020). Seaports as nodal points of circular supply chains: Opportunities and challenges for secondary ports. *Sustainability (Switzerland)*, 12(9). <https://doi.org/10.3390/su12093926>
- Margherita Bruno. (2022). *Port of Vancouver backs \$1 million green tech testing*. Port Technology International. <https://www.porttechnology.org/news/port-of-vancouver-backs-1-million-green-tech-testing/>
- Margherita Bruno. (2023). *DP World, Maersk to green up Jebel Ali Port*. Port Technology International. <https://www.porttechnology.org/news/dp-world-maersk-to-green-up-jebel-ali-port/>
- Marius Bucur. (2019). Port operations and cargo handling operations. Process based approach. *Scientific Bulletin of Naval Academy*, XXII(1), 358–369. <https://doi.org/10.21279/1454-864x-19-i1-050>
- Martínez-Moya, J., Mestre-Alcover, A., Sala-Garrido, R., & Furió-Pruñonosa, S. (2024). Are transshipment ports more efficient in the Mediterranean Sea? Analysing the role of time at ports using DEA metafrontier approach. *Journal of Transport Geography*, 116. <https://doi.org/10.1016/j.jtrangeo.2024.103866>
- Masip Macía, Y., Rodríguez Machuca, P., Rodríguez Soto, A. A., & Carmona Campos, R. (2021). Green hydrogen value chain in the sustainability for port operations: Case study in the region of valparaiso, Chile. *Sustainability (Switzerland)*, 13(24), 1–17. <https://doi.org/10.3390/su132413681>
- Meng, Z., Comer, B., Meyer, M., Callahan, J., Song, A., Lecompte, J., Kaltenstein, J., & Rose, M. (2023). *Electrifying ports to reduce diesel pollution from ships and trucks and benefit public health: Case studies of the Port of Seattle and the Port of New York and New Jersey*. www.theicct.orgcommunications@theicct.org
- Mikael Lind, S. H. W. L. Z. R. E. F. L. A. J. B. X. F. J. S. Dr. P. Z. (2023). *Thinking the future energy model nodes of the world*. UNCTAD. <https://unctad.org/news/transport-newsletter-article-no-103-future-energy-nodes>
- Minchin, D., Gollasch, S., Cohen, A. N., Hewitt, C. L., & Olenin, S. (2009). *Characterizing Vectors of Marine Invasion*.
- Miola, A., Paccagnan, V., Massarutto, A., Perujo, A., & Turvani, M. (2009). External costs of Transportation, Case study : maritime transport. In *JCR Scientific and Technical Reports*. <https://doi.org/10.2788/18349>
- Mjelde, A., Endresen, Ø., Bjørshol, E., Gierløff, C. W., Husby, E., Solheim, J., Mjøs, N., & Eide, M. S. (2019). Differentiating on port fees to accelerate the green maritime

- transition. *Marine Pollution Bulletin*, 149.
<https://doi.org/10.1016/j.marpolbul.2019.110561>
- Mousavi, A., Sowlat, M. H., Hasheminassab, S., Pikelnaya, O., Polidori, A., Ban-Weiss, G., & Sioutas, C. (2018). Impact of particulate matter (PM) emissions from ships, locomotives, and freeways in the communities near the ports of Los Angeles (POLA) and Long Beach (POLB) on the air quality in the Los Angeles county. *Atmospheric Environment*, 195, 159–169.
<https://doi.org/10.1016/j.atmosenv.2018.09.044>
- MSE International. (2024). *A white paper ENERGY STORAGE FOR PORT ELECTRIFICATION*. www.mseinternational.org
- Münter, M. T. (2024). Pestle-Analysis. *Reference Module in Social Sciences*.
<https://doi.org/10.1016/B978-0-443-13701-3.00200-0>
- Muratori, M., & Borlaug, B. (2021). *Perspectives on Charging Medium-and Heavy-Duty Electric Vehicles*.
- Mutarraf, M. U., Terriche, Y., Nasir, M., Guan, Y., Su, C. L., Vasquez, J. C., & Guerrero, J. M. (2020). A Decentralized Control Scheme for Adaptive Power-Sharing in Ships based Seaport Microgrid. *IECON Proceedings (Industrial Electronics Conference)*, 2020-Octob, 3126–3131.
<https://doi.org/10.1109/IECON43393.2020.9255344>
- Mutarraf, M. U., Terriche, Y., Nasir, M., Guan, Y., Su, C. L., Vasquez, J. C., & Guerrero, J. M. (2021). A Communication-Less Multimode Control Approach for Adaptive Power Sharing in Ship-Based Seaport Microgrid. *IEEE Transactions on Transportation Electrification*, 7(4), 3070–3082.
<https://doi.org/10.1109/TTE.2021.3087722>
- Neugebauer, J., Heilig, L., & Voß, S. (2025). Dynamic driving in seaports: Current and future applications. *Cleaner Logistics and Supply Chain*, 100203.
<https://doi.org/10.1016/j.clscn.2025.100203>
- Nnachi, M. A. F., Ehlers, M. P. J., Richards, M. C., Nicolae, D. V., & Member, I. (2013). *Double-port Interface for Small Scale Renewable Sources Integration*.
www.Matlabi.ir
- Notteboom, T., & Haralambides, H. (2023). Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe. *Maritime Economics and Logistics*, 25(1), 1–27. <https://doi.org/10.1057/s41278-023-00253-1>
- Notteboom, T., Pallis, A., & Rodrigue, J.-P. (2021). Chapter 8.3 – Ports and Energy. *Port Economics, Management and Policy*, 1–22.
<https://porteconomicsmanagement.org/pemp/contents/part8/ports-and-energy/>
- O'brien, T., Reeb, T., & Shepherd, G. (n.d.). *PORT OF LONG BEACH ZERO EMISSIONS WORKFORCE DEVELOPMENT REPORT*.
- Olaf Merk. (2015). *Port Hinterland Connectivity*. <https://www.itf-oecd.org/sites/default/files/docs/dp201513.pdf>
- Oslo Havn. (2021). *New electric stacker cranes land at Norway's largest container port*.
<https://www.oslohavn.no/en/news/new-electric-stacker-cranes-land-at-norways-largest-container-port/>
- Ozsoysal, O. A. (2021). *Energy Conversion and Management : X Techno-economic investigation of alternative propulsion systems for tugboats*. 12.
<https://doi.org/10.1016/j.ecmx.2021.100140>
- Pesquera, M. A. (2024). Automation in logistics port and freight transport with blockchain technology. *Transportation Research Procedia*, 78, 394–401.
<https://doi.org/10.1016/j.trpro.2024.02.050>
- Piccoli, T., Fermeglia, M., Bosich, D., Bevilacqua, P., & Sulligoi, G. (2021). Environmental assessment and regulatory aspects of cold ironing planning for a maritime route in the adriatic sea. *Energies*, 14(18), 1–31.
<https://doi.org/10.3390/en14185836>

- Pivetta, D., Dall'armi, C., & Taccani, R. (2022). Multi-Objective Optimization of a Hydrogen Hub for the Decarbonization of a Port Industrial Area. *Journal of Marine Science and Engineering*, 10(2). <https://doi.org/10.3390/jmse10020231>
- Port Authority of Seville. (2022). *The Port of Seville regenerates the Doñana coastline with 62.000 m3 of sand from maintenance dredging*. <https://www.puertodesevilla.com/en/communication/news/the-port-of-seville-regenerates-the-donana-coastline-with-62-000-m3-of-sand-from-maintenance-dredging>
- Port of Los Angeles. (2024). *L.A., Long Beach Ports Invest \$25 Million in Truck Charging*. https://www.portoflosangeles.org/references/2024-news-releases/news_062724_pola_polb_truck_charging
- Port Reform Toolkit. (2025). *Port Reform Toolkit*. <https://doi.org/10.1596/43526>
- Port Strategy. (2023). *Scandinavia ups the ante in methanol bunkering*. https://www.portstrategy.com/environment-and-sustainability/scandinavia-ups-the-ante-in-methanol-bunkering/1484469.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_0bef54b0a13249efdf4b65fc158d1074&utm_source=Email%20marketing%20software&utm_term=Scandinavia%20ups%20the%20ante%20in%20methanol%20bunkering
- Port Strategy. (2025). *Port Strategy*. <https://www.portstrategy.com/searchresults?qkeyword=electric+PORT+EQUIPMENT>
- Port Technology. (2011). *Investment vs. operating costs: a comparison of automatic stacking cranes and RTGs*. www.porttechnology.org
- Port Technology International. (2021). *ZPMC delivers batches of automated equipment to Tuas Port*. <https://www.porttechnology.org/news/zpmc-delivers-batches-of-automated-equipment-to-tuas-port/>
- Port Technology International. (2023). *PSA Sines orders six Konecranes automated RTGs*. <https://www.porttechnology.org/news/psa-sines-orders-six-konecranes-automated-rtgs/>
- Port Technology International. (2024). *AI drivers, ZF retrofit terminal tractors for autonomous operations*. <https://www.porttechnology.org/news/aidrivers-zf-retrofit-terminal-tractors-for-autonomous-operations/>
- Praharsi, Y., Hardiyanti, F., Puspitasari, D., Akseptori, R., & Maharani, A. (2021). *An Integrated Framework of Balance Scorecard-PESTLE-Smart and Green Port for Boosting the Port Performance*.
- Probiez, K., & Śladowski, A. (n.d.). *e Analysis of Recovery Action in Case of Handling Equipment on the Example of Forklift Trucks Used in Seaport Analiza reciklaže opreme za rukovanje na primjeru lučkih viljuškara KEY WORDS forklift truck recycling recovery actions KLJUČNE RIJEČI viljuškar reciklaža obnova*.
- Rahman, S., & Khan, I. A. (2020). Investigation of Power Quality Issues in Cold Ironed (Shore Connected) Grid Connected Electric Ships. *Conference Record - Asilomar Conference on Signals, Systems and Computers, 2020-November*, 1353–1358. <https://doi.org/10.1109/IEEECONF51394.2020.9443569>
- Ramos Velasco, E., González-Cancelas, N., Camarero Orive, A., & Díaz-Gutiérrez, D. (2022). Green Ports Analysis Using an End-to-End Tool Application in the Fishing Port of Vigo. *Journal of Marine Science and Engineering*, 10(12). <https://doi.org/10.3390/jmse10121959>
- REGULATION (EU) 2019/1242 Setting CO2 Emission Performance Standards for New Heavy-Duty Vehicles (2019).
- Regulation (EU) 2023/1805 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport, and Amending 2009/16/EC (2023). https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en

- Sadiq, M., Ali, S. W., Terriche, Y., Mutarraf, M. U., Hassan, M. A., Hamid, K., Ali, Z., Sze, J. Y., Su, C. L., & Guerrero, J. M. (2021). Future Greener Seaports: A Review of New Infrastructure, Challenges, and Energy Efficiency Measures. *IEEE Access*, 9, 75568–75587. <https://doi.org/10.1109/ACCESS.2021.3081430>
- Schenk, E., Carr, E., Associates, E. R., Corbett, J. J. (, & Winebrake, J. J. (2020). *Macroeconomic and Environmental Impacts of Port Electrification: Four Port Case Studies Final Report*.
- Sdoukopoulos, E., Boile, M., Tromaras, A., & Anastasiadis, N. (2019). Energy efficiency in European ports: State-of-practice and insights on the way forward. *Sustainability (Switzerland)*, 11(18). <https://doi.org/10.3390/su11184952>
- Sharifi, F., Burris, M., Quadrifoglio, L., Duffield, N., Xu, X., Meitiv, A., & Xu, Y. A. (2024). Electric truck feasibility for port drayage operations: Port houston case study. *Transportation Research Part D: Transport and Environment*, 135. <https://doi.org/10.1016/j.trd.2024.104355>
- Simone Panigada, G. P. J. A. B. BellaS. G. and C. V. (2008). *Biodiversity impacts of ship movement, noise, grounding and anchoring*. https://www.researchgate.net/publication/230818896_Biodiversity_impacts_of_ship_movement_noise_grounding_and_anchoring
- Song, C., & Cui, W. (2020). Review of Underwater Ship Hull Cleaning Technologies. *Journal of Marine Science and Application*, 19(3), 415–429. <https://doi.org/10.1007/s11804-020-00157-z>
- Sugihara, C., Hardman, S., & Kurani, K. (2024). Who decides which trucks to buy? Implications for electrifying freight fleets. *Transportation Research Part D: Transport and Environment*, 126. <https://doi.org/10.1016/j.trd.2023.104015>
- Surucu-Balci, E., Iris, Ç., & Balci, G. (2024). Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities. *Technological Forecasting and Social Change*, 198. <https://doi.org/10.1016/j.techfore.2023.122978>
- Tao, L., Guo, H., Moser, J., & Mueller, H. (2014). a Roadmap Towards Smart Grid Enabled Harbour Terminals. *Cired.Net*, (June), 11–12. http://www.cired.net/publications/workshop2014/papers/CIRED2014WS_0394_final.pdf
- Transport & Environment. (2023). *The impact of FuelEU Maritime on EU Shipping*. www.transportenvironment.org
- Tsvetkova, A., Hellström, M., Schwartz, H., Rabetino, R., & Syed, H. (2024). A transition towards clean propulsion in shipping: The role of PESTLE drivers and implications for policy. *Marine Policy*, 161. <https://doi.org/10.1016/j.marpol.2023.106002>
- UNCTAD. (2021). *Key performance indicators for ports and the shipping fleet*. <https://doi.org/10.18356/9789210000970c008>
- Wang, Y., Ding, W., Dai, L., Hu, H., & Jing, D. (2021). How would government subsidize the port on shore side electricity usage improvement? *Journal of Cleaner Production*, 278, 123893. <https://doi.org/10.1016/j.jclepro.2020.123893>
- Wayne K. Talley. (2018). *Port Economics* (2nd ed.). Routledge. <https://www.routledge.com/Port-Economics/Talley/p/book/9781138952195?>
- Williamsson, J., Costa, N., Santén, V., & Rogerson, S. (2022). Barriers and Drivers to the Implementation of Onshore Power Supply—A Literature Review. *Sustainability*, 14(10), 6072. <https://doi.org/10.3390/su14106072>
- World Bank Group. (2017). *ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES FOR PORTS, HARBORS, AND TERMINALS*. <https://www.iadc-dredging.com/ul/cms/terraetaqua/document/1/7/6/176/176/1/article-environmental-monitoring-and->
- World Bank Group. (2025). *Port Reform Toolkit - Environmental Sustainability*.

- World Port Sustainability Program. (2016). *Port of Huelva – Ecological recovery project*. <https://sustainableworldports.org/project/port-of-huelva-ecological-recovery-project/>
- World Port Sustainability Program. (2019a). *Port of Marseille – HyAMMED*. <https://sustainableworldports.org/project/port-of-marseille-hyammed/>
- World Port Sustainability Program. (2019b). *Port of Vigo – Sunset Dock Project*. <https://sustainableworldports.org/project/port-of-vigo-sunset-dock-project/>
- World Port Sustainability Program. (2020a). *Port of Algeciras – PortXchange*. <https://sustainableworldports.org/project/port-of-algeciras-portxchange/>
- World Port Sustainability Program. (2020b). *Port of Gothenburg – Cinfracap Carbon Infrastructure Capture*. <https://sustainableworldports.org/project/port-of-gothenburg-cinfracap-carbon-infrastructure-capture/>
- World Port Sustainability Program. (2020c). *RAK Ports – Channel Optimization with DUKC*. <https://sustainableworldports.org/project/rak-ports-channel-optimization-with-duk/>
- World Port Sustainability Program. (2021a). *Flinders Port Holdings – Climate Adaptation Strategy*. <https://sustainableworldports.org/project/flinders-port-holdings-climate-adaptation-strategy/>
- World Port Sustainability Program. (2021b). *Solomon Islands Ports Authority – Renewable Energy for a Sustainable Community*. <https://sustainableworldports.org/project/solomon-islands-ports-authority-renewable-energy-for-a-sustainable-community/>
- World Port Sustainability Program. (2023). *Port of Gothenburg – Hydrogen production facility and filling station*. <https://sustainableworldports.org/project/port-of-gothenburg-hydrogen-production-facility-and-filling-station/>
- Zanne, M., Twrdy, E., & Beškovnik, B. (2021). The Effect of Port Gate Location and Gate Procedures on the Port-City Relation. *Sustainability 2021*, Vol. 13, 13(9). <https://doi.org/10.3390/su13094884>
- Zhang, Y., Liang, C., Shi, J., Lim, G., & Wu, Y. (2022). Optimal Port Microgrid Scheduling Incorporating Onshore Power Supply and Berth Allocation Under Uncertainty. *Applied Energy*, 313. <https://doi.org/10.1016/j.apenergy.2022.118856>
- Zis, T., North, R. J., Angeloudis, P., Ochieng, W. Y., & Bell, M. G. H. (2014). Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports. *Maritime Economics and Logistics*, 16(4), 371–398. <https://doi.org/10.1057/MEL.2014.6/METRICS>

ANNEX I: Port size classification and benchmarking dataset

Table 23. Port profile and classification indicators²

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Large	Europe	Italy	Port of Livorno	3.2	1.85	33	2,282,500	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro, LNG
Large	Europe	Spain	Port of Barcelona	5	7.86	44.3	3,800,000 cruise passengers	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro, LNG
Medium	Europe	Italy	Port of Bari	4.7	1.15	5.1	1,850,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Multipurpose, Ro-Ro
medium	Europe	Italy	Port of Napoli	2.3	1.42	22	7,400,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG
Large	Europe	Italy	Port of Venice	1.4	20	26.4	2,400,000	Break Bulk, Container, Liquid, Passenger, Dry Dock, LPG, Ro-RoSteel & non ferrous products
Large	Europe	Lithuania	Port of Klaipeda	3.9	5.57	29.8	280,300	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Shipyard, Multipurpose, Ro-Ro
Large	Europe	Italy	Port of Genoa	3.5	7	52	3,650,000	
Large	Europe	Slovenia	Port of Koper	1.1	2.8	16		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-RoReefe
Very Large	Europe	Netherlands	Port of Rotterdam	34.2	48.1	434.6		Dry Bulk
Medium	Europe	Scotland	Port of Aberdeen	1.2	38.8	4.5	137,300	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Shipyard, Multipurpose, Ro-RoSteel & non ferrous products

² Throughput figures are indicative, as reporting methodologies may vary across ports. They are used solely for benchmarking and port classification purposes and do not affect the methodology or the results of this dissertation.

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Medium	Europe	Norway	Port of Bergen	0.9	0.15	96	232,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Ro-Ro
Large	Europe	Italy	Port of Civitavecchia	1.9	n/a		2,400,000	Break Bulk, Container, Liquid, Passenger
Very Small	Europe	Greece	Port of Mytilene	1.3	n/a	8.7		Break Bulk, Liquid, Dry Bulk
Very Large	Europe	Spain	Port of Valencia	6.8	6	80	475,000	
Large	Europe	UK	Port of London Authority	3.2		54.9	4,500,000	including shortsea and deepsea, containerised, Ro-Ro, general cargo, project cargo, liquid bulks and dry bulks
Large	Europe	Denmark	Port of Aalborg	7	2.8	2.9	2,400	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
very small	Europe	Greece	Port of Adamas					Break Bulk, Dry Bulk, Passenger, Dry Dock
Large	Europe	Spain	Port of Algeciras	2.7	7.45	69.8	4,800,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	The Netherlands	Port of Amsterdam	5	28.73	74.8	468,500	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Bunkering, Shipyard, Multipurpose, Ro-Ro
Large	Europe	Italy	Port of Ancona	1.3	1.4	8.5	1,655,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Very Large	Europe	Belgium	Port of Antwerp	5	130	187.1		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Bunkering, Multipurpose, Ro-Ro
small	Europe	Montenegro	Port of Bar	2.45	1.91			
Medium	Europe	Spain	Port of Bilbao	12.25	3.5	39	179,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro, LNGSteel & non ferrous products
Medium	Europe	France	Port of Bordeaux	4.59	4.67	8.7	16,270	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Large	Europe	German	Port of Bremen	56	10	11.3		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro, Steel & non ferrous products
Medium	Europe	Spain	Port of Cartagena	4.86	1.7	19.23	104,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro, LNG
Small	Europe	Spain	Port of Cava					
Large	Europe	Denmark	Port of Copenhagen	1	4.34	15	829,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, LPG, Multipurpose, Ro-Ro
Small	Europe	The Netherlands	Port of Den Helder	1.7	3.1			Break Bulk, Container, Liquid, Passenger, Dry Dock, Multipurpose, Ro-Ro
Small	Europe	The Netherlands	port of Den Oever-Hollands Kroon	0	0.8			
Large	Europe	UK	Port of Dover	0	2.56	25.08	13,700,000	Break Bulk, Container, Dry Bulk, Passenger, Multipurpose, Ro-Ro
small	Europe	Albania	Port of Durres	1.88	1.55	0.6	770,800	Break Bulk, Container, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-Ro, Steel & non ferrous products, Reefer
Medium	Europe	Denmark	Port of Esbjerg	1.55	5	4.6	1,840,000	Break Bulk, Container, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-Ro, Steel & non ferrous products, Reefer
Large	Europe	UK	Port of Felixtowe	2	4.5	25.7		Break Bulk, Container, Dry Bulk, Ro-Ro
Small	Europe	Spain	Port of Gandia	1.84	0.53	0.49		Break Bulk, Dry Bulk, Ro-Ro
Medium	Europe	Sweeden	Port of Gävle	5.08	5.66	4.6		Break Bulk, Container, Liquid, Dry Bulk, Multipurpose, Ro-Ro
Large	Europe	Poland	Port of Gdynia	3.14	7.07	15.5	460,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	Sweeden	Port of Gothenburg	1.51	4.61	41,3	1,700,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Very Large	Europe	Germany	Port of Hamburg	9.8	39.79	121.2	112,200	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro/Steel & non ferrous products
Large	Europe	Finland	Port of Helsinki	1.62	7.4	14	10,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-Ro
medium	Europe	Greece	Port of Heraklion	1,029	0.79	3	2,000,000	Container, Liquid, Dry Bulk, Passenger, Multipurpose, Ro-Ro
Small	Europe	Denmark	Port of Hirtshals	0.66	1.4	1.2	1,400,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Ro-Ro
Medium	Europe	Spain	Port of Huelva	0.5	1.58	20.6	525	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro, LNG
Medium	Europe	Greece	Port of Igoumenitsa	1.74	0.32		2,800,000	Liquid, Passenger, Ro-Ro
Medium	Europe	UK	Port of Ipswich	1	0.27	2.8		Break Bulk, Container, Liquid, Dry Bulk, Ro-Ro
Small	Europe	Sweeden	Port of Kapellskär	0	0.18	2		Passenger, Ro-Ro
Medium	Europe	Germany	Port of Kiel	1	0.7	4.8	1,850,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Large	Europe	France	Port of Le Havre	3.7	11.34	68.5	536,700	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	Scotland	Port of Leith	0.9	1.93	1.5	50 cruise vessels annually	Break Bulk, Container, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Medium	Europe	UK	Port of Liverpool		8.09	29.9		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Medium	Europe	Germany	Port of Magdeburg		2.46			
Large	Europe	Copenhagen	Port of Malmo	2.06	10.15	15	829,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	France	Port of Marseille	1	3.56	86	2,760,000	
Medium	Europe	Italy	Port of Monfalcone	2.39	4.9	4		Break Bulk, Liquid, Dry Bulk, Ro-Ro

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Small	Europe	Denmark	Port of Nakskov	0.9	0.8	0.4		Break Bulk, Liquid, Dry Bulk, Passenger, Dry Dock, Ro-Ro
Medium	Europe	Belgium	Port of Oostende	1.54	2.2	8.4	230,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-Ro
Medium	Europe	Italy	Port of Piombino	1.26	1.23	9	4,000,000	Break Bulk, Liquid, Dry Bulk, Passenger, Ro-Ro
Medium	Europe	Croatia	Port of Ploče	1.63	3.27	0.96		Break Bulk, Liquid, Dry Bulk, Passenger, Ro-Ro
Medium	Europe	Italy	Port of Ravenna	7.15	3.16	26.3		Break Bulk, Container, Liquid, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	Croatia	Port of Rijeka	0.8	2.19	9.3		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Small	Europe	Spain	Port of Santander	1.14	4.2	5.9		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Shipyard, Ro-Ro
Medium	Europe	Spain	Port of Sevilla	4.1	2.17	4.8	151,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Medium	Europe	UK	Port of Shoreham	1	1.12	1.7		Break Bulk, Liquid, Dry Bulk, Dry Dock, Multipurpose, Ro-Ro
Medium	Europe	UK	Port of Southampton	2.86	5	37.2		Break Bulk, Container, Liquid, Dry Bulk, Passenger, LPG, Multipurpose, Ro-Ro
Medium	Europe	Sweeden	Port of Stockholm	43.78	1.07	8.5	9,000,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Medium	Europe	Poland	Port of Szczecin	1.73	2.18	19.2	767,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Multipurpose, Ro-Ro
Medium	Europe	Estonia	Port of Tallinn	1.24	1.58	33.2	7,300,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Ro-Ro
Small	Europe	Spain	Port of Tarifa	0.5	0.31		1,280,000	Passenger, Ro-Ro

Port size	Region	Country	Port	Distance from city center (km)	Total port area (km ²)	Total annual throughput (m. tons)	Passenger traffic (annual)	Available facilities
Medium	Europe	Greece	Port of Thessaloniki	1.5	1.91	16	220,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Large	Europe	Italy	Port of Trieste	0.5	2.25	44.4	113,700	Break Bulk, Container, Liquid, Passenger, Dry Dock, Multipurpose, Ro-Ro
Large	Europe	Malta	Port of Valetta	0	2.26	1.8	620,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, LPG, Multipurpose, Ro-Ro
Medium	Europe	Netherlands	Port of Venlo		0.14			
	Europe	Austria	Port of Vienna	6.4	1.71			
Medium	Europe	Spain	Port of Vigo	2.48	3.47	5.2	128,500	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Multipurpose, Ro-Ro
Small	Europe	Netherlands	Port of Vlissingen	1.48	2.44	18		Break Bulk, Container, Liquid, Dry Bulk, Dry Dock, LPG, Multipurpose, Ro-Ro
Medium	Europe	UK	Portsmouth Port		1.49	3.9	2,226,000	Container, Liquid, Dry Bulk, Passenger, Dry Dock, Multipurpose, Ro-Ro
Small	Europe	Norway	Trondheim Port Authority		1.82	1.3		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, Bunkering, Ro-Ro, Reefer
Medium	Europe	Latvia	Port of Riga	0	0.33	34.1	770,000	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Bunkering, Multipurpose, Ro-Ro
Large	Europe	Germany	Port of Wilhelmshaven	4.75	4.57	40.3	1,100	Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Multipurpose, Ro-Ro
Small	Europe	Spain	Port of Santa Cruz		2.02	19.2		Break Bulk, Container, Liquid, Dry Bulk, Passenger, Dry Dock, LPG, Ro-Ro

Table 24. Cargo and passenger throughput data

Port	Country	Containers (TEUs) 2019	Containers (TEUs) 2020	Containers (TEUs) annually	Ro/Ro-cars (tons) 2019	Ro/Ro-cars (tons) 2020	Dry bulk cargo (tons) 2019	Dry bulk cargo (tons) 2020	Liquid bulk (tons) 2019	Liquid bulk (tons) 2020	Passenger traffic 2019	Passenger traffic 2020
Port of Livorno	Italy	790,000	711,000	745,500	13,426,000	467,889	723,000	567,000	5,547,000	4,503,000	832,121	1,436,000
Port of Barcelona	Spain	3,300,000	3,000,000	2,033,500	3,292,000	2,562,000	4,071,000	4,013,000	12,862,000	12,862,000	4,628,562	857,966
Port of Bari	Italy	86,087	n/a	20,000	2,791,000	1,629,000	2,404,000	3,511,000	300,000	29,000	n/a	n/a
Port of Napoli	Italy	681,929	643,540	532,500	4,162,000	2,384	1,247,000	1,104,000	6,321,000	6,507,000	5,993,000	2,908,151
Port of Venice	Italy	547,563	n/a		2,185,000	1,153,000	10,460,000	4,953,846	8,448,000	8,566,470	1,400,000	1,230,000
Port of Klaipeda	Lithuania	705,222	n/a	373,260	1,750,000	1,839,000	20,667,000	23,671,000	10,400,000	9,058,000	n/a	n/a
Port of Genoa	Italy	2,175,615	2,500,000	1,800,000	5,993,000	6,834,000	1,279,000	923,000	15,835,000	10,231,000	n/a	1,500,000
Port of Koper	Slovenia	959,356	945,051		705,993	617,157	7,898,810	5,933,022	4,307,388	3,323,068	n/a	n/a
Port of Rotterdam	Netherlands	14,810,040	14,349,446	10,000,000	24,300,000	24,000,000	105,286,000	793,761,000	211,211,000	191,986,000	n/a	n/a
Port of Aberdeen	Scotland	2,418	n/a	27,000	15,000	n/a	491,000	n/a	2,198,000	n/a	n/a	n/a
Port of Bergen	Norway	36,823	40,671	101,000	168,000	101,000	2,297,000	2,155,000	40,522,000	55,582,000	157,000	66,000
Port of Civitavecchia	Italy	144,936	106,305	33,540	5,154,000	3,206,000	2,203,000	2,295,000	784,000	836,000	n/a	n/a
Port of Mytilene	Greece	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	321,000	200,000
Port of Valencia	Spain	5,420,777	5,413,000		1,532,000	898,000	2,190,000	1,859,000	3,120,000	2,673,000	557,000	393,000
Port of London Authority	UK	1,730,996		2,000,000	7,708,000		15,141,000		14,561,000	11,700,000		
Port of Aalborg	Denmark	62,549			55,000		1,331,000		1,000,000			
Port of Adamas	Greece											
Port of Algeiras	Spain	5,125,385			1,250,000		848,000		30,703			
Port of Amsterdam	The Netherlands	50,736			630,000		44,524,000		49,904			
Port of Ancona	Italy	212,444		110,000	2,697,000		470,000		119,000			
Port of Antwerp	Belgium	11,676,025		8,664,000	6,353,000		13,729,000		71,089			
Port of Bar	Montenegro								300			
Port of Bilbao	Spain	628,413			458,000		4,681,000		20,821			
Port of Bordeaux	France	30,643					1,444,000		4,727			
Port of Bremen	German	7,192			35,000		6,823,000		1,720			
Port of Cartagena	Spain	67,606			79,000		6,836,000		25,982			
Port of Cava	Spain											
Port of Copenhagen	Denmark	139,365			233,000		1,845,000		2,844			
Port of Den Helder	The Netherlands								265,000			
port of Den Oever-Hollands Kroon	The Netherlands											
Port of Dover	UK	26,917			22,998,000		41,000					
Port of Durres	Albania											
Port of Esbjerg	Denmark	27,740		238,000	1,790,000		1,121,000		540			
Port of Felixtowe	UK	3,838,252		3,200,000	3,581,000				45			
Port of Gandia	Spain											
Port of Gävle	Sweeden	176,816					989,000		1,453			

Port	Country	Containers (TEUs) 2019	Containers (TEUs) 2020	Containers (TEUs) annually	Ro/Ro-cars (tons) 2019	Ro/Ro-cars (tons) 2020	Dry bulk cargo (tons) 2019	Dry bulk cargo (tons) 2020	Liquid bulk (tons) 2019	Liquid bulk (tons) 2020	Passenger traffic 2019	Passenger traffic 2020
Port of Gdynia	Poland	876,958					7,356,000		2,499			
Port of Gothenburg	Sweeden	762,902			8,988,000		57,000		22,311			
Port of Hamburg	Germany	9,281,987			469,000		28,139,000		12,405			
Port of Helsinki	Finland	495,058							138			
Port of Heraklion	Greece	21,887					273,000		107			
Port of Hirtshals	Denmark				1,704,000							
Port of Huelva	Spain	71,852			222,000		5,756,000		26,696			
Port of Igoumenitsa	Greece											
Port of Ipswich	UK						2,043,000		112,000			
Port of Kapellskär	Sweeden				2,646,000							
Port of Kiel	Germany	24,38			2,713,00				50,000			
Port of Le Havre	France	2,762,733			844,000		1,224,000		36,131,000			
Port of Leith	Scotland											
Port of Liverpool	UK	885,481			7,768,000		7,345,000		11,926,000			
Port of Magdeburg	Germany											
Port of Malmo	Copenhagen	18,248			4,297,000		577,000		2,252,000			
Port of Marseille	France	1,454,626			2,490,000		13		12,595,000			
Port of Monfalcone	Italy	319			590,000		3,725,000					
Port of Nakskov	Denmark											
Port of Oostende	Belgium			304,500			0		182,000			
Port of Piombino	Italy	71			513,000		2,641,000		132,000			
Port of Ploče	Croatia	33,955							774,000			
Port of Ravenna	Italy	246,983		207,000	2,739,000		15,793,000		7,970,000			
Port of Rijeka	Croatia	287,919			4,000		198,000		1,000			
Port of Santander	Spain	14,316			1,384,000		3,647,000		324,000			
Port of Sevilla	Spain	137			104,000		2,294,000		293,000			
Port of Shoreham	UK						1,565,000		63,000			
Port of Southampton	UK	1,879,606		1,350,000	1,822,000		2,087,000		20,113,000			
Port of Stockholm	Sweeden	61,639		27,840	2,451,000		921,000		347,000			
Port of Szczecin	Poland	76			8,000		4,999,000		1,417,000			
Port of Tallinn	Estonia	222,584			5,365,000		4,516,000		7,367,000			
Port of Tarifa	Spain											
Port of Thessaloniki	Greece	618,816			28,000		3,914,000		6,618,000			

Port	Country	Containers (TEUs) 2019	Containers (TEUs) 2020	Containers (TEUs) annually	Ro/Ro-cars (tons) 2019	Ro/Ro-cars (tons) 2020	Dry bulk cargo (tons) 2019	Dry bulk cargo (tons) 2020	Liquid bulk (tons) 2019	Liquid bulk (tons) 2020	Passenger traffic 2019	Passenger traffic 2020
Port of Trieste	Italy	917,866			3,108,000		4,301,000		39,882,000			
Port of Valetta	Malta	2,835			714,000		787,000		8,000			
Port of Venlo	Netherlands											
Port of Vienna	Austria											
Port of Vigo	Spain	181,310			982,000		298,000		47,000			
Port of Vlissingen	Netherlands											
Portsmouth Port	UK	67,022			2,635,000		405,000					
Trondheim Port Authority	Norway	13,864			43,000				769,000			
Port of Riga	Latvia	472,489			142,000		20,103,000		3,747,000			
Port of Wilhelmshaven	Germany	640,667					2,942,000		20,153,000			
Port of Santa Cruz	Spain	373,830		230,100	2,339,000		422,000		4,811,000			

Table 25. Data sources and descriptive notes

Port	Country	Reference	Notes
Port of Livorno	Italy	https://shipnext.com/port/livorno-itliv-ita	The Port of Livorno handles all types of vessels and cargoes including lift-on/lift-off, roll-on/roll-off, liquid and dry bulk, and passengers. The port is divided into four main parts. Avamporto, Bacino San Stefano, Canale Industriale with its adjoining basins and Porto Vecchio. The approaches are protected by a curved sea wall, with the entrance to the S used by commercial shipping. The port, with 11,000m of quays and 90 berths, handles bulk raw materials to service the heavy industries of the city, which includes ship building and repair. There is a large oil refinery close N of the city.
Port of Barcelona	Spain	https://shipnext.com/port/barcelona-esbcn-esp	The port is formed by breakwaters, the main breakwater running N to S with a total length of over 4,230m. This provides protection against SE'ly gales. The secondary breakwater runs E to W and is about 510m in length. The water area of the harbour is over 18,000,000m ² and the total length of quayage is over 22km.

Port	Country	Reference	Notes
Port of Bari	Italy	https://shipnext.com/port/bari-itbri-ita	The port is sheltered by two breakwaters which can accommodate vessels and tankers loading and discharging. The port is equipped for every type of commercial traffic liquid and solid bulk cargoes, containers, packaged goods, iron and steel products, forestry products and passengers (ferry terminal and cruise terminal). Principal imports include crude oil, bulk chemicals, grain, iron and steel products, timber, livestock, raw hides and general cargo. Exports include oil products, wine, vegetable oils, processed fruit, cement and almonds.
Port of Napoli	Italy	https://shipnext.com/port/naples-itnap-ita	Naples is one of Italy's five main multi function ports and the second largest port in the country. It is an important centre of industry, commerce and tourism. The port has a naval dockyard and an important shipbuilding and repair industry. Of the cargoes, oil and its derivatives make up one third of Naples trade, with foodstuffs, manufactured goods, cars, chemicals, paper, textiles, fruit and vegetables and containers. The harbour service area is 1,355,000m ² with quays extending for a total length of 14km with 70 berths ranging in depth between 10.0-15.0m.
Port of Venice	Italy	https://shipnext.com/port/venice-itvce-ita	Venice is a natural harbour sheltered within a large lagoon. There are two approaches to Venice port , the main port entrance for passenger and ferry vessels is via S Nicolo di Lido, whereby vessels reach the Marittima Cruise Centres, Santa Marta, San Basilio and also through the basin of St Mark and Giudecca Canal to Porto Marghera, the commercial and industrial Port
Port of Klaipeda	Lithuania	https://shipnext.com/port/klaipeda-ltklj-ltu	The Port of Klaipeda is the largest port in Lithuania and the second largest in the Baltic among the European Union ports. The port caters to both cruise ships and freight transport and is equipped to handle most types of moderate to large-sized vessels for bulk liquids, raw products, containers, and general cargo. It remains open throughout the year and can handle fully loaded Panamax tankers

Port	Country	Reference	Notes
Port of Genoa	Italy	https://shipnext.com/port/genoa-itgoa-ita	Port of Genoa is a one-stop multi-purpose seaport with over 20 private terminals that can accommodate any type of vessel and cargo. Cargoes handled in the Port of Genoa include containers, general cargo, liquid and solid bulk, metals, forestry products, perishable goods, petroleum products. In addition it is a major cruise ship and ferry port
Port of Koper	Slovenia	https://shipnext.com/port/koper-sikop-svn	The Port of Koper is Slovenia's largest container port and main Port of Entry. The port serves as a gateway between the markets of Central and Southeast Europe, the Mediterranean Sea and the Far East. The port is well-positioned and provides safe berthing for vessels.
Port of Rotterdam	Netherlands	https://shipnext.com/port/rotterdam-nlrm-nld	The Port of Rotterdam covers a total area of over 10.5 thousand hectares (26 thousand acres), including 5.1 thousand hectares of industrial sites and 5.5 thousand hectares of infrastructure and water surface. The port is 40 kilometers (25 miles) long and contains 89 kilometers (55 miles) of quays and 1500 kilometers (932 miles) of pipelines. When Maasvlakte 2 is completed, the port area will grow by 20%.
Port of Aberdeen	Scotland	https://shipnext.com/port/aberdeen-gbabd-gbr	Aberdeen lies at the S end of Aberdeen Bay, at the mouth of the River Dee on the E coast of Scotland. General overview: Aberdeen has over 5km of modern berthage, easily accessible at all states of tide (according to draught). Aberdeen is a well equipped port and the premier offshore support harbour in Europe, with nine specialist offshore service bases. Imports: Woodpulp, pipes, dry and liquid bulk, animal feed, oil well equipment and petroleum products. Exports: Paper, potatoes, grain, pipes and oil well equipment.
Port of Bergen	Norway	https://shipnext.com/port/bergen-nobgo-nor	The Port of Bergen is well equipped to handle all types of vessels in its well sheltered harbor, which is open year-round. The port home to major offshore oil field support facilities within the harbor district.

Port	Country	Reference	Notes
Port of Civitavecchia	Italy	https://shipnext.com/port/civitavecchia-itcvv-ita	Civitavecchia, known as the seaport of Rome, consists of various basins protected by a long outer mole called Antimurale Colombo on the middle part of which is located the cruise vessel Pier No 12. The port offers a safe, sheltered harbour with numerous facilities for general and bulk cargo, oil products and passengers. Port Civitavecchia has a total of 8 cruise terminals, with 15 berths/quays. Cruise ships dock on the Northwest edge of the town at the Rome Cruise Terminal. A second terminal, the ADM, is for ferries and other shipping services. Besides serving cruise ship lines, there are also ferries embarking to Sardinia, Sicily, Malta, Tunis and Barcelona.
Port of Mytilene	Greece	https://shipnext.com/port/mitylene-grmjt-grc	The port consists of an outer and an inner harbour, sheltered by a 396m length breakwater. Bulk and general cargoes are handled and there are tanker berths to the S. The principal exports are olive oil, soap, tobacco, balsams, sulphur, figs and valonia. Skala Pamfilon tanker berth lies 6km to the N of Mitylene.
Port of Valencia	Spain	Break BulkContainerLiquidDry BulkPassengerDry DockLPGBunkeringMultipurposeRo-Ro	
Port of London Authority	UK	https://www.pla.co.uk/Media-Centre/Annual-Report-and-Accounts-2022#performance	
Port of Aalborg	Denmark	https://shipnext.com/port/aalborg-dkaal-dnk	
Port of Adamas	Greece	https://shipnext.com/port/581fc06054e6080aa866a7df	Adamas is a subport of Milos Island. Cargoes are mainly volcanic mineral ores for export, general and passengers. Ferry services to Peiraias and Kamarai. Port Adamas is served by regularly scheduled ferries (from Piraeus-Athens) operated by MINOAN LINES, ANEK Lines, Zante Ferries, Aegean Speed Lines and Seajets. In Adamas docking is possible for some 40 boats over 30 ft. Ferries and most cruise ships to Milos Island dock (anchor) at Adamas. Smaller ships may stop at Pollonia (on the island's north coast). S&B loads bulk ore at both the Adamas and Voudia Bay facilities by conveyor belt and loader at max. loading rate 500 tonnes/hr.

Port	Country	Reference	Notes
Port of Algeciras	Spain	https://shipnext.com/port/algeciras-esalg-esp	Algeciras is an important centre for handling international transshipments and direct container cargoes, also a terminus for the busy ferry and Ro-Ro traffic between Spain and North Africa. Petroleum products are handled at the oil refinery and associated SBM at the head of the bay where the largest tankers afloat can be handled. The ports of Campamento, Endesa and Tarifa are sub ports of Algeciras. Development work is continuing at Campamento port and Isla Verde Container Terminal.
Port of Amsterdam	The Netherlands	https://shipnext.com/port/amsterdam-nlams-nld	The main imported goods entering this port are grains, ore, coal, fertilizers, crude oil, cocoa powder, coffee, paper, machinery, chemicals and groceries, etc. The principal exported goods leaving this port include coke, oil, wheat, fertilizer, metal utensils, transportation equipment, chemical products, and meat.
Port of Ancona	Italy	https://shipnext.com/port/ancona-itaai-ita	The port covers a total area of 1.4 million square meters, divided into passenger and ferry terminals, container terminals and plants for solid bulk. It has a strategic function in the Adriatic-Ionian Macro Region, as a terminal for international ferry lines to Greece, Croatia, and Albania. Regularly-scheduled cruise ferries link Ancona with Croatia (Split, Zadar, Hvar Island), Albania (Durrës), Greece (Patras, Igoumenitsa, Corfu), Italy (Venice). Among the largest ferry companies are SNAV, Adria Ferries, Minoan Lines, Anek Superfast, Jadrolinija (Croatia). The principal commodities handled are logs, timber, wood pulp, china clay, steel coils and pipes, iron scraps, coal, grains (soybeans, maize, wheat, barley, broad beans, etc), cement, trucks and trailers by Ro-Ro, containers, vegetable oil. The entrance is N of a breakwater and shoaling may, in some instances, make towage advisable. Heavy winter seas can make the more exposed parts of the port unworkable. Vessels using the tanker facilities may proceed to Falconara Terminal (approximately 8km NW), directly following pratique clearance.

Port	Country	Reference	Notes
Port of Antwerp	Belgium	https://shipnext.com/port/antwerp-beanr-bel	Antwerp is a municipal port with cargo handling by private firms. An important multi-product industrial port covering an area of over 13,000ha with over 530ha of covered storage areas. The older part of the port has been made accessible for Panamax vessels. Cargoes include: Petroleum products, ores, coal, steel products, crude oils, cereals, fertilizers, paper and cellulose, sugar and fruit. The port has seen rapid expansion with new, non-tidal, terminals being built to the N and W on the Schelde River.
Port of Bar	Montenegro		

Port	Country	Reference	Notes
Port of Bilbao	Spain	https://shipnext.com/port/bilbao-esbio-esp	Covering 350 hectares of land and almost 2 hectares of water surface, the port contains 17 kilometers of docks, 252 hectares of open storage, 30 thousand square meters of covered storage, and 25.3 thousand square meters of cold storage. It also has five roll-on/roll-off ramps and terminals for containers, solid and liquid bulks, forest products, vehicles, general cargoes, and passengers. There are six clearly defined dock areas: ● Zorroza Wharves: The bottom at Zorroza is soft mud and vessels can lie safely aground, bottom at Canal de Deusto is rocky. Restriction: LOA 135m, draught approx 5.5m. ● Nervion Riverside wharves: On both banks of the river, they are mostly private berths, the bottom is soft mud. Restrictions: LOA 150m, draught varies according to berth. ● Santurtzi-Zierbena area wharves: Located in the outer harbour adjacent to the new breakwater of 3,100m, and the Santurtzi Secondary breakwater of 1,200m. Draught varies from 7.0m, 12.0m, 14.0m in the old area, and 21.0m in the new one for bulk carriers, container ships, general cargo etc. Vessels of LOA 300m, draught of 20.0-21.0m can be accommodated at four berths. Just in front of this area a new cruise ship berth is built with a draught of 11.0m. ● Punta Sollana Wharf: Length 390m, draught 20.0m, is destined to bulk carriers with seeds of grain unloading installations, and to vegetable oil tankers. ● Punta Ceballos area: Draught 18.0m; has bulk liquid loading and unloading installations for gas-oil, petrol and chemical products. ● Punta Lucero area: Has crude oil, petroleum distillates, bulk liquid, loading and discharging and LNG installations. There is also a new wharf for LNG ships up to LOA 290m, draught 21.0m, 145,000m³. Principle imports are crude oil, LNG, iron ore, pyrites, scrap iron, pig-iron, coal, grain and soya beans; principal exports petroleum, iron and steel products.

Port	Country	Reference	Notes
Port of Bordeaux	France	https://shipnext.com/port/bordeaux-frbod-fra	The port comprises 6 terminals along the 100km estuary of the Gironde River as follows: 1. Le Verdon (containers/timber) 2. Pauillac (oil/timber) 3. Blaye (grain and chemicals) 4. Ambes (oil and chemicals) 5. Bassens (grain, bulk cargoes, containers, timber) 6. Bordeaux (cruise ships). The total length of berthage offered by the port is 9,681m. Main imports are refined products and main exports are cereals. Traffic figures: Approx 8,700,000t of cargo, 65,220TEU, 16,270 passengers and 1,300 vessels handled annually.
Port of Bremen	German	https://shipnext.com/port/bremen-debre-deu	The port has excellent communication links with the N European hinterland. The port handles conventional general cargo, containers, vehicles, fruit, dry and liquid bulk cargoes. It has comprehensive ship repair and warehousing facilities. In addition there is a free-port area.
Port of Cartagena	Spain	https://shipnext.com/port/cartagena-escar-esp	The port is situated in a natural harbour, which is entered from the S, entrance width 250m and depth 12.5m. The water area included within the limits of the harbour is approx 5.2ha. The port consists of the Cartagena basin and the eastern Escombreras basin. Cartagena is a major naval, commercial and fishing port with modern facilities for handling all types of vessels. The port mainly handles containers, fruit, vegetables, general cargo and cruise passengers. Escombreras handles solid bulk (grain, ore, cement, clinker and fertilizers) and liquid bulk (LNG, LPG, chemicals, crude oil and refined oils).
Port of Cava	Spain		

Port	Country	Reference	Notes
Port of Copenhagen	Denmark	https://shipnext.com/port/copenhagen-dkcph-dnk	Copenhagen is located on the E coast of Sjaelland and the harbour is formed by a branch of the Sound that runs between the islands of Amager and Sjaelland. General overview: Copenhagen has merged with the port of Malmo to create Copenhagen Malmo Port (CMP). The port handles a wide variety of cargoes and comprises 3 sections; The North Harbour, The Inner Harbour and The Provstenen Harbour. Copenhagen's Free Port is located in the North Harbour. The port extends to 1,108ha with a land area of 413ha and a total quayage length of 39,651m. Traffic figures: Combined total for Copenhagen and Malmo: Approx 8,000 vessels, 15,000,000t of cargo, 153,000TEU and 829,000 passengers handled annually. Load line zone: Summer Zone for ships over 100m in length and Winter Zone for ships of 100m or less in length. Winter Nov 1 to Mar 31, Summer Apr 1 to Oct 30. Max size: Provstenen Harbour: Draught 11.5m.
Port of Den Helder	The Netherlands	https://shipnext.com/port/den-helder-nldhr-nld	Chief role is as a supply centre for North Sea oil and gas platforms and also as a Naval Base and Fish Auction. It provides good shelter, at anchorage and in the harbour especially during bad weather, and is a port of call to many fishing vessels. Cargoes handled include construction material, fuel, wood products and fish. The port handles mainly Ro-Ro, passengers, offshore and breakbulk cargo. Den Helder is also the main base of the Royal Netherlands Navy. Other facilities are available for fishing boats, leisure craft and inland cargo vessels
port of Den Oever-Hollands Kroon	The Netherlands		

Port	Country	Reference	Notes
Port of Dover	UK	https://shipnext.com/port/dover-gbdvr-gbr	The port of Dover is located in the Dover Straits, in the English Channel. General overview: The port is divided into two halves, the Eastern Docks and Western Docks. The Eastern Docks comprise a car ferry terminal with eight Ro-Ro berths and three deep water general cargo berths. The Western Docks comprise a SeaCat Terminal, two small enclosed docks offering yacht berths and two dedicated purpose built cruise liner terminals. The port is synonymous with cross channel traffic and is the busiest international drive-on, drive-off terminal in the world. Ferries and SeaCats flow out of the port entrances on average every 20 minutes destined for, and returning from, three other major European ports. Dover is also Britain's premier S coast port for fresh produce and can handle a wide range of cargoes from a terminal at Eastern Docks. It is also one of Northern Europe's busiest cruise ports for turn round calls and is also a popular port of call for cruise vessels.
Port of Durres	Albania	https://shipnext.com/port/durres-aldrz-alb	Durres is situated approx 120nm E of Bari, Italy, across the Adriatic sea, at the N end of the Bay of Durres, an extensive body of water diving Kala e Turres and Cape Durres. General overview: Durres is the principal port of Albania, formed by two breakwaters which protect ten berths. Access to the port is via a 120m wide buoyed channel with a depth of approx 9.5m. Cargo includes general, bulk, breakbulk, palletised goods and containers. There are regular passenger/cargo ferry services to Bari, Ancona and Trieste. There has recently been substantial redevelopment with new berths still under construction. Traffic figures: Approx 603,000t of cargo and 770,800 passengers handled annually. Load line zone: Summer. Max size: LOA 220m, draught 10.0m, approx 20,000DWT

Port	Country	Reference	Notes
Port of Esbjerg	Denmark	https://shipnext.com/port/durres-aldrz-alb	Durres is situated approx 120nm E of Bari, Italy, across the Adriatic sea, at the N end of the Bay of Durres, an extensive body of water diving Kala e Turres and Cape Durres. General overview: Durres is the principal port of Albania, formed by two breakwaters which protect ten berths. Access to the port is via a 120m wide buoyed channel with a depth of approx 9.5m. Cargo includes general, bulk, breakbulk, palletised goods and containers. There are regular passenger/cargo ferry services to Bari, Ancona and Trieste. There has recently been substantial redevelopment with new berths still under construction.
Port of Felixtowe	UK	https://shipnext.com/port/felixstowe-gbfx-uk	Felixstowe's excellent road/rail communications together with modern and fully equipped cargo handling facilities has made it the UK's premier container port. Major redevelopment is under way at the port. Phase 1 of Felixstowe South Project has been completed giving two new deep water berths, Nos 8 and 9, which can handle the world's largest container vessels. Phase 2 is for a third deep water berth to be constructed at the Landguard Terminal. There are also two Ro-Ro and seven deep water container berths.
Port of Gandía	Spain	https://shipnext.com/port/gandia-esgan-esp	Gandia is a Mediterranean Sea port on Spain's southeastern coast which has suffered a great development in recent years growing considerably. The harbor area also can be divided into the area of the fishing port, marina and commercial port. The port has a water area of 30ha, with an entrance depth of 9.0m. The wharf is protected by a breakwater. The Port of Gandia handles general conventional cargo and specialises in the movement of goods such as reels of paper and pulps, timber imports and local agricultural products. It has an annual traffic capacity of 1.5 % of the entire port of Valencia
Port of Gävle	Sweeden	https://shipnext.com/port/gavle-segvx-swe	Gavle sometimes known as Gefle, is located in the Gulf of Bothnia. General overview: The port is a modern and expanding harbour which remains open all year round, with the aid of ice breakers from Jan-Mar. The Oil jetty at Karskar is under separate entry. Cargoes handled: Ore, oil, scrap metal, china clay, forest products, containers and steel.

Port	Country	Reference	Notes
Port of Gdynia	Poland	https://shipnext.com/port/gdynia-plgdy-pol	The Port of Gdynia is a modern, large port in the Baltic Sea that operates year-round and is free of ice and tides. It is protected by 2.5km-long breakwaters and has excellent rail and road connections. The port is capable of handling a wide range of cargo, including general, dry and liquid cargoes, grain, coal, and vehicles. It is also the largest container port in Poland.
Port of Gothenburg	Sweden	https://shipnext.com/port/gothenburg-segot-swe	Gothenburg is situated on the W coast of Sweden. General overview: The port is the largest port in the Nordic countries. About two thirds of the tonnage is oil, Torshamnen being the crude oil terminal and Ryahamnen and Skarvishamnen handle the smaller tankers, LPG, chemical and bunker vessels. Both crude and refined products are handled by three refineries with a combined output capacity of more than 10,000,000t annually. The port is also the central Nordic port for liner shipping with about 30% of its general cargo imports and exports being transit cargo to or from other Nordic countries. Direct calling deep sea container or Ro-Ro liners connect Gothenburg to all continents with their base at the Scandia Terminal. Ro-Ro ferry liner operations to Continental Europe and UK calls at the Alvsborg Terminal. The total complex of a unit load centre of 2,000,000m² with 2,500m of quay length and 11 container cranes including 2 post Panamax and 3 super post Panamax with a lifting capacity of 103t each. In addition, the port also has cruise liner facilities with berths dedicated to cruise vessels. The port is not hindered by ice and is open to navigation all year round. Traffic can also navigate the Gota River and via locks to Lake Vanern where channel depth is 6.1m.

Port	Country	Reference	Notes
Port of Hamburg	Germany	https://shipnext.com/port/hamburg-deham-deu	Germany's largest and most important port, with over 320 berths, handling a wide variety of cargoes and especially prominent in container and petroleum movements. The Port of Hamburg has several multi-purpose terminals in operation. These have specialized in cargoes of very different types: project cargo, heavy cargo, out-of-gauge loads, RoRo cargo, metals, forestry products, and citrus fruits – with a suitable handling company for every type of cargo. With the strongest port cranes in the Port of Hamburg, Wallmann & Co., C. Steinweg (Süd-West Terminal) and Rhenus Midgard can handle unit loads of up to just over 400 tons.
Port of Helsinki	Finland	https://shipnext.com/port/helsinki-fihel-fin	Helsinki is situated on the S coast of Finland at the mouth of the River Vantaa, in the Gulf of Finland. General overview: The Port of Helsinki is Finland's major foreign trade port and one of Europe's busiest passenger ports. Helsinki port is divided to the Passenger & Cargo Traffic. The Passenger section is connected to Stockholm, Tallinn & Travemünde. It consists of 6 terminals: - West Terminal 1 (No traffic at this time) - West Terminal 2 (Eckerö Line & Tallink Silja) Finland to Estonia - Katajanokka Terminal (Viking Line) Sweden and Estonia - Olympia Terminal (Tallink Silja) to Sweden - Makasiini Terminal (No traffic at this time) - Hansa Terminal (Finnlines) to Germany

Port	Country	Reference	Notes
Port of Heraklion	Greece	https://shipnext.com/port/5824972bc9c19c0be8d8cc1f	The port operates under the name of Heraklion Port Authority SA and consists of 2 areas, the small inner port and the new outer port. The Commercial port (New Outer) is protected by a 2,390 m. breakwater with entrance 250 m. wide. Vessels may berth alongside the north breakwater in depth up to 15.00 m. Old Enetic (Inner) Port: The port can handle vessels up to displacement 300 tons. The entrance is 50 m. wide, depth up to 4.00 m. and is mainly used by fishing boats, small craft and yachts. The ferry port of Heraklion connects the Greek island of Crete with the Greek mainland (Piraeus) and the islands of Halki, Crete, Mykonos, Ios, Thira, Tinos, Kos, Naxos, Karpathos, Rhodes, Syros, Milos, Anafi and Paros. There is a tanker CBM in Linoperamata Bay, to the W of main port. Exports include raisins, olive oil, wine, citrus, vegetables and fruit. Imports include cereals, machinery, timber and manufactured goods. Extensive storing areas are available for containers' terminal and for storage of general cargoes.
Port of Hirtshals	Denmark	https://shipnext.com/port/hirtshals-dkhir-dnk	Hirtshals is situated on the N coast of Jutland opening into the Skagerrak. General overview: The harbour is well protected and is a large fishing centre. Petroleum handling is also prominent. Traffic figures: Approx 1,270,000t of cargo and approx 1,400,000 passengers handled annually. Load line zone: North Atlantic Winter Seasonal Zone II, Winter Nov 1 to Mar 31, Summer Apr 1 to Oct 31. Max size: LOA 150m; draught 9.0m.
Port of Huelva	Spain	https://shipnext.com/port/huelva-eshuv-esp	The Port of Huelva's cargo docks have a total of three thousand meters of berths that include the Ingeniero Juan Gonzalo Wharf of 902 meters with alongside depth of 12 meters and the Northern Zone Wharf of 480 meters long with alongside depth of 13 meters that handle bulk and general cargoes. The Ingeniero Juan Lonzalo Wharf also has almost 20 thousand square meters of covered sheds and a warehouse zone of 95.7 thousand square meters

Port	Country	Reference	Notes
Port of Igoumenitsa	Greece	https://shipnext.com/port/58248d27c9c19c0be8d8cbf5	The port handles mainly ferry passengers. New berths are planned for construction and the port will be able to accept most types of cargo ships. Conventional or fast ferries operate to Ancona, Bari, Brindisi, Corfu, Venice and Trieste. The port is divided into 2 main areas, the central pier and the northern pier. The central pier at the port of Igoumenitsa serves international ferry connections and it is located on the south coast of the city. The northern pier of the port is located closer to the city center and to the central bus station of Igoumenitsa, and it serves domestic ferry lines. There are 18 quays at the port with the quay length of 1,197 m and 10,5 m depth.
Port of Ipswich	UK	https://shipnext.com/port/ipswich-gbips-gbr	The port has two container terminals and a Ro-Ro terminal, with frequent sailings to Ostend, also facilities for dry bulk and liquid cargoes. Container feeder services to Zeebrugge, Antwerp and Rotterdam also run on a regular basis. All quays are backed by hard standing for open storage, most types of cargo can be handled by arrangement. Imports include timber, aggregates, fertilisers and petroleum products. Main exports are grain and pulses.
Port of Kapellskär	Sweeden	https://shipnext.com/port/kapellskar-sekps-swe	Kapellskar is located on the E coast of Sweden, approx 40nm NE of Stockholm. General overview: Kapellskar is a cruise ferry port with a passenger terminal, 4 Ro-Ro ramps and large terminal areas for vehicles and freight
Port of Kiel	Germany	https://shipnext.com/port/kiel-dekel-deu	It is a natural harbour, usually ice free, specialising in Ro-Ro and cruise traffic. There are ship building and repair docks. The port of Kiel consists of the city ports (Schwedenkai, Sartorikai, Ostseekai and Norwegenkai), the Ostuferhafen, the canal ports (Nordhafen and Nordmole) as well as Kiel Airport. The largest coherent part of the port is situated on the east bank of the Kiel Fjord. This is where the ferry lines to Northern Sweden, Russia and to the Baltic States are concentrated. The city port is characterised by the ferries of the liner services to Scandinavia and the cruise ships

Port	Country	Reference	Notes
Port of Le Havre	France	https://shipnext.com/port/le-havre-frleh-fra	Le Havre is one of France's largest ports. Its ideal location and excellent communications links give good access to the European hinterland. Cargo handling facilities offered by the port are numerous and include general, ore and bulk cargo berths, tanker and liquefied gas terminals and specialised container and Ro-Ro berths. In addition, the port is benefited by extensive storage and warehouse facilities and is also a major centre for ship-repair. There are also cross channel ferry and cruise ship passenger facilities. Oil tankers with a draught of more than 21m sail to the port of Antifer, located 20km N of Le Havre in position 49°40.0'N 000°08.0'E, which can accommodate vessels up to 500,000DWT.
Port of Leith	Scotland	https://shipnext.com/port/leith-gblei-gbr	Leith is the port of Edinburgh, located on the S bank of the Firth of Forth on the E coast of Scotland. General overview: Leith is the largest enclosed deepwater port in Scotland and can handle handymax ships up to 50,000DWT. The port consists of 3 docks and a harbour area. These provide 4,700m of quayage and accommodation for tankers, general and bulk cargo, container and Ro-Ro vessels. Leith is also an important cruise destination.
Port of Liverpool	UK	https://shipnext.com/port/liverpool-gbliv-gbr	Liverpool is located at the mouth of the River Mersey on the W coast of England. General overview: The port which covers the Royal Seaforth Docks, Liverpool Docks, Birkenhead Docks and the Tranmere Oil Terminal has extensive cargo handling facilities within its numerous docks, basins and drydocks. Garston Docks are covered under separate entry. The port possesses over 47km of quayage which provide accommodation for tankers, general cargo, bulk cargo, container, Ro-Ro and cruise vessels.
Port of Magdeburg	Germany		
Port of Malmo	Copenhagen	https://shipnext.com/port/malmo-semma-swe	Malmo is located on the southern tip of Sweden at the entrance to the Baltic Sea, approx 14nm ESE of Copenhagen. General overview: Malmo has merged with the port of Copenhagen to create Copenhagen Malmo Port (CMP). Exports: General cargo, grain and grain products, macadam, scrap, cement and containers. Imports: Chemicals, oil products, general cargo, fertilisers, fruit, grain, coal, petcoke, steel products, raw sugar and cars
Port of Marseille	France	https://shipnext.com/port/monfalcone-itmnf-ita	

Port	Country	Reference	Notes
Port of Monfalcone	Italy	https://shipnext.com/port/monfalcone-itmnf-ita	Monfalcone is the northernmost port in the Mediterranean sea. The port, partly natural, and partly man made, has large and important industries including a large shipyard (which is perated by Fincantieri S.p.A.), the manufacture of soda and chemical products, the preparation of asphalt, and oil refining. Imports include coal, fuel oil, grain and wood. The majority of the traffic consists of bulk cargo and oil. The port is well connected to the rest of Italy via road and rail.
Port of Nakskov	Denmark	https://shipnext.com/port/nakskov-dknak-dnk	Nakskov is situated on the W coast of Lolland, at the end of Nakskov Fjord. General overview: The port is sheltered from all winds and is navigable day and night. Facilities are available for dry/bulk cargoes, general cargoes, Ro-Ro passenger/car ferries and liquid cargoes
Port of Oostende	Belgium	https://shipnext.com/port/ostend-beost-bel	Ostend is situated along the major shipping routes in Europe. It is located on the English channel coast of Belgium, close the border with The Netherlands.
Port of Piombino	Italy	https://shipnext.com/port/piombino-itpio-ita	Piombino is situated at the N end of the Gulf of Follonica between two seas (Ligurian and Tyrrhenian) facing Elba Island, south of Livorno.
Port of Ploče	Croatia	https://shipnext.com/port/ploce-hrple-hrv	Ploce is a natural port located on the E coast of the Adriatic Sea at the mouth of the Neretva River and approx 70km NW of Dubrovnik on the Dalmatian coast. The commercial harbour lies on the E side of the inlet.
Port of Ravenna	Italy	https://shipnext.com/port/ravenna-itrان-ita	The port of Ravenna has gradually developed 14km along the Corsini Port Canal, continuously expanding in its industrial and commercial importance. Two breakwaters, each 2.5km long, shelter the canal entrance through which most of the berths are reached. Other tanker berths exist to seaward, S of the entrance, the furthest being a SBM lying approx 9.5nm offshore. The port has 15 terminals and 9 coastal depots.

Port	Country	Reference	Notes
Port of Rijeka	Croatia	https://shipnext.com/port/rijeka-hrrjk-hrv	The port offers a sheltered harbour, protected by 2 breakwaters, with safe anchorage outside the harbour limits. The port handles a wide variety of cargo including, containers, ore, timber, grain, phosphate, crude and refined petroleum products. All types of vessels are handled at a total of 39 berths including tankers, bulk carriers, container carriers, general cargo, passenger and Ro-Ro vessels. The INA Oil Refinery has terminals at Urinj, Mlaka and Omisalj, all within the bay area. See separate entries for Omisalj Oil Terminal, Sepen Bay Petrochemicals terminal and Rasa port
Port of Santander	Spain	https://shipnext.com/port/santander-essdr-esp	The Port of Santander is located in the Bay of Santander on the south side of the Bay of Biscay on the northern coast of Spain
Port of Sevilla	Spain	https://shipnext.com/port/seville-essvq-esp	It is the only commercial river port in the country. The port is navigable as far as Seville for vessels with dimensions that can be accepted by the entrance lock. Vessels reported up to 6.5m draught can be handled, however draughts are affected by frequent floods. The bottom of the river is sand and sludge. The port handles many types of cargo and is the main link in the transport chain between the Canary Islands and mainland Spain
Port of Shoreham	UK	https://shipnext.com/port/shoreham-gbsho-gbr	Shoreham is located on the S coast near Brighton within 88km of London. General overview: A general cargo and small bulker port with many private wharves handling their own cargoes for vessels of 3,500-8,000DWT range according to port location. Third party traffic is handled by port's own and private stevedoring companies. The port works on a tidally restrictive basis with access for commercial ships 7 hours on each high tide dependent on draught
Port of Southampton	UK	https://shipnext.com/port/southampton-gbsou-gbr	Southampton is located in the Solent on the English S coast. General overview: Facilities comprise 2 dock basins and extensive river quays providing a total berthage in excess of 12km. Accommodation exists for a wide variety of vessels including dry bulk, Ro-Ro, container, passenger, reefer and general cargo ships. Tanker facilities are available at the Esso Oil Terminal Fawley and at BP Oil Hamble.
Port of Stockholm	Sweedan	https://shipnext.com/port/stockholm-sesto-swe	Stockholm is situated on the E coast of Sweden. General overview: The quays, which includes 10 cruise berths, have a total length of 16km extending approx 10km from W to E. The area of the harbour is approx 1,750ha.

Port	Country	Reference	Notes
Port of Szczecin	Poland	https://shipnext.com/port/szczecin-plszz-pol	The Port of Szczecin is situated at the mouth of the River Odra, approximately 65km inland from Swinoujscie and the open sea
Port of Tallinn	Estonia	https://shipnext.com/port/tallinn-eetll-est	Tallinn, the capital of Estonia is situated on the S coast of the Finnish Gulf in the Baltic Sea. General overview: The Tallinn Port Authority is responsible for the following five constituent harbours, Vanasadam (Old City Harbour), Palijsaare Harbour (located 6km W of Old harbour in Tallinn Bay), Paldiski South Harbour (located 50km W of the city), Muuga Harbour (located 17km E of the city) and Saaremaa (located 135nm SW of Tallinn)
Port of Tarifa	Spain	https://shipnext.com/port/5829f44c5baa9509b886edd7	The harbour of Tarifa is situated at the entrance to the Strait of Gibraltar, 20 miles SE of Barbate and 15 miles SW of Gibraltar. The harbour lies 0.75 miles NNE of the tip of the island.
Port of Thessaloniki	Greece	https://shipnext.com/port/thessaloniki-grskg-grc	The port is a Free Zone and serves the transit trade of Central and SE Europe. The port is operated by ThPA S.A. All quays are connected to the European Railway network. The main cargoes handled are grain, iron, tin, rice, tobacco, ores, minerals, fertilisers, timber, cement, chemicals, crude oil and refined products
Port of Trieste	Italy	https://shipnext.com/port/trieste-ittrs-ita	Most of the port is a free port area, which is divided into 5 zones: The Old Free Zone, New Free Zone and Timber Terminal are all devoted to commercial activities, while the Mineral Oils Free Zone and the Zaule Canal Free Zone are devoted to industrial activities. There is a total quayage of 12,128m, with 47 operational berths
Port of Valetta	Malta	https://shipnext.com/port/valletta-mtmla-mlt	
Port of Venlo	Netherlands	https://shipnext.com/port/venlo-nlven-nld	Venlo is strategically located in the east of the Netherlands along the border with Germany in the N of the province of Limburg; it is approximately 150 km from both the ports of Rotterdam and Antwerp and only 50 km from Europe's largest inland port Duisburg
Port of Vienna	Austria	https://shipnext.com/port/vienna-usvmd-usa	

Port	Country	Reference	Notes
Port of Vigo	Spain	https://shipnext.com/port/vigo-esvgo-esp	The Vigo Estuary is protected by Cies Isles and the Morazo Peninsular. Vigo is the base for the big fishing companies which have prominent presence in countries such as Namibia, South Africa, Mozambique, Australia, Argentina, the Falkland Islands, Chile and Peru, among others. The port of Vigo is divided into four main areas; the passenger terminal, the fishing port, the Ro-Ro terminal and the commercial port, linked by feeder lines with Algerian, Rotterdam and Felixstowe ports
Port of Vlissingen	Netherlands	https://shipnext.com/port/vlissingen-nlvli-nld	Vlissingen, also known as Flushing, is close to the town and has two port areas. Vlissingen Town, the old port is partly situated behind locks which permits vessels with a LOA of less than 140m access to the inner docks. Flushing-East or Vlissingen-Oost, the new port area located in the deep water area of the River Scheldt, is a tidal harbour and industrial area with direct access to the open sea. There is an LPG terminal, a coal transshipment terminal, a tanker terminal, Ro-Ro and container facilities.
Portsmouth Port	UK	https://shipnext.com/port/portsmouth-united-kingdom-gbpme-gbr	Portsmouth is located on the S coast of England, in the Solent. General overview: The port is the second busiest cross channel ferry with expanding Continental Ferry Port consisting 5 Ro-Ro and passenger berths. In addition, there are a number of commercial wharves handling general cargo, containers, Ro-Ro cargo, and fuels which are handled by various operators. There are regular freight and passenger services to the Isle of Wight, the Channel Islands, France and Spain. Foreign trade consists of imports of fruit and vegetables from the continent and Mediterranean and bananas from South America. There is also a large Naval base with repair and drydock facilities.
Trondheim Port Authority	Norway	https://shipnext.com/port/trondheim-notrd-nor	The Port of Trondheim is located in Trondheim municipality, Trøndelag county, on the banks of the River Nidelva, and is approx. 497km north of Oslo
Port of Riga	Latvia	https://shipnext.com/port/riga-lvriv-lva	The Port of Riga is situated on the Baltic Sea at the mouth of the River Daugava. General overview: The Port of Riga is a significant manufacturing and commercial center in Latvia, with a berth length of 13,818m that can accommodate almost all types of vessels and cargoes, including coal, containers, timber, oil, Ro-Ro, and cruise vessels. It is a vital transit hub for cargo to and from the CIS.

Port	Country	Reference	Notes
Port of Wilhelmshaven	Germany	https://shipnext.com/port/wilhelmshaven-dewvn-deu	Wilhelmshaven is located in the NW of Germany, is situated between the rivers Ems and Weser, on the western banks of the Jade delta, in the SE part of the North Sea. General overview: Wilhelmshaven is the only German deepwater port and has the largest import terminal for crude oil, a significant transfer terminal for mineral oil, coal and chemical products
Port of Santa Cruz	Spain	https://shipnext.com/port/santa-cruz-de-tenerife-essct-	

ANNEX II: Association matrix of environmental aspects and impacts

Port operations		Environmental aspects																																					
		Emissions to air							Emissions to Water				Releases to land & water	Use of raw materials and natural resources										Energy emitted			Waste generation		Use of space		Biodiversity & Ecosystem								
		Emissions of NOx, SOx,	Emissions of CO2	Emissions of VOCs	Odours and smells	Emissions of dust	Emissions of particulates	Welding gases	Refrigeration gases	Discharge to surface water	Emissions to water sediments	Emissions to groundwater	Discharge to sewer	Leaks & spills	Chemicals use and storage	Use of raw materials	Use of consumables	Use of water	Use of bulk fluids	Use of recyclables	Use of electricity	Use of natural gas	Use of diesel/ gasoline/ other fuels	Use of plastics	Hazardous products	Use of compressed air	Noise emissions	Underwater noise emissions	Vibration emissions	Generation of hazardous waste	Generation of non hazardous waste	Generation of inert waste	Port development (land)	Port development (sea)	Changes in marine habitats	Changes in terrestrial habitats	Change in topography (seafloor, land)	Alteration of water currents	Invasive species
Waterside operations	Vessel arrival / departure	x	x			x	x			x				x	x		x	x			x	x				x	x	x	x	x	x				x		x	x	x
	Anchoring	x	x				x													x	x						x	x											
	Pilotage	x	x				x													x	x						x	x											
	Towage	x	x							x										x	x							x	x										
	Mooring	x	x				x			x	x			x				x		x	x					x	x	x			x	x	x		x		x		
	Berthing	x	x				x			x	x			x				x		x	x					x	x			x	x	x		x		x			
	Bunkering	x	x	x						x	x			x	x		x	x	x						x							x	x						
	Dredging (and disposal of dredged material)	x	x				x	x		x	x									x							x	x	x					x	x	x	x		
Ship waste receipt		x	x			x		x						x						x											x	x	x	x					
Intra-terminal operations	Ship unloading/ loading	Break bulk	x	x			x			x				x		x			x	x							x	x	x			x							
		Dry Bulk	x	x				x	x					x				x			x						x	x									x		
		Liquid Bulk	x	x	x									x	x					x							x	x											
		Container	x	x				x						x						x							x	x	x										
		Roll-on-roll-off	x	x																							x	x											
	Cargo handling and storage	Break bulk	x	x				x							x						x							x											
		Dry Bulk	x	x				x	x						x						x							x											
		Liquid Bulk	x	x	x				x						x	x					x																		
		Container	x	x					x						x						x							x											
		Roll-on-roll-off	x	x					x												x							x											
	Passenger embarkation / disembarkation		x	x																x	x							x	x	x									
Transfer of passengers to exit / control area		x	x											x						x	x						x												
Customs control																				x	x																		
Landside operations	Terminal gate operations		x	x			x	x	x						x				x	x								x											
	Hinterland transport operations (road, rail, IWT, pipeline)		x	x	x		x	x	x							x				x	x							x	x										
	Dry port operations (i.e., extended gate concept)		x	x				x	x						x	x	x	x	x			x	x						x	x									
Other operations	Ship building, repair and maintenance		x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	Industrial activities		x	x	x		x	x	x					x	x	x	x	x	x	x	x	x	x	x	x	x	x												
	Clean and renewable energy production		x	x				x												x	x																		
	Product consolidation and value-added activities		x	x																																			

ANNEX III: Comparative overview of port-related emissions by case

TITLE: Hazardous substances in the sediments and their pathways from potential sources in the eastern Gulf of Finland

AUTHORS: Ivan Kuprijanov, Germa Vali, Andrey Sharov, Nadezhda Berezina, Taavi Liblik, Urmas Lips, Natalja Kolesova, Jaakko Maanio, Ville Junttila, Inga Lips

KEY WORDS: Organotins, PAHs, Heavy metals, Simulated accumulation, Baltic Sea

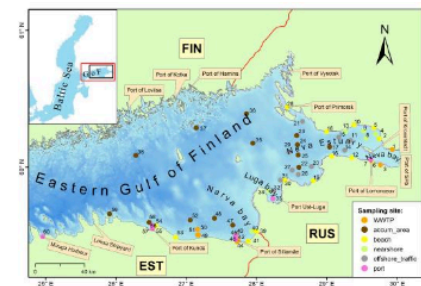
PUBLICATION YEAR: 2021

JOURNAL: Marine Pollution Bulletin

ABSTRACT: Contamination by hazardous substances is one of the main environmental problems in the eastern Gulf of Finland, Baltic Sea. A trilateral effort to sample and analyse heavy metals (HMs), polycyclic aromatic hydrocarbons (PAHs), and organotins from bottom sediments in 2019–2020 were conducted along with harvesting historical data in Russian, Estonian and Finnish waters. We suggest that the input of organotins still occurs along the ship traffic routes. The tributyltin content exceeded the established quality criteria up to more than 300 times. High contamination by PAHs found near the ports, most likely originate from incomplete fuel incineration processes. The Neva River Estuary and Luga Bay might potentially suffer from severe cadmium contamination. The high ecological risk attributed to the HMs was detected at deep offshore areas. The simulated accumulation pattern qualitatively agrees with field observations of HMs in sediments, demonstrating the potential of numerical tools to tackle the hazardous substances problems.

NUMBER ID: EU2

LOCATION: Eastern Gulf of Finland, Baltic Sea
COUNTRY: Finland



PERIOD OF ASSESSMENT: 2019-2020

ENVIRONMENTAL ASPECT: Emissions to water

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Pollution by hazardous substances (heavy metals)

Table 3
An overview of the levels of PAHs, organotins and selected metals measured in different parts of the Baltic Sea, with focus on major harbour areas. NA = data not available.

Location	SPAH	TBT	ΣOrganotins	Pb	Cu	Zn	Cd	Reference
	µg/kg DW	µg/kg DW	µg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	mg/kg DW	
Baltic Sea (station SRS)	2.6 (16 PAH)	<1	<2	0.8	0.5	3.3	<0.1	Berezina et al., 2019
Eastern Gulf of Finland	142.5–923.1 (16 PAH)	12–174	21.6–290	14–59.5	23–51.7	100–219	<0.1–1.9	Present study
Muga Harbour	7380 (16 PAH)	2.3	8.2	12	42	164	0.2	Present study
Port of Kunda	60.2 (16 PAH)	<1	NA	2.8	11	24	<0.1	Present study
Port of Sillamäe	678 (16 PAH)	<1	<1	23	29	74	0.3	Present study
Narva Bay	<10–423 (16 PAH)	<1–5.6	<1–10.1	2.6–17	2.7–27	11–45	<0.1–0.45	Present study
Luga Bay	9.5–469 (16 PAH)	18	39	11.4–35	2.7–42	6.6–138	<0.1–0.8	Present study
Neva Bay	41–239 (16 PAH)	NA	NA	14.6	5.0	18.6	0.1	Present study
Neva estuary:								Present study
Inner	29.3–274.9 (16 PAH)	14–155	14–477	7.1–57.3	3.1–54.5	14.1–174	0.1–2.5	
Outer	30.6–139 (16 PAH)	17–249	17–367	7.1–67.8	4.3–50.4	21.5–305	0.2–3	
Port of Lomonosov	4000 (16 PAH)	NA	NA	29	89	99	0.45	Present study
Klaipėda strait	5456 (16 PAH)	130	NA	35.6	33.8	168	0.71	Galkus et al. (2012); Sundberg and Galkus (2014); Indrikaitis et al. (2016)
Port of Gdansk	2100 (16 PAH)	1200	NA	36	23	140	0.66	Faloutsos et al. (2006)
Port of Gdansk	18,000 (16 PAH)	990	NA	61	34	270	2.1	Faloutsos et al. (2006)
Kiel Harbour	22,100 (14 PAH)	2800	NA	118	42.3	185	NA	Barnard et al. (1999); Borell et al. (2007); Nikulina et al. (2008)
Stockholm Harbour	22,900 (16 PAH)	390	NA	288	367	42	NA	Eklund (2017)

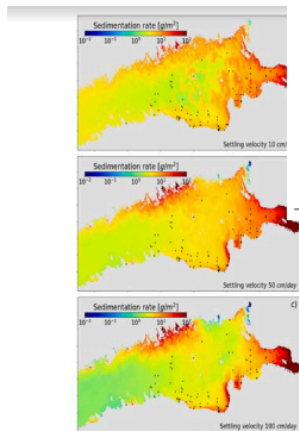


Fig. 10. Distribution of simulated sedimentation (g/m²) within two years of simulation with tracers released from the rivers. Values for the settling velocity in the simulations were 10 cm/s (a), 10 cm/s (b) and 10 cm/s (c). The locations of the available measurements of Cd in the upper sediment layer are shown with black dots.

TITLE: Air pollutant emissions from Piraeus port: External costs and air quality levels

AUTHORS: A.G. Progiou, E. Bakeas, E. Evangelidou, Ch. Kontogiorgi, E. Lagkadinou, I. Sebos

KEY WORDS: Port emissions, Emission inventory, Ships, Air quality, External costs

PUBLICATION YEAR: 2021

JOURNAL: Transportation Research

ABSTRACT: Navigation emissions are an important component of the national emission inventories as they represent a significant part of total NO_x, SO_x and particulate matter emissions as well as of GHG emissions (mainly CO₂). Although emissions from ships at berth are an important source of atmospheric pollutants in dense urban agglomerations, worsening thus air quality conditions of port cities, there is still a significant lack of data and uncertainty in port emissions calculations. Moreover, according to the OECD, most shipping emissions in ports are expected to considerably increase up to 2050. In the last decade, Piraeus port activities have known a significant increase, especially regarding commercial ships. In this context, detailed emission calculations from Piraeus port activities were conducted, external costs were estimated and air pollutant dispersion was simulated through the use of appropriate atmospheric models. Total annual port emissions were compared to previous works. Since 2008, passenger port emissions have witnessed an increase mostly in NO_x due to the increased number of ship calls, whereas SO_x emissions have been decreasing significantly as a result of the significant decrease of S content in fuel used. The anticipated external costs due to health and other damages ship emissions impose, reach to 23.7M€. Finally, air pollutants' concentration levels due to the operation of the port for the scenario with maximum emissions and meteorological conditions favoring pollutant accumulation were estimated.

NUMBER ID: EU3

LOCATION: Port of Piraeus
COUNTRY: Greece

Distance from city center:
12 km
Total ports Area: 39 km²
Total populaion of port city: 448.997



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	5,648,056	5,437,477
RoRo/ Cars (tons)	2,972,000	2,540,000
Dry bulk cargo (tons)	352,000	868,000
Liquid Bulk (tons)	1,314,000	920,000
Passenger	9,331,000	4,370,000

PERIOD OF ASSESSMENT: 2017-2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Maritime emissions & contribution of port emission sources to total air pollution

Table 1
Annual number of ship visits per ship category and annual emissions in t/y (1.10.2017-30.9.2018).

Ship category	Ship calls	Manoeuvring & Hotelling			
		NO _x (t)	NM ₁₀ (t)	PM (t)	SO _x (t)
Passenger ships	13,006	2333	107	101	50
Cruise ships	612	320	13	12	20
Total	13,608	2653	120	113	70
Container ships	3346	1447	64	53	51
Car carriers	634	237	10	10	39
Ro-Ro	347	29	1	1	2
Total	4827	1719	75	74	121
Grand total	17,935	4366	196	188	191

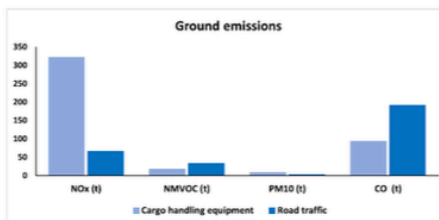


Fig. 4. Annual air pollutant emissions from road traffic and cargo handling equipment (t).

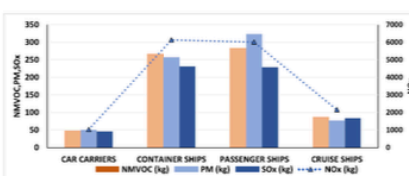


Fig. 5. Air pollutant emissions in the port of Piraeus for August 13th, 2018.

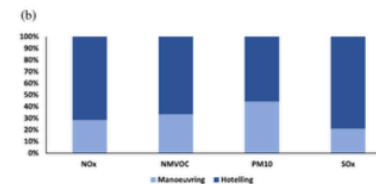


Fig. 5b. Manoeuvring and hotelling contributions to total air pollutant emissions (%).

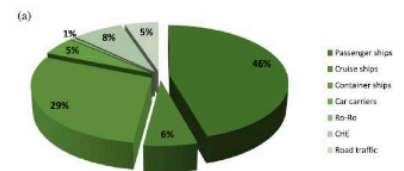


Fig. 5a. Contribution of all ship categories and other port emission sources to total air pollutant emissions (%).

TITLE: Pollutant Emissions in Ports: A Comprehensive Review

AUTHORS: Salvatore Barberi, Mariacrocetta Sambito, Larysa Neduzha and Alessandro Severino

KEY WORDS: emissions; ports; maritime transport; CO₂; renewable energies

PUBLICATION YEAR: 2021

JOURNAL: Infrastructures/ MDPI

ABSTRACT: In recent decades, maritime transport demand has increased along with world population and global trades. This is associated with higher pollution levels, including the emissions of GHG and other polluting gases. Ports are important elements within maritime transport and contribute themselves to pollutant emissions. This paper aims to offer a comprehensive yet technical review of the latest related technologies, explaining and covering aspects that link ports with emissions, i.e., analyzing, monitoring, assessing, and mitigating emissions in ports. This has been achieved through a robust scientific analysis of very recent and significant research studies, to offer an up-to-date and reliable overview. Results show the correlation between emissions and port infrastructures, and demonstrate how proper interventions can help with reducing pollutant emissions and financial costs as well, in ports and for maritime transportation in general. Besides, this review also wishes to propose new ideas for future research: new future experimental studies might spin-off from it, and perhaps port Authorities might be inspired to experiment and implement dedicated technologies to improve their impact on environment and sustainability.

NUMBER ID: EU4A

LOCATION: Port of Volos

COUNTRY: Greece



Distance from city

center: 2.2 km

Total ports Area: 0.9 km²

Total populaion of port city: 144,449

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	25,088	16,793
RoRo/ Cars (tons)	52,000	39,000
Dry bulk cargo (tons)	4,550,000	4,228,000
Liquid Bulk (tons)	74,000	76,000
Passenger	392,596	206,339

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Examination of the relation between port operations with the transportation of containers and bulk shipments on the road network connected to the port. The Logistics Sustainability Index (LSI), a comprehensive index summarizing the other indicators has been calculated with a multi-criteria decision-making tool; a raise in LSI means a general improvement of the system, and in this case, LSI had an increase of circa 21%.

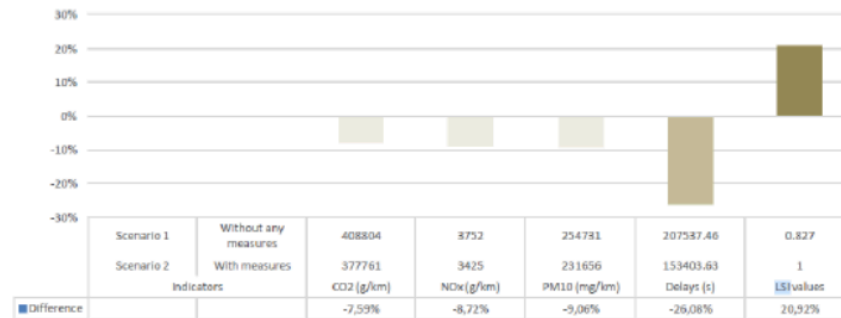


Figure 7. Percentage variation of environmental, delay, and LSI indicators. Reprinted from ref. [43].

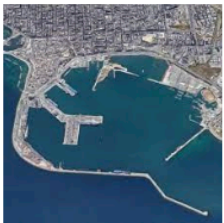
TITLE: Pollutant Emissions in Ports: A Comprehensive Review
AUTHORS: Salvatore Barberi, Mariacrocetta Sambito, Larysa Neduzha and Alessandro Severino
KEY WORDS: emissions; ports; maritime transport; CO2; renewable energies
PUBLICATION YEAR: 2021
JOURNAL: Infrastructures/ MDPI

ABSTRACT: In recent decades, maritime transport demand has increased along with world population and global trades. This is associated with higher pollution levels, including the emissions of GHG and other polluting gases. Ports are important elements within maritime transport and contribute themselves to pollutant emissions. This paper aims to offer a comprehensive yet technical review of the latest related technologies, explaining and covering aspects that link ports with emissions, i.e., analyzing, monitoring, assessing, and mitigating emissions in ports. This has been achieved through a robust scientific analysis of very recent and significant research studies, to offer an up-to-date and reliable overview. Results show the correlation between emissions and port infrastructures, and demonstrate how proper interventions can help with reducing pollutant emissions and financial costs as well, in ports and for maritime transportation in general. Besides, this review also wishes to propose new ideas for future research: new future experimental studies might spin-off from it, and perhaps port Authorities might be inspired to experiment and implement dedicated technologies to improve their impact on environment and sustainability.

NUMBER ID: EU4B

LOCATION: Port of Bari
COUNTRY: Italy

Distance from city center: 4.7 km
Total ports Area: 1.15 km²
Total populaion of port city: 1,260,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	86,087	n/a
RoRo/ Cars (tons)	2,791,000	1,629,000
Dry bulk cargo (tons)	2,404,000	3,511,000
Liquid Bulk (tons)	300,000	29,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2019
ENVIRONMENTAL ASPECT: Emissions to air
METHODOLOGY: Emissions estimation using numerical modelling
KEY FINDINGS: Impact in terms of PMs by port generated emissions

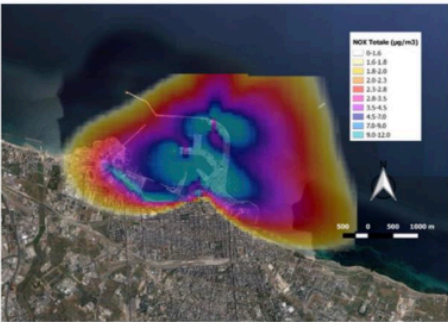


Figure 11. NO_x emissions over the port of Bari. Highest values are colored in blue. Adapted with permission from ref. [45]. Copyright © 2019 Elsevier Ltd. All rights reserved.

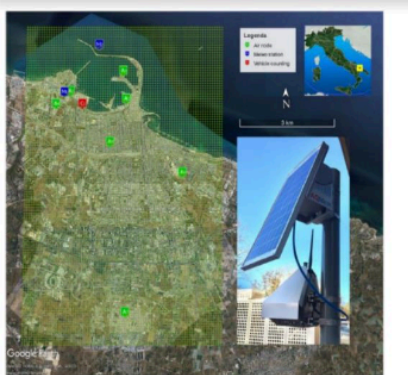


Figure 10. Area of analysis reporting the location of monitoring sensors, the position of Bari in Italy (upper right box), and a typical sensor (lower right box). Reprinted with permission from ref. [45]. Copyright © 2019 Elsevier Ltd. All rights reserved.

TITLE: Pollutant Emissions in Ports: A Comprehensive Review

AUTHORS: Salvatore Barberi, Mariacrosetta Sambito, Larysa Neduzha and Alessandro Severino

KEY WORDS: emissions; ports; maritime transport; CO₂; renewable energies

PUBLICATION YEAR: 2021

JOURNAL: Infrastructures/ MDPI

ABSTRACT: In recent decades, maritime transport demand has increased along with world population and global trades. This is associated with higher pollution levels, including the emissions of GHG and other polluting gases. Ports are important elements within maritime transport and contribute themselves to pollutant emissions. This paper aims to offer a comprehensive yet technical review of the latest related technologies, explaining and covering aspects that link ports with emissions, i.e., analyzing, monitoring, assessing, and mitigating emissions in ports. This has been achieved through a robust scientific analysis of very recent and significant research studies, to offer an up-to-date and reliable overview. Results show the correlation between emissions and port infrastructures, and demonstrate how proper interventions can help with reducing pollutant emissions and financial costs as well, in ports and for maritime transportation in general. Besides, this review also wishes to propose new ideas for future research: new future experimental studies might spin-off from it, and perhaps port Authorities might be inspired to experiment and implement dedicated technologies to improve their impact on environment and sustainability.

NUMBER ID: EU4C



LOCATION: Port of Barcelona

COUNTRY: Spain

Distance from city center: 5 km

Total ports Area: 7.86 km²

Total populaion of port city: 1,620,343

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	3,300,000	3,000,000
RoRo/ Cars (tons)	3,292,000	2,562,000
Dry bulk cargo (tons)	4,071,000	4,013,000
Liquid Bulk (tons)	12,862,000	12,862,000
Passenger	4,628,562	857,966

PERIOD OF ASSESSMENT: 2020

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Improvement in terms of emissions after the application of green initiatives



Figure 8. Area of study around the port of Barcelona. Reprinted with permission from ref. [44]. Copyright © 2020 Elsevier Ltd. All rights reserved.

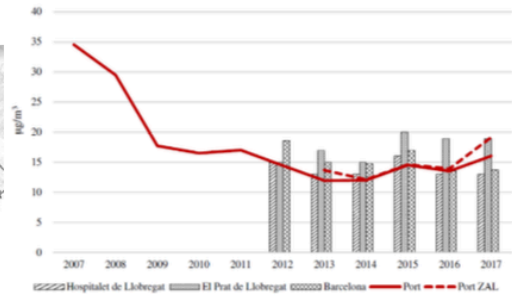


Figure 9. Annual mean of PM_{2.5} emissions between 2007 and 2017, showing an overall decreasing trend. Reprinted with permission from ref. [44]. Copyright © 2020 Elsevier Ltd. All rights reserved.

TITLE: Towards AI driven environmental sustainability: an application of automated logistics in container port terminals

AUTHORS: Naoum Tsolakis, Dimitris Zissis, Spiros Papaefthimiou & Nikolaos Korfiatis

KEY WORDS: intelligent port logistics; artificial intelligence; Automated Guided Vehicles; container port management; vehicle routing; environmental sustainability

PUBLICATION YEAR: 2021

JOURNAL: Taylor & Francis

ABSTRACT: Artificial intelligence and data analytics capabilities have enabled the introduction of automation, such as robotics and Automated Guided Vehicles (AGVs), across different sectors of the production spectrum which successively has profound implications for operational efficiency and productivity. However, the environmental sustainability implications of such innovations have not been yet extensively addressed in the extant literature. This study evaluates the use of AGVs in container terminals by investigating the environmental sustainability gains that arise from the adoption of artificial intelligence and automation for shoreside operations at freight ports. Through a comprehensive literature review, we reveal this research gap across the use of artificial intelligence and decision support systems, as well as optimisation models. A real-world container terminal is used, as a case study in a simulation environment, on Europe's fastest-growing container port (Piraeus), to quantify the environmental benefits related to routing scenarios via different types of AGVs. Our study contributes to the cross-section of operations management and artificial intelligence literature by articulating design principles to inform effective digital technology interventions at non-automated port terminals, both at operational and management levels.

NUMBER ID: EUS

LOCATION: Port of Piraeus

COUNTRY: Greece



Distance from city center: 12 km

Total ports Area: 39 km²

Total populaion of port city: 448.997

PERIOD OF ASSESSMENT: 2020

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: AGVs routing on the gaseous emissions and energy consumption development of two algorithms: (i) 'Loop Routing; and (ii)' Shortest Distance Loop Routing'

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	5,648,056	5,437,477
RoRo/ Cars (tons)	2,972,000	2,540,000
Dry bulk cargo (tons)	352,000	868,000
Liquid Bulk (tons)	1,314,000	920,000
Passenger	9,331,000	4,370,000

Table 3. Environmental impact of AGV for Routing Algorithm #1 – 'Loop Routing' (Total number of containers, C = 40).

AGV Type	Vehicle Status	Total mPt Emissions (mPt)	Total Global Warming Impact (kg CO ₂ -eq)	Total Respiratory Inorganics (kg PM _{2.5} -eq)	Total Electricity (kWh)	Total Primary Energy – Non-renewable Energy (MJ primary)	Total Secondary Energy – Non-renewable Energy (MJ secondary)
LPG	Unloaded	52,461.000	54,810	75.69	0	873,567	41.76
	Loaded (1 t)	185,762.000	175,618	221.90	0	2,794,038	126.80
ELE	Unloaded	3,132.000	10,962	7.83	8,352	130,239	20.88
	Loaded (1 t)	3,804.000	13,631	12.68	10,461	163,255	25.36
DSL	Unloaded	21,924.000	45,414	57.42	0	680,427	28.71
	Loaded (1 t)	39,942.000	77,665	95.10	0	1,153,563	47.55

Symbol: 'LPG' – liquefied gas-powered vehicle; 'ELE' – electric-powered vehicle; 'DSL' – diesel-powered vehicle.

Table 4. Environmental impact of AGV for Routing Algorithm #2 – 'Shortest Distance Loop Routing' (Total number of containers, C = 40).

AGV Type	Vehicle Status	Total mPt Emissions (mPt)	Total Global Warming Impact (kg CO ₂ -eq)	Total Respiratory Inorganics (kg PM _{2.5} -eq)	Total Electricity (kWh)	Total Primary Energy – Non-renewable Energy (MJ primary)	Total Secondary Energy – Non-renewable Energy (MJ secondary)
LPG	Unloaded	52,461	54,810	75.69	0	873,567	41.76
	Loaded (1 t)	152,946	144,594	182.70	0	2,300,454	104.40
ELE	Unloaded	3,132	10,962	7.83	8,352	130,239	20.88
	Loaded (1 t)	3,132	11,223	10.44	8,613	134,415	20.88
DSL	Unloaded	21,924	45,414	57.42	0	680,427	28.71
	Loaded (1 t)	32,886	63,945	78.30	0	949,779	39.15

Symbol: 'LPG' – liquefied gas-powered vehicle; 'ELE' – electric-powered vehicle; 'DSL' – diesel-powered vehicle.

TITLE: Effects of Building Energy Efficiency Measures on Air Quality at the Neighborhood Level in Athens, Greece
AUTHORS: Natasha Frilingou and Demetri Bouris
KEY WORDS: urban air quality; building energy efficiency; mesoscale pollutant dispersion simulation; numerical weather prediction
PUBLICATION YEAR: 2020
JOURNAL: MDPI

ABSTRACT: The high concentration of pollutant sources, complex topography, and regional meteorology are all factors that may contribute to air episodes in dense urban areas. Energy use in buildings is a significant source of pollution in the Greater Athens Area (GAA), Greece, where over 90% of the existing building stock has been classified below energy class B. The present study focuses on the potential effects that a realistic level of building energy efficiency upgrades will have on the air quality over the GAA. Results are expected to be relevant to similar urban areas. Furthermore, the study of primary pollutants' dispersion is applied at a 1.2 km spatial resolution, providing significant local (neighborhood) level information. Numerical simulations were performed using EPA's CALPUFF modeling system with wind field input from an independent numerical weather prediction using NCAR's Weather Research and Forecasting (WRF) model. In order to calculate emission rates from major roads, highways, shipping ports, residential heating installations, and major industrial facilities, data were taken from National and European statistics, demographics, and local topography. After validation, the modeling system was used to examine three building energy efficiency upgrade scenarios, implemented on 20% of the buildings. Ground level concentrations of SO₂, NO_x, CO, and PM₁₀ were calculated and reductions of up to 9% were found for GAA maximum values but up to 18% for local values that were also close to or above the European safety thresholds.

NUMBER ID: EU6

LOCATION: Port of Piraeus
COUNTRY: Greece

Distance from city center: 12 km
Total ports Area: 39 km²
Total population of port city: 448.997



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	5,648,056	5,437,477
RoRo/ Cars (tons)	2,972,000	2,540,000
Dry bulk cargo (tons)	352,000	868,000
Liquid Bulk (tons)	1,314,000	920,000
Passenger	9,331,000	4,370,000

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Estimated emissions from passenger and container ship navigation in the port of Piraeus for the exhausted pollutants SO₂, NO_x, PM₁₀, and GHG (CO₂).

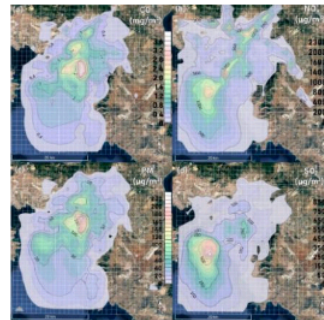


Figure 8. Contours of maximum local concentrations calculated in the present study and overlaid on Google Earth imagery (Map data: Landsat/Copernicus, SIO, NOAA, U.S. Navy, NGA, GEBCO) for the 1 week simulation period, from all source categories (a) CO (b) PM₁₀ (c) NO₂ (d) PM₁₀ (e) PM₁₀ (f) PM₁₀ (g) PM₁₀ (h) PM₁₀ (i) PM₁₀ (j) PM₁₀ (k) PM₁₀ (l) PM₁₀ (m) PM₁₀ (n) PM₁₀ (o) PM₁₀ (p) PM₁₀ (q) PM₁₀ (r) PM₁₀ (s) PM₁₀ (t) PM₁₀ (u) PM₁₀ (v) PM₁₀ (w) PM₁₀ (x) PM₁₀ (y) PM₁₀ (z) PM₁₀ (aa) PM₁₀ (ab) PM₁₀ (ac) PM₁₀ (ad) PM₁₀ (ae) PM₁₀ (af) PM₁₀ (ag) PM₁₀ (ah) PM₁₀ (ai) PM₁₀ (aj) PM₁₀ (ak) PM₁₀ (al) PM₁₀ (am) PM₁₀ (an) PM₁₀ (ao) PM₁₀ (ap) PM₁₀ (aq) PM₁₀ (ar) PM₁₀ (as) PM₁₀ (at) PM₁₀ (au) PM₁₀ (av) PM₁₀ (aw) PM₁₀ (ax) PM₁₀ (ay) PM₁₀ (az) PM₁₀ (ba) PM₁₀ (bb) PM₁₀ (bc) PM₁₀ (bd) PM₁₀ (be) PM₁₀ (bf) PM₁₀ (bg) PM₁₀ (bh) PM₁₀ (bi) PM₁₀ (bj) PM₁₀ (bk) PM₁₀ (bl) PM₁₀ (bm) PM₁₀ (bn) PM₁₀ (bo) PM₁₀ (bp) PM₁₀ (bq) PM₁₀ (br) PM₁₀ (bs) PM₁₀ (bt) PM₁₀ (bu) PM₁₀ (bv) PM₁₀ (bw) PM₁₀ (bx) PM₁₀ (by) PM₁₀ (bz) PM₁₀ (ca) PM₁₀ (cb) PM₁₀ (cc) PM₁₀ (cd) PM₁₀ (ce) PM₁₀ (cf) PM₁₀ (cg) PM₁₀ (ch) PM₁₀ (ci) PM₁₀ (cj) PM₁₀ (ck) PM₁₀ (cl) PM₁₀ (cm) PM₁₀ (cn) PM₁₀ (co) PM₁₀ (cp) PM₁₀ (cq) PM₁₀ (cr) PM₁₀ (cs) PM₁₀ (ct) PM₁₀ (cu) PM₁₀ (cv) PM₁₀ (cw) PM₁₀ (cx) PM₁₀ (cy) PM₁₀ (cz) PM₁₀ (da) PM₁₀ (db) PM₁₀ (dc) PM₁₀ (dd) PM₁₀ (de) PM₁₀ (df) PM₁₀ (dg) PM₁₀ (dh) PM₁₀ (di) PM₁₀ (dj) PM₁₀ (dk) PM₁₀ (dl) PM₁₀ (dm) PM₁₀ (dn) PM₁₀ (do) PM₁₀ (dp) PM₁₀ (dq) PM₁₀ (dr) PM₁₀ (ds) PM₁₀ (dt) PM₁₀ (du) PM₁₀ (dv) PM₁₀ (dw) PM₁₀ (dx) PM₁₀ (dy) PM₁₀ (dz) PM₁₀ (ea) PM₁₀ (eb) PM₁₀ (ec) PM₁₀ (ed) PM₁₀ (ee) PM₁₀ (ef) PM₁₀ (eg) PM₁₀ (eh) PM₁₀ (ei) PM₁₀ (ej) PM₁₀ (ek) PM₁₀ (el) PM₁₀ (em) PM₁₀ (en) PM₁₀ (eo) PM₁₀ (ep) PM₁₀ (eq) PM₁₀ (er) PM₁₀ (es) PM₁₀ (et) PM₁₀ (eu) PM₁₀ (ev) PM₁₀ (ew) PM₁₀ (ex) PM₁₀ (ey) PM₁₀ (ez) PM₁₀ (fa) PM₁₀ (fb) PM₁₀ (fc) PM₁₀ (fd) PM₁₀ (fe) PM₁₀ (ff) PM₁₀ (fg) PM₁₀ (fh) PM₁₀ (fi) PM₁₀ (fj) PM₁₀ (fk) PM₁₀ (fl) PM₁₀ (fm) PM₁₀ (fn) PM₁₀ (fo) PM₁₀ (fp) PM₁₀ (fq) PM₁₀ (fr) PM₁₀ (fs) PM₁₀ (ft) PM₁₀ (fu) PM₁₀ (fv) PM₁₀ (fw) PM₁₀ (fx) PM₁₀ (fy) PM₁₀ (fz) PM₁₀ (ga) PM₁₀ (gb) PM₁₀ (gc) PM₁₀ (gd) PM₁₀ (ge) PM₁₀ (gf) PM₁₀ (gg) PM₁₀ (gh) PM₁₀ (gi) PM₁₀ (gj) PM₁₀ (gk) PM₁₀ (gl) PM₁₀ (gm) PM₁₀ (gn) PM₁₀ (go) PM₁₀ (gp) PM₁₀ (gq) PM₁₀ (gr) PM₁₀ (gs) PM₁₀ (gt) PM₁₀ (gu) PM₁₀ (gv) PM₁₀ (gw) PM₁₀ (gx) PM₁₀ (gy) PM₁₀ (gz) PM₁₀ (ha) PM₁₀ (hb) PM₁₀ (hc) PM₁₀ (hd) PM₁₀ (he) PM₁₀ (hf) PM₁₀ (hg) PM₁₀ (hh) PM₁₀ (hi) PM₁₀ (hj) PM₁₀ (hk) PM₁₀ (hl) PM₁₀ (hm) PM₁₀ (hn) PM₁₀ (ho) PM₁₀ (hp) PM₁₀ (hq) PM₁₀ (hr) PM₁₀ (hs) PM₁₀ (ht) PM₁₀ (hu) PM₁₀ (hv) PM₁₀ (hw) PM₁₀ (hx) PM₁₀ (hy) PM₁₀ (hz) PM₁₀ (ia) PM₁₀ (ib) PM₁₀ (ic) PM₁₀ (id) PM₁₀ (ie) PM₁₀ (if) PM₁₀ (ig) PM₁₀ (ih) PM₁₀ (ii) PM₁₀ (ij) PM₁₀ (ik) PM₁₀ (il) PM₁₀ (im) PM₁₀ (in) PM₁₀ (io) PM₁₀ (ip) PM₁₀ (iq) PM₁₀ (ir) PM₁₀ (is) PM₁₀ (it) PM₁₀ (iu) PM₁₀ (iv) PM₁₀ (iw) PM₁₀ (ix) PM₁₀ (iy) PM₁₀ (iz) PM₁₀ (ja) PM₁₀ (jb) PM₁₀ (jc) PM₁₀ (jd) PM₁₀ (je) PM₁₀ (jf) PM₁₀ (jg) PM₁₀ (jh) PM₁₀ (ji) PM₁₀ (jj) PM₁₀ (jk) PM₁₀ (jl) PM₁₀ (jm) PM₁₀ (jn) PM₁₀ (jo) PM₁₀ (jp) PM₁₀ (jq) PM₁₀ (jr) PM₁₀ (js) PM₁₀ (jt) PM₁₀ (ju) PM₁₀ (jv) PM₁₀ (jw) PM₁₀ (jx) PM₁₀ (jy) PM₁₀ (jz) PM₁₀ (ka) PM₁₀ (kb) PM₁₀ (kc) PM₁₀ (kd) PM₁₀ (ke) PM₁₀ (kf) PM₁₀ (kg) PM₁₀ (kh) PM₁₀ (ki) PM₁₀ (kj) PM₁₀ (kk) PM₁₀ (kl) PM₁₀ (km) PM₁₀ (kn) PM₁₀ (ko) PM₁₀ (kp) PM₁₀ (kq) PM₁₀ (kr) PM₁₀ (ks) PM₁₀ (kt) PM₁₀ (ku) PM₁₀ (kv) PM₁₀ (kw) PM₁₀ (kx) PM₁₀ (ky) PM₁₀ (kz) PM₁₀ (la) PM₁₀ (lb) PM₁₀ (lc) PM₁₀ (ld) PM₁₀ (le) PM₁₀ (lf) PM₁₀ (lg) PM₁₀ (lh) PM₁₀ (li) PM₁₀ (lj) PM₁₀ (lk) PM₁₀ (ll) PM₁₀ (lm) PM₁₀ (ln) PM₁₀ (lo) PM₁₀ (lp) PM₁₀ (lq) PM₁₀ (lr) PM₁₀ (ls) PM₁₀ (lt) PM₁₀ (lu) PM₁₀ (lv) PM₁₀ (lw) PM₁₀ (lx) PM₁₀ (ly) PM₁₀ (lz) PM₁₀ (ma) PM₁₀ (mb) PM₁₀ (mc) PM₁₀ (md) PM₁₀ (me) PM₁₀ (mf) PM₁₀ (mg) PM₁₀ (mh) PM₁₀ (mi) PM₁₀ (mj) PM₁₀ (mk) PM₁₀ (ml) PM₁₀ (mn) PM₁₀ (mo) PM₁₀ (mp) PM₁₀ (mq) PM₁₀ (mr) PM₁₀ (ms) PM₁₀ (mt) PM₁₀ (mu) PM₁₀ (mv) PM₁₀ (mw) PM₁₀ (mx) PM₁₀ (my) PM₁₀ (mz) PM₁₀ (na) PM₁₀ (nb) PM₁₀ (nc) PM₁₀ (nd) PM₁₀ (ne) PM₁₀ (nf) PM₁₀ (ng) PM₁₀ (nh) PM₁₀ (ni) PM₁₀ (nj) PM₁₀ (nk) PM₁₀ (nl) PM₁₀ (nm) PM₁₀ (nn) PM₁₀ (no) PM₁₀ (np) PM₁₀ (nq) PM₁₀ (nr) PM₁₀ (ns) PM₁₀ (nt) PM₁₀ (nu) PM₁₀ (nv) PM₁₀ (nw) PM₁₀ (nx) PM₁₀ (ny) PM₁₀ (nz) PM₁₀ (oa) PM₁₀ (ob) PM₁₀ (oc) PM₁₀ (od) PM₁₀ (oe) PM₁₀ (of) PM₁₀ (og) PM₁₀ (oh) PM₁₀ (oi) PM₁₀ (oj) PM₁₀ (ok) PM₁₀ (ol) PM₁₀ (om) PM₁₀ (on) PM₁₀ (oo) PM₁₀ (op) PM₁₀ (oq) PM₁₀ (or) PM₁₀ (os) PM₁₀ (ot) PM₁₀ (ou) PM₁₀ (ov) PM₁₀ (ow) PM₁₀ (ox) PM₁₀ (oy) PM₁₀ (oz) PM₁₀ (pa) PM₁₀ (pb) PM₁₀ (pc) PM₁₀ (pd) PM₁₀ (pe) PM₁₀ (pf) PM₁₀ (pg) PM₁₀ (ph) PM₁₀ (pi) PM₁₀ (pj) PM₁₀ (pk) PM₁₀ (pl) PM₁₀ (pm) PM₁₀ (pn) PM₁₀ (po) PM₁₀ (pp) PM₁₀ (pq) PM₁₀ (pr) PM₁₀ (ps) PM₁₀ (pt) PM₁₀ (pu) PM₁₀ (pv) PM₁₀ (pw) PM₁₀ (px) PM₁₀ (py) PM₁₀ (pz) PM₁₀ (qa) PM₁₀ (qb) PM₁₀ (qc) PM₁₀ (qd) PM₁₀ (qe) PM₁₀ (qf) PM₁₀ (qg) PM₁₀ (qh) PM₁₀ (qi) PM₁₀ (qj) PM₁₀ (qk) PM₁₀ (ql) PM₁₀ (qm) PM₁₀ (qn) PM₁₀ (qo) PM₁₀ (qp) PM₁₀ (qq) PM₁₀ (qr) PM₁₀ (qs) PM₁₀ (qt) PM₁₀ (qu) PM₁₀ (qv) PM₁₀ (qw) PM₁₀ (qx) PM₁₀ (qy) PM₁₀ (qz) PM₁₀ (ra) PM₁₀ (rb) PM₁₀ (rc) PM₁₀ (rd) PM₁₀ (re) PM₁₀ (rf) PM₁₀ (rg) PM₁₀ (rh) PM₁₀ (ri) PM₁₀ (rj) PM₁₀ (rk) PM₁₀ (rl) PM₁₀ (rm) PM₁₀ (rn) PM₁₀ (ro) PM₁₀ (rp) PM₁₀ (rq) PM₁₀ (rr) PM₁₀ (rs) PM₁₀ (rt) PM₁₀ (ru) PM₁₀ (rv) PM₁₀ (rw) PM₁₀ (rx) PM₁₀ (ry) PM₁₀ (rz) PM₁₀ (sa) PM₁₀ (sb) PM₁₀ (sc) PM₁₀ (sd) PM₁₀ (se) PM₁₀ (sf) PM₁₀ (sg) PM₁₀ (sh) PM₁₀ (si) PM₁₀ (sj) PM₁₀ (sk) PM₁₀ (sl) PM₁₀ (sm) PM₁₀ (sn) PM₁₀ (so) PM₁₀ (sp) PM₁₀ (sq) PM₁₀ (sr) PM₁₀ (ss) PM₁₀ (st) PM₁₀ (su) PM₁₀ (sv) PM₁₀ (sw) PM₁₀ (sx) PM₁₀ (sy) PM₁₀ (sz) PM₁₀ (ta) PM₁₀ (tb) PM₁₀ (tc) PM₁₀ (td) PM₁₀ (te) PM₁₀ (tf) PM₁₀ (tg) PM₁₀ (th) PM₁₀ (ti) PM₁₀ (tj) PM₁₀ (tk) PM₁₀ (tl) PM₁₀ (tm) PM₁₀ (tn) PM₁₀ (to) PM₁₀ (tp) PM₁₀ (tq) PM₁₀ (tr) PM₁₀ (ts) PM₁₀ (tt) PM₁₀ (tu) PM₁₀ (tv) PM₁₀ (tw) PM₁₀ (tx) PM₁₀ (ty) PM₁₀ (tz) PM₁₀ (ua) PM₁₀ (ub) PM₁₀ (uc) PM₁₀ (ud) PM₁₀ (ue) PM₁₀ (uf) PM₁₀ (ug) PM₁₀ (uh) PM₁₀ (ui) PM₁₀ (uj) PM₁₀ (uk) PM₁₀ (ul) PM₁₀ (um) PM₁₀ (un) PM₁₀ (uo) PM₁₀ (up) PM₁₀ (uq) PM₁₀ (ur) PM₁₀ (us) PM₁₀ (ut) PM₁₀ (uu) PM₁₀ (uv) PM₁₀ (uw) PM₁₀ (ux) PM₁₀ (uy) PM₁₀ (uz) PM₁₀ (va) PM₁₀ (vb) PM₁₀ (vc) PM₁₀ (vd) PM₁₀ (ve) PM₁₀ (vf) PM₁₀ (vg) PM₁₀ (vh) PM₁₀ (vi) PM₁₀ (vj) PM₁₀ (vk) PM₁₀ (vl) PM₁₀ (vm) PM₁₀ (vn) PM₁₀ (vo) PM₁₀ (vp) PM₁₀ (vq) PM₁₀ (vr) PM₁₀ (vs) PM₁₀ (vt) PM₁₀ (vu) PM₁₀ (vv) PM₁₀ (vw) PM₁₀ (vx) PM₁₀ (vy) PM₁₀ (vz) PM₁₀ (wa) PM₁₀ (wb) PM₁₀ (wc) PM₁₀ (wd) PM₁₀ (we) PM₁₀ (wf) PM₁₀ (wg) PM₁₀ (wh) PM₁₀ (wi) PM₁₀ (wj) PM₁₀ (wk) PM₁₀ (wl) PM₁₀ (wm) PM₁₀ (wn) PM₁₀ (wo) PM₁₀ (wp) PM₁₀ (wq) PM₁₀ (wr) PM₁₀ (ws) PM₁₀ (wt) PM₁₀ (wu) PM₁₀ (wv) PM₁₀ (ww) PM₁₀ (wx) PM₁₀ (wy) PM₁₀ (wz) PM₁₀ (xa) PM₁₀ (xb) PM₁₀ (xc) PM₁₀ (xd) PM₁₀ (xe) PM₁₀ (xf) PM₁₀ (xg) PM₁₀ (xh) PM₁₀ (xi) PM₁₀ (xj) PM₁₀ (xk) PM₁₀ (xl) PM₁₀ (xm) PM₁₀ (xn) PM₁₀ (xo) PM₁₀ (xp) PM₁₀ (xq) PM₁₀ (xr) PM₁₀ (xs) PM₁₀ (xt) PM₁₀ (xu) PM₁₀ (xv) PM₁₀ (xw) PM₁₀ (xx) PM₁₀ (xy) PM₁₀ (xz) PM₁₀ (ya) PM₁₀ (yb) PM₁₀ (yc) PM₁₀ (yd) PM₁₀ (ye) PM₁₀ (yf) PM₁₀ (yg) PM₁₀ (yh) PM₁₀ (yi) PM₁₀ (yj) PM₁₀ (yk) PM₁₀ (yl) PM₁₀ (ym) PM₁₀ (yn) PM₁₀ (yo) PM₁₀ (yp) PM₁₀ (yq) PM₁₀ (yr) PM₁₀ (ys) PM₁₀ (yt) PM₁₀ (yu) PM₁₀ (yv) PM₁₀ (yw) PM₁₀ (yx) PM₁₀ (yy) PM₁₀ (yz) PM₁₀ (za) PM₁₀ (zb) PM₁₀ (zc) PM₁₀ (zd) PM₁₀ (ze) PM₁₀ (zf) PM₁₀ (zg) PM₁₀ (zh) PM₁₀ (zi) PM₁₀ (zj) PM₁₀ (zk) PM₁₀ (zl) PM₁₀ (zm) PM₁₀ (zn) PM₁₀ (zo) PM₁₀ (zp) PM₁₀ (zq) PM₁₀ (zr) PM₁₀ (zs) PM₁₀ (zt) PM₁₀ (zu) PM₁₀ (zv) PM₁₀ (zw) PM₁₀ (zx) PM₁₀ (zy) PM₁₀ (zz)

Figure 2. The study area of the GAA, Greece (Map modified from Google Maps). Subdomain grid depicted in blue, grid cells in red, highways as orange lines, industrial facilities as purple dots, and the area of Piraeus port (port layout from the work in [30]) outlined in green.



TITLE: Abatement of air pollution at an aegean island port utilizing shore side electricity and renewable energy

AUTHORS: Anna Maria Kotrikla, Theodoros Lilas, Nikitas Nikitakos

KEY WORDS: Cold ironing, Air pollutant emissions, Port, Wind energy, Solar energy

PUBLICATION YEAR: 2017

JOURNAL: Marine Policy

ABSTRACT: The air pollutant emissions of the ships at port represent a small percentage of the overall emissions from shipping however they are concentrated in a small area. In Mytilene, Lesvos, the port is located within the city limits, resulting in air pollution, congestion and noise, especially during the tourist season. The aim of this study is to estimate the quantities of particulate matter and CO₂ emitted by ships in the port of Mytilene and to explore the potential of shore side electricity to reduce the emissions. The emissions were estimated using the bottom-up methodology, based on the activity of the ships in the port (berthing, maneuvering). Simulation of renewable energy sources was made using Homer Energy microgrid simulation software. The results showed that between the 10th and 20th of August 2012, there were 40 calls of passenger ships, tankers and bulk carriers in the port of Mytilene, emitting 441 kg of PM₁₀ and 282 metric tonnes of CO₂. About 63% of PM₁₀ and 77% of CO₂ were emitted at the berthing phase and the remaining during the maneuvering. These emissions could be reduced by providing electricity to the ships from a hybrid renewable energy system with wind turbines and photovoltaics, connected to the grid. Simulations showed that the total energy requirements of the ships in the port of Mytilene could be covered by four 1.5 MW wind turbines combined with a 5 MW photovoltaics. With this configuration, renewable energy will exceed the ships' electricity needs for most of the time in order not to increase the power station's load. The excess energy could be fed to the islands' grid, so a costly battery storage system is not necessary to handle the variations of alternative energy. In this way, a considerable reduction of the CO₂ and PM₁₀ emissions by the ships in the port occurs, providing a viable solution for a cleaner and healthier environment.

NUMBER ID: EU7



LOCATION: Port of Mytilene

COUNTRY: Greece

Distance from city center: 1.3 km

Total ports Area: n/a

Total populaion of port city: 57,872

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	n/a	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	321,000	200,000

PERIOD OF ASSESSMENT: 10th – 20th August of 2012

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Estimation of the emissions from ships

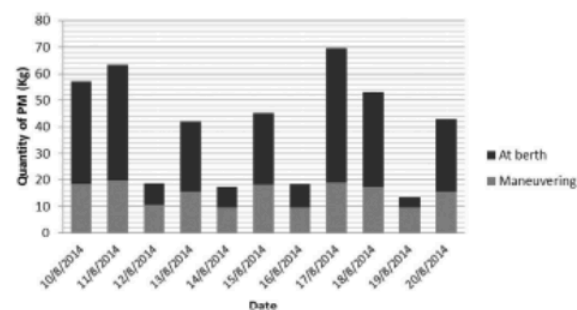


Fig. 5. Daily emissions of PM₁₀ from the shipping activity at the city of Mytilene from 10 to 20 August 2012.

Duration of each phase of the trip, engine load factors and emissions by ships in the port of Mytilene, from 10 to 20 August 2012.

Phase of the trip	Mean time per call (h)	Load factor of main engines (%)	Load factor of auxiliary engines (%)	Emissions of CO ₂ (kg) (% of total)	Emissions of PM ₁₀ (kg) (% of total)
Maneuvering	0.33	20	50	66,000 (23%)	164 (37%)
At berth	5.3	20 for 5% of the time (tankers: 20%)	40–60	216,200 (77%)	277 kg (63%)
TOTAL				282,000	441

TITLE: An evaluation of the impact of the Dublin Port Tunnel and HGV management strategy on air pollution emissions

AUTHORS: Jiayi Tang, Aonghus McNabola, Bruce Misstear, Brian Caulfield

KEY WORDS: Traffic model, Emissions, Dublin Port Tunnel, Air pollution, Transport impacts on environment

PUBLICATION YEAR: 2017

JOURNAL: Transportation Research Part D

ABSTRACT: Heavy Goods Vehicles (HGVs) contribute a large proportion (about 40%) of the emissions of air pollutants while only representing a small proportion (about 10%) of all transport operations. In Ireland, the Dublin Port Tunnel (DPT) was opened in 2006 as a dedicated route for HGVs between Dublin Port and the motorway system in order to reduce the HGV volume in the city centre. An HGV management strategy to restrict HGVs travelling through the city centre was also introduced. The aim of this study was to estimate the emission changes brought about by these infrastructural and regulatory changes. A transport model built in VISUM was utilized. Emissions were calculated using COPERT 4. The results showed that the DPT and HGV management strategy reduced the traffic in the city centre, and the HGV management improved traffic speed distribution. However the DPT and HGV management resulted in vehicles travelling further (travel distance increased by 16% and 51%, respectively) and increased the total emissions (increased by 8% and 21% in NO_x, respectively). Total traffic and emission changes over time in Dublin were also estimated in this study. The traffic conditions and emissions in 2006, 2007 and 2013 were evaluated and the results indicated that a travel demand reduction in 2013 could also improve speed distribution. Emissions reduced from 2006 to 2013 and the fleet technology improvements had a positive impact on this reduction. The study shows that a traffic management policy and/or infrastructure change may bring about some localised environmental benefits within the management area; however, such a policy does not always reduce the total traffic emissions in the network as a whole and the impact to the wider environment could be negative in some circumstances.

NUMBER ID: EU8

LOCATION: Dublin Port
COUNTRY: Ireland



Distance from city center: 4.5 km
Total ports Area: 2.6 km²
Total populaion of port city: 1,255,963

PERIOD OF ASSESSMENT: 2006, 2007, 2013

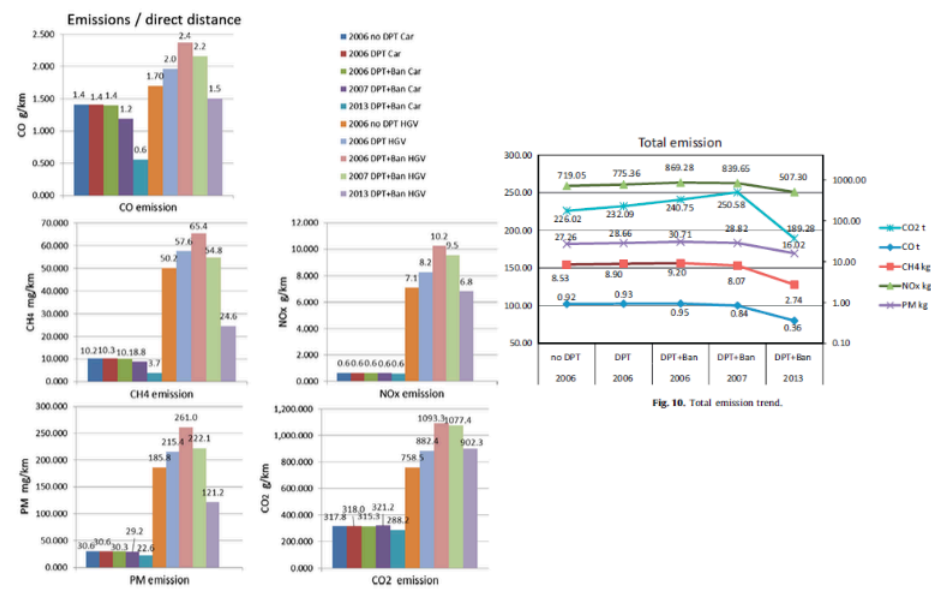
ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Different scenarios simulated on traffic and emission in Dublin port-city traffic

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	774,043	758,034
RoRo/ Cars (tons)	1,491,613	1,484,894
Dry bulk cargo (tons)	1,837,000	1,990,000
Liquid Bulk (tons)	4,662,000	3,871,000
Passenger	323,234	505,000



TITLE: Combining Chemical Composition Data and Numerical Modelling for the Assessment of Air Quality in a Mediterranean Port City

AUTHORS: Rita Cesari , Alessandra Genga , Riccardo Buccolieri , Silvana Di Sabatino, Maria Siciliano, Tiziana Siciliano, Adelaide Dinoi , Alberto Maurizi and Pierina Ielpo

KEY WORDS: mesoscale chemistry model; local scale model; chemical characterization; principal component analysis; linear discriminant analysis; ship emissions; Mediterranean port city

PUBLICATION YEAR: 2021

JOURNAL: Appl. Sci./ MPDI

ABSTRACT: The aim of this study is to characterize the air quality in a Mediterranean port city. The impact of ship emissions on both gaseous and particulate pollutants has been investigated through an integrated methodology which includes atmospheric flow and dispersion numerical modelling as well as chemical composition and statistical analyses. Specifically, chemical compositional data (ionic fraction, carbonaceous compounds, and metals) of PM_{2.5} were acquired during an experimental field campaign carried out in the port city of Brindisi (Apulia Region, Southern Italy). The sampling site was located on the roof of a building (ASI) within the port area. Given the complexity of the site in which both domestic buildings and a large industrial area are present, analyses were done by selecting different wind sectors to test different techniques to discriminate between sources. Linear Discriminant Analysis (LDA) and Principal Component Analysis (PCA) were applied to evaluate statistical differences in the composition of PM_{2.5} sampled within the area when the sampling site was downwind to the port or to the urban-industrial area. Only LDA allowed to discriminate the separation between urban-industrial and port macroareas. Those results were further confirmed in terms of PM_{2.5} concentrations directly associated to ship emissions using a coupled modelling approach. The mesoscale model BOLCHEM was used to investigate the contribution of ship emissions both on primary and secondary PM_{2.5} concentration in the area surrounding the port, as well as on PM₁₀, NO_x and O₃ concentrations. Then, the model was coupled offline with the local dispersion model ADMS-Urban. The adopted approach was crucial to evaluate the spatial distribution of the impact of ship emissions. BOLCHEM results showed that in the cell of the port the average impact of ship emissions on NO_x was 37.6%, and 11.7% on O₃. The average impact on PM_{2.5} was 6.1%, distributed between primary (2.7%) and secondary fraction (3.4%). At local scale, the analysis of high-resolution modelling results obtained from ADMS-Urban highlighted that, at ASI position, the impact of ship emissions on PM_{2.5} was 6.8% when the sampling site was positioned downwind to the port area and reduced to lower than 3.0% at about 2 km.

NUMBER ID: EU9

LOCATION: Port of Brindisi

COUNTRY: Italy

Distance from city center: 5.6 km

Total ports Area: 1.2 km²

Total populaion of port city: 87,820



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,654	n/a
RoRo/ Cars (tons)	1,928,000	1,943,000
Dry bulk cargo (tons)	3,789,000	2,811,000
Liquid Bulk (tons)	2,241,000	2,610,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2012

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Ship emissions from the maritime transport sector should be considered as a significant source of NO₂, PM₁₀, and PM_{2.5}

Table 5. BOLCHEM modelled and measured concentrations ($\mu\text{g m}^{-3}$) averaged over ARPA-Puglia and ASI monitoring stations and over the whole period June–October 2012.

	Modelled ($\mu\text{g m}^{-3}$)	Measured ($\mu\text{g m}^{-3}$)	MB ($\mu\text{g m}^{-3}$)	RMSE ($\mu\text{g m}^{-3}$)	R
NO _x	25.61	24.68	0.93	11.17	0.68
O ₃	83.54	79.71	3.83	16.19	0.78
PM _{2.5}	14.91	13.59	1.32	5.69	0.64
PM ₁₀	21.53	20.85	0.68	5.97	0.61

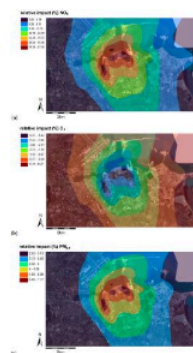


Figure 7. Average modelled impact of ship emissions (T1) on the NO_x, O₃, and PM_{2.5} concentrations in the port area.

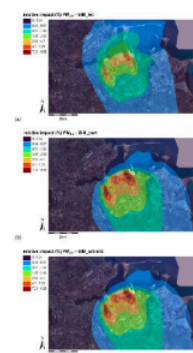


Figure 8. Average modelled impact of ship emissions (T2) on the NO_x, O₃, and PM_{2.5} concentrations in the port area.

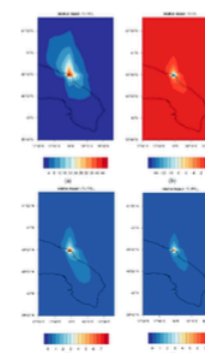


Figure 9. Average modelled impact of ship emissions (T3) on the NO_x, O₃, and PM_{2.5} concentrations in the port area.

TITLE: Optimal decision making for emissions reduction measures for Italian container terminals

AUTHORS: Fabio Ballini, Seyedvahid Vakili, Alessandro Schonborn, Aykut Olcer, Monica Canepa and Davide Sciutto

KEY WORDS: Air pollution, emission, energy, multi-discipline, fuzzy analytic hierarchy process – Port-sustainable development

PUBLICATION YEAR: 2021

JOURNAL: Engineering for the Maritime Environment

ABSTRACT: The importance of sea ports in the global logistics maritime supply chain and its connectivity is increasing, as is the focus on optimizing daily operational activities and minimizing the negative impact on society. One of the most significant negative externalities for sea ports is air pollution that remains one of the main concerns and environmental priority for Port Authorities and Government and their strategic policies. The growth of containerization in the shipping industry stimulates the demand for infrastructure development and increased energy use. This paper strives to propose the best alternative sources of energy to transit from traditional fuel to the greener ones for two important container terminals in Italy. The analyses focus on energy consumption of the most important container terminals Voltri and La Spezia in Italy and analysed using alternative sources of energy. Based on the priorities chosen by twelve experts, the cost, societal and environmental criteria are assigned the highest weight respectively. The Fuzzy Analytic Hierarchy Process (FAHP) and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) techniques are used, to identify the best alternative sources of energy.

NUMBER ID: EU10A



LOCATION: Port of Genoa (Voltri Terminal)

COUNTRY: Italy

Distance from city center: 3.5 km

Total ports Area: 7 km²

Total population of port city: 645,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	2,175,615	2,500,000
RoRo/ Cars (tons)	5,993,000	6,834,000
Dry bulk cargo (tons)	1,279,000	923,000
Liquid Bulk (tons)	15,835,000	10,231,000
Passenger	n/a	1,500,000

PERIOD OF ASSESSMENT: 2014-2016

ENVIRONMENTAL ASPECT: Use of raw materials and natural resources

METHODOLOGY: Energy consumption recordings

KEY FINDINGS: Energy consumption levels

Table 2. Energy consumption of Genoa Port (Voltri Terminal).

Energy consumption	2014	2015	2016	Changes 2014–2015	Changes 2015–2016	Changes 2014–2016
Total fuel consumption (litres)	3,668,567.0	3,885,157.0	4,453,384.0	5.9	14.6	21.4
Total electricity consumption (KWh)	18,932,665.0	18,612,540.0	1,7939,984.0	–1.7	–3.6	–5.2

TITLE: Optimal decision making for emissions reduction measures for Italian container terminals

AUTHORS: Fabio Ballini, Seyedvahid Vakili, Alessandro Schonborn, Aykut Olcer, Monica Canepa and Davide Sciutto

KEY WORDS: Air pollution, emission, energy, multi-discipline, fuzzy analytic hierarchy process – Port- sustainable development

PUBLICATION YEAR: 2021

JOURNAL: Engineering for the Maritime Environment

ABSTRACT: The importance of sea ports in the global logistics maritime supply chain and its connectivity is increasing, as is the focus on optimizing daily operational activities and minimizing the negative impact on society. One of the most significant negative externalities for sea ports is air pollution that remains one of the main concerns and environmental priorities for Port Authorities and Government and their strategic policies. The growth of containerization in the shipping industry stimulates the demand for infrastructure development and increased energy use. This paper strives to propose the best alternative sources of energy to transit from traditional fuel to the greener ones for two important container terminals in Italy. The analyses focus on energy consumption of the most important container terminals Voltri and La Spezia in Italy and analysed using alternative sources of energy. Based on the priorities chosen by twelve experts, the cost, societal and environmental criteria are assigned the highest weight respectively. The Fuzzy Analytic Hierarchy Process (FAHP) and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) techniques are used, to identify the best alternative sources of energy.

NUMBER ID: EU10B



LOCATION: La Spezia Port
COUNTRY: Italy

Distance from city center: 2 km
Total ports Area: 15 km²
Total population of port city: 93,678

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,658,873	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	421,000	263,000
Liquid Bulk (tons)	2,243,000	2,401,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2014-2016

ENVIRONMENTAL ASPECT: Use of raw materials and natural resources

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Energy consumption levels

Table 3. Energy consumption of La Spezia Port (La Spezia Terminal).

Energy consumption	2014	2015	2016	Changes 2014–2015	Changes 2015–2016	Changes 2014–2016
Total fuel consumption (litres)	1,597,214.2	1,977,453.0	1,795,215.0	23.8	−9.2	19.1
Total electricity consumption (KWh)	13,301,364.0	14,148,439.0	13,475,883.0	6.4	−4.8	1.3

TITLE: The Importance of Environmental Factors in the Planning of Container Terminals: The Case Study of the Port of Augusta

AUTHORS: Nadia Giuffrida, Maja Stojakovi, Elen Twrdy and Matteo Ignaccolo

KEY WORDS: maritime transport; environmental impact; maritime pollution

PUBLICATION YEAR: 2021

JOURNAL: Appl. Sci./MDPI

ABSTRACT: Container terminals are the main hubs of the global supply chain but, conversely, they play an important role in energy consumption, environmental pollution and even climate change due to carbon emissions. Assessing the environmental impact of this type of port terminal and choosing appropriate mitigation measures is essential to pursue the goals related to a clean environment and ensuring a good quality of life of the inhabitants of port cities. In this paper the authors present a Terminal Decision Support Tool (TDST) for the development of a container terminal that considers both operation efficiency and environmental impacts. The TDST provides environmental impact mitigation measures based on different levels of evolution of the port's container traffic. An application of the TDST is conducted on the Port of Augusta (Italy), a port that is planning infrastructural interventions in coming years in order to gain a new role as a reference point for container traffic in the Mediterranean.

NUMBER ID: EU11



LOCATION: Port of Augusta
COUNTRY: Italy

Distance from city center: 1.5 km

Total ports Area: n/a

Total populaion of port city: 197,535

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: CO2 Emissions & Noise Pollution from container terminal

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	504	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	885,000	815,000
Liquid Bulk (tons)	20,532,000	21,265,000
Passenger	n/a	n/a

Abbreviations	
CD _{CNTR}	total CO2 emission at a container terminal
CD _{CNTR;M}	carbon emissions from the processes of ship manoeuvre inside the port basin
CD _{CNTR;B}	ship at berth
CD _{CNTR;L}	container loading and unloading
CD _{CNTR;T}	container transportation
CD _{CNTR;R}	container receiving and delivery

Table 2. Results of total carbon emission for the terminal container of the Port of Augusta (kg).

Base Emission (kg/TEU)	CD _{CNTR;M}	CD _{CNTR;B}	CD _{CNTR;L}	CD _{CNTR;T}	CD _{CNTR;R}	CD _{CNTR}
	1.99	0.02324	1.39	0.04287	0.06873	
Scenario	TEUs					
1. Feeder	3000	5970	69.72	8340	206.19	1159.35
2. Panamax	5000	9950	116.2	13,900	343.65	1932.25
3. Hub	14,000	27,860	325.36	116,760	962.22	10,820.6
						156,728.18

Table 3. Results of noise pollution for the terminal container of the Port of Augusta.

Scenario	L _w (dB(A))	L _{P500} (dB(A))	L _{P1000} (dB(A))	L _{max} (dB(A)) (Night-Day)
Feeder	110	45.03	39.01	40–50
Panamax	112	47.03	41.01	40–50
Hub	114	49.03	43.01	40–50

TITLE: Pass-by Characterization of Noise Emitted by Different Categories of Seagoing Ships in Ports

AUTHORS: Luca Fredianelli, Marco Nastasi, Marco Bernardini, Francesco Fidecaro and Gaetano Licitra

KEY WORDS: port noise; harbor noise; noise emission; vessels noise; ship noise; sustainable management; noise pass-by; noise spectra; noise measurements; noise characterization

PUBLICATION YEAR: 2020

JOURNAL: MDPI

ABSTRACT: In the light of sustainability, satisfactory living conditions is an important factor for people's positive feedback in their own living environment. Acoustic comfort and noise exposure should then be carefully monitored in all human settlements. Furthermore, it is already well-known that high or prolonged noise levels may lead to unwanted health effects. Unfortunately, while in the last decades scientists and public authorities have investigated the noise produced by roads, trains, and airports, not enough efforts have been spent in studying what happens around the coastal and port areas. Following the attention brought to the subject by recent European projects on noise in port areas, the present paper characterizes the sound power level and 1/3 octave band sound power spectrum of seagoing ships while moving at low speeds. Five different categories have been distinguished: Roll-on/roll-off (RORO), container ship, oil tanker, chemical tanker, and ferry. The analysis is based on a continuous noise measurement lasting more than three months, performed in the industrial canal of the port of Livorno (Italy). The resulting noise emissions are new and useful data that could be inserted in acoustic propagation models to properly assess the noise in the areas affected by port activities. Thus, the present work can act as a supporting tool in planning ship traffic in ports towards better sustainability.

NUMBER ID: EU12

LOCATION: Port of Livorno

COUNTRY: Italy

Distance from city

center: 3.2 km

Total ports Area: 1.85 km²

Total populaion of port city: 337,334



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	790,000	711,000
RoRo/ Cars (tons)	13,426,000	467,889
Dry bulk cargo (tons)	723,000	567,000
Liquid Bulk (tons)	5,547,000	4,503,000
Passenger	832,121	1,436,000

PERIOD OF ASSESSMENT: 24th May 2018 to 5th September 2018

ENVIRONMENTAL ASPECT: Energy emitted/ Noise emissions

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Different noise emissions levels from different categories of seagoing ships

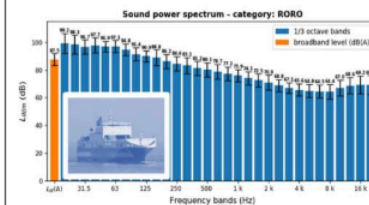


Figure 4. L_{wp} and 1/3 octave band sound power spectrum of RORO (Roll-on/roll-off) ships, together with uncertainties.

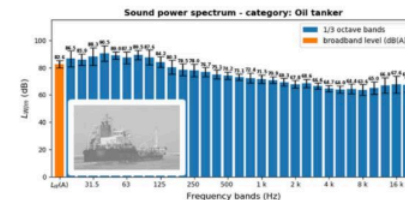


Figure 6. L_{wp} and 1/3 octave band sound power spectrum of oil tanker ships, together with uncertainties.

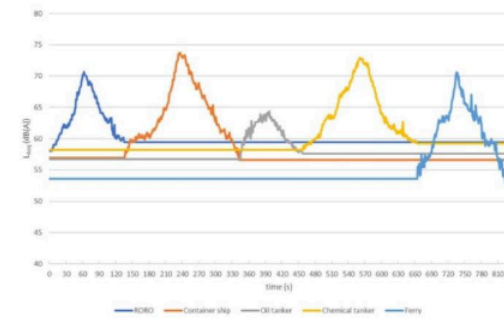


Figure 3. Example of a typical pass-by for each category of vessel from the time-history of noise level.

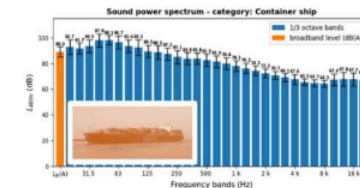


Figure 8. L_{wp} and 1/3 octave band sound power spectrum of container ships, together with uncertainties.

TITLE: A methodology for the design of an effective air quality monitoring network in port areas

AUTHORS: Luigia Mocerino, Fabio Murena, Franco Quaranta, Domenico Toscano

KEY WORDS:

PUBLICATION YEAR: 2020

JOURNAL: Scientific Report

ABSTRACT: The assessment of the impact of ship emissions is generally realised by a network of receptors at ground level inside the port area or in the nearby urban canopy. Another possibility is the use of dispersion models capable of providing maps of concentrations to the ground taking into account ship emissions and weather conditions. In this work traffic data of passengers ships in the port of Naples were used to estimate pollutant emissions starting from EMEP/EEA (European Environment Agency/European Monitoring and Evaluation Programme) methodology and real data of power engines. In this way, a hourly file of emission rates was produced and input to CALPUFF together with meteorological data. Then SO₂ concentrations at different heights (0–60m) in correspondence of selected points within the port area were evaluated. Results are compared with data measured at ground level in monitoring campaigns showing how is possible to better identify and quantify the air pollution from ships in port by positioning the receptors inside the port area at different heights from ground-level. The results obtained give useful information for designing an optimum on-site air quality monitoring network able to quantify the emissions of pollutants due to naval traffic and to individuate the contribution of single ships or ships' categories.

NUMBER ID: EU13

LOCATION: Port of Napoli
COUNTRY: Italy



Distance from city center: 2.3km
Total ports Area: 1.42 km²
Total populaion of port city: 3,085,000

PERIOD OF ASSESSMENT: 2012

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Concentration levels of CO₂, NO_x, SO_x, PM₁₀ at selected points inside the port area

Pollutant	Averaging Time	Statistical Parameter	Monitoring campaign	
			March - April	November
NO ₂ (µg/m ³)	1h	Maximum	156.6	84.2
	Period	Average	48.4	35.8
SO ₂ (µg/m ³)	1h	Maximum	26.6	35.5
	24h	Maximum	3.7	2.5
PM ₁₀ (µg/m ³)	24h	Maximum	40.8	44.2
	Period	Average	27.2	31.6
CO (mg/m ³)	8h mobile	Maximum	0.1	0.9

Table 1. Results of the monitoring campaigns.

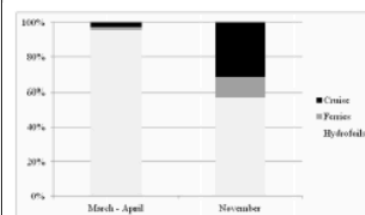


Figure 9. Contribution at SO₂ airborne concentration of vessel categories at ground level ("Stazione Marittima 1").

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	681,929	643,540
RoRo/ Cars (tons)	4,162,000	2,384
Dry bulk cargo (tons)	1,247,000	1,104,000
Liquid Bulk (tons)	6,321,000	6,507,000
Passenger	5,993,000	2,908,151

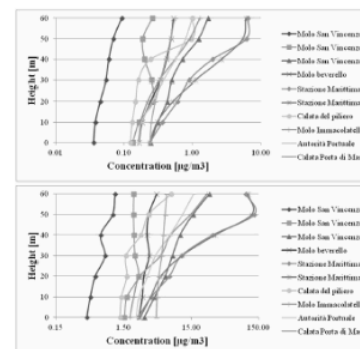


Figure 8. Vertical profiles of SO₂ concentration, November: Up Period Average; Down 98th Percentile.

TITLE: Dry ports and related environmental benefits: a case study in Italy

AUTHORS: Angela Carbonia, Federico Orsini

KEY WORDS: Dry port, Intermodal freight terminal, Simulation-based method, Environment, Emission model

PUBLICATION YEAR: 2020

JOURNAL: Case Studies on Transport Policy

ABSTRACT: The maritime containerised transport continues to grow; thus, an efficient seaport inland access becomes crucial for the performance of the entire intermodal transport chain. Dry ports are inland intermodal terminals directly connected to seaports via rail, which operate as trans-shipment hubs and provide services, such as: storage, consolidation, depot and custom clearance. In addition to offering benefits in terms of operational costs and efficiency, dry port concept implementation can produce positive effects also under an environmental point of view, promoting the modal shift from road to rail. This paper presents a simulation-based method to estimate the environmental benefits, in terms of emissions reduction, of a dry port implementation. This method is organized into three parts: (i) traffic demand analysis, (ii) traffic supply model, (iii) assignment and emission model. The methodology is applied to a real-world case study in Northern Italy, where the current scenario is compared to a future scenario in which a new railway connection is established between a seaport (Port of Venice) and an existing intermodal freight hub (Interporto of Padua). According to our findings, in the future scenario emissions of the main pollutants are reduced by 17%. In terms of CO₂ this corresponds to about 8000 tons per year.

NUMBER ID: EU14



LOCATION: Port of Venice

COUNTRY: Italy

Distance from city center: 1.4 km

Total ports Area: 20 km²

Total populaion of port city: 258,685

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	547,563	n/a
RoRo/ Cars (tons)	2,185,000	1,153,000
Dry bulk cargo (tons)	10,460,000	4,953,846
Liquid Bulk (tons)	8,448,000	8,566,470
Passenger	1,400,000	1,230,000

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Future scenario emissions of the main pollutants produced by HDV traffic to/from the Port of Venice

Table 5

Comparison of emissions between scenarios S0 and S1, considering HDV trips of the whole Veneto region and those whose origin/destination is the Port of Venice.

	Veneto total			To/From Port of Venice		
	Baseline (S0)	Future (S1)	Reduction	Baseline (S0)	Future (S1)	Reduction
CO [tons]	5.939213	5.8835	−0.94%	0.31879	0.263077	−17.48%
CO ₂ [tons]	3328.646	3297.246	−0.94%	179.0652	147.6657	−17.54%
NO _x [tons]	27.04236	26.78907	−0.94%	1.450778	1.197488	−17.46%
PM [kg]	660.7999	654.6055	−0.94%	35.45021	29.25583	−17.47%
VOC [kg]	1169.225	1159.131	−0.86%	60.76533	50.67143	−16.61%

TITLE: Development of an integrated modelling-measurement system for near-real-time estimates of harbour activity impact to atmospheric pollution in coastal cities

AUTHORS: Eva Merico, Adelaide Dinoi, Daniele Contini

KEY WORDS: Shipping emissions, Air quality modelling, Low-cost sensors, ADMS, AIS, Harbour pollution management

PUBLICATION YEAR: 2019

JOURNAL: ELSEVIER

ABSTRACT: Several studies focused on harbour impact on air quality of port-cities showing that maritime emissions could be comparable to traffic emissions of a medium-size town having relevant impact on air quality nearby the harbours. In order to plan efficient mitigation strategies, environmental and port authorities have an increasing need of reliable tools for investigating the impact of ships traffic and harbour logistics on atmospheric pollutants. In this work a system based on the integration of measurements collected using a network of low-cost on-line sensors with local scale dispersion modelling was developed. It was implemented, as a pilot action, in the information and management software of the Bari harbour (SE Italy). It can operate in near-real-time, in forecast mode, and on archived data for long-term assessments. It was tested studying the impact of the Bari harbour for the year 2018. The lowest impact was observed for CO, being the pollutant with the lowest share of the contribution of ships (between 8% and 68%) compared with the total harbour contribution. The impacts on PM2.5 and PM10 are larger arriving up to 11.8% of concentrations in the harbour area with an influence of shipping between 44% and 97%. The impact on SO2 is almost solely due to ships and it arrives up to 80% in the harbour area. The impact on NOx ranges from a few percent in the urban area up to 40% in the harbour area and it is the pollutant of major concern regarding compliance with air quality standards.

NUMBER ID: EU15

LOCATION: Port of Bari
COUNTRY: Italy

Distance from city center: 4.7 km
Total ports Area: 1.15 km²
Total populaion of port city: 1,260,000

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Results from studying the impact of the Bari harbour for the year 2018

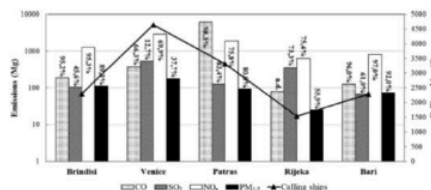


Fig. 4. Yearly emissions of Bari harbour (this study) compared with those of other harbours of the Adriatic-Ionian Sea (Merico et al., 2017). Marks represent the number of calling ships and the percentage represent the fractions of emissions due to handling phase.

Table 1

Yearly emissions of road vehicles (sum of exhaust and non-exhaust) inside the harbour area for the different pollutants. Last line reports the total number of vehicles counted (summing vehicles entering and leaving the harbour) in the year 2018.

Kg/year	Motorcycles	Cars	Light duty vehicles	Bus	Heavy duty vehicles
CO	2100.70	10,027.66	331.22	72.44	1419.88
SO ₂	0.44	8.11	0.39	0.18	2.99
NO _x	41.74	1808.28	283.35	354.19	6925.50
PM _{2.5}	16.98	75.61	41.37	14.20	315.93
PM ₁₀	33.96	151.22	82.75	28.40	631.86
Counted vehicles	59,948	1,046,128	96,131	17,355	350,172

Table 2

Yearly emissions (2018) due to the three identified sources related to harbour activities.

Typology of source	CO (Mg/year)	NOx (Mg/year)	PM _{2.5} (Mg/year)	PM ₁₀ (Mg/year)	SO ₂ (Mg/year)
Ships	125.2	821.7	73.0	73.0	67.0
Vehicular traffic	13.9	9.4	0.46	0.93	0.01
Cranes	1.2	2.7	0.11	0.11	0.001
Harbour total	140.3	833.8	73.6	74.0	67.0



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	86,087	n/a
RoRo/ Cars (tons)	2,791,000	1,629,000
Dry bulk cargo (tons)	2,404,000	3,511,000
Liquid Bulk (tons)	300,000	29,000
Passenger	n/a	n/a

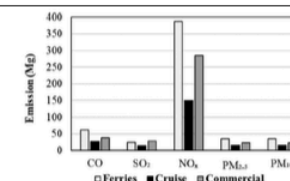


Fig. 3. Yearly contributions of ship emissions to the different pollutants, divided by category.

TITLE: Impact of port emissions on EU-regulated and non-regulated air quality indicators: The case of Civitavecchia (Italy)

AUTHORS: Gian Paolo Gobbi, Luca Di Liberto, Francesca Barnaba

KEY WORDS: Port emissions, Port-city pollution, Marine fuels, Ultra-fine particles, Black carbon

PUBLICATION YEAR: 2019

JOURNAL: Science of the Total Environment

ABSTRACT: Current shipping activities employ about 3% of the world-delivered energy. Most of this energy is conveyed by diesel engines. In Europe, release of NO_x and particulate matter (PM) from shipping is expected to equal the road-transport one by the year 2020. This paper addresses a typical central Mediterranean city-port condition to evaluate the relative contribution of shipping activities to the local air quality. A 3-year long air quality dataset collected at the boundary between the port of Civitavecchia (the major port in central Italy) and the city itself was analyzed to evaluate the long-term, relative contribution of the port and of the city at determining the loads of EU-regulated pollutants (NO₂, PM₁₀ and SO₂). In addition, black carbon and ultrafine-to-coarse particles data collected along a short-term, intensive campaign were used to assess the port's role at emitting these unregulated pollutants. Cross-analysis of the measurements, allowed to assess which shipping-related activities and port's sectors represent the principal emitters. At the city-port boundary, the annual share of regulated pollutants originating in the port area by shipping and ground movements is of 33% for PM₁₀, 43% for NO₂, and 60% for SO₂. Analysis of nonregulated pollutants shows the in-port, high polluting potential of some ship categories, in particular those employing low-sulfur but poorly refined oils. These conditions appear to be more often associated with Ro-Ro passenger ships. Piers closest to the Civitavecchia urban settlements are also observed to host the largest emissions. Meteorology and location of the piers with respect to residential areas are confirmed to govern the port's share at impacting the city air quality. Even though air quality thresholds for regulated pollutants are not exceeded in Civitavecchia, constant consideration of an enlarged set of environmental variables should drive actions implemented to mitigate the port's impact onto the nearby city's air quality.

NUMBER ID: EU16

LOCATION: Port of Civitavecchia
COUNTRY: Italy

Distance from city center: 1.9 km

Total ports Area: n/a

Total populaion of port city: 53,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	144,936	106,305
RoRo/ Cars (tons)	5,154,000	3,206,000
Dry bulk cargo (tons)	2,203,000	2,295,000
Liquid Bulk (tons)	784,000	836,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: May 2013-April 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Original insights about the role of the port at influencing the air quality in Civitavecchia

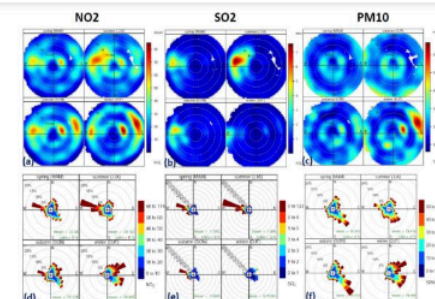


Table 3

Estimated yearly emissions (2013–2016 average) per ship category and hosting pier at the port of Civitavecchia. Estimates of emissions originating outside the port area (off-port anchor and TVN piers) are included in the last row.

Ship type	NO _x [t/year]	TSP [t/year]	SO ₂ [t/year]	Piers
Ro-Ro Pax	407.9	13.8	42.3	2-14-16-18-20-21
Cruise	393.9	13.4	40.9	10-11-12-13-25S
Bulk	48.0	1.6	5.0	22-23-24
Cargo	85.7	2.9	8.9	25 N-26-27-28
Port Total	929.6	31.9	97.5	All Piers
Port + Anchor + TVN pier	1177.7	40.0	122.2	All piers + Anchor & TVN pier

Table 5

The three-year (2013–2016) statistics of regulated pollutants and wind speeds at the Civitavecchia Arpa Porto station. Wind speed averages "from port" (angular range 180°–360°), and "from port and to the city" (angular range 250°–340°) are given as % occurrences.

Site Arpa Porto	NO ₂ [µg/m ³]	SO ₂ [µg/m ³]	PM ₁₀ [µg/m ³]	Wind Speed [m/s]
Year average ± st.dev.	26.3 ± 22.0	1.21 ± 2.7	22.4 ± 18.5	3.4 ± 2.1
Year average from port (% of year average)	11.4 (43%)	0.7 (60%)	7.4 (33%)	40% of wind data from port
Year average from port to Civitavecchia	6.6 (25%)	0.5 (43%)	4.2 (19%)	20% of wind data to Civitavecchia
Winter average	26.8	0.8	24.5	3.7
Winter average from port (% of winter average)	5.4 (20%)	0.2 (30%)	4.9 (20%)	28% of wind data from port, 13% to Civitavecchia
Summer average	29.8	1.8	23.5	2.9
Summer average from port (% of summer average)	16.4 (55%)	1.4 (80%)	11.8 (50%)	50% of wind data from port, 30% to Civitavecchia

TITLE: Environmental impact assessment of an urban port: noise pollution survey in the port area of Napoli (S Italy)

AUTHORS: Marco Casazza, Francesca Boggia, Gianmarco Serafino, Vincenzo Severino, Massimiliano Lega

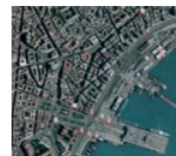
KEY WORDS: Noise pollution, Acoustic monitoring, Low-cost, sensors, Port cities

PUBLICATION YEAR: 2018

JOURNAL: Journal of Environmental Accounting and Management

ABSTRACT: The quality of life, particularly in the urban environment, becomes degraded, due to a cumulative effect of multiple exposition to pollutants. A special case is represented by urban ports, due to the fact that multiple impacts are superimposed. Moreover, being the port connected to the surrounding urban context, the potential negative impacts are magnified by the high number of exposed citizens in the close vicinity. This is why appropriate monitoring actions constitute the basis to define strategic planning options toward a more livable environment in of port cities. Considering the specific case of noise pollution, due to the cost of monitoring tools, it is important to develop scientifically-sound methodological options to perform preliminary surveys, using available low-cost technologies. This choice has the purpose of minimizing the costs of monitoring, while maximizing its effectiveness. Considering the specific case study of the port area of Napoli (S Italy), this work refers to the use of a freeware, which can be downloaded and installed in a smartphone, with the purpose of performing geo-localized noise pollution surveys. In particular, after defining the quality of collected data through a preliminary laboratory intercalibration, a series of field surveys were performed in 12 different points and measures were analyzed. Sound Pressure Level measures, which were found to be of higher quality, allowed to define two areas having different noise characteristics. Consequently, these areas could be disentangled in future monitoring operations, reducing the points of measure from 12 to 2. The obtained results suggest an option, which could be applied to other environmental parameters. Moreover, the quality of surveys could be further implemented through the use of aerial platforms, in order to obtain future 3D enhanced environmental scenarios assessment.

NUMBER ID: EU17



LOCATION: Port of Napoli
COUNTRY: Italy

Distance from city center: 2.3km
Total ports Area: 1.42 km²
Total populaion of port city: 3,085,000

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Energy emitted/ Noise emissions

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Noise Pollution

Table 2 Mean values of SPL data recorded during December 2, 2016. Measures are reported in the table according to the same spatial orientation of the map. In particular, points closer to the sea are found in the lower part of the table. Measures are separated in three categories: urban area; port vicinity; port area. Point 5, which can be disentangled from the others as a future monitoring activity, is reported as italic character.

Position	Point	SPL [dB]	Point	SPL [dB]	Point	SPL [dB]
Urban area	10	=	11	=	12	=
Port vicinity	7	79	8	76	9	81
Port	4	71	5	<i>67</i>	6	69
	1	79	2	66	3	68

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	681,929	643,540
RoRo/ Cars (tons)	4,162,000	2,384
Dry bulk cargo (tons)	1,247,000	1,104,000
Liquid Bulk (tons)	6,321,000	6,507,000
Passenger	5,993,000	2,908,151

Table 3 Mean values of SPL data recorded during December 7, 2016. Measures are reported in the table according to the same spatial orientation of the map. In particular, points closer to the sea are found in the lower part of the table. Measures are separated in three categories: urban area; port vicinity; port area. Point 5, which can be disentangled from the others as a future monitoring activity, is reported as italic character.

Position	Point	SPL [dB]	Point	SPL [dB]	Point	SPL [dB]
Urban area	10	71	11	73	12	77
Port vicinity	7	65	8	73	9	78
Port area	4	75	5	59	6	75
	1	78	2	61	3	68

Table 4 Mean values of data recorded during December 9, 2016. Measures are reported in the table according to the same spatial orientation of the map. In particular, points closer to the sea are found in the lower part of the table. Measures are separated in three categories: urban area; port vicinity; port area.

Position	Point	SPL [dB]	Point	SPL [dB]	Point	SPL [dB]
Urban area	10	71	11	76	12	76
Port vicinity	7	75	8	75	9	77
Port area	4	67	5	59	6	75
	1	78	2	61	3	67

TITLE: Impact on air quality of cruise ship emissions in Naples, Italy

AUTHORS: F. Murena, L. Mocerino, F. Quaranta, D. Toscano

KEY WORDS: Cruise ships, Emissions, Modelling, CALPUFF, NO₂, SO₂

PUBLICATION YEAR: 2018

JOURNAL: Atmospheric Environment

ABSTRACT: The Municipality of Naples, with about 1 million residents and about 3 million people living in the surroundings, suffers, as for many a city, from low air quality, as demonstrated by the concentration level of pollutants measured by fixed monitoring stations of the Regional Air Quality Network. The port of Naples is among the most important ports in the Mediterranean Sea with a large traffic of passengers and goods. Therefore, it contributes to atmospheric pollution of the nearby urban area with ship emissions. Public authorities need to know the contribution of different sources of atmospheric pollutants to put effective environmental policies into practice. In this article, a bottom-up methodology has been developed to assess the amount of atmospheric pollutants emitted by cruise ships traffic and its impact on the atmospheric pollution in Naples. A detailed description of in-port activities of cruise ships has been applied to calculate emission rates of NO_x and SO_x by using standard procedures corrected and integrated by real data to better evaluate actual engine power applied and fuel consumption. Considered activities include: navigation in port both at arrival and departure; maneuvering for berthing and unmooring and hoteling at berth. The study covers all cruise ship calls during the year 2016. The impact of cruise ship emissions on the urban area has been assessed by using the Gaussian puff model CALPUFF, thus obtaining contour maps of 1-h and year average values. Finally, in order to assess the contribution of cruise ship emissions to air quality, simulations have been compared with concentrations measured at fixed monitoring stations and during a monitoring campaign.

NUMBER ID: EU18



LOCATION: Port of Napoli
COUNTRY: Italy

Distance from city center: 2.3 km
Total ports Area: 1.43 km²
Total population of port city: 3,085,000

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Analysis of data measured at selected fixed stations and collected during a monitoring campaign performed

Table 4
Field data from fixed stations and monitoring campaign in 2016.

Period	Receptor		Period average		1-h maximum	
			NO ₂ [µg/m ³]	SO ₂ [µg/m ³]	NO ₂ [µg/m ³]	SO ₂ [µg/m ³]
Year	NA06	CA	44.0		178.6	
	NA07	CA	56.2		198.8	
	UP	CA	28.2	2.7	154.9	53.2
Jun-Sep	NA06	CA	39.5		149.7	
	NA07	CA	56.4		174.5	
	UP	CA	20.3	2.2	80.4	44.6
20 th Jan - 8th Mar	P1*	PS	7.87	3.46		
	P2*	PS	10.3	1.83		
	P3*	PS	6.57	7.23		
	U1*	PS	7.94	1.35		
	U2*	PS		1.23		
	NA06	CA	45.7		178.6	
	NA07	CA	53.3		155.8	
	UP	CA	36.5	2.4	124.7	9.5

CA= continuous analyser; PS = passive sampler.
* Murena et al., 2018.

Table 5
Data on traffic ships in the port of Naples compared with other ports.

Port	Reference period	Total tonnage	Cruise passengers	Total passengers	TEU
Naples	2017	22,396,568	927,458	6,684,772	509,876
Venice	2017	25,077,324	1,446,635	1,650,631	606,008
Genoa	2016	31,595,637	1,017,368	3,110,432	2,297,917
Barcelona	2017	60,070,134	2,712,247	4,136,999	2,968,757

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	681,929	643,540
RoRo/ Cars (tons)	4,162,000	2,384
Dry bulk cargo (tons)	1,247,000	1,104,000
Liquid Bulk (tons)	6,321,000	6,507,000
Passenger	5,993,000	2,908,151

Table 6
Annual emissions from cruise ships in the port of Naples in year 2016.

Activity	NO _x		SO _x	
	[t/y]	[%]	[t/y]	[%]
Navigation in port	6.09	1.45	0.18	1.29
Docking approach	2.02	0.48	0.08	0.57
Hoteling at berth	411	98.1	13.7	98.1
Total cruise ship	419	100	14.0	100

TITLE: External costs of Transportation Case study: maritime transport
AUTHORS: A. Miola, V. Paccagnan, I., Mannino, A. Massarutto, A. Perujo, M. Turvani
KEY WORDS: -
PUBLICATION YEAR: 2009
JOURNAL:

ABSTRACT: This report aims at proposing a methodological approach to estimate the external costs of maritime transport. In order to do so, It is organised into two sections: (i) identification of all environmental impacts of maritime transport (at sea and in ports) and a detailed analysis for those already studied in previous researches in literature; (ii) Estimation of identified environmental impacts focusing on those related to air pollutants. In the first paragraph we review external costs of transportation. Then, a description of maritime transportation activities (par. 2) and vessels (par.3) is provided. This will contribute to clarify the sources of environmental impacts. The central part of this report will be devoted to a detailed analysis of all environmental impacts listed above. The ultimate objective is to highlight the gaps that have to be filled in future research works. All the environmental effects entailed by maritime activities (both in port and at sea) are analysed (par. 4). The following environmental impacts of maritime transport have been considered: emissions to air and water, soil and sediment contamination, erosion, biodiversity loss and habitat degradation, and waste generation. In order to emphasise the complexity and uncertainty about the analysis of environmental impacts entailed by maritime transport, a review of research findings is provided (par. 5) and suggest research directions (par. 6). Next, we make a step forward and discuss the methodological aspects related to the economic valuation of these impacts (par. 7), so as to derive a monetary indicator able to summarise them. In particular, we review the economic literature regarding the valuation of the several environmental impacts discussed previously (par. 8 and 9), to sketch the state of the art. This review will provide a description of proposed methods for measuring each external cost. Then, we focus on impacts on air (par. 10). The strengths and limitations of existing approaches are described, by proposing at the same a methodological approach to estimate maritime pollution activities (par. 11). The proposed approach is tested through a case study, by estimating the external costs of a type of maritime activities in Venice (par. 12). The idea is to determine the relevant parameters that should be taken into account in the definition of an analytical approach, to signal research gaps so as to pave the way to future research activities. This will make possible to propose a methodology to be developed in future research for maritime transport and to test through a case study what are the main steps of such analysis. The last part of the report will emphasise future research directions.

NUMBER ID: EU19



LOCATION: Port of Venice
COUNTRY: Italy

Distance from city center: 1.4 km
Total ports Area: 20 km²
Total populaion of port city: 258,685

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	547,563	n/a
RoRo/ Cars (tons)	2,185,000	1,153,000
Dry bulk cargo (tons)	10,460,000	4,953,846
Liquid Bulk (tons)	8,448,000	8,566,470
Passenger	1,400,000	1,230,000

PERIOD OF ASSESSMENT: 2005

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Emissions to air from ships estimated by Regional Agency for Environmental Protection (ARPAV)

Table 39 – Emissions of Port of Venice

Shipping activity	Estimate	Emissions (tonnes/year)					
		NO _x	SO ₂	CO ₂	CO	HC	PM
National	Without tug boat	544.33	518.66	30733.98	71.54	48.78	76.64
	With tug boat	579.14	555.66	33039.87	76.91	52.62	83.67
International	Without tug boat	2952.43	2806.44	166884.15	388.47	259.23	409.59
	With tug boat	3068.75	2930.02	174587.67	406.40	272.07	433.09

Table 40 – Contribution of each vessel type to emissions (2005)

Vessel Type	Emissions (tonnes/year)									
	NO _x		SO ₂		CO ₂		HC		PM	
	A.V.	%	A.V.	%	A.V.	%	A.V.	%	A.V.	%
Passengers	1038.97	29.71	1104.6	33.22	66610.89	33.71	98.5	31.98	169.02	34.76
Mixed	10.25	0.29	10.21	0.31	603.80	0.31	0.9	0.29	1.47	0.3
Cargo	2447.54	69.99	2210.29	66.47	130403.44	65.99	208.61	67.73	315.74	64.94

Table 41 – Contribution of each shipping phase to emissions (2005)

Shipping phase	Emissions (tonnes/year)									
	NO _x		SO ₂		CO ₂		HC		PM	
	A.V.	%	A.V.	%	A.V.	%	A.V.	%	A.V.	%
Manoeuvring	632.04	18.08	611.70	18.4	36781.70	18.61	75.67	24.57	114.86	23.62
Stationing	2864.72	81.92	2713.4	81.6	160836.43	81.39	232.34	75.43	371.37	76.38

TITLE: Geochemistry of the Dust Collected by Passive Samplers as a Tool for Search of Pollution Sources: The Case of Klaipėda Port, Lithuania

AUTHORS: Paulius Rapalis, Rimantė Zinkutė, Nadežda Lazareva, Sergej Suzdalev and Ričardas Taraškevičius

KEY WORDS: total suspended particulates; stevedoring; Spectro Xepos EDXRF analysis; geochemical indices and mapping; cluster and principal component analysis; hotspots of contaminants

PUBLICATION YEAR: 2021

JOURNAL: Appl. Scienc./ MDPI

ABSTRACT: Geochemical investigations of total suspended particulates (TSP) help detect hotspots and emission sources in port cities with stevedoring operations. The aim was to reveal these sources via geochemical indices (gl). TSP were collected in Klaipėda using original passive samplers in ten sites during four periods, during one of them, in ten additional sites near iron ore stevedoring (IOS). The contents of 22 elements (PHEs, crustal, Br, Cl) were determined by EDXRF in TSP and characteristic dust (CD) of stevedored iron ore, apatite, phosphorite, potassium fertilizers, and in waste incineration ash. Median Fe content in TSP near IOS was ~29%. The significant anthropogenic origin of clusters Fe–Cr, Sr–P, V–Ni–Zn–Cu, Pb–As, and Mg–Ca, Br–S–Cl was confirmed by gl mapping and analysis of CD. Significant temporal variability of Cl, S, Sr, Ni, Br, V, and Zn due to weather changes was revealed. Near IOS, significantly higher values of gl were found for Fe and Cr, while far from IOS, for K, Sr, Ti, Rb, Cu, Al, Si, Zr, Ca, Mg. Significantly higher values of normalized enrichment factor near IOS were not only for Fe and Cr, but also for As, Pb, S, Mn, Br, and Cl.

NUMBER ID: EU20

LOCATION: Klaipėda Port

COUNTRY: Lithuania

Distance from city center: 3.9 km

Total ports Area: 5.57 km²

Total populaion of port city: 152,818

PERIOD OF ASSESSMENT: 2020

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Air pollutants sampling collection & statistical analysis

KEY FINDINGS: Contaminants identification and their emission sources



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	705,222	n/a
RoRo/ Cars (tons)	1,750,000	1,839,000
Dry bulk cargo (tons)	20,667,000	23,671,000
Liquid Bulk (tons)	10,400,000	9,058,000
Passenger	n/a	n/a

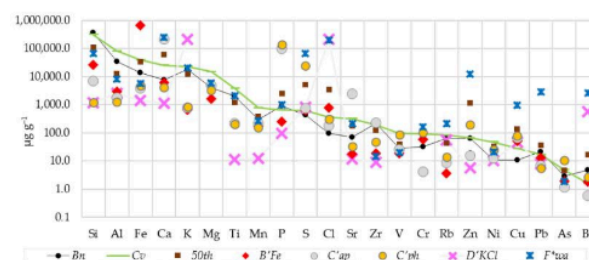


Figure 1. Location of TSP sampling sites (their identification number is in the circle) and potential sources of impact in Klaipėda port city. In the port area, the main stevedoring terminals are: A—bulk products loading (fertilizers: KCl, NH₄NO₃, (NH₂)₂CO, etc.; grain: wheat, barley, etc.); B—open loading (iron ore, scrap metal, building materials, etc.); C—bulk products loading (cement, apatite, phosphorites, etc.); D—bulk products loading (KCl fertilizers). Other companies and works: E—open warehousing, handling, transportation of granite, dolomite, mineral powder production by rail and trucks; F—waste incineration plant (70-m-high chimney, power plant burns about 255,000 tons per year); FEZ—works of free economic zone (manufacture of electrical installation, PET, HDPE, metal structures, cement packaging etc.); a—oil terminal; b—winter port; c—yacht port; d—ship repair and shipbuilding; e—paper and cardboard factory; f—ferry terminal; g—railway station; h—manufacture of wood products; i—heat, energy production (natural gas, biofuel); j—production and storage of concrete, building mixtures, etc.; k—location of former galvanic batteries factory; Cr—anomaly of contaminated topsoil [21]. 1–20 Sampling locations. Orthophoto map layer data: google maps.

TITLE: The Method to Decrease Emissions from Ships in Port Areas

AUTHORS: Vytautas Paulauskas, Ludmila Filina-Dawidowicz and Donatas Paulauskas

KEY WORDS: Maritime transport; emission from ships; sustainable port; energy sources; ship's crew and port pilots qualification; green shipping; environmentally friendly fuels

PUBLICATION YEAR: 2020

JOURNAL: MDPI

ABSTRACT: Nowadays great attention is being paid to the ecological aspects of maritime transport functioning, including the problem of pollution and emission of poisonous substances from ships. Such emissions have a significant impact on the environment and sustainable operation of ports, especially those located close to intensive waterways. A decrease in emissions from ships may be achieved by implementing different methods, among others, through the use of environmentally friendly fuels, electrical and hybrid vehicles, as well as through the improvement of port approach and inside navigational channels, optimization of the transport processes organization, etc. However, the size of the influence of ships' crew and ports pilots' qualification on the possibility to decrease the emissions from ships during maneuvering in port areas remains a question. This article aims to develop a method to assess the possible decrease of the emissions from ships in ports, considering human factor influence. The method has been developed and verified on the selected case study example. The influence of ships' crew and ports pilots' qualification on time spent on maneuvering operations by ships in port areas and consequently the volume of emissions has been investigated. The research results show that for the set conditions it is possible to reduce emissions from ships up to 12.5%. For that reason, appropriate education and training are needed to improve the qualifications of decision-makers performing ship maneuvers at ports areas.

NUMBER ID: EU21

LOCATION: Port of Klaipeda

COUNTRY: Lithuania

Distance from city center: 3.9 km

Total ports Area: 5.57 km²

Total populaion of port city: 152,818



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	705,222	n/a
RoRo/ Cars (tons)	1,750,000	1,839,000
Dry bulk cargo (tons)	20,667,000	23,671,000
Liquid Bulk (tons)	10,400,000	9,058,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2019

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Calculated emissions from LNG tankers

Table 3. Emissions from LNG Standard tanker during sailing in Klaipeda port calculated for diesel oil/LNG usage, based on experimental results obtained from the "SimFlex Navigator" simulator and real ship.

Operator, No.	CO ₂ , kg	SO _x , kg	CO, kg	NO, kg	PM, kg
1	2821/2002	0.91/0	32.3/22.6	6.5/4.5	3.23/0.32
2	2976/2112	0.96/0	32.1/22.4	6.4/4.5	3.21/0.32
3	3162/2244	1.02/0	32.6/22.8	6.5/4.6	3.26/0.33
4	3038/2156	0.98/0	32.1/22.5	6.4/4.5	3.21/0.32
5	2945/2090	0.95/0	32.3/22.6	6.5/4.5	3.23/0.32
6	3146/2233	1.02/0	33.1/23.1	6.6/4.6	3.31/0.33
7	2868/2035	0.93/0	31.9/22.3	6.4/4.5	3.19/0.32
8	2759/1958	0.89/0	31.1/21.8	6.2/4.4	3.11/0.31
9	3255/2310	1.05/0	33.05/23.1	6.6/4.6	3.31/0.33
10	3069/2178	0.99/0	32.6/22.8	6.5/4.6	3.26/0.33
Real LNG tanker	2759/1958	0.89/0	32.1/22.5	6.4/4.5	3.21/0.32

Table 5. The bands of the selected ship's sailing and emission parameters received by dispersion and maximal distribution methods.

Ship's Sailing and Emission Parameters	Parameter's Band Received by Dispersion Method, %	Parameter's Band Received by Maximal Distribution Method, %
Sailing time	4.2	4.2
Engine power	3.4	3.9
Fuel consumption	11.2	10.8
CO ₂ (diesel fuel)	11.3	10.8
CO ₂ (LNG fuel)	11.3	10.8
CO (diesel fuel)	3.4	3.7
CO (LNG fuel)	3.5	3.5
NO _x (diesel fuel)	4.0	4.0
NO _x (LNG fuel)	4.0	3.1
PM (diesel fuel)	3.7	4.3
PM (LNG fuel)	6.5	6.2
SO _x (diesel fuel)	12.5	10.4
SO _x (LNG fuel)	0	0

TITLE: Sustainability Performance of Port Infrastructure—A Case Study of a Quay Wall

AUTHORS: Poonam Taneja , Godert van Rhede van der Kloot and Mark van Koningsveld

KEY WORDS: Sustainability performance; GHG emissions; sustainable infrastructure; quay walls

PUBLICATION YEAR: 2021

JOURNAL: MDPI

ABSTRACT: Ports form a vital link in the global maritime supply chain, and adherence to the UN sustainable goals in each port development and operation is all-important. Improving the sustainability performance of port infrastructure requires identifying all relevant aspects of sustainability, defining suitable performance measures, applying tools for quantification, and proposing intervention measures if needed. We present a framework for assessing and managing the sustainability performance of port infrastructure incorporating these elements. We apply the framework to quay walls in the Port of Rotterdam (PoR); however, the information to assess only four out of fourteen sustainability themes was available. This fact underlines the need for sustainability monitoring and reporting. We also present a case study of a quay wall in PoR. Based on the vision of PoR and literature, the sustainability theme ‘air pollutants’ was given priority, the selected performance measure being the Greenhouse Gas (GHG) emissions. Dubocalc was chosen as a quantification tool and estimated a total emission of 1.9 kt of CO₂e_q for a 100-m length of quay wall over a 100-year lifecycle. The measures proposed to achieve climate neutrality in 2050 include using renewable energy for the Impressed Current Cathodic Protection and the temporary drainage systems, electrified transport and machinery, hydrogen as dredging fuel, and steel with hydrogen as a reduction-agent in the future. These could result in a total GHG reduction of 86% by the year 2050.

NUMBER ID: EU22

LOCATION: Port of Rotterdam

COUNTRY: Netherlands

Distance from city center: 1.1 km

Total ports Area: 2.8 km²

Total populaion of port city: 25,319



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	959,356	945,051
RoRo/ Cars (tons)	705,993	617,157
Dry bulk cargo (tons)	7,898,810	5,933,022
Liquid Bulk (tons)	4,307,388	3,323,068
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2015-2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: GHG impact of the proposed interventions result in a total GHG reduction by 2050

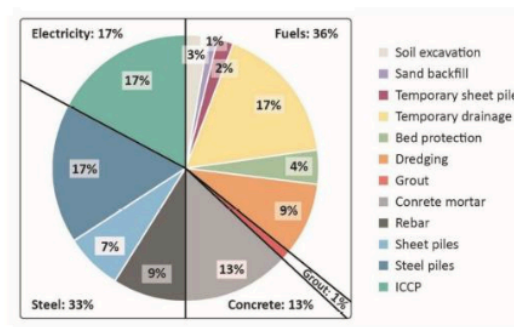


Figure 5. Carbon emissions expressed as a percentage of the total emission.

Table 1. Alternative fuels for dredging.

Material	Kg CO ₂ e _q /ton	MJ/kg
Marine Diesel Oil (MDO) [1 ton]	3749.92	42
Liquified Natural Gas [1 ton]	3987.11	49
Hydrotreated Vegetable Oil (HVO) [1 ton]	979.46	44

TITLE: Differentiating on port fees to accelerate the green maritime transition

AUTHORS: Alvar Mjelde, Øyvind Endresen, Einar Bjørshol, Caroline Wang Gierløff, Even Husby, Johanne Solheim, Narve Mjøs, Magnus S. Eide

KEY WORDS: Environmental Port Index, Environmental port fees, LNG cruise ship, AIS modelling, Air emission, Social cost of pollutants

PUBLICATION YEAR: 2019

JOURNAL: Marine Pollution Bulletin

ABSTRACT: This study investigates conditions under which differentiating port fees based on vessels' environmental performance could be an additional driver for cruise-ship owners to invest in green technologies. Our case study on liquefied natural gas (LNG) as fuel for a cruise ship shows that port-based incentives could help reduce emissions to air and drive uptake of green technologies. Assuming an average rebate of EUR 1500 per port visit, the accumulated rebates globally for our case study ship exceed EUR 400,000 per year. Applying a rebate of nearly EUR 4800 per visit as currently offered in Norwegian ports, and assuming 50% of ports globally adopt the scheme, gives a cost benefit of EUR 700,000 per year, reducing the LNG technology payback time up to one year. Our case study also shows that significantly reducing ship emissions in ports will bring social benefits through reduced risks of loss of life, health and wellbeing.

NUMBER ID: EU23



LOCATION: Port of Bergen

COUNTRY: Norway

Distance from city center: 0.9 km

Total ports Area: 0.15km²

Total populaion of port city: 271,949

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	36,823	40,671
RoRo/ Cars (tons)	168,000	101,000
Dry bulk cargo (tons)	2,297,000	2,155,000
Liquid Bulk (tons)	40,522,000	55,582,000
Passenger	157,000	66,000

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Port-based incentives could help reduce emissions to air and drive uptake of green technologies and significantly reducing ship emissions in ports will bring social benefits

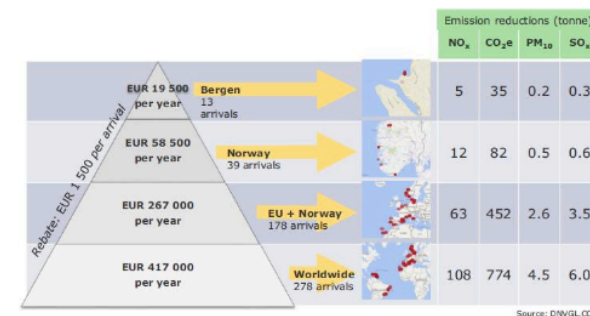


Fig. 1. Case modelling results for 2016 with geographical breakdown on emissions and accumulated rebate size for the LNG case ship compared with a ship using marine gas oil (MGO) and 0.1% sulphur.

Table 3
The social benefit of emission reductions in Port of Bergen for the LNG case ship in 2016.

	CO ₂	NO _x	SO _x	PM ₁₀	Total
Emission reductions using LNG instead of MGO (tonne)	35	5	0.3	0.2	–
Corresponding social benefit of emission reduction (EUR) ^a	1300	127,000	3400	68,600	~200,000

^a 2018 damage costs from Table 2 have been used. It is expected that the unit cost difference between 2016 and 2018 is negligible.

Table 2

Damage costs as unit price per emission component.

Sources: The Norwegian Public Roads Administration (Norwegian: Statens Vegvesen), 2018; The Norwegian Pollution Control Authority (Norwegian: Statens forurensningstilsyn - SFT), 2005.

Area breakdown	2018-unit price per emission component (EUR)			
	CO ₂ (2020) (EUR/kg)	NO _x (EUR/kg)	SO _x (EUR/kg)	PM ₁₀ (EUR/kg)
Larger city area (Oslo)	38.0	25.4	11.4	461
Larger city area (Bergen, Trondheim)		25.4	(average)	343
Other large cities		12.7		194
Areas > 15,000 inhabitants		12.7		52
Other areas		6.4		52

TITLE: Shipping emissions in a Nordic port: Assessment of mitigation strategies

AUTHORS: Susana López-Aparicio, Dag Tønnesen, The Nguyen Thanh, Heidi Neilson

KEY WORDS: Shipping emissions, Oceangoing vessels, Onshore power, Mitigation

PUBLICATION YEAR: 2017

JOURNAL: Transportation Research Part D

ABSTRACT: We use a bottom-up approach to develop a comprehensive emissions inventory for the Port of Oslo for current and future scenarios, including compliance with environmental legislation. We estimate the emission of air pollutants (NO_x, PM₁₀, SO₂) and greenhouse gases (GHGs; CO₂, CH₄, N₂O) from shipping and land activities in the port. The inventory shows that oceangoing vessels are the main contributor, providing 63–78% of the total NO_x, PM₁₀, SO₂ and CO₂e emissions. The main contributors among oceangoing vessels are international ferries, cruises and container vessels, and the main contributors to emissions among harbour vessels are domestic ferries. We estimate the emissions from oceangoing vessels for different operational modes, obtaining the highest values at berth followed by emissions during vessel manoeuvres. We evaluate a 2020 scenario that takes account of (i) the expected increase in maritime traffic; (ii) compliance with a new regulation regarding sulphur content in ship fuel (<0.1%); and (iii) implementation of various mitigation measures. These measures include implementation of onshore power, and its combination with a speed reduction zone in the port, and the increase use of liquid natural gas (LNG). The results show that compliance with regulation provides a reduction of 90% and 10% in SO₂ and PM₁₀ emissions, respectively. Onshore power in combination with a speed reduction zone provides reductions of up to 15% in NO_x and CO₂ emissions by 2020 compared with 2013, and further reductions of up to 23% (NO_x) and 17% (CO₂e) if we extend the use of LNG among domestic ferries.

NUMBER ID: EU24



LOCATION: Port of Oslo

COUNTRY: Norway

Distance from city center: 0.6 km

Total ports Area: 1.2 km²

Total population of port city: 673,469

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	257026	n/a
RoRo/ Cars (tons)	392,000	267,000
Dry bulk cargo (tons)	1,588,000	1,535,000
Liquid Bulk (tons)	2,020,000	1,669,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2013

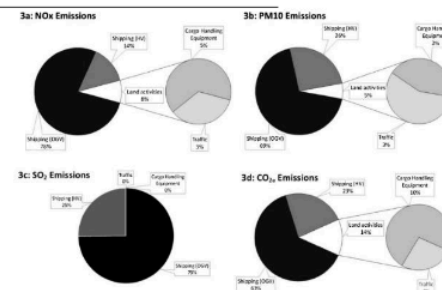
ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Emission contribution per sectors operating in the Port of Oslo. OGV identified as the main contributor to emissions, especially when OGV are at berth.

Table 6
Emissions (ton) estimated for different types of vessels and sectors (traffic and CHE) operating in the Port of Oslo in 2020.

Vessels/sector	NO _x	PM ₁₀	SO ₂	CO ₂	CH ₄	N ₂ O	CO ₂ -eq
Bulk carrier	11.14	0.14	0.30	502.91	0.00	0.02	510.15
Ro-Ro	26.37	0.35	0.71	1232.15	0.01	0.06	1250.14
Container	70.78	0.92	1.92	3269.38	0.02	0.15	3316.55
Cruise	190.98	3.20	6.76	11391.90	0.07	0.52	11554.96
International ferry	299.89	5.01	10.25	17600.03	0.11	0.82	17855.74
General cargo	35.67	0.47	0.98	1665.59	0.01	0.08	1689.65
Oil/chemical tankers	45.99	0.63	1.33	2240.04	0.01	0.10	2272.05
Commercial fishing	0.30	0.01	0.00	30.42	0.00	0.00	30.77
Domestic ferry	89.89	3.32	1.03	11592.97	1.56	0.35	11733.15
Recreational	5.15	0.20	0.06	522.14	0.07	0.02	528.26
Supply vessels	2.04	0.08	0.02	207.33	0.03	0.01	209.76
Tug - push boat	7.41	0.28	0.09	751.42	0.10	0.02	760.23
Work boats	6.45	0.24	0.08	654.70	0.09	0.02	662.37
Other vessels	9.97	0.38	0.12	1011.21	0.13	0.03	1023.06
Traffic	17.74	0.61	0.02	2369.67	0.05	0.12	2408.04
Cargo handling equipment	8.30	0.52	0.00	6429.69	0.06	0.04	6442.39
Total	828.07	16.36	23.66	61471.53	2.30	2.35	62247.27



TITLE: Assessment of source contribution to air quality in an urban area close to a harbor: Case-study in Porto, Portugal

AUTHORS: Sandra Sorte, Saravanan Arunachalam, Brian Naess, Catherine Seppanen, Vera Rodrigues, Alejandro Valencia, Carlos Borrego, Alexandra Monteiro

KEY WORDS: Ship emissions, Source contribution, Air quality, Dispersion modelling, Port areas

PUBLICATION YEAR: 2019

JOURNAL: Science of the Total Environment

NUMBER ID: EU25



LOCATION: Port of Leixões, Porto
COUNTRY: Portugal

Distance from city center: 3.4 km
Total ports Area: 1.75 km²
Total populaon of port city: 220,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	620,718	528,535
RoRo/ Cars (tons)	1,047,000	1,335,555
Dry bulk cargo (tons)	2,607,000	999,000
Liquid Bulk (tons)	7,759,000	5,554,000
Passenger	88,696	6,477

ABSTRACT: Several harbors, like the Port of Leixões (Porto, Portugal), are located near urban and industrial areas, places where residential urban areas, highways and the refinery industry coexist. The need for assessing the contribution of the port to the air quality in its vicinity around the port is the motivation for the present study. This contribution was investigated using a numerical modelling approach based on the web-based research screening tool C-PORT. The impact of the meteorological conditions (namely atmospheric stability and wind direction) was first evaluated, and the most critical conditions for pollutants dispersion were identified. The dominant wind direction, from WSW, was responsible for the transport of pollutants over the surrounding urban area, which was potentiated by the diurnal sea breeze circulation. Multiple scenario runs were then performed to quantify the contribution of each emission sector/activity (namely maritime emissions; port activities; road traffic and refinery) to the ambient air quality. The multiple scenario runs indicated that land-based emission sources at the Port (including trucks, railways, cargo handling equipment and bulk material stored) were the major contributors (approximately 80%) for the levels of surface PM10 concentrations over the study area. Whereas, the main drivers of NOX concentrations were docked ships, responsible for 55–73% of the total NOX concentrations.

PERIOD OF ASSESSMENT: 2013-2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Evaluation of the impact of meteorological conditions and identification of critical conditions for pollutants dispersion

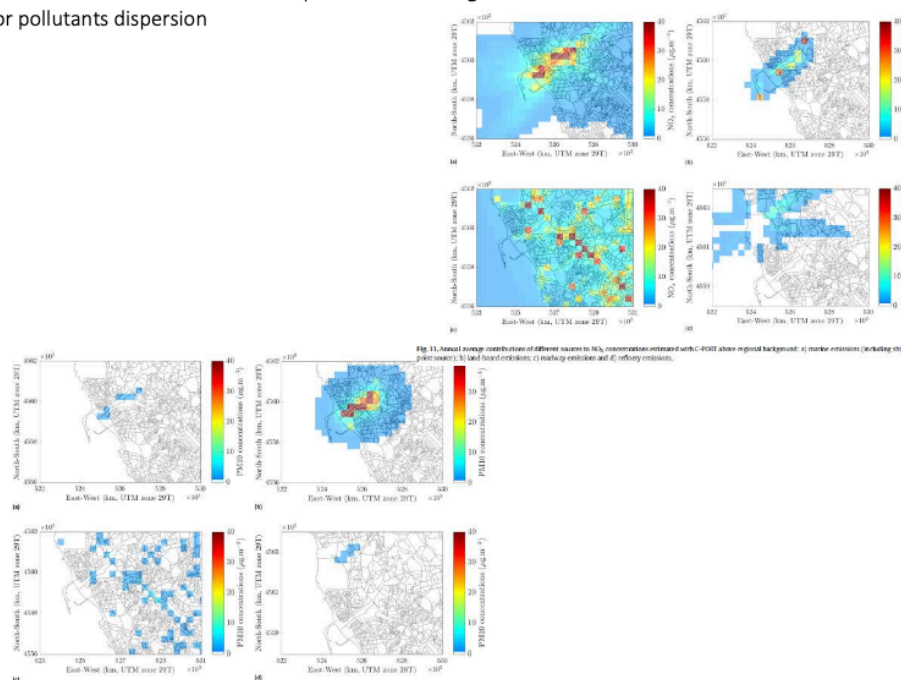


Fig. 10. Annual average contributions of different sources to PM10 concentrations estimated with C-PORT above regional background; a) maritime emissions (including ship in transit and port sources); b) land-based emissions; c) maritime emissions and d) refinery emissions.

TITLE: Impact of SO₂ shipping emissions on air quality: The Airship Project

AUTHORS: Alexandra Monteiro, Michael Russo, Carla Gama, Carlos Borrego Cesam

KEY WORDS: SO₂ pollutant, emissions, shipping, air quality modelling, Portugal

PUBLICATION YEAR: 2018

JOURNAL: WIT Transactions on Ecology and the Environment

ABSTRACT: Due to its dependence on fossil fuel combustion, emissions from the marine transport sector can significantly contribute to air pollution. The AIRSHIP research project (<http://airship.web.ua.pt/>) aims to evaluate this contribution and how it affects air quality in Europe, and over Portugal in particular, using a numerical air quality modelling approach with high-resolution emission data. Emissions from the MACC project inventory were compiled and pre-processed at hourly and high spatial resolutions. Scenarios with and without the maritime emissions were then simulated with the WRF-CHIMERE modelling system, amply tested and validated for both simulation domains, in order to evaluate its impact on air quality. This modelling system was applied for Europe (27x27 km²) and Portugal (3x3km²) domains, using nesting approach. The talk will focus on presenting part of the work of the research project, namely regarding the comparison of the modelling results (with and without considering maritime emissions) for Europe and Portugal domains, with focus on SO₂ pollutant, one of the most critical pollutants associated to shipping activity. The main differences/impacts for SO₂ are located over the international shipping routes and major ports. The modelling results also indicate that the two main hotspots areas are located in the Baltic and Mediterranean Sea. Over Portugal domain, the impact of these maritime emissions reaches the coast and is responsible for deltas of SO₂ superior to 2 µg.m⁻³.

NUMBER ID: EU26

LOCATION:

Portugal

CONTINENT: Europe

PERIOD OF ASSESSMENT: 2015

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Impacts of current ship emissions on the air quality over Europe and Portugal

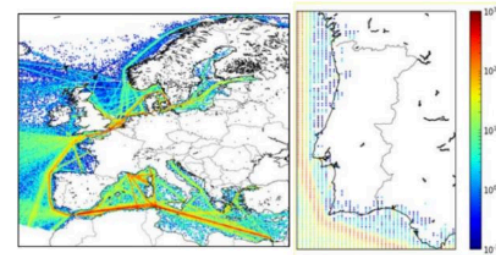


Figure 4: SO₂ emissions from shipping over Europe (left) and Portugal (right) domains in tonnes per year.

Abbreviations

Energy production	S1
Industry sector	S3 and S4
Shipping	S8

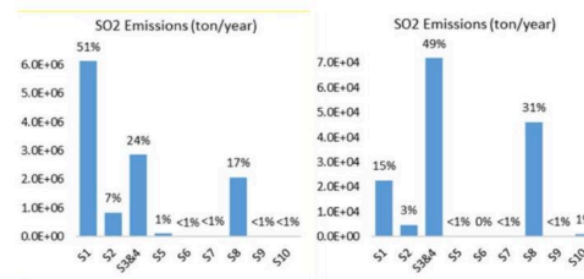


Figure 3: SO₂ emissions per activity sector for Europe (left) and Portugal (right) in tonnes per year.

TITLE: Assessment of shipping emissions on four ports of Portugal

AUTHORS: R.A.O. Nunes, M.C.M. Alvim-Ferraz, F.G. Martins, S.I.V. Sousa

KEY WORDS: Portuguese ports, Activity-based method, Air pollution, Shipping emissions, Climate change

PUBLICATION YEAR: 2017

JOURNAL: Environmental Pollution

ABSTRACT: In the last few years, ship emissions have attracted growing attention in the scientific community. The main reason is the constant increase of marine emissions over the last twenty years due to the intensification of port traffic. Thus, this study aimed to evaluate ship emissions (PM10, PM2.5, NOx, SO2, CO, CO2, N2O CH4, NMVOC, and HC) through the activity-based methodology in four of the main ports of Portugal (Leixoes, Setúbal, Sines and Viana do Castelo) during 2013 and 2014. The analysis was performed according to ship types (bulk carrier, container, general cargo, passenger, Ro-Ro cargo, tanker and others) and operational modes (manoeuvring, hotelling and during cruising). Results indicated that tankers were the largest emitters in two of the four analysed ports. Regarding cruising emissions, container ships were the largest emitters. CO2, NOx and SO2 estimated emissions represented more than 95% of the cruising and in-port emissions. Results were also compared with the total national emissions reported by the Portuguese Environment Agency, and if the in-port emissions estimated in the present study would have been taken into account to these totals, emissions of NOx and SO2 would increase 15% and 24% in 2013 and 16% and 28% in 2014. Summing up ships seem to be an important source of air pollution, mainly regarding NOx and SO2.

NUMBER ID: EU27

Distance from city center: 3.4 km
Total ports Area: 1.75 km²
Total populaion of port city: 220,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	620,718	528,535
RoRo/ Cars (tons)	1,047,000	1.335.555
Dry bulk cargo (tons)	2,607,000	999,000
Liquid Bulk (tons)	7,759,000	5,554,000
Passenger	88,696	6,477

LOCATION: Main ports of Portugal (Leixoes, Setúbal, Sines)
COUNTRY: Portugal

Distance from city center: 2 km
Total ports Area: n/a
Total populaion of port city: 118,166

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	141,697	123,538
RoRo/ Cars (tons)	519,000	335,000
Dry bulk cargo (tons)	3,446,00	3,149,000
Liquid Bulk (tons)	367,000	337,000
Passenger	n/a	n/a

Distance from city center: 2 km
Total ports Area: 6.31 km²
Total populaion of port city: 13,500

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,423,212	1,612,000
RoRo/ Cars (tons)	34000	41,000
Dry bulk cargo (tons)	3,160,000	1,535,000
Liquid Bulk (tons)	21,332,000	21,511,000
Passenger	22861	n/a

PERIOD OF ASSESSMENT: 2013-2014

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Estimation of the ship emissions of PM10, PM2.5, NOx, SO2, CO, CO2, N2O CH4, NMVOC, and HC

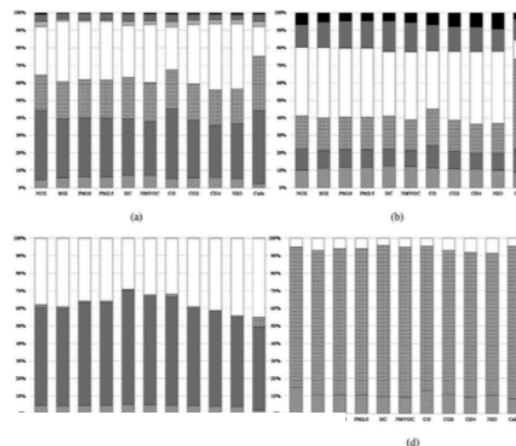


Table 1
In-port Emissions of air pollutants and ship calls by port during 2013 and 2014 (in t y⁻¹).

Port	Year	NO _x	SO ₂	PM10	PM2.5	HC	NMVOC	CO	CO ₂	CH ₄	N ₂ O	Total	Calls
Leixões	2013	8.1E+03	3.3E+03	3.5E+02	3.2E+02	2.6E+02	1.0E+02	3.1E+02	1.9E+05	2.7	9.9	2.1E+05	2564
	2014	8.2E+03	3.3E+03	3.6E+02	3.3E+02	2.7E+02	1.1E+02	3.1E+02	2.0E+05	2.8	1.0E+01	2.1E+05	2612
Setúbal	2013	9.8E+03	4.2E+03	4.7E+02	4.3E+02	3.8E+02	1.6E+02	3.7E+02	2.6E+05	3.8	1.3E+01	2.8E+05	1350
	2014	1.1E+04	4.9E+03	5.5E+02	5.1E+02	4.4E+02	1.8E+02	4.2E+02	2.9E+05	4.4	1.5E+01	3.1E+05	1514
Sines	2013	9.4E+03	5.0E+03	5.6E+02	5.2E+02	4.4E+02	1.8E+02	3.9E+02	3.0E+05	4.5	1.5E+01	3.1E+05	1982
	2014	1.0E+04	5.5E+03	6.1E+02	5.6E+02	4.9E+02	2.0E+02	4.3E+02	3.2E+05	4.9	1.6E+01	3.4E+05	1975
Viana do Castelo	2013	3.6E+02	1.4E+02	1.5E+01	1.4E+01	1.1E+01	4.1	1.4E+01	8.1E+03	1.1E-01	4.1E-01	8.6E+03	199
	2014	3.5E+02	1.4E+02	1.6E+01	1.4E+01	1.2E+01	4.6	1.4E+01	8.3E+03	1.1E-01	4.1E-01	8.9E+03	181

Legend: Container Ship (white), Ro-Ro (light gray), Dry Bulk (dark gray), Liquid Bulk (black), Passenger (white).
a) Leixoes Port and b) Setubal Port, c) Sines Port and d) Viana do Castelo Port.

TITLE: Identifying the unique challenges of installing cold ironing at small and medium ports – The case of aberdeen
AUTHORS: Alexander Innes, Jason Monios
KEY WORDS: Cold ironing, Shore-side power, Onshore power supply, Seaports, Environmental, Sustainability, Policy
PUBLICATION YEAR: 2018
JOURNAL: ELSEVIER

ABSTRACT: Emissions from shipping contribute significantly to both climate change and local air pollution. Cold ironing (onshore power supply) reduces emissions while ships are berthed in port by providing power from shore-side electricity rather than onboard auxiliary generators. Previous research has focused on installing the technology in large ports but if policy goals (particularly in the EU) are to be achieved then smaller ports must also install the technology. Therefore, this study examines the feasibility of installing cold ironing in a medium sized port with several small berths, based on the case of Aberdeen. Vessel call data were analysed to calculate energy demand and a cold ironing system was designed, including separate OPS units for numerous small berths. The total capital cost was £6.6m (€7.4 m) and the system could save annual emissions of 108 tonnes of NOx, 2.7 tonnes of PM and 4,767 tonnes of CO₂ emissions worth £1.3m (€1.4 m). Payback scenarios were examined via SCBA, based on the external costs of potential emission savings. In the best case scenario, the substantial external cost benefits would return the system capital and operating costs in only 7.0 years, or 3.5 years if subsidised 50% by the EU. Challenges result from several small berths needing individual OPS units, long cables and cable reel storage, as well as the need for several vessels to install the onboard technology, which must be overcome if ports besides the large cruise and container ports are to install cold ironing.

NUMBER ID: EU28

LOCATION: Port of Aberdeen
COUNTRY: Scotland

Distance from city center: 1.2 km
Total ports Area: 38.8 km²
Total populaion of port city: 198,590



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	2,418	n/a
RoRo/ Cars (tons)	15,000	n/a
Dry bulk cargo (tons)	491,000	n/a
Liquid Bulk (tons)	2,198,000	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air/ energy consumption

METHODOLOGY: Energy consumption recordings

KEY FINDINGS: This study has shown that it is feasible to install cold ironing technology in a medium sized port for vessels which are smaller than those traditionally connected to shore power

Table 7
Emissions from ferries and OSVs.

	Ferries	All OSVs	21 OSVs
Fuel consumption (tons)	452.13	1542.76	818.86
Energy Demand (kWh)	2,055,148	6970701.45	3751243.01
Total NOx from ships (tons)	26.32	82.38	43.73
Total NOx from grid (tons)	0.154	0.52	0.28
NOx saved using Shore Power (tons)	26.17	81.86	43.45
Total PM _{2.5} from ships (kg)	300.67	1025.93	544.54
Total PM ₁₀ from ships (kg)	316.49	1079.93	573.21
Total PM from grid (kg)	6.988	23.84	12.71
PM saved using Shore Power (kg)	610.17	2082.02	1105.04
Total CO ₂ from ship (tons)	1449.54	4946.08	2625.28
Total CO ₂ from grid (tons)	370.81	1257.71	670.33
CO ₂ saved Using Shore Power (tons)	1078.73	3688.37	1954.951

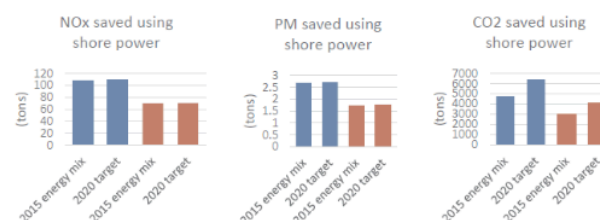


Fig. 5. Nox, PM and CO₂ savings using OPS.

TITLE: The Effect of Port Gate Location and Gate Procedures on the Port-City Relation

AUTHORS: Marina Zanne , Elen Twrdy and Bojan Bešković

KEY WORDS: Port gates; gate procedures; port-related truck traffic; external costs; port-city relation

PUBLICATION YEAR: 2021

JOURNAL: MDPI

ABSTRACT: Ports are important hubs that have positive impacts on the regions they serve, but they also pose some challenges that need to be addressed. Many ports around the world have aligned their development strategies with the concept of green growth; however, the green and efficient performance of ports does not only depend on the port management itself; some elements need to be negotiated and approved by local and national governments. One of such elements is road port access. We investigated the impact of port gate location and port gate procedures on port's performance by examining the case of the Adriatic port of Koper, the only Slovenian international cargo port. We found that significant external costs are incurred due to a non-optimized situation caused by the lack of coordination and cooperation on all levels, although the port of Koper is one of European core ports. Further, delayed digitalization of port gate procedures caused by port management adds to degradation of port city relations.

NUMBER ID: E29



LOCATION: Port of Koper
COUNTRY: Slovenia

Distance from city center: 1.1 km
Total ports Area: 2.8 km²
Total populaion of port city: 25,319

PERIOD OF ASSESSMENT: 2008-2020

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Emissions from port related traffic

Table 7. Estimated emissions from port-related truck traffic.

	Trucks	Personal Cars	Total
2008	147,442	32,938	180,380
2009	101,470	30,555	132,025
2010	118,613	28,172	146,786
2011	133,817	25,789	159,606
2012	137,014	24,722	161,737
2013	138,505	23,557	162,062
2014	116,096	21,840	137,937
2015	130,796	21,798	152,594
2016	144,600	20,619	165,219
2017	163,150	19,099	182,249
2018	178,523	19,640	198,162
2019	175,934	17,390	193,324
2020	142,592	17,390	159,981
Sum	1,828,552	303,509	2,132,061

Source: Authors.

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	959,356	945,051
RoRo/ Cars (tons)	705,993	617,157
Dry bulk cargo (tons)	7,898,810	5,933,022
Liquid Bulk (tons)	4,307,388	3,323,068
Passenger	n/a	n/a

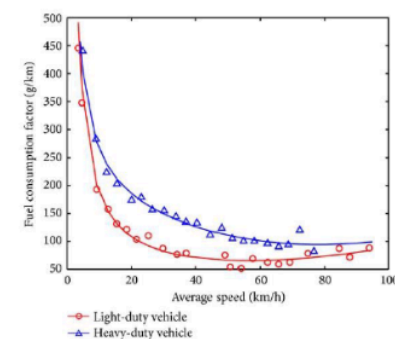


Figure 8. Speed related fuel consumption of commercial vehicles.

TITLE: Impact of COVID-19 on environmental noise emitted from the port
AUTHORS: Luka Čurović, Sonja Jeram, Jure Murovec, Tadej Novaković, Klara Rupnik, Jurij Prezelj
KEYWORDS: COVID-19, Noise pollution, Continuous environmental noise monitoring, Noise mapping, Port, Slovenia
PUBLICATION YEAR: 2020
JOURNAL: Science of the Total Environment

ABSTRACT: Identification of noise sources and their ranking is a crucial part of any noise abatement program. This is a particularly difficult task when a complex source, such as a seaport, is considered. COVID-19 epidemic has had a significant impact on environmental noise related to road, rail, air and ship traffic and provided a unique opportunity to observe immediate noise reduction. In order to identify the noise sources, whose reduction was most effective in reducing noise from the port area, this study compared and quantified noise emissions between the historical and epidemic periods. Environmental noise measurements from three noise monitoring stations at the port boundary were analysed. In addition, noise emissions from ship, road, rail and industry as well as meteorological data in the historical pre – COVID-19 (January 2018–February 2020) and COVID-19 (April 2020) period were analysed in detail. The characteristics of the noise sources mentioned, geographical data and noise measurements were used to develop and validate a noise model of the port area, which was used to calculate noise contour maps. Our results show that the reduction in noise levels observed at all monitoring stations coincides with the reduced shipping traffic. The A weighted equivalent sound pressure levels in the day, evening and night periods were reduced by 2.2 dB to 5.7 dB compared to the long-term averages, and the area of the 55 dB day evening-night noise contour was reduced by 23%. Compared to the historical period, the number of people exposed to noise levels above 55 dB(A) in the day-evening-night period due to shipping and industrial activities was reduced by 20% in the COVID-19 period. Such results show that environmental noise generated by moored ships is a problem for port cities that should be regulated internationally. In addition, this paper provides precise guidance on noise emission characteristics, ship categorisation and the post-processing of long-term measurement data, taking into account wind conditions and undesired sound events, which can be applied to future research at other locations near shipping ports and used to prepare strategies for noise reduction in ports.

NUMBER ID: EU30



LOCATION: Port of Koper
COUNTRY: Slovenia

Distance from city center: 1.1 km
Total ports Area: 2.8 km²
Total populaion of port city: 25,319

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	959,356	945,051
RoRo/ Cars (tons)	705,993	617,157
Dry bulk cargo (tons)	7,898,810	5,933,022
Liquid Bulk (tons)	4,307,388	3,323,068
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 1 January 2018 to 30 June 2020

ENVIRONMENTAL ASPECT: Energy emitted/ Noise emissions

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Reduction of environmental noise and the impact of Covid-19

Table 7
Average noise levels during the historical (January 2018–February 2020) period and March, April, May and June 2020 periods.

Noise monitoring terminal/noise level [dB]	January 2018–February 2020	March 2020	April 2020	May 2020	June 2020
NMT1					
$L_{Aeq,05:00-18:00}$	52.9 ± 0.6	52.0 ± 0.7	49.7 ± 0.7	50.8 ± 0.7	51.5 ± 0.7
$L_{Aeq,18:00-22:00}$	50.9 ± 0.6	48.9 ± 0.7	47.0 ± 0.7	47.0 ± 0.7	49.5 ± 0.7
$L_{Aeq,22:00-06:00}$	48.4 ± 0.6	47.5 ± 0.7	46.2 ± 0.7	46.0 ± 0.7	47.0 ± 0.7
$L_{Aeq,05:00-24:00}$	55.9 ± 0.4	54.9 ± 0.5	53.3 ± 0.5	53.4 ± 0.5	54.5 ± 0.5
NMT2					
$L_{Aeq,05:00-18:00}$	62.4 ± 0.6	61.9 ± 0.7	59.3 ± 0.7	61.6 ± 0.7	60.5 ± 0.7
$L_{Aeq,18:00-22:00}$	61.8 ± 0.6	61.1 ± 0.7	59.4 ± 0.7	60.9 ± 0.7	60.3 ± 0.7
$L_{Aeq,22:00-06:00}$	61.2 ± 0.6	60.5 ± 0.7	58.0 ± 0.7	60.2 ± 0.7	59.5 ± 0.7
$L_{Aeq,05:00-24:00}$	67.8 ± 0.4	67.2 ± 0.5	64.8 ± 0.5	66.9 ± 0.5	66.1 ± 0.5
NMT3					
$L_{Aeq,05:00-18:00}$	52.6 ± 0.6	51.8 ± 0.7	49.3 ± 0.7	50.2 ± 0.7	52.9 ± 0.7
$L_{Aeq,18:00-22:00}$	50.5 ± 0.6	49.2 ± 0.7	46.2 ± 0.7	45.8 ± 0.7	51.5 ± 0.7
$L_{Aeq,22:00-06:00}$	49.0 ± 0.6	48.5 ± 0.7	43.3 ± 0.7	46.2 ± 0.7	50.3 ± 0.7
$L_{Aeq,05:00-24:00}$	56.2 ± 0.4	55.5 ± 0.5	51.3 ± 0.5	53.3 ± 0.5	57.2 ± 0.5



(a) Jan 2018 - Feb 2020, night period.



(c) Jan 2018 - Feb 2020, day-evening-night period.

TITLE: Quantification of the impact of port activities on PM₁₀ levels at the port-city boundary of a mediterranean city

AUTHORS: Clemente, E. Yubero, N. Galindo, J. Crespo, J.F. Nicolas, M. Santacatalina, A. Carratala

KEYWORDS: PM₁₀, Port, Harbor, Bulk materials, Source apportionment, PMF

PUBLICATION YEAR: 2021

JOURNAL: Journal of Environmental Management

ABSTRACT: The main objective of this work was to quantify the impact of handling of bulk materials on PM₁₀ levels measured at the port-city border of Alicante (Spain), located on the western Mediterranean coast. To achieve that goal, 355 PM₁₀ samples were collected at the perimeter of the harbor of Alicante from March 2017 to February 2018. A 181 sample subgroup was chemically characterized in order to perform a source apportionment study with the EPA PMF 5.0 model. Eight factors were identified, two of them directly related to the handling of bulk materials (Limestone + gypsum and Clinker), accounting jointly for 35% of the average PM₁₀ concentration. A Road traffic factor was the second highest contributor to PM₁₀ levels (17%) while the Shipping emissions factor accounted for only 6% of the average PM₁₀ mass. Other factors such as Biomass burning+ secondary nitrate and Aged sea salt represented a joint contribution of 25% of the PM₁₀ mass. Results indicate that emission abatement strategies should primarily focus on the reduction of fugitive emissions caused by the handling of bulk materials at the docks. Moreover, scenarios including reductions of more than 50% in bulk handling sources and 10% in other anthropogenic sources would help to reduce anthropogenic exceedances of the daily PM₁₀ limit (50 $\mu\text{g}\cdot\text{m}^{-3}$) and to approach to WHO daily PM₁₀ standard (20 $\mu\text{g}\cdot\text{m}^{-3}$).

NUMBER ID: EU31

LOCATION: Port of Alicante
COUNTRY: Spain

Distance from city center: 2.4 km

Total ports Area: n/a

Total populaion of port city: 331,577



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	171,264	158,043
RoRo/ Cars (tons)	7,000	2,000
Dry bulk cargo (tons)	1,441,000	1,397,000
Liquid Bulk (tons)	32,000	34,000
Passenger	15,047,840	3,740,000

PERIOD OF ASSESSMENT: 2017-2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Level and impacts of PM₁₀

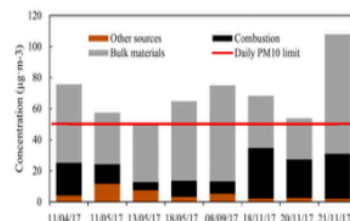


Fig. 9. Contribution of the handling of bulk materials, combustion and secondary sources and other sources to PM₁₀ daily levels on exceedance days.

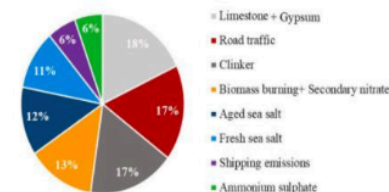


Fig. 3. Percentage contribution of the different PMF factors to the mean modelled PM₁₀ concentration.

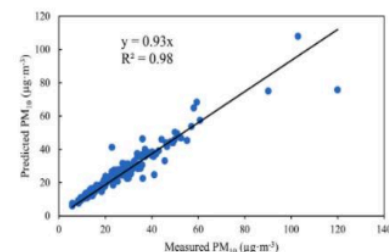


Fig. 4. PMF modelled versus measured PM₁₀ concentrations ($\mu\text{g}\cdot\text{m}^{-3}$).

TITLE: Prediction of the impact on air quality of the cities receiving cruise tourism: the case of the Port of Barcelona
AUTHORS: Ignacio Ruiz-Guerra, Valentín Molina-Moreno, Francisco J. Cortés-García, Pedro N. Uñez-Cacho
KEY WORDS: Environmental science
PUBLICATION YEAR: 2019
JOURNAL: ELSEVIER

ABSTRACT: The cruise tourism industry has experienced significant growth in recent years and has a very positive outlook for the future. However, its environmental impact requires a review of its sustainability, including the analysis of its social, economic and environmental balance, and the evaluation of its impact on port cities receiving cruise ships. The purpose of this document is twofold: First, to analyze the relationship between air quality, as an environmental variable, and the volume of cruise ships and passengers that visit a port with the aim of generating information. Secondly, it is intended to develop an index, based on the information already available that allows cities to predict the impact of this activity, so that decisions are made to alleviate these effects. Methods: The primary data taken monthly for the period 2006-2017, related to the level of emissions and the number of cruises and passengers, are used as a basis. A regression analysis is performed to determine the relationship between air pollution and the number of tourists coming from the cruise ships. As a contribution, the results show the influence of this type of tourism on environmental indicators. In addition, in an original way, a regression function is established that allows estimating the future impact of the cruise industry in the port cities. So that, cities can prevent this type of environmental impact. This will make it easier for the cruise tourism industry to develop more sustainable models in the long term.

NUMBER ID: EU32



LOCATION: Port of Barcelona
COUNTRY: Spain

Distance from city center: 5 km
Total ports Area: 7.86 km²
Total population of port city: 1,620,343

PERIOD OF ASSESSMENT: 2006 - 2017

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Calculation of marine air emissions using numerical modelling

KEY FINDINGS: Environmental impact of cruise tourism in the Port of Barcelona

Table 3. Correlation between variables.

		MONTH	YEAR	SO ₂ (µg/m ³)	NO (µg/m ³)	NO ₂ (µg/m ³)	O ₃ (µg/m ³)
MONTH	Pearson Correlation	1	.000	-.093	.115	-.138	-.172*
	Sig. (2-tailed)		1.000	.267	.170	.099	.039
	N	144	144	144	144	144	144
YEAR	Pearson Correlation	.000	1	-.809**	-.127	-.320**	.103
	Sig. (2-tailed)		1.000	.000	.131	.000	.218
	N	144	144	144	144	144	144
SO ₂ (µg/m ³)	Pearson Correlation	-.093	-.809**	1	.101	.375**	-.053
	Sig. (2-tailed)		.267	.000	.228	.000	.525
	N	144	144	144	144	144	144
NO (µg/m ³)	Pearson Correlation	.115	-.127	.101	1	.715**	-.849**
	Sig. (2-tailed)		.170	.131	.228	.000	.000
	N	144	144	144	144	144	144
NO ₂ (µg/m ³)	Pearson Correlation	-.138	-.320**	.375**	.715**	1	-.602**
	Sig. (2-tailed)		.099	.000	.000	.000	.000
	N	144	144	144	144	144	144
O ₃ (µg/m ³)	Pearson Correlation	-.172*	.103	-.053	-.849**	-.602**	1
	Sig. (2-tailed)		.039	.218	.000	.000	.000
	N	144	144	144	144	144	144
CO (mg/m ³)	Pearson Correlation	-.013	-.800**	.850**	.208*	.413**	-.109
	Sig. (2-tailed)		.880	.000	.000	.012	.000
	N	144	144	144	144	144	144
ICQA	Pearson Correlation	.296**	.349**	-.437**	.067	-.298**	-.316**
	Sig. (2-tailed)		.000	.000	.422	.000	.000
	N	144	144	144	144	144	144
PASSENGERS	Pearson Correlation	.400**	.044	-.036	-.644**	-.574**	.606**
	Sig. (2-tailed)		.000	.603	.000	.000	.000
	N	144	144	144	144	144	144
CRUISES	Pearson Correlation	.428**	-.032	-.010	-.584**	-.468**	.550**
	Sig. (2-tailed)		.000	.700	.000	.000	.000
	N	144	144	144	144	144	144

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	3,300,000	3,000,000
RoRo/ Cars (tons)	3,292,000	2,562,000
Dry bulk cargo (tons)	4,071,000	4,013,000
Liquid Bulk (tons)	12,862,000	12,862,000
Passenger	4,628,562	857,966

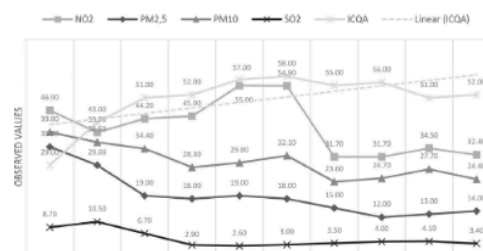


Fig. 1. Evolution of the indicators of air pollution in the port of Barcelona (2006–2017).

Source: the authors.

TITLE: Energy efficiency and CO2 emissions of port container terminal equipment: Evidence from the Port of Valencia

AUTHORS: Julián Martínez-Moya, Barbara Vazquez-Paja, Jose Andrés Gimenez Maldonado

KEY WORDS: CO2 emissions, Port container terminal, Port container terminal equipment, Port energy management, Energy efficiency, Port sustainability

PUBLICATION YEAR: 2019

JOURNAL: Energy Policy

ABSTRACT: Energy efficiency has emerged as a key point in port industry because of different factors such as the adoption of stronger environmental regulations and the increasing pressure of the local community on the surrounding ports. As gathering operational data from port terminals can be difficult due to privacy, studies on emissions and energy efficiency of these terminals are scarce. The following research provides key information about the real energy consumption and CO2 emissions of one of the most relevant container terminals in the Mediterranean area, located in Valencia, Spain. The results show that yard terminal tractors and rubber tyred gantry cranes (RTGs) are the main emission sources, accounting for 68.1% of the terminal's total CO2 emissions. After identifying the equipment responsible for the environmental problem, two solutions aimed at improving the energy efficiency of the terminal have been studied: the retrofitting of RTGs cranes and the replacement of terminal tractors powered by fuel for a new liquefied natural gas tractor, which contributed to a large reduction of CO2 emissions. Additionally, the present research explores the different policies at the disposal of port authorities in order to foster the implementation of solutions aimed at mitigating the environmental externalities by terminal operators.

NUMBER ID: EU33



LOCATION: Port of Valencia

COUNTRY: Spain

Distance from city center: 6.8 km

Total ports Area: 1.2 km²

Total populaion of port city: 791,413

PERIOD OF ASSESSMENT: 2011

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Calculation of energy consumption and CO2 emissions

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	5,420,777	5,413,000
RoRo/ Cars (tons)	1,532,000	898,000
Dry bulk cargo (tons)	2,190,000	1,859,000
Liquid Bulk (tons)	3,120,000	2,673,000
Passenger	557,000	393,000

Table 5
NCTV CO₂eq emissions in 2011.
Source: Own Elaboration

	Tonnes	Percentage
CO ₂	15 814.080	99.99800%
NO ₂	0.17185	0.00100%
CH ₄	0.00146	0.00001%
CO ₂ eq	15 814.2533	100.00%

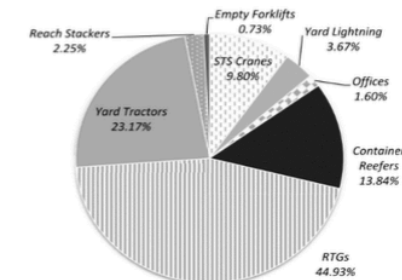


Fig. 1. NCTV CO₂ Emissions distribution in 2011.
Source: Own Elaboration

Table 4
NCTV Carbon dioxide emissions in 2011.
Source: Own Elaboration

Type of Consumer Centre		2011			
		kWh	CO ₂ Tonnes	kg CO ₂ /TEU	kWh/TEU
Electrical Consumption	STS Cranes	6 510 256	2180.935	1.14	3.40
	Yard Lightning	2 438 803	816.999	0.43	1.27
	Offices	1 061 346	355.551	0.19	0.55
	Container Reefers	9 193 395	3070.787	1.60	4.81
	TOTAL	19 203 800	6 424.272	3.36	10.03
2011					
Type of Consumer Centre		TOEs	CO ₂ Tonnes	kg CO ₂ /TEU	Litres/TEU
Diesel Fuel Consumption	RTGs	3266.7	9996.102	5.20	0.0017
	Yard Tractors	1684.6	5154.876	2.68	0.0009
	Reach Stackers	163.9	501.534	0.26	0.0001
	Empty Forklifts	52.8	161.568	0.08	0.0000
	TOTAL	5168.0	15 814.080	8.22	0.0027
TOTAL (electrical + diesel)			22 238.352	11.58	

TITLE: Comparative analysis between different methods for calculating on-board ship's emissions and energy consumption based on operational data

AUTHORS: Juan Moreno-Gutiérrez, Emilio Pájaro-Velázquez, Yolanda Amado-Sánchez, Rubén Rodríguez-Moreno, Fátima Calderay-Cayetano, Vanesa Durán-Grados

KEY WORDS: Shipping energy, Shipping emissions, Ro-Pax, Ship energy load factors, Emission factors

PUBLICATION YEAR: 2018

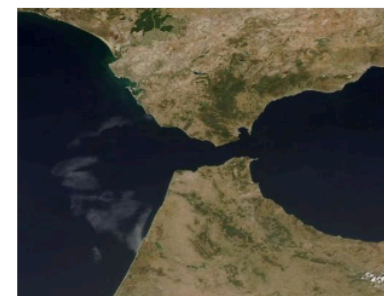
JOURNAL: Science of the Total Environment

ABSTRACT: With the aim of more reliably measuring ships' fuel consumption and emissions several different estimation methods have been put forward and are in use but there is ongoing debate still on the best way to measure maritime emissions. Fuel and emissions monitoring are already a common practice in the shipping industry. But there are currently neither harmonised guidelines nor legal requirements that clearly define the method and the rules to follow to monitor on-board fuel consumption for each situation during navigation. In this context, this article describes and compares four existing methods (EPA, IMO, Jalkanen and MAN) for calculating energy consumption and emissions, and presents a more realistic method, based on a case study. The purpose is to examine the differences between all of these methods, in order to propose the most suitable method of obtaining the data needed for better energy management, and a method that can be applied to any type of ship. The case study was carried out on Ro-Pax ships, comparing these four different methods through the application of a bottom-up integrated system approach. The study describes in detail and applies the most complete methodology for calculating energy consumption and emissions during cruising, operating in a Speed Reduction Zone (SRZ), manoeuvring and berthing. Application of the new improved method proposed in this paper could be the first step in implementing operational measures for detecting both abnormal high emissions and abnormal fuel consumption. The application of this method does not, in itself, reduce fuel use or improve efficiency, but it should be the necessary first step to establish uniform operational measures that will improve the management of energy on board ship and monitor accurately the performance of the fleet.

NUMBER ID: EU34

LOCATION: Strait of Gibraltar
COUNTRY: Spain

Distance from city center: 6.8 km
Total ports Area: 1.2 km²
Total populaion of port city: 791,413



PERIOD OF ASSESSMENT: 2017

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Presentation various methods for monitoring fuel consumption and air emissions

Table 4
Method proposed: emissions (total and by operating mode) by auxiliary engines (kg) for each pollutant studied (same as IMO method).

Mode	CO ₂	CO	SO _x	NO _x	PM ₁₀	PM _{2.5}
Cruising (HFO)	285.7	0.45	5	5.97	0.61	0.6
Speed reduction (HFO)	35.13	0.055	0.615	0.735	0.075	35.13
Manoeuvring	163.68	0.272	0.54	3.44	0.094	0.086
Arrival	173.88	0.26	3.04	3.64	0.37	0.36
Departure	31.7	0.052	0.1	0.66	0.018	0.016
At berth (MDO)	33.67	0.052	0.59	0.7	0.072	0.069
At berth (HFO)	30.88	0.051	0.1	0.65	0.017	0.016
At berth (MDO)	32.81	0.05	0.57	0.68	0.07	0.068
Total	413.37	0.68	1.37	8.68	0.23	0.21
Total	1200.82	1.922	11.925	25.155	1.556	1.498

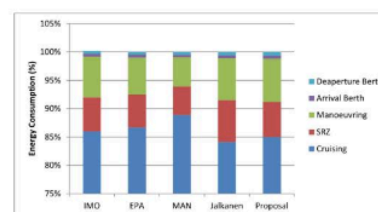


Fig. 1. Energy consumption by Main Engines, from each of the five methods: proportion of total accounted for by each operating mode (percent). Correction: Departure from berth, Arrival at berth.

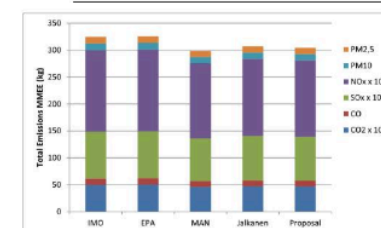


Fig. 3. Total emissions (kg) by Main Engines, from each of the methods analysed: proportion of total accounted for by each pollutant studied (percent).

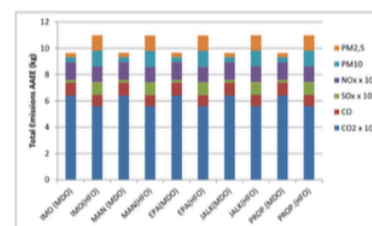


Fig. 5. Total emissions (kg) AE per pollutant and method studied and fuel used.

TITLE: Air emissions from ships in port: Does regulation make a difference?

AUTHORS: Miluše Tichavska, Beatriz Tovar, Daria Gritsenko, Lasse Johansson, Jukka Pekka Jalkanen

KEY WORDS: Air emissions, Automatic Identification System (AIS), Port-Cities, Regulation

PUBLICATION YEAR: 2017

JOURNAL: Transport Policy

ABSTRACT: Vessel operations at port play a particular role in port-related air emissions. Hotelling, manoeuvring and cruising operations in the harbour areas generate a large share of local and global pollution, external costs and public health issues. Emission abatement demands effective regulation for vessel compliance and enforcement adequacy in despite of geographic differences in jurisdiction. A connecting relation between regulatory frameworks and atmospheric pollution from vessels operations at port is so far, missing in literature. This paper aims at filling in this gap by addressing exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port with differing regulatory frameworks (Las Palmas, St. Petersburg, and Hong Kong). Estimations are based on the Ship Traffic Emission Assessment Model (STEAM) and AIS traffic information over a twelve-month timeframe. Contribution of this paper relates to revealing emission patterns of vessel operations in port and the assessment of current regulatory frameworks. Results and lower emission profiles shed light to sulphur regulation differences and the potential benefits in new policy measures (polluter pays principle, cold ironing and others) of accounting operative modes and shipping sub-sectors.

NUMBER ID: EU35



LOCATION: Port of Las Palmas

COUNTRY: Spain

Distance from city center: 5 km

Total ports Area: 3.05 km²

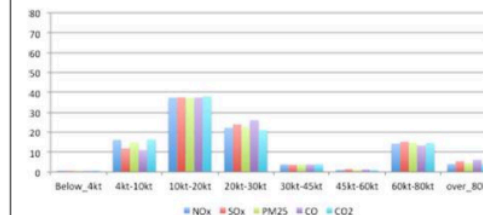
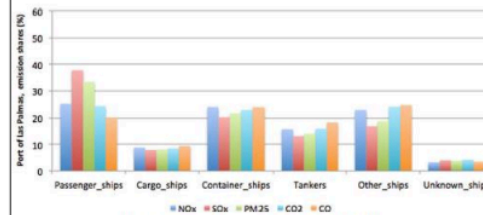
Total populaion of port city: 378,517

PERIOD OF ASSESSMENT: 2011

ENVIRONMENTAL ASPECT: Emissions to air

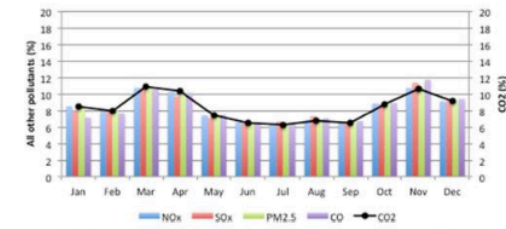
METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,006,853	n/a
RoRo/ Cars (tons)	334,000	228,000
Dry bulk cargo (tons)	453,000	248,000
Liquid Bulk (tons)	8,018,000	7,580,000
Passenger	n/a	n/a



TITLE: Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port

AUTHORS: Miluše Tichavska, Beatriz Tovar

KEY WORDS: Exhaust emissions modeling, Automatic Identification System (AIS), Ferry, Cruise, Port externalities, Regulation

PUBLICATION YEAR: 2015

JOURNAL: Transportation Research

ABSTRACT: Exhaust emissions cause air pollution and climate change. The exhausts of shipboard fuel combustion are equally damaging particularly, so close to the environmentally sensitive mainland and island coasts, as well as at ports due to their urbanized character. This paper estimates, for the first time, exhaust pollutants related to cruise and ferry operations in Las Palmas Port and, in an island context. Emission assessment is based on a full bottom-up model and messages transmitted by the Automatic Identification System during 2011. Results are described as a breakdown of NO_x, SO_x, PM_{2.5}, CO and CO₂, according to ship classes, operative type and time, providing valuable information to environmental policy makers in port-city areas and islands under similar conditions. It is generally concluded that vessel traffic and passenger shipping in particular are a source of air pollution in Las Palmas Port. Emission maps confirm location of hot spots in quays assigned for cruise and ferry operations. Policy recommendations encourage regular monitoring of exhaust emissions and market-based incentives supported by details on polluting and operative profiles. On the other hand, feasibility studies are suggested for automated mooring, LNG bunkering facilities and also shore-side energy services, prioritizing berthing of shipping sectors (or sub-sectors) with the highest share of exhaust emissions once their local effects have been confirmed by a dispersion, exposure and impact assessment.

NUMBER ID: EU36

LOCATION: Las Palmas Port

COUNTRY: Spain

Distance from city center: 5 km

Total ports Area: 3.05 km²

Total populaion of port city: 378,517



PERIOD OF ASSESSMENT: 2011

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Emissions allocation to seaside and intraterminal port operations

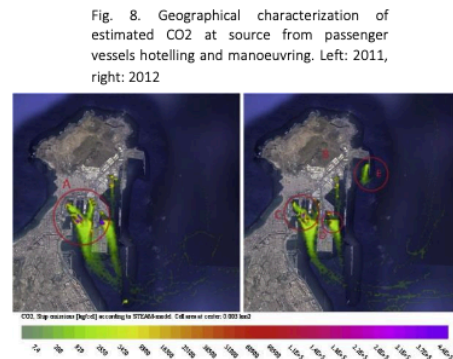
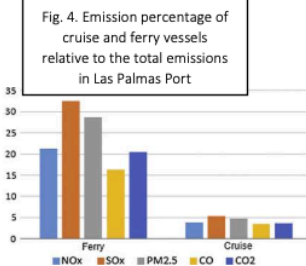
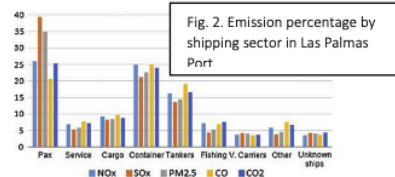


Table 2
Emissions and operative time related to traffic sectors as predicted by the STEAM.

Las Palmas Port (2011)	Exhaust emission					Operative time			
	NO _x (ton)	SO _x (ton)	PM _{2.5} (ton)	CO (ton)	CO ₂ (ton)	M (h)	M (h)	C (h)	T (h)
Port/Sea sector									
Passenger	1863	536	113	99	56,426	22,100	597	4254	26,960
Service	283	72	19	37	14,500	26,543	338	116	27,237
Cargo	373	112	27	47	17,700	59,444	2121	3861	65,426
Container	1019	288	73	119	48,000	63,889	1648	2712	68,249
Tankers	607	186	47	91	31,300	65,833	2889	3638	71,750
Other	241	52	15	37	13,300	78,889	4500	2361	85,750
Fishing	296	59	17	33	15,100	43,611	229	349	44,188
Vehicle Carriers	153	56	13	17	7479	4583	245	699	9528
Unknown ships	143	58	13	18	8892	90,833	3667	5972	100,472
Total	4237	1420	338	497	208,697	459,776	16,233	23,551	499,560

Time spent in Hotelling (H), Manoeuvring (M), Cruising (C) and its Total (T) is expressed in hours.
Note: Fuel consumption and emissions released while at berth are included. Compliance of IMO and EU regulatory frameworks for marine fuels is assumed and also included in these estimations.

TITLE: Environmental Assessment and Regulatory Aspects of Cold Ironing Planning for a Maritime Route in the Adriatic Sea

AUTHORS: Tobia Piccoli, Matteo Fermeglia, Daniele Bosich, Paolo Bevilacqua and Giorgio Sulligoi

KEY WORDS: cold ironing; shore-to-ship power; port electrical grid; environmental externalities; CO₂

emissions; social cost of carbon; ETS

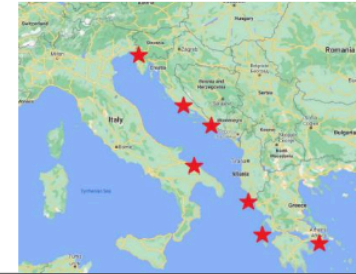
PUBLICATION YEAR: 2021

JOURNAL: Energies/ MDPI

ABSTRACT: The technology of cold ironing (or shore-to-ship power) can meaningfully reduce greenhouse gases and air pollutant emissions from ships at the berth by powering the vessels from the electrical shore grid. While cold ironing constitutes an effective and affordable solution in northern Europe and America, economic, legal, and environmental factors still render this technology less attractive in southern Europe. This paper aims to unpack and analyze the economic, regulatory, and environmental factors that can foster cold ironing as a standard installation in the Mediterranean Sea. Based on a model design for the port of Trieste (Italy) as applied to a cluster of target ports in the Adriatic Sea (in Italy, Croatia, and Greece), this article evaluates the cold ironing payback period by comparing costs of shore side-plants with environmental externalities and O&M costs. Moreover, the paper addresses key regulatory bottlenecks arising in different European jurisdictions with regard to the setting-up and development of cold ironing, while appraising the legal and economic consequences of deploying cold ironing in light of the future inclusion of the maritime sector in the EU Emission Trading System.

NUMBER ID: EU37

LOCATION: Ports of Adriatic Sea
REGION: Mediterranean



PERIOD OF ASSESSMENT: 2019

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Calculation of marine air emissions/ energy consumption/ cost using numerical modelling

KEY FINDINGS: Evaluation of avoided energy consumption, air pollutant emissions and cost from ships at the berth by using electrical shore grid

Table 10. Emission factors for the different undesired substances (main/auxiliary engines).

Pollutant-GHG	Unit	Main Engines	Auxiliary Engines
NO _x	g/kWh	9.80	13.45
NM VOC	g/kWh	1.38	0.40
PM _{10-2.5}	g/kWh	2.14	0.75
SO _x	kg/ton fuel	2.00	2.00
CO ₂	g/kWh	750.00	750.00

Table 16. Avoided emissions in the cluster with cold ironing (yearly rated values).

Port	Mooring Time	HVSC Time	C Fuel	Rated Values (tons Emitted)					
				NO _x	NM VOC	PM ₁₀	PM _{2.5}	SO _x	CO ₂
Trieste	673.40	627.40	690.79	39.97	1.47	2.63	2.63	1.38	2281.32
Dubrovnik	3417.70	3060.70	2779.98	160.86	5.91	10.59	10.59	5.56	9180.76
Piraeus	4804.81	4364.81	4354.26	251.96	9.26	16.88	16.88	8.71	1,4379.78
Argostoli	972.00	864.00	869.79	50.33	1.85	3.31	3.31	1.74	2872.46
Corfu	2660.50	2337.50	2175.55	125.89	4.63	8.28	8.28	4.35	7184.68
Split	1569.50	1399.50	1259.50	72.88	2.68	4.80	4.80	2.52	4159.45
Bari	1678.80	1450.80	1501.21	86.87	3.19	5.72	5.72	3.01	4957.68
GLOBAL	15,776.71	14,104.71	13,632.80	788.87	29.00	51.92	51.92	27.27	45,021.79

Table 22. First year avoided externalities: overall summary.

Port	Rated (EUR)	Minimum (EUR)	Maximum (EUR)
Trieste	1,745,448.10	1,202,408.03	2,289,617.87
Dubrovnik	5,296,163.05	3,684,647.94	6,910,467.01
Piraeus	4,852,390.99	3,349,550.40	6,357,953.72
Argostoli	969,296.50	669,094.36	1,270,042.39
Corfu	2,424,436.69	1,673,561.11	3,176,672.34
Split	2,399,488.07	1,669,372.46	3,130,867.19
Bari	3,797,467.75	2,616,007.72	4,981,385.59
GLOBAL	21,484,691.14	14,864,642.02	28,117,006.11

TITLE: Environmental cost and eco-efficiency from vessel emissions under diverse SOx regulatory frameworks: A special focus on passenger port hubs

AUTHORS: Beatriz Tovar, Miluše Tichavska

KEY WORDS: Vessel emissions, Environmental cost, Port-city Eco-efficiency, Automatic Identification System, Diverse geographical and regulatory contexts, SECA

YEAR: 2019

JOURNAL: ELSEVIER

ABSTRACT: Emissions related to economic activities including shipping and its contribution to the degradation of air quality, health and built environment in port-cities increasingly raise attention. Sustained market growth and shipping, also deriving into pollution concentration and an exposure increase over residents and visitors, stresses the need to identify and internalize environmental impacts. In order enhance abatement actions towards shipping sectors, this paper estimates for the first time the environmental cost and eco-efficiency performance indicators from vessel traffic in general and passenger sub-sectors in particular under diverse geographical and regulatory contexts. Emission assessment (NOx, SOx, PM2.5, CO and CO2) of EU (Las Palmas), non-EU but SECA (St. Petersburg) and non-EU non-SECA (Hong Kong) ports is based on the full bottom-up Ship Traffic Emission Assessment Model (STEAM) and messages transmitted by the Automatic Identification System (AIS) over a twelve-month period. Environmental cost is obtained from a top-down approach and the latest seaport-related cost figures. At last, eco-efficiency performance indicators are presented as the ratio of product/service impacts (externality costs) its added value (port profiles). Results present a first approximation to the externality cost of shipping traffic by sea and in port. Conclusions support international and regional policy design within the selected harbours and ports under similar traffic conditions.

NUMBER ID: EU38

LOCATION: Port of Las Palmas, St Petersburg, Hong Kong
COUNTRY: Spain, USA, China

PERIOD OF ASSESSMENT: 2012

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Results from vessels emission calculation

St Petersburg
Distance from city center: 6.67 km
Total ports Area: 3.04 km²
Total populaion of port city: 5,432,743

	2019	2020
Containers (TEUs)	1,865,816	1,750,295
RoRo/ Cars (tons)	1,026,000	943,000
Dry bulk cargo (tons)	17,286,000	16,336,800
Liquid Bulk (tons)	8,140	9512200
Passenger	666,240	n/a

Hong Kong
Distance from city center: 8.6 km
Total ports Area: 2.79 km²
Total populaion of port city: 506,922

	2019	2020
Containers (TEUs)	18,303,000	17,969,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

Table 8

Eco-efficiency performance by passenger shipping subsector and ports.

Passenger Subsector	Eco-efficiency performance (€/pax)						
	Local only					Local and global	
	NOx	SOx	PM _{2.5}	CO	Total	Low	High
<i>Las Palmas Port (EU15)</i>							
Cruise	3.38	0.51	1.98	0.000084	5.87	6.24	8.05
Ferry	4.18	0.61	2.38	0.000102	7.17	7.62	9.82
Total	3.90	0.57	2.24	0.000095	6.71	7.14	9.20
<i>St. Petersburg Port (EU15)</i>							
Cruise	12.78	1.48	7.18	0.000294	21.44	22.87	29.78
Ferry	26.42	3.08	14.35	0.000528	43.84	46.78	61.01
Total	15.94	1.85	8.84	0.000348	26.63	28.41	37.01
<i>Hong Kong Port (EU15)</i>							
Cruise	3.31	3.54	4.91	0.000027	11.75	11.89	12.57
Ferry	0.03	0.02	0.03	0.000000	0.08	0.08	0.09
Total	0.19	0.20	0.28	0.000001	0.67	0.68	0.72

Note: this approximation to eco-efficiency has been based on AIS-STEAM-based vessel emission calculations in Tichavska et al. (2017). Emission calculations for passenger vessels include manoeuvring and berthing vessels navigating at a speed 0–5 knots, only. This allows a more refined comparability among ports (not with Table 7 since emission calculations are different) and uncertainty reduction in terms of fairway distances/ differences within ports. Externality cost calculation has also been based on EU15 BeTa cost factors only.

TITLE: Environmental upgrading in global value chains: The potential and limitations of ports in the greening of maritime transport

AUTHORS: René Taudal Poulsen, Stefano Ponte, Henrik Sornn-Friese

KEYWORDS: Environmental upgrading, Ports, Maritime transport, Global value chains, Emission visibility, Tool implementation complexity

PUBLICATION YEAR: 2018

JOURNAL: Geoforum

ABSTRACT: Ports are crucial hubs in the functioning of the global economy, and maritime transport is a major emitter of air pollutants. Ports have considerable potential for promoting environmental upgrading in maritime transport and along global value chains more generally, but so far have been only partially successful in doing so. We examine results, limitations and future potential of voluntary initiatives that have been carried out by selected European and North American port authorities, which are considered frontrunners in environmental management. Drawing from the insights of global value chain analysis and organizational theory, we find that low 'tool implementation complexity' and high 'issue visibility' concerning emissions are key facilitators of environmental upgrading. We suggest that ports can intervene in two main ways to improve the environmental performance of maritime transport beyond their organizational and physical boundaries: by lowering tool implementation complexity through stronger collaboration within global value chains; and by enhancing emission visibility through alliances with cargo-owners and regulators.

NUMBER ID: EU39

LOCATION: Ports of Antwerp, Hamburg, Los Angeles, Rotterdam, Vancouver

CONTINENT: North America and Europe

Antwerp		Hamburg		Los Angeles		Vancouver					
Distance from city center: 12.7 km		Distance from city center: 3 km		Distance from city center: 38 km		Distance from city center: 0.7 km					
Total ports Area: 5.4 km ²		Total ports Area: 43.31 km ²		Total ports Area: 30 km ²		Total ports Area: 10 km ²					
Total populaion of port city: 506,922		Total populaion of port city: 1,840,000		Total populaion of port city: 73,264		Total populaion of port city: 662,248					
2019	2020	2019	2020	2019	2020	2019	2020				
Container (n TEU)	11,676,000	11,970,000	Container (n TEU)	9,300,000	8,500,000	Container (n TEU)	9,300,000	9,200,000	Container (n TEU)	3,399,000	3,468,000
RoRo/ Cars (Banc)	1,373,000	1,045,000	RoRo/ Cars (Banc)	469,000	414,000	RoRo/ Cars (Banc)	127,042	103,453	RoRo/ Cars (Banc)	420,000	345,000
Dry bulk cargo (Banc)	13,729,000	11,509,000	Dry bulk cargo (Banc)	28,139,000	26,829,000	Dry bulk cargo (Banc)	838	729,000	Dry bulk cargo (Banc)	16,686,200	11,850,100
Liquid Bulk (Banc)	71,089,000	67,574,000	Liquid Bulk (Banc)	12,405,000	11,570,000	Liquid Bulk (Banc)	13,425,000	12,267,000	Liquid Bulk (Banc)	n/a	n/a
Passenger (r)	32,000	2,000	Passenger (r)	n/a	n/a	Passenger (r)	650,010	173,947	Passenger (r)	1,071,000	n/a

PERIOD OF ASSESSMENT: 2016-2017

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Results on estimated released emissions SO₂, NO_x, PM₁₀, PM_{2.5} and air quality improvements

Table 6

Emissions from all emitters (selected ports; metric tons).

Sources: POA (2017, pp. 77–85), POLA (2017a, pp. 3–4), POV (2017, p. 38).

Port	Year	SO _x	SO ₂	NO _x	DFM	PM ₁₀	PM _{2.5}
Antwerp	2015	n/a	11,500	22,000	n/a	1,000	n/a
Los Angeles	2016	114	n/a	7023	115	n/a	n/a
Vancouver	2015	250	n/a	10,500	n/a	n/a	300

Table 7

Improvements in air quality (Antwerp and Rotterdam; % reduction in average annual air concentrations of air pollutants within the port area; micrograms per M3).

Sources: POA (2017, pp. 77–85), POR (2017, p. 198).

Port	Period	SO ₂	NO ₂	PM ₁₀
Antwerp	2000–16	n/a	–18%	n/a
Antwerp	2006–16	–76%	n/a	–42%
Rotterdam	2006–15	–67%	–17%	–51%

Table 8

Earliest and most recent estimates of GHG emissions in ports (tons).

Sources: POA (2017), Cannon (2014), POLA (2017b), Hamburg Port Authority (2013), Hamburg Port Authority (2015), POV (2013), POV (2017a), POR (2017).

Port	Emissions	Earliest estimate (year)	Most recent estimate (year)
Antwerp	CO ₂ e - Energy consumption in port authority operations + port authority electricity consumption (kWh)	11,000,000 (2008)	8,500,000 (2016)
	CO ₂ e - All port users (tons)	19,000,000 (2000)	17,500,000 (2015)
Hamburg	CO ₂ e - Scope 1 (tons)	6363 (1990)	6095 (2014)
	CO ₂ e - Scope 2 (tons)	10,071 (1990)	407 (2014)
Los Angeles	CO ₂ e - Scope 1 (tons)	1911 (1990)	3818 (2013)
	CO ₂ e - Scope 2 (tons)	6232 (1990)	6878 (2013)
	CO ₂ e - Scope 3 (tons) – tenants (i.e. ships, harbour craft, cargo handling equipment, rail, heavy duty vehicles)	1,053,028 (1990)	884,496 (2016)
Rotterdam	CO ₂ - Scope 1 (tons)	6800 (2010)	6300 (2016)
	CO ₂ - Scope 2 (tons)	700 (2010)	100 (2016)
	CO ₂ - Scope 3 (tons) - business travel and employee commuting	2400 (2010)	2700 (2016)
	CO ₂ - All port users (tons)	24,000,000 (1990)	32,000,000 (2015)
Vancouver	CO ₂ e - Scope 1 (tons)	402 (2010)	401 (2016)
	CO ₂ e - Scope 2 (tons)	254 (2010)	264 (2016)
	CO ₂ e - Scope 3 (tons) – Employee business travel, commuting, paper and waste	424 (2010)	629 (2016)
	CO ₂ e - Tenants, ships in port, trucks, trains in immediate hinterland	950,000 (2010)	1,100,000 (2015)

Note: Antwerp port authority reporting concerns kWh energy consumption. All other reported figures are in tons.

TITLE: A comparative analysis of the competition strategy of seaports under carbon emission constraints

AUTHORS: Mi Gan, Dandan Li, Jiawei Wang, Jiankui Zhang, Qinglan Huang

KEY WORDS: Carbon emissions policy, Seaports, Competitive analysis, Harbor city

PUBLICATION YEAR: 2021

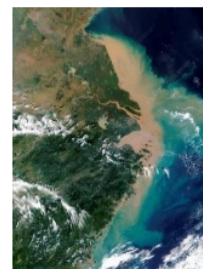
JOURNAL: Journal of Cleaner Production

ABSTRACT: The development of ports is essential to the competitiveness of cities. Harbor cities in China have put much effort into expanding the business of their ports, ignoring the overlapping of hinterland markets with other ports. Excess resources expended by ports may intensify regional environmental issues, such as carbon emissions. Motivated by the emissions reduction targets proposed by the International Maritime Organization and the urgent need for the development of green and sustainable ports, the Chinese government is trying to draft a carbon constraint policy to prevent the disorderly development of ports. It is thus necessary to study competition strategies under the context of carbon emission constraints. In this paper, the improved Hotelling model is used to describe the competitive relationship between ports. Then, three competition scenarios of the seaports under no carbon emissions policy, a carbon emission cap policy, and a carbon cap-and-trade policy are examined to analyze the effects of carbon emissions policy on port service prices, demand for goods, maximum profits, and social welfare. The results show that (1) from the perspective of port managers, only when government-defined carbon emission limits are lower than the critical value, the carbon cap policy is binding on port competition; when it comes to the cap-and-trade policy, government-defined carbon emission limits only affect profits. (2) From the government's perspective, the cap-and-trade policy maximizes social welfare more than the other policies regardless of the value of government-defined carbon emission limits.

NUMBER ID: AS1

LOCATION: Yangtze River Delta area

COUNTRY: China

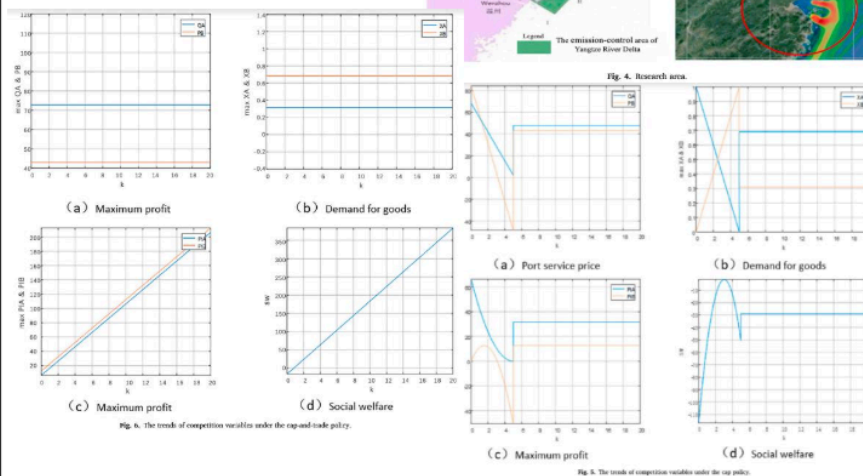


PERIOD OF ASSESSMENT: -

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Examination of three competition scenarios for seaports under a no carbon emissions policy.



ASIA

TITLE: Port-Related Emissions, Environmental Impacts and Their Implication on Green Tra_c Policy in Shanghai

AUTHORS: Yuyan Zhou, Yan Zhang, Dong Ma, Jun Lu, Wenbin Luo, Yu Fu, Shanshan Li, Junlan Feng, Cheng Huang, Wangqi Ge and Hong Zhu

KEYWORDS: Port-related emission; cargo-handling equipment; emission inventory; external container trucks; air quality

PUBLICATION YEAR: 2020

JOURNAL: MDPI

ABSTRACT: The port of Shanghai, as the world’s largest container port, has been experiencing rapid development in recent years, with increasing cargo throughput capacity. The combustion of diesel fuels used by internal and external port-related container trucks and in-port machineries can release various pollutants, causing air pollution. The terminals are close to the residential area, and the emissions are concentrated, which is worth paying attention to. This study aims to synthetically assess the port-related emissions and their environmental impacts. We firstly constructed an emission inventory of air pollutants in the port of Shanghai and then used the WRF-CMAQ model to estimate the influence of port-related source emissions on air quality. The results show that the annual emissions of SO₂, NO_x, CO, VOCs, PM, PM₁₀, PM_{2.5}, CO₂, BC and OC caused by cargo-handling equipment were 21.88 t, 1811.22 t, 1741.72 t, 222.76 t, 61.52 t, 61.42 t, 58.41 t, 141,805.40 t, 26.80 t and 10.07 t in 2015. The emissions of NO_x, CO, VOCs, PM₁₀ and PM_{2.5} caused by external port-related container trucks were 18,002.92 t, 5308.0 t, 1134.57 t, 711.12 t and 640.58 t. The exhaust of external port-related container trucks was much larger than that of cargo-handling equipment, so the impact on air quality was also higher than that of the machinery. The peak annual average concentrations of PM_{2.5} and NO_x contributed by the port-related sources were 1.75 μ g/m³ and 49.21 μ g/m³, respectively, which accounted for 3.08% and 36.7%, respectively, of the simulated ambient concentrations by all the anthropogenic emissions in Shanghai. Our results imply that the emission control policy to reduce the combined port-related emissions, especially for the cargo-delivery transportation phase from port to city, is key for large coastal port cities such as Shanghai.

NUMBER ID: AS2

LOCATION: Port of Shanghai
COUNTRY: China

Distance from city center: 1.9 km
Total ports Area: 3,619
Total population of port city: 24,880,000

PERIOD OF ASSESSMENT: 2015

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: A systematic port-related emission inventory for the port of Shanghai and the emissions of NO_x, CO, VOCs, PM₁₀ and PM_{2.5} from port-related sources are presented

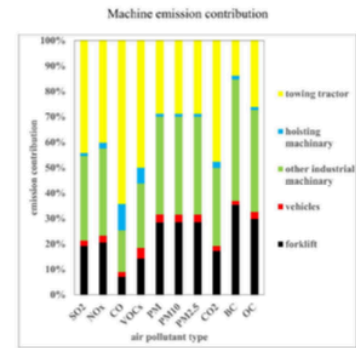


Figure 3. Emission contribution of different machine types in 2015 in the port of Shanghai.

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	43,303,000	43,503,400
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	75,649,000
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

Table 1. Emission inventory from different types of cargo-handling equipment in port.

In-Port Sources of Pollution	Forklift	Vehicles	Other Industrial Machinery	Hoisting Machinery	Towing Tractor	Total of Machineries	External Container Trucks
Holding volume	1274.00	232.00	882.00	78.00	1444.00	3910.00	—
Fuel consumption/t	7743.54	876.67	13,848.27	1185.81	21,921.23	45,575.51	—
SO ₂	4.20	0.47	7.28	0.24	9.70	21.88	—
NO _x	372.24	48.49	621.47	40.59	728.42	1811.22	18,002.9
CO	122.74	32.90	286.41	179.75	1119.91	1741.72	5308.05
VOC _s	31.78	9.33	56.43	13.89	111.32	222.76	1134.57
PM	17.53	1.89	23.66	0.70	17.74	61.52	—
PM ₁₀	17.53	1.80	23.66	0.70	17.74	61.43	711.12
PM _{2.5}	16.66	1.74	22.48	0.67	16.87	58.41	640.59
CO ₂	24,459	2766	43,558	3441	67,581	141,805	—
BC	9.49	0.39	12.81	0.38	3.73	26.80	—
OC	3.00	0.28	4.05	0.12	2.63	10.07	—

TITLE: Single-Vessel Plume Dispersion Simulation: Method and a Case Study Using CALPUFF in the Yantian Port Area, Shenzhen (China)

AUTHORS: Shubin Bai, Yuanqiao Wen, Li He, Yiming Liu, Yan Zhang, Qi Yu and Weichun Ma

KEY WORDS: Single vessel diffusion model; SO₂ emissions; Shenzhen Yantian Port

PUBLICATION YEAR: 2020

JOURNAL: MDPI

ABSTRACT: To study the impact of vessel pollution on the atmospheric environment of the surrounding area, we present a numerical simulation method based on regional emissions inventories. The general spatial resolution is 1 km and the temporal resolution is 1 h; parameters which are suitable for the study of larger space-time scales. In this paper, the WRF/CALMET/CALPUFF model and Automatic Identification System (AIS) data are employed to develop a single-vessel atmospheric pollution diffusion model. The goal of this research uses existing meteorological models and diffusion models to provide a simulation technology method for studying the diffusion of SO₂ from a single ship. We take the outgoing phase of ocean-going container vessels in Yantian Port as an example. It can be used to set the position of sensitive receptors near the port area. Simulations are implemented with CALPUFF and the results are compared with data derived from on-site monitoring instrument. The CALPUFF modelling domain covers an area of 925 km² with a grid spacing of 500 m. The simulation results demonstrated agreement with the measured data. The ground concentration contribution value ranged from 10 to 102 $\mu\text{g}/\text{m}^3$, while the affected area was about 4–26 km² and the high-value area of the ground concentration contribution was distributed within 1–2 km from the ship track. Emissions generated by the vessels represent a considerable contribution to SO₂ pollution around the harbor areas.

NUMBER ID: ASS3

LOCATION: Port of Yantian

COUNTRY: China

Distance from city center: 4.3 km

Total ports Area: 3.73 km²

Total population of port city: 237,200



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	25,700,000	26,550,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Emissions generated by the vessels around the harbor areas, simulating the impact of the single-vessel departure phase on air quality

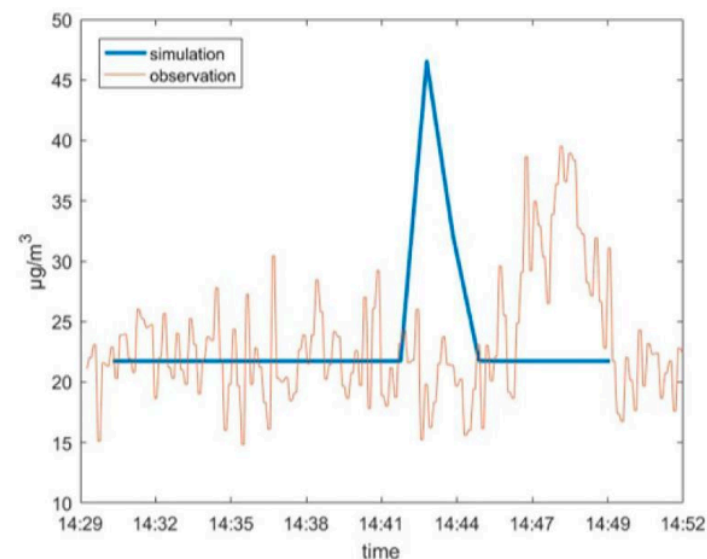


Figure 3. Vessel B's SO₂ time-series comparison of simulations and observations.

TITLE: Shipping emission inventories in China's Bohai Bay, Yangtze River Delta, and Pearl River Delta in 2018

AUTHORS: Zheng Wan, Shaojie Ji, Yati Liu, Qiang Zhang, Jihong Chen, Qin Wang

KEY WORDS: Pollutant emissions, Ships, Ports, Bohai Bay, Yangtze River Delta, Pearl River Delta

PUBLICATION YEAR: 2020

JOURNAL: Marine Pollution Bulletin

ABSTRACT: Pollutant emissions from ships could increase with expanding international trade and shipping fleet size, posing a severe but often overlooked threat to public health. China houses the three biggest port clusters in the world: the Bohai Bay (BB), the Yangtze River Delta (YRD), and the Pearl River Delta (PRD) and must combat pollutant emissions. This study examines the emissions of key pollutants (i.e., NO_x, PM₁₀, PM_{2.5}, HC, CO, SO_x, CO₂, NMVOC, and CH₄) utilizing a bottom-up methodology with the aid of automatic identification system data. Our results show that among the three regions studied, ships in the YRD produce the most emissions, accounting for 47.84% of the combined total emissions in 2018. We evaluate the emissions from different ship types, operation modes, and discharge equipment. Container ships account for ~50% of all emissions, which are mainly generated during the cruising phase. Different power sources produce varying levels of pollutants owing to power, load, and discharge variations. In addition, ship emissions have seasonal characteristics, which are reflected by the decline trend recorded in February, July, August, and December. This baseline dataset could aid comparisons with historic or future emission data and help establish regulatory actions to improve air quality.

NUMBER ID: AS4

LOCATION: Port clusters of Bohai Bay, Yangtze River Delta, Pearl River Delta

COUNTRY: China

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Estimation of ship pollutant emissions in the BB, YRD, and PRD regions of China



Ship emissions (tons) in the three regions.

Regions	NO _x	PM ₁₀	PM _{2.5}	HC	CO	SO _x	CO ₂	NMVOC	CH ₄	Share	Emission total	Ship numbers
BB	162,787.39	10,055.44	9274.36	5410.90	13,136.81	76,310.50	7,428,511.25	9620.81	64.56	33.41%	7,715,172.03	48,401
YRD	257,919.39	19,305.16	17,778.86	8495.16	20,134.53	143,976.94	10,569,006.48	12,305.08	94.49	47.84%	11,049,016.09	84,144
PRD	101,883.10	7601.06	6998.11	3347.70	7935.85	56,628.13	4,140,072.69	4833.18	37.42	18.75%	4,329,337.25	28,535
Total	522,589.88	36,961.66	34,051.34	17,253.76	41,207.19	276,915.57	22,137,590.43	26,759.08	196.47	100.00%	23,093,525.37	161,080

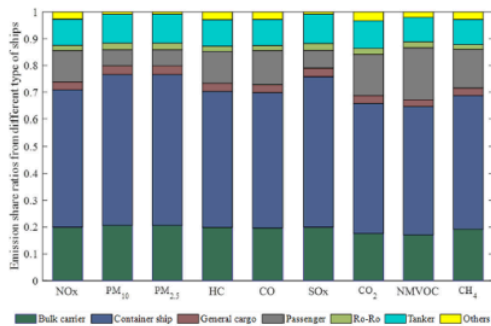


Fig. 3. Ship emissions of different ship types.

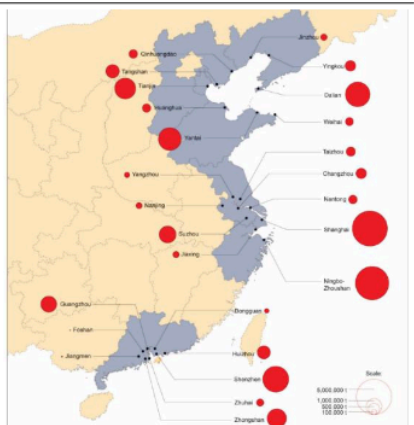


Fig. 6. Port Emissions: (a) total emissions for each port; (b) pollutant emission share excluding CO₂.

TITLE: Effects of underground logistics system on urban freight traffic:
A case study in Shanghai, China

AUTHORS: Dejun Hai, Junhong Xu, Zhengyu Duan, Chuan Chen

KEY WORDS: Underground logistics system, Port, Container transportation, Traffic analysis, Emission

PUBLICATION YEAR: 2020

JOURNAL: Journal of Cleaner Production

ABSTRACT: With the rapid development of China's ports, the growth of port throughput has led to a large increase in the amount of hinterland container transportation, causing traffic congestion and significant vehicle emissions. While a port promotes the prosperity of a city, the contradiction between the expansion of urban space and the land use required for ports has become more serious. The underground logistics system (ULS) provides a good technical option for solving these problems. Because of the large-scale projects that the ULS undertakes and the major investment required to conduct these projects, it is important to study the impact of ULS from the perspective of the urban transportation system. In this paper, an empirical method is proposed to assess the impact of the ULS on the state of traffic and the issue of emissions from the perspective of the urban road network; the specific research area is the ULS from Waigaoqiao Port to the Jiading District in Shanghai. Using highway toll data, traffic flow data, and traffic survey data, a traffic analysis model and an emissions model are established. These models are used to analyze the changes in traffic flows and emissions in the urban road network before and after the construction of the ULS. The analysis results show that the ULS can account for 27.0% of the highway transportation of containers from Waigaoqiao Port. After the construction of the ULS, the container traffic volume of the expressway segments near Waigaoqiao Port decreased by more than 20%, the emissions on most parts of Outer Ring Expressway dropped 16%e28%, and the emissions on expressways parallel to the ULS decreased 20%e40%. The empirical method proposed in this study can be considered as references for the benefit assessment of the ULS for container transportation.

NUMBER ID: ASS

LOCATION: Port of Shanghai
COUNTRY: China

Distance from city center: 1.9 km
Total ports Area: 3,619
Total population of port city: 24,880,000

PERIOD OF ASSESSMENT:
ENVIRONMENTAL ASPECT: Emissions to air
METHODOLOGY: Emissions estimation using numerical modelling
KEY FINDINGS: Impact of traffic and emissions from the perspective of the overall urban road network for the ULS from Waigaoqiao Port to the Jiading District in Shanghai



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	43,303,000	43,503,400
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	75,649,000
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

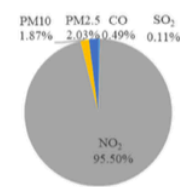


Fig. 5. Proportions of normalized harm of air pollutant emissions from container vehicles during the peak hour.



Fig. 6. Proportions of air pollutants from container vehicles during the peak hour.

Table 8
Emissions of the ULS during the peak hour.

	CO	SO ₂	NO _x	PM10	PM2.5
Emissions of ULS (unit: kg)	2.85	0.56	0.83	0.10	0.10
Considering ULS emissions, the reduction of total emissions on the road network after the construction of ULS	4.40%	-32.84%	5.88%	5.68%	5.34%

TITLE: A System Dynamics Model for CO2 Mitigation Strategies at a Container Seaport

AUTHORS: Yuliya Mamatok, Yingyi Huang, Chun Jin and Xingqun Cheng

KEY WORDS: System dynamics; container seaport; carbon dioxide emissions; mitigation strategies; scenarios simulation; decision-making mechanism

PUBLICATION YEAR: 2019

JOURNAL: MDPI/ sustainability

ABSTRACT: With the rapid development of the container shipping industry, the mitigation of carbon dioxide (CO2) emissions from container seaport activities have become an urgent problem. Therefore, the purpose of this research is to investigate dynamic problems in mitigation strategies at a container seaport. As a result, a system dynamics model for CO2 mitigation strategies at a container seaport was established. Three methods were combined to construct the system dynamics model: the activity-based method to estimate CO2 emissions; the representation of a container seaport as a system with several sub-systems; the system dynamics modeling for strategic decision-making in CO2 mitigation strategies. The key model component was the amount of CO2 emissions produced by container seaport activities. The other components represented container seaport operations and the main spots of CO2 concentration at berth, yard, gates, and region areas. Several CO2 mitigation strategies were included in the model to be simulated. The real case of Qingdao Port in China was used to simulate the scenarios of the current situation with CO2 emission amounts and the increasing container throughput. The other scenarios demonstrate the effects from CO2 mitigation strategies, such as operating time optimization, spatial measures, equipment modernization, and modal shift. The obtained results enable container seaport executives to evaluate which mitigation scenario is more effective for every container seaport area. The system dynamics model serves as a useful decision-making mechanism providing flexibility and variability in strategic planning.

NUMBER ID: AS6

LOCATION: Port of Qingdao
COUNTRY: China

Distance from city center: 3.2 km
Total ports Area: 2.25 km²
Total population of port city: 9,000,000



PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Calculation of marine air emissions using numerical modelling

KEY FINDINGS: Results of the model of CO2 emission dynamics at CS areas

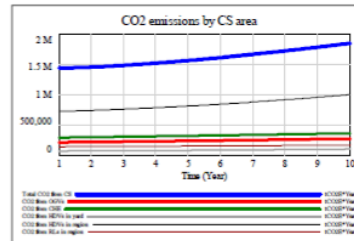


Figure 5. Scenario 1: current input parameters.

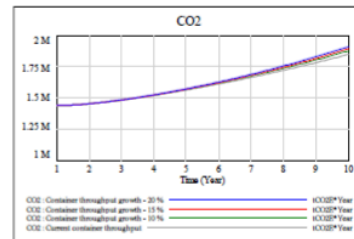


Figure 6. Scenario 2: container throughput growth.

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,010,000	22,000,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	10,000,000
Passenger	n/a	n/a

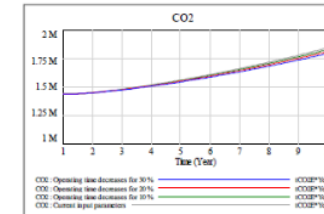


Figure 7. Scenario 3: operating time optimization.

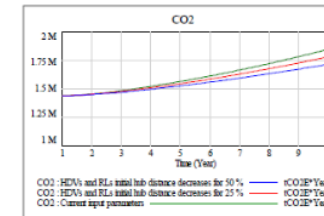


Figure 8. Scenario 4: spatial measures.

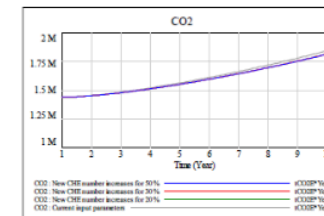


Figure 9. Scenario 5: equipment modernization.

TITLE: Characterization of PM2.5-bound polycyclic aromatic hydrocarbons and their derivatives (nitro-and oxy-PAHs) emissions from two ship engines under different operating conditions

AUTHORS: Jingbo Zhao, Yanjie Zhang, Ting Wang, Luna Sun, Zhiwen Yang, Yingchao Lin, Yunyue Chen, Hongjun Mao

KEY WORDS: PACs, PM2.5, Ship emissions, Operation conditions, EFs

PUBLICATION YEAR: 2019

JOURNAL: Chemosphere

ABSTRACT: Emissions from ship exhaust have been recognized as an important source of air pollution in coastal areas. To investigate the impacts of engine type, fuel and operating conditions on polycyclic aromatic compounds (PACs) emissions, particle matter (PM2.5) samples emitted from an inland-river bulk freighter (BF) using marine diesel oil (MDO) and an ocean-going passenger vessel (PV) using heavy fuel oil (HFO) were collected under five operation conditions (preheating, leaving, cruising, entering and berthing). The concentrations of 17 polycyclic aromatic hydrocarbons (PAHs), 12 nitro-PAHs (NPAHs) and 4 oxygenated- PAHs species were determined. The concentrations of SPAHs, SNPAHs and SOPAHs measured on the BF and PV exhausts ranged from 1.95 to 417 mg/m³, 86.5 to 6.89 10³ ng/m³ and 2.00e102 mg/m³, respectively. Both ships showed a high proportion of four-ring PAHs, while the BF had more three-ring PAHs (34.00e70.38%) and the PV had more five-ring PAHs (30.02e35.95%). The calculation of indicator PACs are able to increase the precision of source appointment. The emission factors (EFs) of PACs under maneuvering (including preheating, leaving, entering and berthing) was much higher than those under cruising, which might be due to the engine load, fuel consumption, and secondary reactions. Compared with HFO, combustion with MDO decreased the power-based SPAH EFs by 82e99%, power-based SNPAH EFs by 86e98%, and power-based SOPAHs EFs by 50e82%. These data highlight the importance of quantifying and monitoring ship emissions in close proximity to port area, and are useful for enhancing the relevant databases and improving the accuracy of ship emission inventories.

NUMBER ID: AS7

LOCATION: Ports of Zhenjiang, Yantai and Dalian

COUNTRY: China

Zhenjiang
Distance from city center: 1.4 km
Total ports Area: n/a
Total populaion of port city: 506,922

FREIGHT AND PASSENGER PORT TRAFFIC

No data available

Dalian
Distance from city center: 6.5 km
Total ports Area: n/a
Total populaion of port city: 506,922

FREIGHT AND PASSENGER PORT TRAFFIC

No data available

PERIOD OF ASSESSMENT: 2016-2017

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Different concentrations of emissions

Table 3
Indicator PAHs, NPAHs and OPAHs for ship emission fingerprint.

	indicator PAHs		indicator NPAHs	indicator OPAHs
BF				
Leaving	Ace, Fl	1-NPyr, 6-NChr	9-FO	
Cruising	Ace, Fl	1-NPyr, 7-NBaA	9-FO	
Berthing	Ace, Fl	1-NPyr, 1-NNap	9-FO	
PV				
Preheating	ICP, BgP	6-NChr, 6-NBaP	BaAQ	
Leaving	ICP, BgP	6-NChr, 6-NBaP	BaAQ	
Cruising	BaA, BkF	7-NBaA, 6-NBaP	BaAQ	
Entering	BaA, BgP	6-NChr, 6-NBaP	BaAQ	
Berthing	ICP, BgP	6-NChr, 6-NBaP	BaAQ	

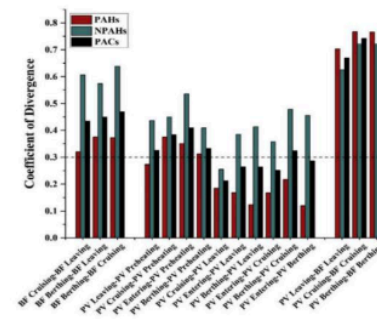


Fig. 3. Comparison of CD₀ for PAHs profiles among different operating condition and ships.

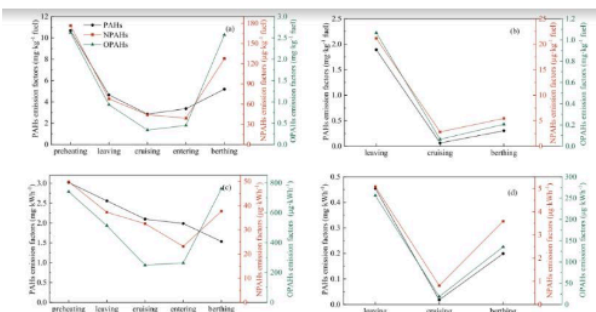


Fig. 4. EFs of particulate PAHs, NPAHs and OPAHs from the PV and BF under different operating conditions. (a) Fuel-based EFs of the PV. (b) Fuel-based EFs of the BF. (c) Power-based EFs of the PV. (d) Power-based EFs of the BF.

Abbreviations	
BF	bulk freighter
PV	passenger vessel
PACs	polycyclic aromatic compounds
PAHs	polycyclic aromatic hydrocarbons
NPAHs	nitro-PAHs

TITLE: Estimation of Vessel Emissions Inventory in Qingdao Port Based on Big data Analysis
AUTHORS: Xing Sun, Zhe Tian , Reza Malekian and Zhixiong Li
KEY WORDS: Bigdata analysis; systematical analysis; emission inventory; maritime
PUBLICATION YEAR: 2018
JOURNAL: MDPI

ABSTRACT: Exhaust emissions from vessels have increasingly attracted attention in the continuously growing marine transport world trade market. The International Maritime Organization (IMO) has introduced a number of measures designed to reduce exhaust emissions from global shipping. As one of the busiest ports in the world, Qingdao port has been studied to propose possible support to the development of efficient emission reduction. In this study, a large amount data of emissions inventory in Qingdao port was used to predict its annual exhaust emissions, and hence, to help understand maritime pollution in Qingdao port. Bigdata analysis methodology was employed to perform accurate predictions on vessel emissions. The analysis results show that the emissions were dominated by container ships, oil tankers, and bulk cargo ships. The comparison between Qingdao port and other ports in emission control areas demonstrates the necessity of control measures for exhaust emissions. The adoption of shore power and efficient cargo handling seems to be a potential solution to reduce exhaust emissions. The findings of this study are meaningful for maritime safety administration to understand the current emission situation in Qingdao port, propose corresponding control measures, and perform pollution prevention.

NUMBER ID: AS8

LOCATION: Port of Qingdao
COUNTRY: China

Distance from city center: 3.2 km
Total ports Area: 2.25 km²
Total population of port city: 9,000,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,010,000	22,000,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	10,000,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: The emissions exhausted by container ships, oil tankers, and bulk cargo ships

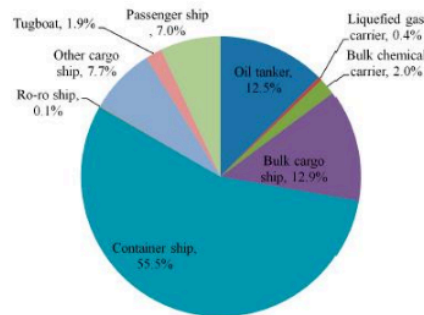


Figure 3. NO_x emissions proportions for different ship types.

Table 8. Ship emission inventory in Qingdao port, 2016 (ton).

	NO _x	CO	HC	CO ₂	SO ₂	PM _{2.5}
Oil tanker	3751.7	256.0	147.3	304,455.5	2824.3	227.3
Liquefied gas carrier	122.0	8.4	4.8	9828.3	91.3	7.3
Bulk chemical carrier	591.9	39.0	23.8	49,119.0	453.6	36.5
Bulk cargo ship	3878.0	352.7	159.6	290,243.6	2698.9	217.2
Container ship	16,672.5	1720.7	707.7	1,275,197.5	11,880.8	956.0
Ro-ro ship	22.2	2.5	0.7	1459.9	13.6	1.1
Other cargo ship	2308.0	193.9	106.6	192,812.5	1755.1	141.2
Tugboat	581.9	33.1	22.2	49,797.4	14,258.0	418.1
Passenger ship	2103.3	128.9	83.0	174,965.5	1575.6	126.8
Sum	30,031.5	2735.3	1255.7	2,347,879.2	21,711.3	1747.1

TITLE: National- to port-level inventories of shipping emissions in China

AUTHORS: Mingliang Fu, Huan Liu, Xinxin Jin and Kebin He

KEY WORDS: Shipping emission, air pollution, CO₂ emission, port-level inventory, China

PUBLICATION YEAR: 2017

JOURNAL: IOP Publishing

ABSTRACT: Shipping in China plays a global role, and has led worldwide maritime transportation for the last decade. However, without taking national or local port boundaries into account, it is impossible to determine the responsibility that each local authority has on emission controls, nor compare them with land-based emissions to determine the priority for controlling these emissions. In this study, we provide national- to port-level inventories for China. The results show that in 2013, the total emissions of CO, non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), particulate matter (PM), SO₂ and CO₂ were 0.0741 ± 0.0004 Tg·yr⁻¹, 0.0691 ± 0.0004 Tg·yr⁻¹, 1.91 ± 0.01 Tg·yr⁻¹, 0.164 ± 0.001 Tg·yr⁻¹, 1.30 ± 0.01 Tg·yr⁻¹ and 86.3 ± 0.3 Tg·yr⁻¹ in China, respectively. By providing high-resolution spatial distribution maps of these emissions, we identify three hotspots, centered on the Bohai Rim Area, the Yangtze River Delta and Pearl River Delta. These three hotspots account for 8% of the ocean area evaluated in this study, but contribute around 37% of total shipping emissions. Compared with on-road mobile source emissions, NO_x and PM emissions from ships are equivalent to about 34% and 29% of the total mobile vehicle emissions in China. Moreover, this study provides detailed emission inventories for 24 ports in the country, which also greatly contributes to our understanding of global shipping emissions, given that eight of these ports rank within the top twenty of the port league table. Several ports in China suffer emissions 12–147 times higher than those at Los Angeles port. The ports of Ningbo-Zhou Shan, Shanghai, Hong Kong and Dalian dominate the port-level inventories, with individual emissions accounting for 28–31%, 10–14%, 10–12% and 8–14% of total emissions, respectively.

NUMBER ID: AS9

LOCATION: the Bohai Rim Area, the Yangtze River Delta and Pearl River Delta

COUNTRY: China

PERIOD OF ASSESSMENT: 2013

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Air emissions in three port areas

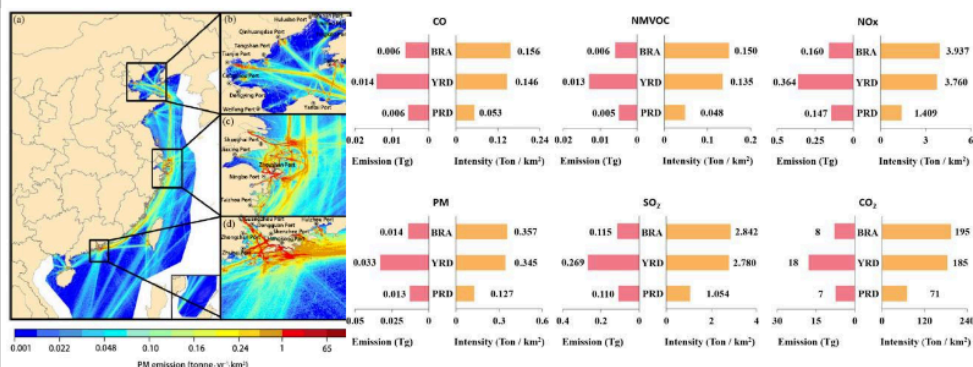


Figure 1. Spatial distribution of particulate matter (PM) emissions from maritime transportation in China. Map (a) shows sea areas within Chinese waters, while maps (b), (c) and (d) are detailed maps of hotspot regions centered on the Bohai Rim Area (BRA), Yangtze River Delta (YRD) and Pearl River Delta (PRD) respectively.

Figure 3. Emission intensities for various pollutants with the three hotspots: Bohai Rim Area (BRA), Yangtze River Delta (YRD) and Pearl River Delta (PRD). Sea areas of China, BRA, YRD and PRD are 2997×104 , 104×104 , 97×104 and 41×104 km² respectively. PM = particulate matter; NMVOC = non-methane volatile organic compounds.

TITLE: A Carbon Emission Evaluation for an Integrated Logistics System—A Case Study of the Port of Shenzhen

AUTHORS: Lei Yang, Yiji Cai, Xiaozhe Zhong, Yongqiang Shi and Zhiyong Zhang

KEY WORDS: Carbon emissions; port-integrated logistics system; shore power; low sulfur fuel oil

PUBLICATION YEAR: 2017

JOURNAL: MDPI/ sustainability

ABSTRACT: The port is an important node in logistics, and its energy consumption constitutes a considerable proportion of the transportation industry. In port logistics, not only does the energy consumption generate carbon emissions, but other business activities do as well. This paper firstly characterizes the sources of carbon emissions and the basic elements in the port system, and proposes the concept of a port-integrated logistics system. Secondly, a case study of The Port of Shenzhen is conducted and a method is provided to measure the carbon emissions in the port-integrated logistics system. This paper then suggests two approaches to reducing carbon emissions, and their economic and environmental benefits are compared. Finally, some policies are put forward to reduce carbon emissions, such as improving the efficiency of loading and unloading, and replacing the heavy fuel oil by low sulfur fuel oil and shore power. The proposed method of carbon emission reduction for port-integrated logistics systems can be generalized for the analysis of various types of ports.

NUMBER ID: AS10

LOCATION: Port of Shenzhen
COUNTRY: China



Distance from city center: 33.1 km
Total ports Area: 6,340 km²
Total population of port city: 12,356,820

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	25,698,000	26,548,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2013 - 2014

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Carbon emission analysis per emission sources at terminals

Table 2. Carbon emissions from the Port of Shenzhen (tons).

Terminals	Emissions Sources	Details	2013	2014
Chiwan Container Terminal	Transportation	Vehicles on road	9982.86	9298.15
		Vehicles idling	4000.89	3810.72
		Ships at berth	55,111.72	53,113.42
	RTG	Ships at anchorage	7434.43	10,978.32
		RTG	360.00	386.99
	Heavy equipment	Top handlers and side handlers	12,048.85	13,983.69
		Forklifts	716.43	785.28
		Other equipment	11,271.69	13,584.72
	Material consumption	Paper material	7831.28	6983.83
		Plastic material	9981.93	9297.30
		Wood and other materials	479.27	444.47
Dachan Bay Terminal	Transportation	Vehicles on road	6766.68	6275.47
		Vehicles idling	2730.24	3136.30
		Ships at berth	14,149.68	16,634.97
	RTG	Ships at anchorage	1522.35	3435.06
		RTG	0	0
	Heavy equipment	Top handlers and side handlers	2632.67	3095.43
		Forklifts	167.90	171.54
		Other equipment	3228.76	3398.70
	Material consumption	Paper material	1843.41	1768.77
		Plastic material	2045.64	2344.34
		Wood and other materials	98.22	112.57
Shekou Container Terminal	Transportation	Vehicles on road	1386.73	1889.20
		Vehicles idling	10,996.98	9936.85
		Ships at berth	4513.53	3799.23
	RTG	Ships at anchorage	56,972.68	49,355.46
		RTG	427.86	486.94
	Heavy equipment	Top handlers and side handlers	7608.18	10,191.99
		Forklifts	13,255.86	17,710.69
		Other equipment	972.96	994.04
	Material consumption	Paper material	18,710.14	19,694.88
		Plastic material	8508.92	7349.81
		Wood and other materials	11,277.73	9741.42
	Energy consumption		541.48	467.72
			7645.10	6605.67

TITLE: Inland port vessel emissions inventory based on Ship Traffic Emission Assessment Model–Automatic Identification System

AUTHORS: Yan Zhang, Jian Gu, Wei Wang, Yiqiang Peng, Xiaojing Wu and Xuejun Feng

KEY WORDS: Vessel, emission inventory, inland port, Ship Traffic Emission Assessment Model, Automatic Identification System

PUBLICATION YEAR: 2017

JOURNAL: Advances in Mechanical Engineering

ABSTRACT: The designation of ship emission control areas in China evidenced increased attention to ship emissions. Ships calling ports along inland waterways are of particular concern as their emissions exacerbate air pollution in nearby cities. Adapting the Ship Traffic Emission Assessment Model to the local context, this study combines data from Automatic Identification System, vessel profile database, and field investigation results to build a “bottom-up” activity-based inventory of ship emissions. The Nanjing Longtan Container Port was taken as a case study. Results show that total ship emissions for PM10, PM2.5, NOx, SOx, CO, HC, and CO2 in 2014 are 3.45, 2.76, 196.00, 2.90, 20.62, 8.13, and 12,554.29 t, respectively. Accordingly, ship emission reduction measures were proposed based on the analysis of emission characteristics. The methods and conclusions of the study provide a scientific basis for the inventory and control of the ship emissions in China.

NUMBER ID: AS11

LOCATION: Port of Nanjing Longtan

COUNTRY: China

Distance from city center: 12.2 km

Total ports Area: 135 km²

Total population of port city: 57,364



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	724,400	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Share of ship emissions

Table 6. Emission factors of the main and auxiliary engine (g/kWh).

Sulfur content	Engine	PM ₁₀	PM _{2.5}	NO _x	SO _x	CO	HC	CO ₂
2.7%	Main engine	1.5	1.2	11.2	11.5	1.1	0.5	683
	Auxiliary engine	1.5	1.2	11.2	12.3	1.1	0.4	722

Table 7. Fuel correction factors of engine.

Sulfur content	PM	NO _x	SO _x	CO	HC	CO ₂
0.035%	0.12	0.93	0.013	1	1	0.94

Table 8. Marine vessel emissions inventory in NLCP in 2014 (tons).

Engine	PM		NO _x	SO _x	CO	HC	CO ₂
	PM ₁₀	PM _{2.5}					
Main engine	1.15	0.92	65.65	0.93	6.91	3.14	4050.91
Auxiliary engine	2.30	1.84	130.35	1.97	13.71	4.99	8503.38
Total	3.45	2.76	196.00	2.90	20.62	8.13	12,554.29

PM: particulate matter; NLCP: Nanjing Longtan Container Port.

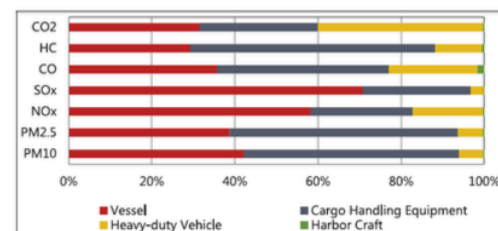


Figure 5. Ship emissions share in NLCP in 2014.

TITLE: Air emission inventory of container ports' cargo handling equipment with activity-based "bottom-up" method

AUTHORS: Yan Zhang, Yi-qiang Peng, Wei Wang, Jian Gu, Xiao jingWu and Xue-jun Feng

KEY WORDS: Air emission inventory, container port, bottom-up method, cargo handling equipment

PUBLICATION YEAR: 2017

JOURNAL: Advances in Mechanical Engineering

ABSTRACT: With the rapid development of China's container port industry, the emissions of air pollutants in port areas have been increasing. Cargo handling equipment as a non-road mobile source of emissions has become a focus of public attention. This article adopted a full activity-based "bottom-up" method to establish the inventory of emissions by cargo handling equipment at a container port. Drawing on the OFFROAD model, we conducted investigation and analysis of cargo handling equipment holdings, activity levels, and equipment-related parameters and modified the emission factors. The Nanjing Longtan Container Port was taken as a case study. Results show that in 2014, emissions by cargo handling equipment of the Nanjing Longtan Container Port were as follows: PM₁₀ 4.25 t, PM_{2.5} 3.91 t, NO_x 82.98 t, SO_x 1.06 t, CO 23.84 t, and HC 16.39 t, all lower than results from an earlier research based on 2013 fuel consumption data. Cargo handling equipment produced more PM and HC emissions than any other emission source at the port. The method and main conclusions of this article provide support for future work on energy conservation and emission reduction in port areas.

NUMBER ID: AS12

LOCATION: Port of Nanjing Longtan

COUNTRY: China

Distance from city center: 12.2 km

Total ports Area: 135 km²

Total population of port city: 57,364



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	724,400	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2014

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Calculation of marine air emissions using numerical modelling

KEY FINDINGS: Emissions by equipment type

Table 4. 2014 NLCP CHE emission factors (container trailers as an example).

CHE type	Pop	Power (kW)	Cumulative hours	Emission factor (g/(kWh))						
				PM ₁₀	PM _{2.5}	NO _x	SO _x	CO	HC	CO ₂
Container trailer	4	170	9800	0.0183	0.0165	2.0565	0.08	1.5494	0.3344	762
	1	177	15,600	0.2661	0.2449	3.9507	0.08	1.7384	0.6531	762
	2	177	21,200	0.3077	0.2832	4.1895	0.08	1.9209	0.8408	762
	7	177	24,500	0.3401	0.3129	7.9498	0.08	2.0285	0.9484	762
	4	193	14,700	0.2594	0.2387	3.9123	0.08	1.7091	0.6229	762
	5	205	15,600	0.0000	0.0000	3.5500	0	0.0900	0.6711	662
	6	205	21,200	0.0000	0.0000	3.5500	0	0.0900	0.8438	662
	1	205	24,500	0.0000	0.0000	3.5500	0	0.0900	0.9456	662

NLCP: Nanjing Longtan Container Port; CHE: cargo handling equipment.

Some of the pollutant emission factors are reduced to zero when liquefied natural gas is used by the equipment engine.

Table 5. 2014 NLCP CHE emission inventory by equipment type (tons).

Equipment type	Pop	PM ₁₀	PM _{2.5}	NO _x	SO ₂	CO	HC
RTG	22.00	0.11	0.10	1.31	0.03	0.44	0.40
Reach stacker	6.00	0.82	0.75	10.82	0.33	3.55	2.24
Container handler	14.00	1.37	1.26	26.72	0.83	7.69	4.06
Container trailer	30.00	1.57	1.44	40.38	1.04	9.62	9.14
Forklift	22.00	0.40	0.37	3.76	0.10	2.54	0.55
Total	94	4.25	3.91	82.98	2.33	23.84	16.39

NLCP: Nanjing Longtan Container Port; CHE: cargo handling equipment; RTG: rubber tired gantry.

CO₂ and other greenhouse gases do not belong to the atmospheric pollution and therefore they are separately listed in Table 6 instead of Table 5.

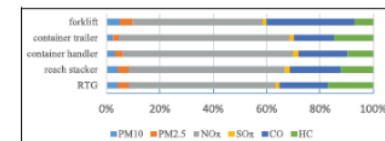


Figure 4. Emission shares of criteria pollutants of CHE (%).

TITLE: Ship emission inventory and its impact on the PM_{2.5} air pollution in Qingdao Port, North China

AUTHORS: Dongsheng Chen, Xiaotong Wang, Peter Nelson, Yue Li, Na Zhao, Yuehua Zhao, Jianlei Lang, Ying Zhou, Xiurui Guo

KEY WORDS: Ship emissions, Qingdao Port, PM_{2.5} concentrations, WRF/Chem, Source apportionment

PUBLICATION YEAR: 2017

JOURNAL: Atmospheric Environment

ABSTRACT: In this study, a first high temporal-spatial ship emission inventory in Qingdao Port and its adjacent waters has been developed using a “bottom-up” method based on Automatic Identification System (AIS) data. The total estimated ship emissions for SO₂, NO_x, PM₁₀, PM_{2.5}, HC and CO in 2014 are 3.32 10⁴, 4.29 10⁴, 4.54 10³, 4.18 10³, 1.85 10³ and 3.66 10³ tonnes, respectively. Emissions of SO₂ and NO_x from ships account for 9% and 13% of the anthropogenic totals in Qingdao, respectively. The main contributors to the ship emissions are containers, followed by fishing ships, oil tankers and bulk carriers. The inter-monthly ship emissions varied significantly due to two reasons: stopping of the fishing ship activities during the fishing moratorium and the reduction of freight volume around the Chinese New Year Festival. Emissions from transport vessels concentrated basically along the shipping routes, while fishing ships contributed to massive irregular spatial emissions in the sea. The impact of ship emissions on the ambient air quality was further investigated using the Weather Research and Forecasting with Chemistry (WRF/Chem) model. The results reveal that the contribution of ship emissions to the PM_{2.5} concentrations in Qingdao is the highest in summer (13.1%) and the lowest in winter (1.5%). The impact was more evident over densely populated urban areas, where the contributions from ship emissions could be over 20% in July due to their close range to the docks. These results indicated that the management and control of the ship emissions are highly demanded considering their remarkable influence on the air quality and potential negative effects on human health.

NUMBER ID: AS13

LOCATION: Port of Qingdao

COUNTRY: China

Distance from city center: 3.2 km

Total ports Area: 2.25 km²

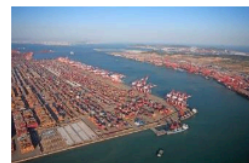
Total population of port city: 9,000,000

PERIOD OF ASSESSMENT: 2014

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: The exhaust emissions of SO₂, NO_x, PM₁₀, PM_{2.5}, HC and CO from ships were calculated from the main engines (MEs), auxiliary engines (AEs) and boilers



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,010,000	22,000,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	10,000,000
Passenger	n/a	n/a

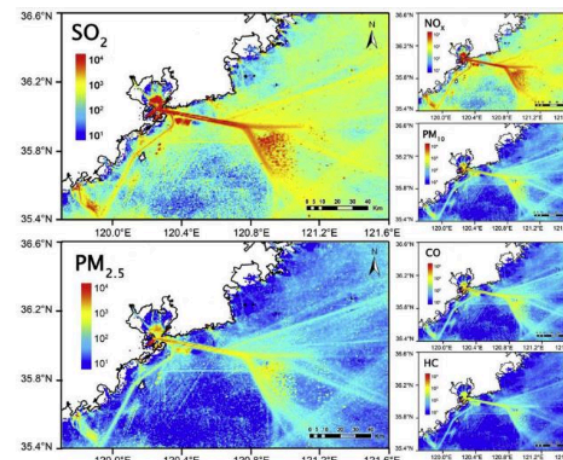


Fig. 3. Spatial distribution of annual ship emissions in 2014 (kgpy/ten⁴).

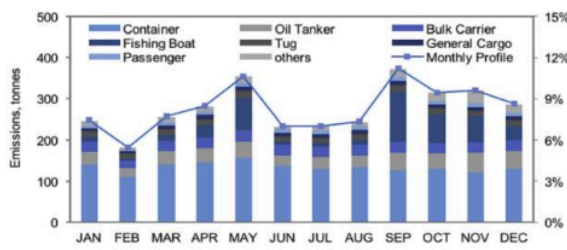


Fig. 5. Inter-Monthly variation of SO₂ emissions from each vessel type for Qingdao port in 2014.

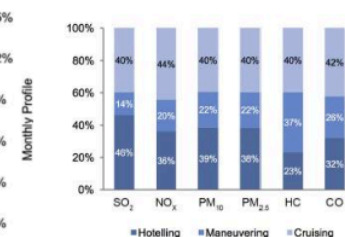


Fig. 6. Shares of ship emissions classified by operating modes for different species.

TITLE: Air emissions from ships in port: Does regulation make a difference?

AUTHORS: Miluše Tichavska, Beatriz Tovar, Daria Gritsenko, Lasse Johansson, Jukka Pekka Jalkanen

KEY WORDS: Air emissions, Automatic Identification System (AIS), Port-Cities, Regulation

PUBLICATION YEAR: 2017

JOURNAL: Transport Policy

ABSTRACT: Vessel operations at port play a particular role in port-related air emissions. Hotelling, manoeuvring and cruising operations in the harbour areas generate a large share of local and global pollution, external costs and public health issues. Emission abatement demands effective regulation for vessel compliance and enforcement adequacy in despite of geographic differences in jurisdiction. A connecting relation between regulatory frameworks and atmospheric pollution from vessels operations at port is so far, missing in literature. This paper aims at filling in this gap by addressing exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port with differing regulatory frameworks (Las Palmas, St. Petersburg, and Hong Kong). Estimations are based on the Ship Traffic Emission Assessment Model (STEAM) and AIS traffic information over a twelve-month timeframe. Contribution of this paper relates to revealing emission patterns of vessel operations in port and the assessment of current regulatory frameworks. Results and lower emission profiles shed light to sulphur regulation differences and the potential benefits in new policy measures (polluter pays principle, cold ironing and others) of accounting operative modes and shipping sub-sectors.

NUMBER ID: AS14

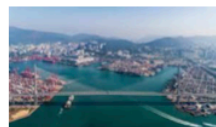
LOCATION: Port of Hong Kong

COUNTRY: China

Distance from city center: 8.6 km

Total ports Area: 2.79 km²

Total population of port city: 1,270,876



FREIGHT AND PASSENGER PORT TRAFFIC

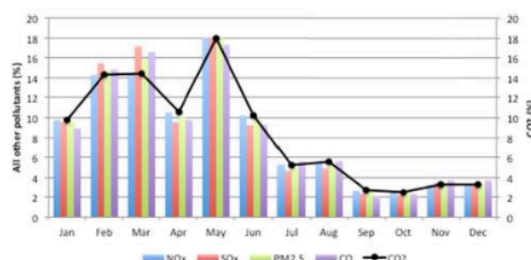
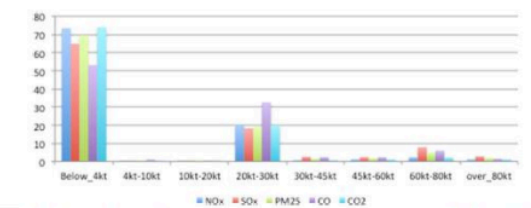
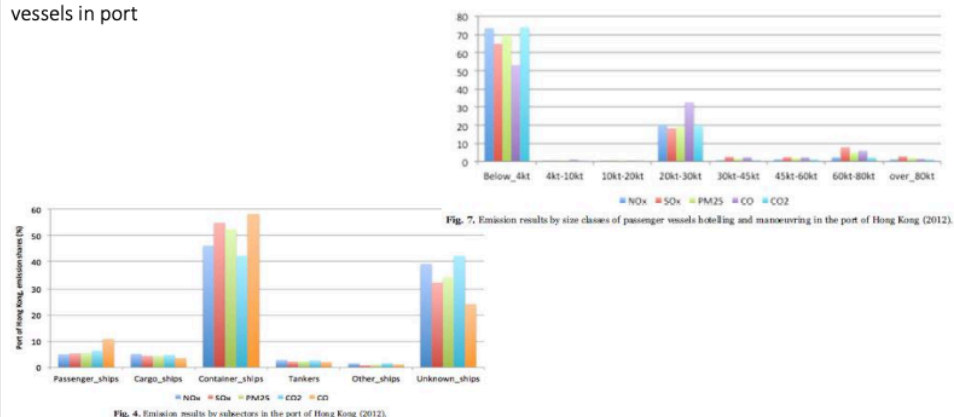
	2019	2020
Containers (TEUs)	18,303,000	17,969,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2012

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port



TITLE: Surface sediment quality relative to port activities:

A contaminant-spectrum assessment

AUTHORS: Yu Shen, Hong Bing, Ma Jun, Chen Yongshan, Xi Xiuping, Gao Jingbo, Hu Xiuqin, Xu Xiangrong, Sun Yuxin

KEY WORDS: Contaminant spectrum, Heavy metal, Persistent organic pollutant, Sediment quality guidelines, Surface sediment, Port activity

PUBLICATION YEAR: 2017

JOURNAL: Science of the Total Environment

ABSTRACT: Ports are facing increasing environmental concerns with their importance to the global economy. Numerous studies indicated sediment quality deterioration in ports; however, the deterioration is not discriminated for each port activity. This study investigated a spectrum of contaminants (metals and organic pollutants) in surface sediments at 20 sampling points in Port Ningbo, China, one of the top five world ports by volume. The spectrum of contaminants (metals and organic pollutants) was quantified following marine sediment quality guidelines of China and USA and surface sediment quality was assessed according to thresholds of the two guidelines. Coupling a categorical matrix of port activities with the matrix of sedimentary contaminants revealed that contaminants were highly associated with the port operations. Ship repair posed a severe chemical risk to sediment. Operations of crude oil and coal loadings were two top activities related to organic pollutants in sediments while port operations of ore and container loadings discharged metals. Among the 20 sampling points, Cu, Zn, Pb, and DDT and its metabolites were the priority contaminants influencing sediment quality. Overall, surface sediments in Port Ningbo had relatively low environmental risks but ship repair is an environmental concern that must be addressed. This study provides a practical approach for port activity-related quality assessment of surface sediments in ports that could be applicable in many world sites.

NUMBER ID: AS15



LOCATION: Port of Ningbo

COUNTRY: China

Distance from city center: 9.9 km

Total ports Area: n/a

Total population of port city: 8,200,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	27,530,000	28,700,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2014

ENVIRONMENTAL ASPECT:

Emissions to water

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS:

Calculation/evaluation of surface sediments and estimation of levels of environmental risks from sediment's concentration

Table 2a
Characteristics pH, electric conductivity, total carbon, and metals (As, Cr, Cu, Ni, Pb, and Zn) of sediments from the five investigated ports in Port Ningbo, China.

Port	Number of sampling points	pH	Electric conductivity mS cm^{-1}	Total C ^a g kg^{-1}	As mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Beilan	4	8.33 ± 0.07 ns	2.60 ± 0.44 B	12.2 ± 0.7 ns	11.7 ± 0.5 C	80.3 ± 2.1 ns	29.6 ± 1.2 ns	36.8 ± 0.9 A	21.4 ± 1.6 C	88.6 ± 2.4 ns
Daoie	5	8.33 ± 0.07 ns	4.05 ± 0.53 A	12.5 ± 0.8 ns	13.4 ± 1.6 ABC	82.0 ± 4.2 ns	33.9 ± 3.4 ABC	39.7 ± 3.4 ABC	26.6 ± 1.7 ABC	95.2 ± 8.7 ns
Chuanhsan	6	8.51 ± 0.16 ns	3.03 ± 0.77 AB	11.8 ± 0.9 ns	12.9 ± 1.5 BC	79.4 ± 4.9 ns	34.7 ± 3.9 ns	35.7 ± 2.2 A	25.5 ± 1.7 BC	101 ± 30 ns
Meishan	5	8.49 ± 0.08 ns	5.94 ± 0.80 AB	11.6 ± 0.8 ns	14.9 ± 0.9 A	83.5 ± 2.8 ns	35.1 ± 3.8 ns	41.8 ± 2.9 A	27.7 ± 1.9 AB	101 ± 9 ns
Xiangshan	2	8.40 ± 0.04 ns	2.71 ± 0.57 AB	13.9 ± 0.5 ns	15.1 ± 1.0 AB	85.7 ± 4.9 ns	36.8 ± 2.9 ns	42.9 ± 4.2 A	30.3 ± 2.0 A	111 ± 2 ns
Median		8.42	3.15	12.7	12.8	81.6	32.0	37.8	26.0	94.3
Max		8.85	4.52	14.4	16.0	89.2	54.3	45.5	31.7	104
Min		8.24	1.81	9.07	9.45	74.0	28.4	32.6	21.2	85.1
Number of sampling points exceeding threshold of the sediment quality guidelines			China-SQG Class P ^b	0	0	13	7	0	0	1
			US-SQG ERRL ^c	0	0	0	0	0	0	0
Thresholds of sediment quality guidelines			China-SQG Class P ^b	20 ^d	20	80	35	90	150	150
			China-SQG Class B ^b	40 ^d	93	270	290	230	600	600
			US-SQG ERL ^c	8.2	81	34	20.9	46.7	150	150
			US-SQG ERRL ^c	70	70	270	270	51.6	218	410

^a Total C represents total carbon including inorganic and organic carbon.

^b Marine sediment quality guidelines were issued by the National Oceanic Administration of China (NOAC) in 2002 (GB18686-2002).

^c Sediment quality guidelines were issued by National Oceanic and Atmospheric Administration of the United States (US-NOAA) in 1995 (ERL is shortened from Effect Range Low and ERL from Effect Range Median).

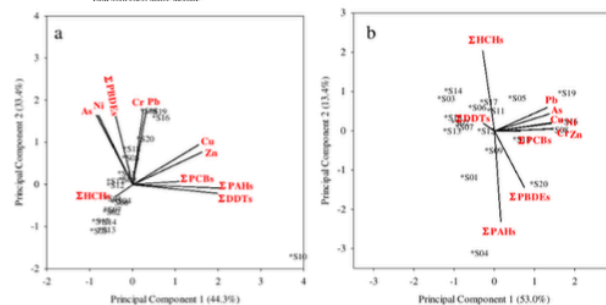


Fig. 3. Patterns of sediment quality in the five investigated ports in Port Ningbo, China with S10 (a) and without S10 (b) according to the contaminant spectrum using principal component analysis and redundancy analysis after standardization. The contaminant spectrum includes metals (As, Cr, Cu, Ni, Pb, and Zn) and sums of polycyclic aromatic hydrocarbons (ΣPAHs), polychlorinated biphenyls (ΣPCBs), dichlorodiphenyl trichloroethane and its metabolites (ΣDDTs), hexachlorocyclohexanes (ΣHCHs), and polybrominated diphenyl ethers (ΣPBDEs). Sampling points S01 - S04 were located in the Beilan Port, S05 - S10 in the Daoie Port, S11 - S15 in the Chuanhsan Port, S16 - S18 in the Meishan Port, and S19 - S20 in the Xiangshan Port.

TITLE: An integrated framework for carbon footprinting at container seaports: the case study of a Chinese port
AUTHORS: Yuliya Mamatok and Chun Jin
KEY WORDS: Integrated framework; carbon footprinting; container seaport; emissions calculation; Qingdao Port
PUBLICATION YEAR: 2016

JOURNAL: Routledge

ABSTRACT: The objective of this research is to establish an integrated framework for carbon footprinting (CF) at container seaports (CSs). Three methodological approaches are used in this research: the multiple case study to choose suitable evaluation methods, the case study for verification of the proposed framework, and the quantitative method to calculate the emissions. The proposed integrated framework consists of five modules: policy components, sources structure, input data, emissions estimation and mitigation strategies. The effectiveness of the integrated framework is demonstrated through the practical application in Qingdao Port in China. The case study results in the detailed estimation of CO₂ emissions and detects the problem of data collection and data accuracy for CF and the necessity of stakeholders' cooperation. The integrated framework serves to evaluate, analyze and control CO₂ emissions from the CS operations.

NUMBER ID: AS16

LOCATION: Qingdao Port
COUNTRY: China

Distance from city center: 3.2 km
Total ports Area: 2.25 km²
Total population of port city: 9,000,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,010,000	22,000,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	10,000,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2012

ENVIRONMENTAL ASPECT: Emissions to air
METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Emissions produced within Qingdao Port CS activities, compared to Los Angeles & Saigon port

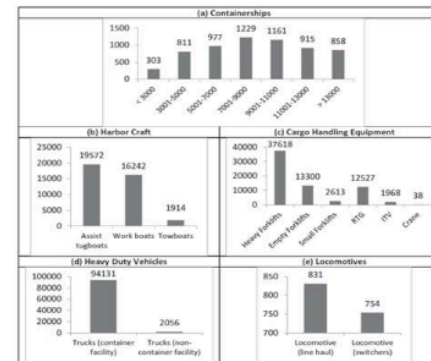


Figure 6. Emissions structure by the source category, tCO₂E.

Table 8. Total emissions structure in 2012.

	Emissions mobile sources	tCO ₂ E	%
1	Containerships	6254	3.0
2	Harbor craft	37728	18.0
3	Cargo handling equipment	68063	32.4
4	Heavy-duty vehicles	96187	45.8
5	Locomotives	1585	0.8
	Total	209818	100

Table 9. Comparison of CO₂ emissions between several seaports, tCO₂E.

Source group	QQCT		LA		SG	
Throughput/ year	14.5million TEUs	Ratio in total amount, %	8.08 million TEUs	Ratio in total amount, %	0.43 million TEUs	Ratio in total amount, %
OGVs	6254	3.0	203846	26.1	24784	74.4
HC	37728	18.0	50330	6.4	355	1.1
CHE	68063	32.4	146046	18.7	8147	24.4
HDVs	96187	45.8	380665	48.7	40	0.1
RLs	1585	0.8	—	—	—	—
Total	209818	100	780887	100	33327	100

TITLE: GHG emission accounting and mitigation strategies to reduce the carbon footprint in conventional port activities – a case of the Port of Chennai

AUTHORS: Atulya Misra, Karthik Panchabikesan, Senthil Kumar Gowrishankar, Elayaperumal Ayyasamy and Velraj Ramalingam

KEY WORDS: Carbon footprint; emission mitigation strategies; greenhouse gas emissions; port environmental management; renewable energy

PUBLICATION YEAR: 2016

JOURNAL: Carbon Management/ Taylor & Francis

ABSTRACT: Ports as an industry account for »3% of the total greenhouse gas (GHG) emissions worldwide. The Port of Chennai, India, uses an enormous amount of electricity and diesel for intermodal transportation of goods and for other essential services. The inventory of GHG emissions in the Port of Chennai is made by accounting the various facilities of the port along with the housing colony and fishing harbor which come under the management of the Port of Chennai. Quantification of GHG emissions is made following the guidelines of the Intergovernmental Panel on Climate Change (IPCC) and World Port Climate Initiative (WPCI). The estimation of GHG emissions showed that 280,558 tonnes of CO₂e/year was generated from the port and portrelated facilities. Several GHG mitigation strategies and their impact are quantified and discussed. The technology suggestions presented in the paper will be very useful to plan effective mitigation strategies incorporating technological advancement and management policies.

NUMBER ID: AS17



LOCATION: Port of Chennai

COUNTRY: India

Distance from city center: 4.3 km

Total ports Area: 2.37 km²

Total population of port city: 11,503,293

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,383,971	n/a
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	12,441	13,374
Liquid Bulk (tons)	16,203	12,414
Passenger	10,658	11,000

PERIOD OF ASSESSMENT: 2014-2015

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: GHG emissions and energy consumption by various port operations

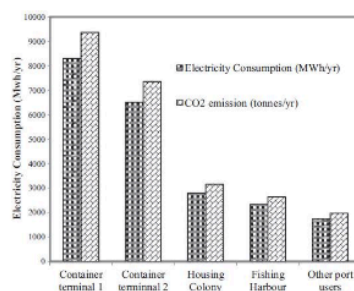


Figure 3. Electricity consumption by port tenants/users, and its equivalent CO₂e emissions.

Table 1. Diesel consumption and corresponding emissions by various port-owned vehicles and equipment.

Sources of emission	Diesel consumption (L/year)	CO ₂ e emissions (tonnes/year)	Total (%)
Generator	16,000	43	0.62
Vehicles	142,186	381	5.52
Mobile equipment	163,143	437	6.34
Diesel locomotives	261,487	701	10.17
Pilot launches	125,896	337	4.89
Mooring launches	12,337	33	0.48
Dredgers	243,199	652	9.45
Tugs	1,606,692	4306	62.44
Others	2380	6	0.09
Total	2,573,320	6896	100

Table 2. GHG emissions by various types of merchant vessel during the maneuvering and hoteling period.

Vessel type	No. of calls/yr	Emissions during maneuvering (tonnes/yr)			Emissions during hoteling (tonnes/yr)			Total emissions (tonnes/yr)
		Main engine	Auxiliary engine	Boiler	Auxiliary engine	Boiler		
Dry bulk	165	200	772	217	1796	2269		5253
Container	780	298	4282	995	12,121	7180		24,876
Tanker	429	1508	5722	4092	8743	67,035		87,100
General Cargo	293	141	1646	225	9656	2631		14,300
Roll-on/roll-off (RO-RO)	89	102	1040	250	866	375		2633
Cruise	48	18	629	154	14,843	5817		21,461
Total	1804	2267	14,091	5933	48,024	85,307		
Total emissions during maneuvering/hoteling	22,291	133,332	155,623					

TITLE: Marine Air Pollution in Israel: Extent, Proposed Mitigation Targets, Benefits and Feasibility

AUTHORS: Eyal Razy-Yanuv, Yogev Barak, Oran Noam and Daniel Madar

KEY WORDS: marine air pollution, port air pollution, criteria air pollutants, sulfur oxides (Sox), nitrogen oxides (NOx), PM2.5 (particulate matter), MARPOL Annex VI regulation 13, air pollution regulations, external benefits, air pollution mitigation

PUBLICATION YEAR: 2022

JOURNAL: Atmosphere

ABSTRACT: Marine air pollution is a major contributor to seaports and coastal air pollution, and Israel has yet to seriously confront this issue. This study aimed to update previous marine air pollution estimations in Israel's two major ports: Haifa and Ashdod. The objectives were to examine technical and regulatory measures to address the problem, to propose mitigation targets and to estimate their potential benefits. Based on a model of emission-calculations that relies on an updated ship-inventory data as well as real-time ships' location and movement tools, the combined marine NOx, SOx and PM2.5 annual emissions in these ports were found to be 18,415, 15,128 and 1453 tons, respectively. These values are considerably higher than previous estimates, are comparable to the constant pollution emitted at ground level from a 1000-MW coal powered city power plant and are 3–20 times higher than the industrial and land transportation sectors in these cities. Relatively high nickel concentration in PM was found in Israel only relatively adjacent to the Haifa and Ashdod ports. Since high nickel concentration in PM is today mainly associated with marine air pollution, this finding supports the hypothesis that marine air pollution worsens the air quality in these cities. SOx and PM2.5 emissions can be reduced by 78% and 27%, respectively, if Israel enforces the revised International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI regulations in its territorial waters. While the latter step can achieve external benefits of NIS 518.4 million/year (EUR 132 million/year), additional mitigation actions and local regulations are suggested, focusing on NOx emissions but also on other pollutant criteria. Such actions can achieve further benefits of NIS 274.3 million/year (EUR 70 million/year). Achieving the suggested targets is challenging yet attainable, and their potential benefits will probably outweigh their costs.

NUMBER ID: AS18A



LOCATION: Port of Haifa

COUNTRY: Israel

Distance from city center: 10.3 km

Total ports Area: 0.7 km²

Total population of port city: 279,247

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	904,000	1,463,997
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	31,100,000
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	240000

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Air pollutant emissions allocated to seaside port operations

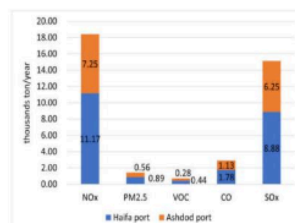


Figure A2. Calculated 2018 annual emissions of air pollutants from the ship sector in Haifa and Ashdod ports. Y-axis is tons pollutant per year. All values are based on marine port activity data for the year 2018. See Tables A9 and A18.

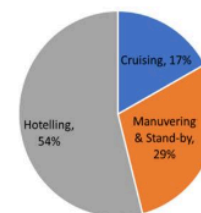


Figure 5. Share of different marine activities in NOx emissions.

Table A28. Emissions from the Haifa and Ashdod industrial zones and land transportation and a 1000 MW coal power plant.

Sources	NOx	VOCs	SOx	PM _{2.5}	CO
Haifa					
Port	11,167	444	8877	889	1778
Industrial Zone	1800	700	650	60	
Transport	2031	513	4	116	3919
1000 MW coal plant	9827	3	14,947	153	807
Ashdod					
Port	7248	281	6251	564	1127
Ind. Zone	2550	500	700	42	
Transport	923	233	2	53	1781

Table A9. Total emissions from vessels (Haifa, 2018).

Pollutant	Emissions (Ton/Year)				
	Cruising	Maneuvering + Stand-By	Hotelling	Total	
NOx	1946	3228	5993	11,167	
PM _{2.5}	156	304	429	889	
VOC	39	190	214	444	
CO	312	608	857	1778	
SO ₂	460	1891	6526	8877	

TITLE: Marine Air Pollution in Israel: Extent, Proposed Mitigation Targets, Benefits and Feasibility

AUTHORS: Eyal Razy-Yanuv, Yogev Barak, Oran Noam and Daniel Madar

KEY WORDS: marine air pollution, port air pollution, criteria air pollutants, sulfur oxides (Sox), nitrogen oxides (NOx), PM2.5 (particulate matter), MARPOL Annex VI regulation 13, air pollution regulations, external benefits, air pollution mitigation

PUBLICATION YEAR: 2022

JOURNAL: Atmosphere

ABSTRACT: Marine air pollution is a major contributor to seaports and coastal air pollution, and Israel has yet to seriously confront this issue. This study aimed to update previous marine air pollution estimations in Israel's two major ports: Haifa and Ashdod. The objectives were to examine technical and regulatory measures to address the problem, to propose mitigation targets and to estimate their potential benefits. Based on a model of emission-calculations that relies on an updated ship-inventory data as well as real-time ships' location and movement tools, the combined marine NOx, SOx and PM2.5 annual emissions in these ports were found to be 18,415, 15,128 and 1453 tons, respectively. These values are considerably higher than previous estimates, are comparable to the constant pollution emitted at ground level from a 1000-MW coal powered city power plant and are 3–20 times higher than the industrial and land transportation sectors in these cities. Relatively high nickel concentration in PM was found in Israel only relatively adjacent to the Haifa and Ashdod ports. Since high nickel concentration in PM is today mainly associated with marine air pollution, this finding supports the hypothesis that marine air pollution worsens the air quality in these cities. SOx and PM2.5 emissions can be reduced by 78% and 27%, respectively, if Israel enforces the revised International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI regulations in its territorial waters. While the latter step can achieve external benefits of NIS 518.4 million/year (EUR 132 million/year), additional mitigation actions and local regulations are suggested, focusing on NOx emissions but also on other pollutant criteria. Such actions can achieve further benefits of NIS 274.3 million/year (EUR 70 million/year). Achieving the suggested targets is challenging yet attainable, and their potential benefits will probably outweigh their costs.

NUMBER ID:
AS18B



LOCATION: Port of Ashdod
COUNTRY: Israel

Distance from city center: 4.8 km
Total ports Area: 0.5 km²
Total population of port city: 220,883

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,538,000	1,584,000
RoRo/ Cars (tons)	144,830	122,761
Dry bulk cargo (tons)	11,212	11,265
Liquid Bulk (tons)	n/a	n/a
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Air pollutant emissions allocated to seaside port operations

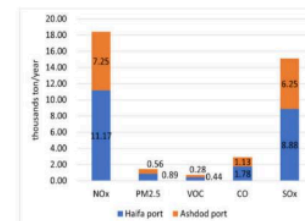


Figure A2. Calculated present (2018) annual emissions of air pollutants from the ship sector in Haifa and Ashdod ports. Y axis is in thousands tons per year. All values are based on marine port activities data

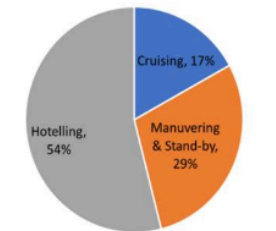


Figure 5. Share of different marine activities in NOx emissions.

Table A28. Emissions from the Haifa and Ashdod industrial zones and land transportation and a 1000 MW coal power plant.

Sources	NOx	VOCs	SOx	PM _{2.5}	CO
Haifa					
Port	11,167	444	8877	889	1778
Industrial Zone	1800	700	650	60	
Transport	2031	513	4	116	3919
1000 MW coal plant	9827	3	14,947	153	807
Ashdod					
Port	7248	281	6251	564	1127
Ind. Zone	2550	500	700	42	
Transport	923	233	2	53	1781

Table A18. Total emissions from vessels (Ashdod, 2018).

Pollutant	Emissions (Ton/Year)				Total
	Cruising	Maneuvering + Stand-By	Hotelling		
NOx	973	13%	1614	22%	4661
PM _{2.5}	78	14%	152	27%	333
VOC	20	7%	95	34%	167
CO	156	14%	304	27%	667
SO ₂	230	4%	946	15%	5076
				81%	6251

TITLE: Occurrence of microplastics in the sediments of Baseco Port area at Manila Bay, Philippines
AUTHORS: L J A Castro, A M Monsada and K D Cruz
KEY WORDS: Microplastics, Manila Bay, sediments
PUBLICATION YEAR: 2021
JOURNAL: IOP Conference Series: Earth and Environmental Science

ABSTRACT: Microplastic in marine sediments is nowadays considered an environmental pollutant. Seaports are particularly susceptible to microplastic pollution through series of human activities occurring in these areas. In the Philippines, research on microplastics is still limited and there is still no study determining the occurrence of microplastics in the harbour of Manila Bay, Philippines. Hence, this work conducted a preliminary investigation of microplastics in the sediments of Baseco Port area, Manila Bay. Nine stations within the study region were sampled. The types of microplastics found are fragments, foam, fiber, film, pellet, and filament with an average size measurement of 1.6±1.4 mm. Results from this study suggest that anthropogenic impacts are most likely the dominant sources of accumulation and distribution of microplastics in the sediments of Baseco port. This study provides preliminary assessment of microplastics contamination in the area that may serve as important reference for further studies.

NUMBER ID: AS19

LOCATION: Port of Baseco
COUNTRY: Philippines

Distance from city center: 1.3 km
Total ports Area: 0.52 km²
Total population of port city: 2,700,000

PERIOD OF ASSESSMENT: -
ENVIRONMENTAL ASPECT: Use of raw materials and natural resources
METHODOLOGY: Pollutants data collection and analysis
KEY FINDINGS: Distribution of microplastics by type

Table 3. Average size measurement of microplastics.

Station	Ave size (mm)	Ave Min size (mm)	Ave Max size (mm)	U
1	2.5	2.0	3.1	0.5
2	2.9	2.6	3.2	0.4
3	3.5	2.5	4.4	1.4
4	0.7	0	1.4	1.0
5	0.2	0	0.4	0.3
6	3.2	2.2	4.2	1.4
7	ND	ND	ND	ND
8	0.2	0	0.4	0.3
9	1.3	0	2.5	1.8
Average	1.6			1.4

U- uncertainty obtained as standard deviation
ND- not detected
Total runs were 27. Only 19 runs were included in the calculations due to removal of outliers.

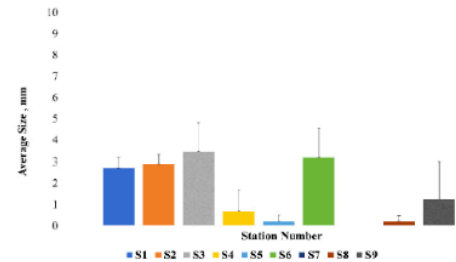
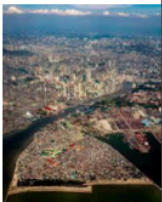


Figure 5. Average size distribution of microplastics from the sediments of Baseco Port Area, Manila Bay.



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	10,428,634	9,620,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	53,771,280	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	151,900	71,800



TITLE: Air emissions from ships in port: Does regulation make a difference?

AUTHORS: Miluše Tichavska, Beatriz Tovar, Daria Gritsenko, Lasse Johansson, Jukka Pekka Jalkanen

KEY WORDS: Air emissions, Automatic Identification System (AIS), Port-Cities, Regulation

PUBLICATION YEAR: 2017

JOURNAL: Transport Policy

ABSTRACT: Vessel operations at port play a particular role in port-related air emissions. Hotelling, manoeuvring and cruising operations in the harbour areas generate a large share of local and global pollution, external costs and public health issues. Emission abatement demands effective regulation for vessel compliance and enforcement adequacy in despite of geographic differences in jurisdiction. A connecting relation between regulatory frameworks and atmospheric pollution from vessels operations at port is so far, missing in literature. This paper aims at filling in this gap by addressing exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port with differing regulatory frameworks (Las Palmas, St. Petersburg, and Hong Kong). Estimations are based on the Ship Traffic Emission Assessment Model (STEAM) and AIS traffic information over a twelve-month timeframe. Contribution of this paper relates to revealing emission patterns of vessel operations in port and the assessment of current regulatory frameworks. Results and lower emission profiles shed light to sulphur regulation differences and the potential benefits in new policy measures (polluter pays principle, cold ironing and others) of accounting operative modes and shipping sub-sectors.

NUMBER ID: AS20

LOCATION Port of St. Petersburg

COUNTRY: Russia

Distance from city center: 6.67 km

Total ports Area: 3.04 km²

Total populaion of port city: 5,432,743



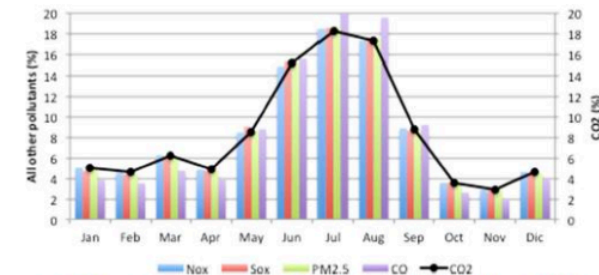
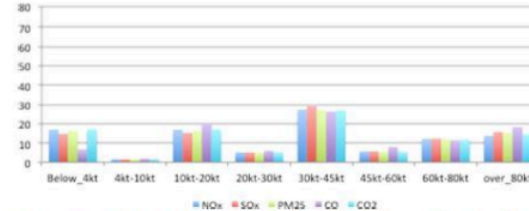
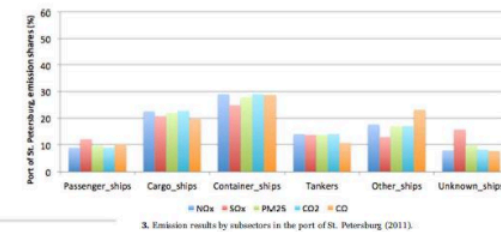
FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,865,816	1,750,295
RoRo/ Cars (tons)	1,026,000	943,000
Dry bulk cargo (tons)	17,286,000	16,336,800
Liquid Bulk (tons)	8,140	9512200
Passenger	666,240	n/a

PERIOD OF ASSESSMENT: 2011

ENVIRONMENTAL ASPECT: Emissions to air
METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Exhaust gasses (NOx, SOx, CO, CO₂) and particles (PM_{2.5}) released from operative vessels in port



TITLE: A carbon emission evaluation model for a container terminal

AUTHORS: Jaehun Sim

KEY WORDS: Carbon emission, Container terminal, Container transport, System dynamics

PUBLICATION YEAR: 2018

JOURNAL: Journal of Cleaner Production

ABSTRACT: South Korea has focused on strategic economic growth for the last several decades, resulting in booming international trade. To accommodate this trade, activity in container terminals has been steadily increasing, with corresponding environmental impacts. This study proposed a model using a system dynamics approach to evaluate the total amount of carbon emissions produced in a container terminal, while calculating the required reduction amount of carbon emissions in the container terminal at a given carbon emission reduction goal from the year 2017 to the year 2030. The results of this study indicated that the container terminal will produce annually on average 108.18 million kg of CO₂ equivalent emissions from the five types of processes: vessel maneuver, vessel at berth, container loading and unloading, container transportation, and container receiving and delivery from the year 2017 to the year 2030. The total carbon emissions of the container terminal were comprised of 51.13% from the container vessel maneuver process, 0.57% from the vessel at berth process, 37.34% from the container loading and unloading process, 1.04% from the container transportation process, and 9.92% from the container receiving and delivery process. The results of this study indicated that the container terminal required the annual reduction of on average 0.53 million kg of CO₂ equivalent emissions from the year 2023 to the year 2030 in order to comply with the South Korean government's emission reduction targets.

NUMBER ID: AS21

LOCATION: Port of Busan

COUNTRY: South Korean

Distance from city center: 6.7 km

Total ports Area: 1.53 km²

Total population of port city: 3,429,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,992,000	21,823,995
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	850,802	78,714

PERIOD OF ASSESSMENT: 2017

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: CO₂ emissions by various port operations

Table 1

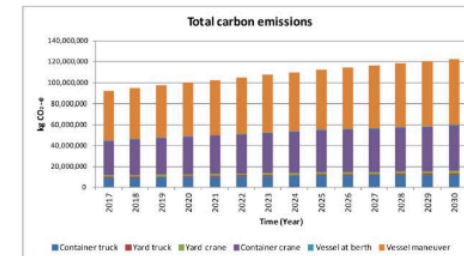
The carbon emission density of major vessel and equipment activities.

Type	CO ₂ -e (kg/TEU)
Container ship maneuver	1.99
Container ship at berth	0.02324
Container crane	1.39
Yard truck	0.04287
Yard crane	0.06873
Container trailer	0.38645

Table 2

The carbon emission production of major vessel and equipment activities.

Type	Carbon Production (M kg of CO ₂ -e)	Contribution (%)
Container ship maneuver	55.22	51.13
Container ship at berth	0.64	0.57
Container crane	38.52	35.66
Yard crane	1.90	1.67
Yard truck	1.19	1.04
Container trailer	10.71	9.92



TITLE: Spatial Analysis of the Ship Gas Emission Inventory in the Port of Busan Using Bottom-Up Approach Based on AIS Data

AUTHORS: Donghan Woo and Namkyun Im

KEY WORDS: air pollution; greenhouse gases (GHGs); ship gas emission; Automatic Identification

System (AIS); spatial analysis

PUBLICATION YEAR: 2021

JOURNAL: Marine Science and Engineering/ MDPI

ABSTRACT: Dense hub port-cities have been suffering from ship gas emissions causing atmospheric pollution and a threat to the health of coastal residents. To control ship gas emissions, many regulations have been established internationally. Analyses of ship gas emission inventories are essential to quantify mass and track emission changes over time in a given geographical area. Based on the gas emissions inventory, applicable regulations such as Emission Control Area (ECA) realization and Vessel Speed Reduction (VSR) may be established. The ship gas emission inventory (CO₂, CO, NO_x, SO_x and PM) from the Busan Port (BP), including the North Port (NP) and Gamcheon Dadaepo Port (GDP), which is the biggest port in the Republic of Korea and which is also surrounded by residential, commercial, and industrial areas, were spatially analyzed. To calculate geographical ship gas emissions in real-time, this study introduces a bottom-up methodology using Automatic Identification System (AIS) data. According to the geographical density analysis of the gas emissions inventory, this study highlights that about 35% of the annual ship gas emissions of BP in 2019 were concentrated in the passageway to NP because of high ship speeds when leaving or arriving at the port. To protect the health of coastal residents, ship speed limit regulations along the passageway should be revised based on our spatial analysis results. The spatial analysis of the ship gas emission inventory in BP will be useful basic data for properly evaluating the local gas emission state on newly established or revised environmental regulations for BP.

NUMBER ID: AS22

LOCATION: Port of Busan

COUNTRY: South Korea

Distance from city center: 6.7 km

Total ports Area: 1.53 km²

Total population of port city: 3,429,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,992,000	21,823,995
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	850,802	78,714

PERIOD OF ASSESSMENT: 2019

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Estimation of fuel consumption and spatial distributions of CO₂, CO, NO_x, SO_x and PM

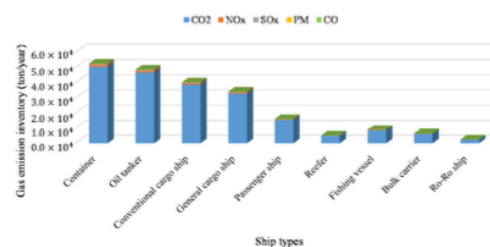
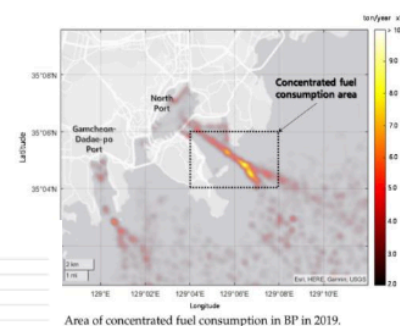


Figure 6. Proportion of the gas emission by ship type in BP in 2019.



Ship Type	CO ₂	CO	NO _x	SO _x	PM
Container	507,264	451	10,608	7995	1139
Oil tanker	468,500	417	9797	7384	1052
Conventional cargo ship	388,682	346	8128	6126	872
General cargo ship	329,685	293	6894	5196	740
Passenger ship	156,167	139	3266	2461	351
Reefer	50,320	45	1052	793	113
Fishing vessel	86,759	77	1814	1367	195
Bulk carrier	62,467	56	1306	985	140
Ro-Ro ship	24,293	22	508	383	55
Total	2,074,138	1845	43,374	32,691	4656

(unit: ton/year).

TITLE: Policies for Improving PM2.5 Particles and GHGs Emissions in a Maritime Port of Taiwan: Evidence Based on the INDC and GGRMA Regulations

AUTHORS: Ching-Chih Chang and Yi-An Tsai

KEY WORDS: onshore power system; liquid natural gas; air pollution; battery-electric power; electrification; particulate matters

PUBLICATION YEAR: 2021

JOURNAL: Marine Science and Engineering

ABSTRACT: The impact of possible emission reduction policies designed to reduce port emissions in the Port of Kaohsiung in Taiwan was analyzed, focusing on ways to reduce air pollution from CO₂, CH₄, N₂O, PM₁₀, PM_{2.5}, NO_x, and SO_x generated by vessels, cranes, and truck tractors in the port. This paper was set up in two stages to determine how pollution reduction policies could reach the 2030 and in 2050 goals. The results showed that emissions of CO₂, CH₄, N₂O, PM₁₀, PM_{2.5}, NO_x, and SO_x could be reduced by 46%, 26%, 25%, 77%, 77%, 76%, and 68%, respectively, in the first stage (in 2030, INDC), and by 57%, 59%, 53%, 79%, 79%, 80%, and 69%, respectively, in the second stage (in 2050, GGRRMA), as compared to 2005 data. This paper concludes as follows: (1) for vessels, the use of liquid natural gas is the best way to reduce GHGs when navigating by water; (2) for bridge cranes, electrification is the better policy during operation; (3) in the case of truck tractors, the generation of battery-electric power is the best way to reduce emissions. These policy proposals for improving air quality can be applied to all ports in Taiwan.

NUMBER ID: AS23



LOCATION: Port of Kaohsiung
COUNTRY: Taiwan

Distance from city center: 13.5 km
Total ports Area: 5 km²
Total population of port city: 9,000,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	21,010,000	9,620,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	n/a	n/a
Liquid Bulk (tons)	n/a	10,000,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: -

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Air pollutants allocated to seaside and intraterminal port operations

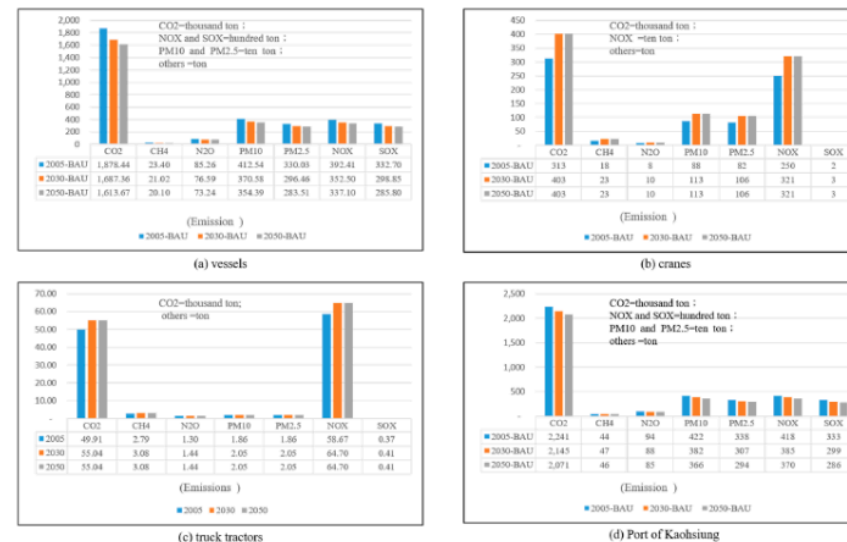


Figure 2. Emissions of vessels, cranes, truck tractors, and the Port of Kaohsiung in the BAU scenario.

TITLE: Evaluating the emission reduction efficiency of automatic mooring system and cold ironing: the case of a port in Izmit Bay

AUTHORS: Alper Seyhan, Cenk Ay and Cengiz Deniz

KEY WORDS: Automatic Mooring Systems; Cold Ironing; Emission Reduction

PUBLICATION YEAR: 2022

JOURNAL: Routledge

ABSTRACT: Maritime transportation contributes to air pollution, which adversely affects life on Earth. Ship-borne emissions, especially in port areas, threaten public health. This study evaluated the emission reduction rates when Automatic Mooring System (AMS) and Cold Ironing (CI) methods were applied separately, and together at a port in Izmit Bay. We used Entec and EPA methodologies to estimate ship-borne emissions. As a result, when only the AMS was used as a reduction method instead of the current situation, in which no reduction method is used, the emission reduction rates of CO₂, NO_x, PM, and SO₂ were 3.58%, 3.55%, 11.19% and 3.45%, whereas these rates were 21.21%, 88.85%, 47.17% and 2.33% respectively when only the CI was used. Additionally, when both systems were applied together, emission reduction rates increased to 24.79% for CO₂, 92.40% for NO_x, 58.37% for PM, and 5.78% for SO₂.

NUMBER ID: AS24

LOCATION: Port in the Izmit Bay

COUNTRY: Turkey

Distance from city center: 17.2 km

Total ports Area: n/a

Total population of port city: 354,000



FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,715,000	1,801,000
RoRo/ Cars (tons)	41,000	5,000
Dry bulk cargo (tons)	22,136,000	25,377,000
Liquid Bulk (tons)	25,220,000	24,109,000
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2020

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Climate change, health and safety issues

Table 6. Total emissions in current situation.

Operation mode	Emission with Entec method (kg)			Emission with EPA method (kg)			
	CO ₂	NO _x	PM	CO ₂	NO _x	PM	SO ₂
Berthing (Ropes)	24677.81	423.82	55.46	23918.59	424.08	21.29	71.69
Hoteling (AE)	1026422.34	18182.98	446.27	1034904.45	18065.30	509.16	3155.49
Unberthing (Ropes)	15182.08	260.20	34.04	14732.37	260.35	13.08	44.10
$\sum E_{CS}$	1066282.23	18867.00	535.77	1073555.42	18749.73	543.52	3271.28

Table 10. Comparisons: the result of methods.

Comparison	Efficiency period	Reduction of Emission (%)			
		CO ₂	NO _x	PM	SO ₂
AMS vs. Ropes	Berthing, and unberthing times	97.51	97.52	97.53	95.01
CI vs. AE	Hoteling times	22.02	92.20	53.29	2.42
(AMS + CI) vs. (Ropes + AE)	Berthing, Hoteling, and Unberthing times	24.79	92.40	58.37	5.78

TITLE: Assessment of shipping emission factors through monitoring and modelling studies

AUTHORS: Araks Ekmekçioğlu, S. Levent Kuzu, Kaan Ünlügençoğlu, Uğur Buğra Çelebi

KEY WORDS: Ship emission, Emission factors, ENTEC, Dispersion, AERMOD

PUBLICATION YEAR: 2020

JOURNAL: Science of the Total Environment

ABSTRACT: In this study, 3990 movements of 629 different ships approaching to the Ambarlı port of Istanbul and 10,272 movements of 2798 different ships arriving at Kocaeli port which are the largest ports of Turkey were monitored for a year between September 1, 2017 and September 1, 2018. It is well known that ship exhaust emissions have a significant impact on pollutant and global warming agent mass inputs and diminish air quality around port areas. We calculated ship exhaust emissions for three different modes by ENTEC method. The annual estimated emissions were 72,802, 1430.4, 900.3, 105.3, 60.9, and 59 tons for CO₂, NO_x, SO₂, PM₁₀, VOC, and CO, respectively, in Ambarlı Port. Higher emissions were estimated for Kocaeli Port due to marine traffic intensity. The annual estimated emissions at Kocaeli Port were 134,120.8, 2655.1, 1652.3, 181.4, 108.3, and 106.4 tons for CO₂, NO_x, SO₂, PM₁₀, VOC, and CO, respectively. In order to determine the impact of ship emissions, we employed AERMOD air quality dispersion modelling. Ground-level PM₁₀, NO_x, and SO₂ concentrations were calculated. Their spatial distribution was plotted and results were evaluated by air quality measurement station results. Only estimated SO₂ concentrations were higher than the observed concentrations. We concluded that ENTEC calculations produce excessive SO₂ concentrations. Because sulphur content of marine fuel may vary and recent amendments in the related regulations limit its amount to lower values. Advancement of on-board SO₂ emission control on ships can also have a reducing effect on emitted SO₂ emissions. As a result, we emphasize that current ENTEC emission factors don't represent SO₂ emissions accurately. Further, the advancement of SO₂ emissions factors is required.

NUMBER ID: AS25



LOCATION: Port of Ambarlı

COUNTRY: Turkey

Distance from city center: 7.1 km

Total ports Area: 89.7 km²

Total population of port city: 15,460,000

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	3,104,883	2,887,807
RoRo/ Cars (tons)	436,000	27,000
Dry bulk cargo (tons)	2,843,000	2,638,000
Liquid Bulk (tons)	240,000	237,000
Passenger	161,000	123,000

PERIOD OF ASSESSMENT: September 2017-September 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Concentration & distribution of SO₂, NO_x, CO₂, VOC, PM, and CO emissions

Table 6
Emission amounts from main and auxiliary machinery for Ambarlı Port (ton/year).

	AE			ME	
	Cruise	Manoeuvre	Port	Cruise	Manoeuvre
NO _x	24	30.1	706.8	581.8	87.7
SO ₂	13.1	16.4	388	399.6	83.2
CO ₂	1386.2	1741.7	41,190.8	23,592.3	4891
VOC	0.8	1	23.9	22.5	12.7
PM	0.8	1	23.9	62.5	17.1
CO	1.1	1.4	32.2	20.4	3.9

Table 8
Emission amounts by ship types for Ambarlı Port (ton/year).

Ship type	Search & rescue ship	General cargo	Chemical tanker	LPG tanker	Oil tanker	RoRo	Container
NO _x	0.21	198.73	8.99	10.99	1.06	39.30	1171.14
SO ₂	0.15	113.59	5.31	6.51	0.64	25.64	748.48
CO ₂	11.57	11,359.01	528.67	632.64	59.20	2027.48	58,183.38
VOC	0.01	6.97	0.33	0.42	0.04	1.75	51.4
PM	0.01	7.68	0.36	0.53	0.05	3.14	93.5
CO	0.01	8.91	0.41	0.50	0.05	1.65	47.45

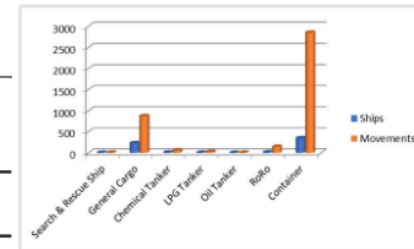


Fig. 4. Distribution of ship types arriving at the Ambarlı Port.

TITLE: Decision-making instruments for container seaport sustainable development: management platform and system dynamics model

AUTHORS: Yingyi Huang, Yuliya Mamatok, Chun Jin

KEY WORDS: Management platform, System dynamics model, Container seaport, Sustainable development, Decision-making instruments

PUBLICATION YEAR: 2021

JOURNAL: Springer Science & Business Media

ABSTRACT: Global seaborne container trade accounts for approximately 60% of all world seaborne trade. A container seaport is a key node in maritime transport, where (un)loading operations produce GHG emissions. Therefore, the effective emissions reduction decisions should be taken by the container seaport executives on operational, tactical and strategic levels. This research contributes in developing the decision-making instruments for emissions reduction at a container seaport, namely: (1) a management platform (based on three management levels); (2) a system dynamics model (with the variables that reflect the main sources of emissions from container seaport activities). A management platform consequently leads the executives through the process of emissions estimation and three-level decision-making to reduce the emissions. A system dynamics model serves as the instrument to evaluate the decisions taken and to analyze the container seaport system environmental performance over the defined period. The representation of a seaport as a system, the system dynamics modeling and the case study methods were used in the research. Four “what if” scenarios of emissions reduction decisions were performed using the case study method. The suggested management platform and the system dynamics model can serve as the decision-making instruments for the container seaport authorities on operational, tactical and strategic management levels when they develop the container seaport environmental programs.

NUMBER ID: NA1



LOCATION: Port of Los Angeles

COUNTRY: USA

Distance from city center: 38 km

Total ports Area: 30 km²

Total population of port city: 73,264

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	9,300,000	9,200,000
RoRo/ Cars (tons)	127,042	103,453
Dry bulk cargo (tons)	838,000	729,000
Liquid Bulk (tons)	13,425,000	12,267,000
Passenger	650,010	173,947

PERIOD OF ASSESSMENT: 2018

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Calculation of marine air emissions using numerical modelling

KEY FINDINGS: CO₂ emissions in current situation and predicted values.

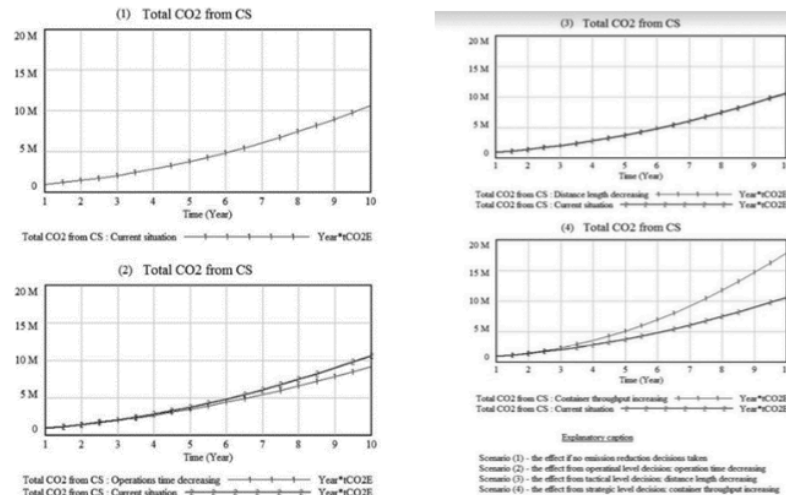


Fig. 7 Total CO₂ emissions levels of scenarios 1, 2, 3, 4

TITLE: Simulation of cargo VOC emissions from petroleum tankers in transit in Canadian waters
AUTHORS: Guilin Hu, James Butler, Jennifer Littlejohns, Qianpu Wang & Guoneng Li
KEY WORDS: VOCs emission; tanker transit; numerical simulation; temperature variation
PUBLICATION YEAR: 2020
JOURNAL: Taylor & Francis

ABSTRACT: The emissions of volatile organic compounds (VOCs) from petroleum product tankers potentially represent a significant source of VOCs in port cities. Emission factors are used to estimate the produced VOCs. VOC emissions from transit operations were simulated using a twopart model of heat and mass transfer. Using local meteorological data of air temperatures, solar radiation and wind speed, the heat transfer within the tank was modeled. Results showed that bulk cargo temperature remained relatively steady at 25–28°C, the oil surface oscillated diurnally by 1–2°C, and the deck temperature oscillates diurnally by 15–20°C. The solar insolation had the largest effect on the tank temperatures. VOC emissions for two crude oils and gasoline, two tank configurations, and two meteorological conditions were estimated using a model derived from a mass balance on the tank and the obtained temperature profile. Only 3 of 8 scenarios had pressure increases large enough to cause venting of VOC. C2-C5 compounds constituted the majority of VOCs released from crude oils and ethanol made up the majority of the VOCs released from the gasoline carrying barge. The calculated daily emission factors for crude oil and gasoline (barge) were 10 mg/L/day and 135 mg/L/day respectively.

**NUMBER
ID: NA2**



LOCATION: Port of Montreal
and Vancouver
COUNTRY: USA



MONTREAL
Distance from city center: 6 km
Total ports Area: 6.35 km²
Total population of port city:
1,762,949

**FREIGHT AND PASSENGER PORT
TRAFFIC**

	2019	2020
Containers (TEUs)	1700000	1,600,000
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	24,375,482	22,703,850
Liquid Bulk (tons)	16,214,695	12,397,584
Passenger	111604	n/a

VANCOUVER
Distance from city center: 0.7 km
Total ports Area: 175 km²
Total population of port city:
150.277

**FREIGHT AND PASSENGER PORT
TRAFFIC**

	2019	2020
Containers (TEUs)	3,399,000	3,468,000
RoRo/ Cars (tons)	420,000	345,000
Dry bulk cargo (tons)	166,862,000	118,501,000
Liquid Bulk (tons)	n/a	n/a
Passenger	1,071,000	n/a

PERIOD OF ASSESSMENT: -

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: VOC emissions from transit operations in two of the larger crude oil-exporting ports in Canada

Table 2. Release events for each scenario and resulting emission factors.

	Metrological Conditions	Temperature Profile	Oil	Release Events	Time of Release (hr)	Mass of VOCs (kg)	Emission Factor (mg/L/day)
1	Montreal Summer	VOC Avg.	CLB	1	19	62.8	10
2	Montreal Summer	Surface	CLB	None	–	–	–
3	Montreal Summer	Surface	MSC	1	7	128.8	21
4	Vancouver Summer	Surface	MSC	None	–	–	–
5	Vancouver Summer	Surface	CLB	None	–	–	–
6	Vancouver Summer	Barge Surface	CLB	None	–	–	–
7	Vancouver Summer	Surface	Gasoline	None	–	–	–
8	Vancouver Summer	Barge Surface	Gasoline	None	–	–	–

CLB: Cold Lake Blend, MSC: Mixed Sweet Crude.

TITLE: Near-port air quality assessment utilizing a mobile measurement approach

AUTHORS: Jonathan Steffens Education Postdoctoral Fellow, Sue Kimbrough, Richard Baldauf, Vlad Isakov, Ryan Brown, Alan Powell, Parikshit Deshmukh

KEY WORDS: Air quality, Mobile monitoring, Near-source, Seaport, Particulate

PUBLICATION YEAR: 2017

JOURNAL: Atmospheric Pollution Research

ABSTRACT: Mobile monitoring is a strategy to characterize spatially and temporally variable air pollution in areas near sources. EPA's Geospatial Measurement of Air Pollution (GMAP) vehicle e an all-electric vehicle is outfitted with a number of measurement devices to record real-time concentrations of particulate matter and gaseous pollutants e was used to map air pollution levels near the Port of Charleston in South Carolina. High-resolution monitoring was performed along driving routes near several port terminals and rail yard facilities, recording geospatial coordinates and concentrations of pollutants including black carbon, size-resolved particle count ranging from ultrafine to coarse (6 nm to 20 μm), carbon monoxide, and nitrogen dioxide. Additionally, a portable meteorological station was used to characterize local conditions. The primary objective of this work was to characterize the impact of port facilities on local scale air quality. The study determined that elevated concentration measurements of black carbon and PM correlated to periods of increased port activity and a significant elevation in concentration was observed downwind of ports. However, limitations in study design prevented a more complete analysis of the port effect.

NUMBER ID: NA3



LOCATION: Port of Charleston
COUNTRY: USA

Distance from city center: 1.2 km
Total ports Area: 53 km²
Total population of port city: 150.277

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	2,440,000	1,200,000
RoRo/ Cars (tons)	225,191	135,747
Dry bulk cargo (tons)	725,828	n/a
Liquid Bulk (tons)	n/a	n/a
Passenger	262,776	n/a

PERIOD OF ASSESSMENT: February 20, 2014 to March 13, 2014

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Results of measurements of various air pollutants

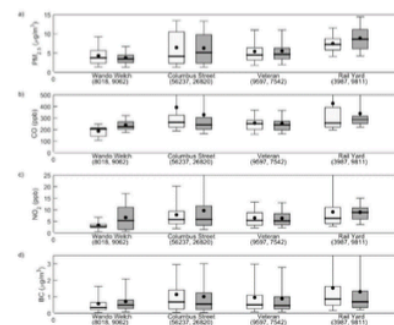


Fig. 4. Concentration measurements for each sampling location (residential area where location is upwind of source (white) and downwind of source (grey)) for pollutants: a) PM_{2.5}, b) CO, c) NO₂, and d) BC. Major distribution lines show 5, 25, 50, 75, and 95 percentiles. Number of samples given in parentheses.

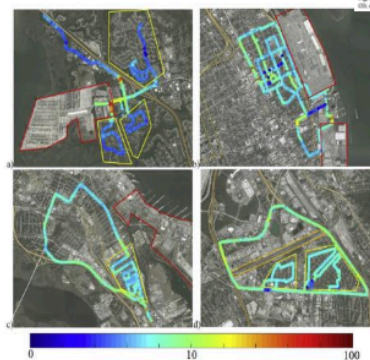


Fig. 3. Measured PM_{2.5} concentrations (μg/m³) along driving routes at a) Wharfe Wharf terminal, b) Columbus Street/Union Pier terminal, c) Verrill's Terminal, and d) Bennett Rail Yard. Port areas outlined in red, rail yard outlined in orange, neighborhood regions outlined in yellow.

TITLE: Management of plastic wastes at Brazilian ports and diagnosis of their generation

AUTHORS: Clarice Neffa Gobbia, Vânia Maria Lourenço Sanchesc, Elen Beatriz Acordi Vasques Pachecod, Maria José de Oliveira Cavalcanti Guimarães, Marcos Aurélio Vasconcelos de Freitasb

KEY WORDS: Plastics, Wastes, Brazilian ports, Waste management

PUBLICATION YEAR: 2017

JOURNAL: Marine Pollution Bulletin

ABSTRACT: This study evaluated the management of plastic wastes at 20 Brazilian maritime ports, from three sources: vessels, leased and non-leased areas. The data were obtained from documents on port wastes organized in a relational database with defined protocols (closed form). Analysis of the spreadsheets prepared and field visits revealed that the main bottleneck in managing plastic wastes at ports is their segregation. In general, more material is segregated and sent for recycling from leased areas than non-leased ones (administered by the government). This relatively better performance in managing the wastes generated in leased areas is probably due to the need for private operators to comply with the international standards such as the Code of Environmental Practice to satisfy the international market.

NUMBER ID: SA1



LOCATION: Brazilian ports (east coast)

COUNTRY: Brazil

Port of Santos
Distance from city center: 8.5 km
Total ports Area: 7.7 km²
Total populaon of port city: 697,315

	2019	2020
Container rs (TEU)	4,100,000	n/a
Refuse/ Cargo	n/a	n/a
Dry bulk cargo	n/a	n/a
Liquid Bulk (ton)	n/a	n/a
Passenger r	n/a	n/a

Port Of Santarém
Distance from city center: 3 km
Total ports Area: 0.49 km²
Total populaon of port city: 475,344

	2019	2020
Container rs (TEU)	n/a	n/a
Refuse/ Cargo	n/a	n/a
Dry bulk cargo	4,577,210	n/a
Liquid Bulk (ton)	n/a	n/a
Passenger r	32,000	2,000

Port of Salvador
Distance from city center: 13.6 km
Total ports Area: 0.09 km²
Total populaon of port city:
506,922

	2019	2020
Container rs (TEU)	11,676,000	11,970,000
Refuse/ Cargo	1,373,000	1,045,000
Dry bulk cargo	13,729,000	11,509,000
Liquid Bulk (ton)	71,089,000	67,574,000
Passenger r	32,000	2,000

PERIOD OF ASSESSMENT: 2010-2013

ENVIRONMENTAL ASPECT: Waste generation

METHODOLOGY: Pollutants data collection and analysis

KEY FINDINGS: Quantities of plastic wastes segregated and sent for recycling

Description of the categories of wastes.

Category	Description
Common trash	Includes mixed items, recyclable or not, without any segregation.
Recyclable wastes (Class II)	All wastes segregated and declared as "recyclable", without specific identification of the material (e.g., metal, glass, wood, paper/cardboard, plastic) or not clearly identified (e.g., total recyclable wastes).
Plastic wastes	*Not hazardous in conditions of technical feasibility for segregation and recycling.
Others	All wastes segregated and declared as being plastic.
	Includes hazardous wastes (Class I), civil construction debris, easily biodegradable organic wastes, unidentified wastes and others. These wastes were not included in the study.

Demonstration of the source categories that presented documents with information on segregation of plastic wastes.

Ports	Non-leased areas	Leased areas	Vessels
Itaquí	X	—	X
Suaípe	X	—	—
Vitória	X	—	—
Fortaleza	—	X	—
Salvador	—	X	X
Rio de Janeiro	—	X	X
Itaguaí	—	X	—
Santos	—	X	—
Rio Grande	—	X	—
Natal	—	—	X
Cabedelo	—	—	X
Recife	—	—	X

Quantities of plastic wastes segregated and sent for recycling from non-leased and leased areas, and vessels.

Ports	Total solid wastes (t)	Plastic wastes segregated (t)	Plastic wastes segregated (%)	Plastic wastes sent for recycling (t)	Plastic wastes sent for recycling (%)
Non-leased areas					
Itaquí	845.5	15.2	2.0	15.2	100
Suaípe	275.5	1.6	0.6	1.6	100
Vitória	994.7	4.4	0.4	4.4	100
Total	2115.7	21.2	1.0	21.2	100
Leased areas					
Fortaleza	488.0	0.3	0.1	0.3	100
Salvador	50.1	2.0	4.0	2.0	100
Rio de Janeiro	16,607.7	238.0	1.0	210.8	89
Itaguaí	7755.1	111.6	1.0	103.0	92
Santos	27,572.8	356.0	1.3	319.1	90
Rio Grande	15,543.4	2528.0	16.0	2351.0	93
Total	68,017.1	3235.9	4.7	2986.2	92
Vessels					
Itaquí	522.6	68.6	13.0	24.9	36
Natal	93.9	1.0	1.0	1.0	100
Cabedelo	263.9	11.8	5.0	0	0
Recife	456.5	4.5	1.0	0	0
Salvador	5482.0	1.6	0.03	0	0
Rio de Janeiro	1908.9	350.0	18.3	4.2	1
Total	8727.8	437.7	5.0	30.1	7

TITLE: A Reconfigured Whale Optimization Technique (RWOT) for Renewable Electrical Energy Optimal Scheduling Impact on Sustainable Development Applied to Damietta Seaport, Egypt

AUTHORS: Noha H. El-Amary, Alsnosy Balbaa, R. A. Swief and T. S. Abdel-Salam

KEY WORDS: biomass energy; carbon oxides emissions; Damietta seaport; energy scheduling; global warming; green energy; intelligent scheduling (IS); photovoltaic energy; sustainable development; Reconfigured Whale Optimization Technique (RWOT)

PUBLICATION YEAR: 2018

JOURNAL: MDPI

ABSTRACT: This paper studies the effect on the rate of growth of carbon dioxide emission in seaports' atmosphere of replacing a part of the fossil fuel electrical power generation by clean renewable electrical energies, through two different scheduling strategies. The increased rate of harmful greenhouse gas emissions due to conventional electrical power generation severely affects the whole global atmosphere. Carbon dioxide and other greenhouse gases emissions are responsible for a significant share of global warming. Developing countries participate in this environmental distortion to a great percentage. Two different suggested strategies for renewable electrical energy scheduling are discussed in this paper, to attain a sustainable green port by the utilization of two mutual sequential clean renewable energies, which are biomass and photovoltaic (PV) energy.

NUMBER ID: AF1



LOCATION: Damietta Port

COUNTRY: Egypt

Distance from city center: 10.7 km

Total ports Area: 11.8 km²

Total population of port city: 337,303

FREIGHT AND PASSENGER PORT TRAFFIC

	2019	2020
Containers (TEUs)	1,154,223	1,130,607
RoRo/ Cars (tons)	n/a	n/a
Dry bulk cargo (tons)	22,976,727	19,119,143
Liquid Bulk (tons)	564,509	585,860
Passenger	n/a	n/a

PERIOD OF ASSESSMENT: 2016

ENVIRONMENTAL ASPECT: Emissions to air

METHODOLOGY: Emissions estimation using numerical modelling

KEY FINDINGS: Numerical results in terms of energy consumption and CO₂ emissions, from replacing the conventional electrical power generation of the seaport with alternative energy sources, based on several techniques.

Table 3. The calculated average daily PV energy, power, CO₂ emission and obsoleted CO₂ emission through different months based on Eco-Availability strategy.

Months	Average Length of Day (Hours)	Average Daily Sunshine Hours	Insolation (kWh/m ² /day)	Average Daily Solar Energy (MWh/day)	Power (MW/day)	CO ₂ Emission (kg CO ₂)	Obsoleted Emissions (kg CO ₂)
January	10.8	4	3.16	266.625	11.1	14,397.75	213,300
February	11.5	5	4.02	361.171	15	19,503.234	288,936.8
March	12.4	6	5.42	525.062	21.8	28,353.348	420,049.6
April	12.4	6	6.85	663.593	27.6	35,834.022	530,874.4
May	14.2	8	7.77	861.984	35.9	46,547.136	689,587.2
June	14.6	8	8.43	961.547	40	51,923.538	769,237.6
July	14.4	8	8.33	937.125	39	50,604.75	749,700
August	13.7	7	7.73	827.351	34.4	44,676.954	661,880.8
September	12.7	6	6.65	659.804	27.4	35,629.416	527,843.2
October	11.8	5	5.05	465.546	19.3	25,139.484	372,436.8
November	11	5	3.7	317.968	13.2	17,170.272	254,374.4
December	10.6	4	2.97	245.953	10.2	13,281.462	196,762.4

ANNEX IV: List of Good Green practices related to ports

Table 26. Policy and Governance Characteristics of Green Port Practices

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Los Angeles	United States	US	Port of Los Angeles pioneered a process that captures emissions as ships plug into shore power—while they're at berth.	NO	YES	NO	YES
Ports of Brunswick and Savannah	Georgia, United States	US	a variety of initiatives that share one central purpose—emissions reduction	NO	NO	NO	YES
Port of Antwerp	Belgium	EU	Powerpack for sustainable Energy Management	NO	YES	NO	NO
Port, City and Borough of Juneau, Vancouver Fraser Port Authority, and Leading Global Cruise Lines	global	global	Port, City and Borough of Juneau, Vancouver Fraser Port Authority, and Leading Global Cruise Lines to Explore Feasibility for First-of-its-kind 'Green Corridor'	NO	YES	NO	NO
C40 Green Ports Forum	global	global	Connecting ports around the world to take collective action on the climate crisis and decarbonising global supply chains	NO	YES	NO	NO
PSA International	Singapore	AS	CMA CGM and PSA to expand collaboration with new digital solutions to reduce carbon footprint. Opt-E-Arrive digital solution will enable CMA CGM vessels to arrive just-in-time at berth at terminal, skipping the anchorage stop	NO	YES	NO	NO
American Association of Port Authorities	United States	US	American port hydrogen plans	NO	YES	NO	NO
Port of Baltimore	United States	US	Dray Truck Replacement Program that allows truck owners and operators to trade in their old model trucks for newer models that reduce air emissions	NO	YES	NO	YES
Port of Long Beach	United States	US	the port seeks to improve its air quality through various initiatives of the San Pedro Bay Ports Clean Air Action Plan	NO	YES	NO	YES
Port of Oakland	United States	US	to help diminish air pollution from mobile and stationary on-, near-, and off-shore areas, the port has created a Maritime Air Quality Improvement Plan (MAQIP)	NO	YES	NO	NO
Port of Portland	United States	US	Port of Portland has implemented an array of sustainability initiatives.	NO	YES	NO	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			Installed shore power at Terminal 6 for all tugs that are moored, so that they can plug into an electric grid. Installed meters to track energy cost savings				
Port of San Diego	United States	US	22-year Climate Action Guide to reduce emissions, the SCPA has replaced traditional diesel conveyors with electrified ones, and upgraded its terminal equipment, including fully electrified ship-to-shore and rubber-tired gantry cranes	NO	NO	YES	YES
South Carolina Port Authority	United States	US	Clean Air Strategy	NO	YES	NO	YES
Port Authority of New York and New Jersey	United States	US	THE NORTHWEST SEAPORT ALLIANCE	NO	YES	NO	NO
Ports of Seattle and Tacoma	United States	US	Belgium's two large ocean ports announced that they will merge their operations to strengthened their position and prepare for future developments.	NO	YES	YES	YES
Ports of Antwerp and Zeebrugge	Belgium	EU	Hamad Port is considered the region's largest and most environmentally-friendly project and this title has been well deserved for several factors, the most important of which is its success in relocating and moving more than 12,500 pieces of hard coral reefs	NO	NO	NO	NO
Port of Hamad	Qatar	AS	The first phase of a green hydrogen plant in Egypt is under way.	NO	YES	YES	NO
Port of Ain Sokhna	Egypt	AF	A solar energy plant at the Port of Gandia in Spain will reportedly generate enough power to make the port the first in Europe to be energy self-sufficient	NO	YES	NO	NO
Port of Gandia	Spain	EU	Port of Aberdeen has been awarded GB£200,000 in UK Government funding to accelerate its drive to net zero which includes the progression to cleaner fuels	NO	YES	NO	NO
Port of Aberdeen	Scotland	EU	SSA Marine has completed a multi-year project to convert nine ZPMC diesel-electric 1,000 hp RTGs to 100% grid-tied electric.	NO	YES	NO	NO
Port of Long Beach	United States	US	ambitious partnerships with two of the world's largest cruise companies are enhancing the Port of Galveston's capacity to ensure a sustainable passenger shipping future	NO	YES	NO	NO
Port of Galveston	Texas, United States	US	NORTHWEST SEAPORT ALLIANCE ANNOUNCES DECARBONIZATION	NO	YES	NO	NO
Seattle-Tacoma & Busan	Washington State, South Korea	US					

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Gothenburg	Sweeden	EU	PARTNERSHIP WITH BUSAN PORT AUTHORITY DESCARBONIZATION BUSINESS MODEL - PANEL DISCUSSION	NO	YES	NO	NO
Port of Barcelona	Spain	EU	DESCARBONIZATION BUSINESS MODEL - PANEL DISCUSSION	NO	YES	NO	NO
Port of Antwerp	Belgium	EU	HIGH LEVEL ROUNDTABLE	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	HIGH LEVEL ROUNDTABLE	NO	YES	NO	NO
Barcelona Europe South Terminal	Spain	EU	Barcelona Europe South Terminal (BEST) has installed half a hectare of solar panels on the roofs of its buildings	NO	YES	YES	YES
Port of Antwerp	Belgium	EU	Alternative fuelled tugs	NO	YES	NO	NO
Port of Vancouver	Canada	US	Zero-emission testing	NO	YES	NO	NO
Pilbara Ports	Australia & Japan	global	Pilbara Ports and Japan team up on green energy	NO	NO	YES	NO
Port of Bellingham	US	US	Green Marine certification	NO	NO	NO	NO
Port of Corpus Christ	US	US	centralized solution to capture and manage CO2 emissions	NO	YES	NO	NO
Port of San Diego	US	US	TWO CRUISE SHIPS USE SHORE POWER SIMULTANEOUSLY AT THE PORT OF SAN DIEGO FOR THE FIRST TIME	NO	YES	NO	NO
Port of Hamburg	Germany	EU	Fuelling the need for North Sea hydrogen bunkering	NO	YES	NO	NO
Virginia Inland Port	US	US	Renewables help US port achieve carbon neutrality	NO	YES	NO	YES
Pilbara Ports	Australia	AU	Pilbara Ports and Japan team up on green energy	NO	YES	YES	NO
Port of Shoreham	UK	EU	Financing green growth	NO	YES	YES	NO
Port of Oakland	US	US	Port turns solar power supplier	NO	YES	YES	NO
Port of Mombasa	Kenya	AF	Kenyan shore-based power study	NO	YES	NO	NO
Port of Tianjin	China	AS	Solar and wind takes off at Tianjin Port	NO	NO	NO	YES
Port of Gothenburg	Sweeden	EU	Gothenburg expands electric truck fleet	NO	YES	NO	YES
Port of Stockholm	Sweeden	EU	Baltic ports tackle emissions with onshore power	NO	YES	NO	NO
Port of Leith	Scotland	EU	Shore power electrifies Leith	NO	YES	NO	NO
Port of Southampton	UK	EU	Biofuel used in race to meet carbon targets	NO	YES	NO	NO
Port of Liverpool	UK	EU	Growing sustainable cruise facilities always requires balancing the interests of multiple stakeholders	NO	YES	NO	NO
Kotug Canada Inc	US	US	Fighting underwater noise using green vessel coatings	NO	YES	NO	NO
Port of Los Angeles, Port of Shanghai, and C40 Cities	global	global	Port of Los Angeles, Port of Shanghai, and C40 Cities announce partnership to create world's first transpacific green shipping corridor between ports in the United States and China	NO	YES	NO	NO
Portsmouth Port	England	EU	Using smart grid technology to decarbonise	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
22 countries	global	global	The digital revolution to tackle air quality at ports	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	Priority for electric trucks at Gothenburg	NO	YES	NO	YES
Port of Gothenburg	Sweeden	EU	Electric truck fleet breaks Nordic records	NO	NO	NO	NO
Haropa Port	France	EU	France ramps up its biofuels logistics chain	NO	YES	NO	NO
Port of London Authority	England	EU	PLA in net-zero milestone	NO	YES	NO	NO
Associated British Ports	England	EU	ABP plans for the energy transition and net zero	NO	YES	NO	NO
Port of Aberdeen	Scotland	EU	World's first H2 shipping project	NO	YES	NO	NO
Port of Kembla	Australia	AU	support off shore wind development projects	NO	YES	NO	NO
Port of Portsmouth	England	EU	PORTSMOUTH PILOTS A NEW SMART ENERGY SYSTEM	NO	YES	NO	NO
Port Everglades	US	US	SHORESIDE POWER MOMENTUM	NO	YES	NO	NO
Virginia Inland Port	US	US	Renewables help US port achieve carbon neutrality	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	The Port of Gothenburg is ready for methanol bunkering ship-to-ship	NO	YES	NO	NO
west European routes	Norway	EU	Green hydrogen milestone for short sea feeder vessels	NO	YES		
Port of Antwerp	Belgium	EU	New milestone in sustainable methanol production in the port of Antwerp	NO	YES		
Port of Singapore	Singapore	AS	Port dues concessions	NO	YES		
Port of Kapellskär	Sweeden	EU	Onshore Power Supply in Port of Kapellskär	NO	YES		
Port of Kapellskär	Sweeden	EU	Electric lift trucks, a Step Towards Electrified Ports	NO	YES		
Port of Ipswich	UK	EU	Electric-powered hydraulic cranes for the Port of Ipswich	NO	YES		
Trondheim Port Authority	Norway	EU	ElMar – Electrification of maritime transport and the ports of the future	NO	YES		
San Francisco bay	California	US	Innovative Hydrogen-Powered Vessels	NO	YES		
Port of Barcelona	Spain	EU	LNG cruise ship bunkered at Barcelona	NO	YES		
	Groningen	EU	First LNG Tanker Docks At New Dutch Floating Terminal	NO	NO		
Port Coronel	Chile	US	Zero-Emission Equipment Drive for Chile Port	NO	YES		
Port of Antwerp	Belgium	EU	New milestone in sustainable methanol production in the port of Antwerp	NO	YES		
Port of Rotterdam	Netherlands	EU	Green hydrogen production from wind farms	NO	YES		
Gothenburg	Sweeden	EU	Scandinavia ups the ante in methanol bunkering	NO	YES		
Tauranga	New Zealand	EU	Tauranga takes the hybrid approach to getting greener	NO	YES		
European Ports		EU	European ports join forces to create hydrogen corridors	NO	YES		

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Klaipeda port	Lithuania	EU	Klaipėda to transition into an energy port	NO	YES		
Port of Vancouver	Vancouver	US	Vancouver to use hydrogen trucks to decarbonise	NO	YES		
Port of Stephenville	Canada	US	Canadian energy firm acquires key hydrogen port	NO	YES		
Port of Detroit	Canada	US	Detroit begins work on net-zero plan	NO	NO		
Kalmar company			Kalmar charges ahead with electric equipment roll-out	NO	NO		
port Wallhamn	Sweeden		Recycling waste into green methanol for port use	NO	YES		
Freeport Texas	USA	US	USA fixes sights on blue ammonia production	NO	YES		
Port of Valencia	Spain		Valencia shares hydrogen ambitions	NO	YES		
Fjords	Norway		Norwegian Fjords transition into H2 hub	NO	YES		
Port of Brownsville	Texas, United States	US	Port of Brownsville business park	NO	YES		
Port of Singapore	Asia	AS	Singapore plays host to biofuel bunkering	NO	YES		
DP World Yarimca	Asia	AS	Turkish port in remote-control crane first	NO	YES		
Port of Auckland	Californian	US	Oakland invests in geothermal energy	NO	YES		
Stockholm	Sweeden		New solar farms at Ports of Stockholm	NO	YES		
Port of Muuga	Estonia		Solar farm opens at Estonian port	NO	YES		
Port of Vigo	Italy		Port of Vigo – Welfare Committee	NO	YES		
National Ports Agency of Morocco	Morocco		National Ports Agency of Morocco – Smart port innovation approach	NO	YES		
Fiji Ports	Fiji		Fiji Ports – Integrated Management System certification	NO	YES		
Port of Long Beach Board	USA	US	Port of Long Beach – Water quality programs result in port biodiversity	NO	YES		
Port of Santa Cruz	Tenerife		Port Authority of Santa Cruz de Tenerife – Tenerife Port ZERO	NO	YES		
Port of Vienna	Austria	EU	The aim of the exploratory project “H2 meets H2O” is to assess the feasibility and applicability of hydrogen supply along the Danube as logistics backbone from a technical, legal and socio-economic point of view	NO	YES	NO	NO
Solomon Ports	Honiara	AU	Solomon Ports exhibits the largest solar outfit for a Port in the Pacific Region	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	Considering various climate change scenarios, we developed adaptation strategies for coping with flood risk in collaboration with the companies and public organizations. We have mapped out the probabilities and	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			consequences of flooding, assessed these risks with an assessment framework, specifically developed for our port, and listed and selected appropriate measures.				
Port of London Authority	UNITED KINGDOM	EU	develop a UK hydrogen highway network which consists of land, sea and ports. The hydrogen highway could significantly support the integration of hydrogen technologies into a range of different sectors with six projects planned for the highway.	NO	YES	YES	NO
Port of Amsterdam	Netherlands	EU	Upcycle Factory	NO	YES	YES	NO
Port of Seattle	Canada	US	Ocean Acidification Action Plan	NO	YES	NO	YES
North Sea Port	Belgium	EU	Solar Park	NO	YES	NO	NO
Port of Busan	Republic of Korea	AS	recycling network together with stakeholders which sees the implementation of innovative, green technologies and approaches	NO	YES	YES	YES
Flinders Port Holdings	Australia	AU	In 2021, Flinders Port Holdings (FPH) developed its first comprehensive Climate Change Adaptation Strategy, which sets out: the climate science and local projections we face; the risks and opportunities we have identified and assessed; and the short-term actions we plan to address on the road to more detailed adaptation pathways	NO	YES	YES	NO
Port of Baku	Azerbaijan	AS	"Port of Baku Climate Strategy 2035" and the respective Action Plan	NO	NO	YES	NO
Port of Igoumenitsa	Greece	EU	The ALFION project aims at providing the necessary final studies and engineering designs for the development of onshore power supply at the Port of Igoumenitsa, introducing renewable energy sources to the power system of the port, and at creating a central power management system that will regulate the energy network of the port, maximizing the environmental and financial benefits for the port and the entire area.	NO	YES	NO	NO
RAK Ports	Arab Emirates	AS	comprehensive port optimization and risk management solution, underpinned by detailed modelling of port operations, ship motions, and hydro-dynamics, and the AI assisted assimilation of real-time and forecast environmental conditions	NO	NO	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Amsterdam	Netherlands	EU	Multi Fuel Port	NO	YES	NO	NO
Fiji Ports	FIJI	US	Green Port Initiative	NO	YES	NO	NO
Port of Puna	Ecuador	US	blue carbon ecosystems	NO	YES	NO	NO
Port of Vigo	Spain	EU	Coastal and Marine Infrastructure (CMI)	NO	YES	NO	NO
Port of Colombo	Sri Lanka	AS	Sri Lanka Ports Authority with collaboration with the other terminal operators and port stakeholders have taken joint measures through smaller but impactful contributions towards GHG emission reduction	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	the port has identified hydrogen as a promising alternative for the future	NO	YES	NO	NO
Port of Yokohama	Japan	AS	study on a potential business collaboration for the development of a hydrogen supply chain in Yokohama's waterfront area	NO	YES	YES	NO
Port of Los Angeles	US	US	Zero Emissions Pathway Technology Demonstrations	NO	YES	NO	NO
Port of Kaohsiung	Taiwan	AS	comprehensive Master Plan for Future Development and Construction 2017-2021	NO	YES	YES	NO
Port of Antwerp	Belgium	EU	To this end, a multi-year program was drawn up to renew, green and optimize the port's own fleet	NO	YES	NO	NO
Port of Guangzhou	China	AS	the company actively promoted the construction and application of the port shore power	NO	NO	NO	NO
Port of Gothenburg	Sweeden	EU	The CinfraCap project is focused on the transport of captured carbon and how this can be done in a climate-smart and cost-effective way	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	OPS installation	NO	YES	NO	YES
Ports of Auckland	New Zeland	EU	Actions that reduce the GHG emissions	NO	YES	NO	YES
Guangzhou Container Terminal	China	AS	GCT has voluntarily adopted energy-efficient port equipment designs that contribute towards lowering carbon emissions.	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	eelgrass replant due to terminal extension	NO	NO	NO	YES
PSA Marine	Singapore	AS	LNG dual-fuel tugs. They underwent the requisite training to carry out LNG bunkering operations, operation and maintenance of the dual-fuel engine and the LNG storage and supply systems.	NO	YES	NO	YES
Port of Seattle, Port of Tacoma, Northwest Seaport Alliance, and Vancouver Fraser Port Authority	Canada	US	reduce and ultimately eliminate air and climate emissions from their seaport activities across the Georgia Strait-Puget Sound airshed. In 2020, the ports renewed the Strategy and embraced a bold, shared vision	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Valencia	Spain	EU	Port Authority of Valencia's (PAV) Strategy towards zero emissions by 2030	NO	YES	NO	NO
Port of Marseille	France	EU	The project includes the construction of Europe's first high-pressure hydrogen station for long-distance trucks	NO	YES	NO	NO
Port of Taipei	Taiwan	AS	port in northern Taiwan that was constructed fully by land reclamation, adopting innovative management for ecological conservation with cutting-edge technologies is a significant feature in the development of the port	NO	YES	YES	YES
Port of Amsterdam	Netherlands	EU	technical and economic feasibility of hydrogen bunkering and propulsion for shipping and will identify the conditions for successful market entry for the technology.	NO	YES	NO	NO
Port of Algeciras	Spain	EU	PortXchange is a digital collaboration platform that shipping lines, port authorities, terminals, and agents can use to optimally plan, execute and monitor all activities during a port call in real-time	NO	YES	NO	NO
Port of Marseille	France	EU	pilot station simulator	NO	YES	NO	YES
Port of Marseille	France	EU	A mobile device that supplies Reefers with renewable energy allows to increase the number of containers on the terminal (import and export), optimize the logistic flows regardless of plug location and respect the environment	NO	YES	NO	NO
Solomon Ports	Solomon Islands	AU	With an holistic approach, Solomon Ports initiated the 3R (Reduce-Reuse-Recycle) campaign to make the society aware of the depletion of resources, the need to reduce our usage and recycle as much as we can to reduce our impact to the environment.	NO	NO	NO	NO
Port of Marseille	France	EU	innovative environmental technology developed by Interxion that uses water-based free cooling	NO	NO	NO	YES
Port of Marseille	France	EU	As part of the Port of Marseille Smart Port Challenge 2, EDF and ACQUA.ecologie developed a solution around 3 objectives: minimizing wastewater discharges into the sea, maximizing the low carbon energy recovery of wastewater and reducing the overall environmental impact of wastewater treatment.	NO	NO	NO	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Brisbane	Australia	AU	NCOS Online – world-leading technology that provides a near real-time seven-day detailed forecast of environmental conditions and a vessel's under keel clearance (UKC)	NO	NO	NO	YES
Port of Rotterdam	Netherlands	EU	As part of its vision to be the world's Smartest Port and its commitment to GHG emissions reduction, the Port of Rotterdam has established a start-up called PortXchange for the global roll out of Pronto; a platform for optimizing port calls to reduce CO2 emissions globally in shipping	NO	YES	YES	YES
Port of Vigo	Spain	EU	Through the implementation of its Blue Growth strategy, the Port of Vigo brings together its port community stakeholders in achieving sustainable development and establishes 4 concrete objectives.	NO	YES	NO	NO
Port of Helsinki	Finland	EU	While the Port is pledging to be fully carbon neutral by 2035 at the latest, a strong focus of the program is also on incentivizing and helping customers and stakeholders in their own carbon neutrality work	NO	NO	YES	NO
Port of Huelva	Spain	EU	The commitment of the Port of Huelva at the highest level is reflected in its environmental strategy that sets ambitious policy objectives	NO	NO	NO	NO
European ports	global	EU	The purpose of PASSport (Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS high Accuracy and Authentication to improve Security & Safety in port areas) is to engineer and qualify a solution extending situational awareness to improve safety and security in port areas.	NO	NO	NO	NO
Port of Hamburg	Germany	EU	A team of autonomous robots finds and collects seabed litter. Underwater detection sensors allow it to operate under low-visibility conditions.	NO	YES	NO	NO
North Sea Port	MALAYSIA	AS	Northport has formulated a strategic roadmap to operate its business activities to the highest level of Health, Safety and Environment (HSE) standards in our journey towards achieving HSE excellence.	NO	NO	NO	YES
Port of Long Beach	US	US	demonstrate five zero-emissions cargo handling vehicles	NO	NO	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Bari	Italy	EU	the ISMAEL Platform is an innovative monitoring and Decision Support System	NO	YES	NO	NO
Port of Genoa	Italy	EU	To comply with indications and provisions of EC Recommendations 2005/33 and 2006/339, the Ports Authority of Genoa has implemented Onshore Power Supply (OPS) facilities to serve three types of vessels (cruise ships, cargo ships and ferries) with different power supply requirements	NO	YES	NO	YES
Tenerife Port	Spain	EU	Port Authority of Santa Cruz de Tenerife – Tenerife Port ZERO				
Port of Long Beach	Canada	US	Port of Long Beach – Water quality programs result in port biodiversity				
Port of Acu	Berazil	US	Port of Açu – Climate Resilience				
Port of Brisbane	Australia	AU	Port of Brisbane – Net Zero Emissions (Scope 1 & 2)				
New Owendo International Port	Gabon	AF	New Owendo International Port – Decarbonization initiatives				
NSW Ports – Offshore wind energy hub	Australia	AU	NSW Ports – Offshore wind energy hub				
Port of Kapellskär	Sweeden	EU	PORT OF KAPELLSKÄR OFFERS ONSHORE POWER SUPPLY (OPS) TO FERRIES	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	THE PORT OF ANTWERP-BRUGES DETECTS FLOATING DEBRIS WITH A DRONE	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	CIRCULAR ECONOMY HOTSPOT NEXTGEN DISTRICT AT THE PORT OF ANTWERP	NO	YES	YES	NO
Port of Vlissingen	Netherlands	EU	CHEMICAL RECYCLING OF PLASTIC WASTE AT NORTH SEA PORT	NO	NO	NO	NO
Port of Valencia	Spain	EU	PORT OF VALENCIA GETS RID OF PLASTIC BOTTLES	NO	YES	NO	NO
Port of Valencia	Spain	EU	Circular economy in the port sector	NO	NO	NO	NO
Port of Kiel	Germany	EU	WASTE WATER TREATMENT FACILITY AT KIEL'S OSTSEEKAI	NO	NO	NO	YES
Port of Antwerp	Belgium	EU	WASTE HEAT IN THE PORT OF ANTWERP	NO	YES	NO	NO
Port of Algeciras	Spain	EU	PLASTICS REDUCTION CAMPAIGN OF THE PORT OF ALGECIRAS	NO	YES	NO	NO
Port of Barcelona	Spain	EU	PORT OF BARCELONA: ELIMINATION OF PLASTIC BOTTLES	NO	YES	NO	YES
Port of Vigo	Spain	EU	PORT OF VIGO: ML-STYLE	NO	NO	NO	NO
Port of Amsterdam	Netherlands	EU	CIRCULAR ECONOMY AT THE PORT OF AMSTERDAM	NO	NO	YES	NO
Port of Nakskov	Denmark	EU	APPLYING CIRCULAR ECONOMY PRINCIPLES TO NAVIGATIONAL EQUIPMENT	NO	NO	YES	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Santander	Spain	EU	USE OF RAINWATER FOR CLEANING IN THE PORT OF SANTANDER	NO	NO	NO	YES
Port of Dover	UK	EU	THE DOVER SEA AWARD FOR CRUISE WASTE MANAGEMENT	NO	NO	YES	YES
Port of Ipswich	UK	EU	ELECTRIC HYDRAULIC CRANES AT THE PORT OF IPSWICH	NO	NO	NO	YES
Port of Hamburg	Germany	EU	HYBRID PORT VESSELS AT THE PORT OF HAMBURG	NO	NO	NO	NO
Port of Barcelona	Spain	EU	USE OF LNG AT THE PORT OF BARCELONA	NO	NO	NO	YES
Port of Marseille	France	EU	LNG BUNKERING OPERATION AT THE PORT OF MARSEILLE FOS	NO	YES	NO	NO
Port of Bilbao	Spain	EU	NEW LNG BUNKERING TERMINAL AT THE PORT OF BILBAO	NO	YES	NO	NO
Port of Mukran	Germany	EU	OFFSHORE WIND FARM AT GERMANY'S MUKRAN PORT	NO	NO	NO	NO
Port of Wilhelmshaven	Germany	EU	HYDROGEN PRODUCTION AT WILHELMSHAVEN	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	HYDROGEN PRODUCTION AT THE PORT OF ROTTERDAM	NO	YES	NO	NO
Port of Kiel	Germany	EU	PORT OF KIEL'S BLUE PORT MEASURES	NO	YES	NO	YES
Port of Felixstowe	UK	EU	BATTERY-POWERED VEHICLES AT THE PORT OF FELIXSTOWE	NO	YES	NO	YES
Port of Hamburg	Germany	EU	ONSHORE POWER FOR CONTAINER SHIPS AT THE PORT OF HAMBURG	NO	YES	NO	NO
North Sea Port	Belgium and the Netherlands	EU	HYDROGEN NETWORK FOR NORTH SEA PORT	NO	YES	NO	NO
Port of Genoa	Italy	EU	ONSHORE ELECTRICITY AT PORTS OF GENOA	NO	YES	NO	YES
Shoreham Port	UK	EU	DEVELOPMENT OF A HYDROGEN HUB AT SHOREHAM PORT	NO	YES	YES	YES
Port of Gothenburg	Sweeden	EU	HYDROGEN PRODUCTION FACILITY AT THE PORT OF GOTHENBURG	NO	YES	NO	NO
Port of Antwerp	Belgium	EU	PORTS OF ANTWERP AND MONTREAL TO CREATE GREEN SHIPPING CORRIDOR	NO	YES	NO	NO
Ports of Stockholm, Helsinki, and Tallinn	Sweeden	EU	ONSHORE POWER FOR FERRIES BETWEEN PORTS OF STOCKHOLM, HELSINKI, AND TALLINN	NO	YES	NO	NO
Port of Valencia, Port of Hamburg	Europe	EU	NEW AGREEMENT AROUND HYDROGEN BETWEEN THE PORT OF VALENCIA AND HAMBURG	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	PORT OF ANTWERP, PORT OF ZEEBRUGGE AND CHILE COLLABORATE TO PRODUCE HYDROGEN	NO	NO	NO	NO
Port of Rotterdam	Netherlands	EU	SHORE-BASED POWER AT THE PORT OF ROTTERDAM	NO	NO	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Rotterdam	Netherlands	EU	PORT OF ROTTERDAM: SUSTAINABLE INLAND SHIPPING	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	ONSHORE POWER SUPPLY AT THE PORT OF GOTHENBURG	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	TRANZERO INITIATIVE OF THE PORT OF GOTHENBURG	NO	YES	NO	NO
Port of Kiel	Germany	EU	SHORE POWER FOR CRUISE SHIPS AND RORO-FERRIES AT THE PORT OF KIEL	NO	YES	NO	YES
Port of Rotterdam	Netherlands	EU	PORT OF ROTTERDAM SIGNS MOU FOR TRANSPORT OF BLUE AMMONIA	NO	YES	NO	NO
Port of Antwerp	Belgium	EU	FIRST TUGBOAT USING METHANOL TO BE USED IN PORT OF ANTWERP	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	ONSHORE POWER SUPPLY IN THE PORTS OF ANTWERP, BREMEN, HAMBURG, HAROPA AND ROTTERDAM	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	HYDROGEN-POWERED TRUCKS IN THE PORT OF ROTTERDAM	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	SHORE POWER IN THE PORT OF ROTTERDAM	NO	YES	NO	NO
Associated British Ports	UK	EU	ABP HAS STEPPED UP ITS SUSTAINABILITY EFFORTS FOR GREEN RECOGNITION	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	PORT OF ROTTERDAM: INCENTIVE SCHEME CLIMATE-FRIENDLY SHIPPING	NO	YES	NO	YES
Associated British Ports	UK	EU	JOINT BID FOR A LOW CARBON HYDROGEN SUPPLY TO ABP'S PORT OF IMMINGHAM	NO	YES	YES	NO
Port of Gdynia	Poland	EU	PORT OF GDYNIA TO BECOME AN OFFSHORE WIND HUB	NO	YES	NO	NO
North Sea Port	Belgium and the Netherlands	EU	CONSTRUCTION OF A SOLAR FARM AT VALUEPARK TERNEUZEN	NO	YES	NO	YES
Port of Copenhagen	Denmark	EU	ONSHORE POWER SUPPLY (OPS) FACILITY AT THE DFDS FERRY TERMINAL IN PORT OF COPENHAGEN	NO	YES	NO	NO
Port of Amsterdam	Netherlands	EU	METHANOL PRODUCED FROM NON-RECYCLABLE WASTE AT THE PORT OF AMSTERDAM	NO	YES	NO	NO
Port of Bilbao	Spain	EU	GREEN HYDROGEN PRODUCTION PLANT IN THE PORT OF BILBAO	NO	YES	NO	NO
Port of Gdynia	Poland	EU	FIRST ONSHORE POWER SUPPLY (OPS) CHARGING STATION IN POLAND AT THE PORT OF GDYNIA	NO	YES	NO	NO
Port of Lowestoft	UK	EU	LOWESTOFT EASTERN ENERGY FACILITY (LEEF)	NO	YES	NO	NO
Port of Kiel	Germany	EU	PORT OF KIEL: METHANOL: ALTERNATIVE MARINE FUEL	NO	YES	NO	YES
Port of Piombino	Italy	EU	ENERGY EFFICIENCY AT THE PORT OF PIOMBINO (NORTH	NO	NO	NO	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
TYRREHNIAN PORTS NETWORK)							
Port of Antwerp	Belgium	EU	ANTWERP@C	NO	YES	NO	NO
Port of Valencia	Spain	EU	PORT OF VALENCIA: H2PORTS ENERGY EFFICIENCY PROJECTS OF THE PORT OF VALENCIA	NO	YES	NO	NO
Port of Valencia	Spain	EU	PORT OF MARSEILLE FOS: JUPITER 1000: HYDROGEN ELECTROLYSIS	NO	YES	NO	YES
Port of Marseille	France	EU	COMPREHENSIVE ELECTRIFICATION OF THE PORT OF MARSEILLE FOS	NO	NO	NO	NO
Port of Marseille	France	EU	RENEWABLE ENERGY PLAN OF THE PORT OF BARCELONA	NO	YES	NO	NO
Port of Barcelona	Spain	EU	PORT OF BARCELONA: COMPREHENSIVE ELECTRIFICATION	NO	NO	NO	NO
Port of Barcelona	Spain	EU	PORT OF VIGO: FISH MARKET 4.0	NO	YES	NO	NO
Port of Vigo	Spain	EU	PORT OF ROTTERDAM: CO2 CAPTURE, USE AND STORAGE	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	THE WORLD'S FIRST FLOATING LNG TERMINAL AT THE PORT OF KLAIPEDA	NO	YES	NO	YES
Port of Klaipeda	Lithuania	EU	PORT OF VALLETTA: WESTMOPOCO/IMAROS	NO	YES	YES	NO
Port of Valetta	Malta	EU	PORT OF ESBJERG: MONITORING ENERGY CONSUMPTION AND EMISSIONS IN THE PORT	NO	NO	NO	NO
Port of Esbjerg	Denmark	EU	PORT OF ESBJERG: CONSOLIDATING MARKET LEADERSHIP IN WINDMILL SUPPLY	NO	NO	NO	NO
Port of Esbjerg	Denmark	EU	PORT OF HIRTSHALS: COMMERCIAL AND SUSTAINABLE ENERGY PRODUCTION	NO	NO	NO	NO
Port of Hirtshals	Denmark	EU	NORTH SEA PORT: UPGRADING BUILDING INFRASTRUCTURE TO THE HIGHEST ENERGY EFFICIENCY STANDARDS	NO	NO	NO	YES
North Sea Port	Belgium and the Netherlands	EU	NORTH SEA PORT: WORKING TO BOOST RENEWABLE ENERGY INFRASTRUCTURE	NO	YES	NO	NO
North Sea Port	Belgium and the Netherlands	EU	DEVELOPING ROOFTOP SOLAR CELL SYSTEMS IN PORTS OF STOCKHOLM	NO	YES	NO	YES
Port of Stockholm	Sweeden	EU	PORT OF GOTHENBURG: FACILITATING AND ENCOURAGING THE UPTAKE OF ALTERNATIVE FUELS	NO	YES	NO	YES
Port of Gothenburg	Sweeden	EU	LOCALLY-PRODUCED GREEN ENERGY IN THE PORT OF TALLINN	NO	NO	YES	NO
Port of Tallinn	Estonia	EU	ENERGY EFFICIENCY AND SUSTAINABLE USE OF	NO	NO	NO	YES
Port of Tallinn	Estonia	EU		NO	NO	NO	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			NATURAL RESOURCES IN THE PORT OF TALLINN				
North Adriatic Sea Port	Italy, Slovenia, Croatia, Albania	EU	NORTH ADRIATIC SEA PORT AUTHORITY (NASPA): INCREASING ENERGY EFFICIENCY IN PORT AND TERMINAL ACTIVITIES AND ESTABLISHING AN ENERGY STRATEGY	NO	YES	NO	YES
Port of Rotterdam	Netherlands	EU	DIGITAL PLATFORM TO IDENTIFY PORT OF ROTTERDAM'S EMISSIONS	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	PORT OF ROTTERDAM: CO2 NEUTRAL IN 3 STEPS	NO	YES	YES	YES
Port of Rotterdam	Netherlands	EU	PORT OF ROTTERDAM: DIGITAL SOLUTIONS FOR SUSTAINABLE SHIPPING	NO	YES	NO	YES
Port of Bergen	Norway	EU	BATTERY-RUN WORKBOAT FOR THE PORT OF BERGEN	NO	YES	NO	NO
Port of Hamburg	Germany	EU	NEW HYBRID WORKBOAT FOR THE HAMBURG PORT AUTHORITY	NO	YES	NO	NO
Port of Valencia	Spain	EU	CABINS TO CONTROL AIR QUALITY AND ENVIRONMENTAL FACTORS IN THE PORT OF VALENCIA	NO	YES	NO	NO
Port of Oostende	France	EU	PORT OF OOSTENDE: ISHY PROJECT (IMPLEMENTATION OF HYBRID SHIPPING)	NO	YES	NO	NO
Port of Helsinki	Finland	EU	OPS AND AUTOMOORING SYSTEMS OF THE PORT OF HELSINKI	NO	YES	NO	NO
Port of Valencia	Spain	EU	PORT OF VALENCIA: GREEN PORTS: DIGITAL TOOLS TOWARDS SUSTAINABILITY	NO	YES	NO	NO
Port of Rotterdam	Netherlands	EU	CARBON FOOTPRINT OF THE PORT OF ROTTERDAM	NO	YES	NO	YES
Port of Valetta	Malta	EU	PORT OF VALLETTA: GRAND HARBOUR CLEAN PROJECT	NO	YES	NO	NO
Port of Tallinn	Estonia	EU	CLEAN AIR PROJECTS IN THE PORT OF TALLINN	NO	YES	NO	NO
Port of Dover	UK	EU	PORT OF DOVER: ACHIEVING EMISSIONS REDUCTIONS TARGETS THROUGH SOLAR ENERGY AND BUILDING DESIGN	NO	YES	NO	YES
Port of Venice	Italy	EU	NORTH ADRIATIC SEA PORT AUTHORITY (NASPA): ACHIEVING EMISSIONS REDUCTIONS THROUGH DIALOGUE WITH CRUISE COMPANIES	NO	YES	YES	YES
Port of Vigo	Spain	EU	LIVING PORTS INFRASTRUCTURE PROJECT AT THE PORT OF VIGO	NO	YES	NO	YES
Port of Rotterdam	Netherlands	EU	NEW PARK AT MAASHAVEN, PORT OF ROTTERDAM	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Stockholm	Sweeden	EU	SOLAR-POWERED SMART BUOYS TESTS AT THE PORTS OF STOCKHOLM	YES	YES	NO	YES
Port of Tallinn	Estonia	EU	NEW SUSTAINABLE CRUISE TERMINAL OPENS AT PORT OF TALLINN	NO	YES	NO	NO
Port of Malmo	Copenhagen	EU	NEW GREEN CONTAINER TERMINAL IN COPENHAGEN MALMÖ PORT	NO	NO	NO	NO
Port of Helsinki	Finland	NO	ENVIRONMENTAL INCENTIVES AT THE PORT OF HELSINKI	NO	NOT MENTIONED	NO	YES
Port of Algeciras	Spain	EU	THE APBA REPLACES MORE THAN 60% OF ITS MOBILE FLEET WITH ELECTRIC AND HYBRID VEHICLES	NO	YES	NO	NO
Port of Amsterdam	Netherlands	NO	CLEAN SHIPPING AT THE PORT OF AMSTERDAM				
North Sea Port	Belgium and the Netherlands	EU	ENSURING STAFF OF NORTH SEA PORT HAVE THE GREENEST OPTIONS ON THEIR COMMUTE	NO	NO	NO	NO
Port of Antwerp	Belgium	EU	THE PORT OF ANTWERP-BRUGES REDEVELOPS POLLUTED SITE TO RESTORE VALUABLE HABITAT AND PROVIDE FLOOD PROTECTION	NO	NO	NO	NO
Port of Sevilla	Spain	EU	REGENERATION OF THE DOÑANA COASTLINE AT THE PORT OF SEVILLA	NO	YES	NO	YES
Port of Tarifa	Spain	EU	PILOT PROJECT FOR THE REPOSITIONING OF ROCKY BLOCKS WITH SPECIMENS OF PATELLA FERRUGINEA PRESENT IN THE BREAKWATER OF THE PORT OF TARIFA	NO	YES	NO	NO
Port of Algeciras	Spain	EU	EARLY DETECTION OF POTENTIALLY INVASIVE ALGAE AT THE PORT OF ALGECIRAS	NO	NO	NO	NO
Port of Riga	Latvia	EU	FREEPORT OF RIGA AUTHORITY'S SOIL REMEDIATION TECHNOLOGY	NO	NO	NO	NO
Port of Bremen	German	EU	PORT OF BREMEN'S CLEAN PROJECT	NO	YES	NO	NO
Port of Roenne	Denmark	EU	PORT OF ROENNE IS PLANTING TREES ON BORNHOLM	NO	NO	NO	NO
North Sea Port	Belgium and the Netherlands	EU	WATER QUALITY MONITORING AT THE GHENT-TERNEUZEN SEA CANAL	NO	YES	NO	NO
Port of Algeciras	Spain	EU	CLEANING OF THE ALGECIRAS COASTLINE	NO	YES	NO	NO
Port of Le Havre	France	EU	NEST BOXES FOR BIRDS AND BATS AT THE PORT OF LE HAVRE (HAROPA)	NO	NO	NO	YES
Port of Livorno	Italy	EU	LIVORNO: NEW VENICE CANALS	NO	YES	NO	YES
Port of Cava	Spain	EU	ELBA ISLAND: REPOPULATION OF PROTECTED SPECIES	NO	NO	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Piombino	Italy	EU	PORT OF PIOMBINO (NORTH TYRREHNIAN PORTS NETWORK): BEACH CLEAN	NO	NO	NO	YES
Port of Antwerp	Belgium	EU	PORT OF ANTWERP: AGRICULTURE INNOVATION FUND TO STIMULATE NATURE-INCLUSIVE AGRICULTURE	NO	NO	NO	NO
Port of Algeciras	Spain	EU	PORT OF ALGECIRAS: LIFE REMOPAF PROJECT	NO	NO	NO	YES
Port of Valencia	Spain	EU	PORT OF VALENCIA: HISEA	NO	NO	NO	NO
Port of Marseille	France	EU	WATER TREATMENT SYSTEM OF THE PORT OF MARSEILLE FOS	NO	NO	NO	NO
Port of Vigo	Spain	EU	PORT OF VIGO: SUNSET DOCK	NO	NO	NO	NO
Port of Rotterdam	Netherlands	EU	NATURE IN THE PORT: THE BIRD VALLEY OF THE PORT OF ROTTERDAM	NO	YES	NO	NO
Port of Gothenburg	Sweeden	EU	ENSURING THE EXPANSION OF PORT OF GOTHENBURG MINIMISES BIODIVERSITY LOSS IN TORSVIKEN	NO	NO	NO	NO
Port of Dover	UK	EU	ANNUAL BEACH CLEAN AT THE PORT OF DOVER	NO	YES	NO	NO
North Adriatic Sea Port		EU	NORTH ADRIATIC SEA PORT AUTHORITY (NASPA): INVESTIGATING HOW TO REDUCE SHIP NOISE POLLUTION, PROVIDING CRUISE SHIPS WITH RECOMMENDATIONS	NO	NO	NO	NO
Port of Koper	Slovenia	EU	An Evaluation of Marine Sediments in Terms of their usability in the Brick Industry: Case Study Port of Koper	NO	NO	NO	NO
Port of Rotterdam	Netherlands	EU	Carbon Lock-Out: Leading the Fossil Port of Rotterdam into Transition	NO	YES	NO	NO
Port of Gävle	Sweeden	EU	Securing a port's future through Circular Economy: Experiences from the Port of Gävle in contributing to sustainability	NO	YES	YES	YES
Port of Barcelona	Spain	EU	Open-Loop Exhaust-Gas Cleaning System: Analysis of Effects Produced on Barcelona Port Water pH	NO	YES	YES	YES
Port of Izmit Bay	Turkey	AS	Evaluating the emission reduction efficiency of automatic mooring system and cold ironing: the case of a port in Izmit Bay	NO	NO	NO	NO
Port of Casablanca	Morocco	AF	Machine learning for cleaner production in port of Casablanca	NO	NO	NO	YES
Port of Valparaiso	Chile	US	Green Hydrogen Value Chain in the Sustainability for Port Operations: Case Study in the Region of Valparaiso, Chile	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Aberdeen	Scotland	EU	Identifying the unique challenges of installing cold ironing at small and medium ports – The case of aberdeen	NO	YES	NO	NO
Mediterranean ports	Europe	EU	Environmental policies and practices in Cruise Ports: Waste reception facilities in the Med	NO	NO	YES	YES
Port of Djibouti	Africa	AF	Critical barriers to the introduction of shore power supply for green port development: case of Djibouti container terminals	NO	YES	NO	YES
Port of Mongla	Bangladesh	AS	DREDGING AND DREDGED MATERIAL MANAGEMENT: A CASE STUDY OF MONGLA PORT	NO	NO	NO	YES
Port of Bagladesh	Bangladesh	AS	Towards a prioritization of alternative energy sources for sustainable shipping	NO	NO	NO	NO
Port of Amsterdam	Netherlands	EU	development of green hydrogen facilities	NO	YES	NO	NO
Port of Den Helder	Netherlands	EU	storing the CO2 captured during the ATR/POX-production process	NO	YES	YES	YES
The Groningen Seaports	Netherlands	EU	landfall of offshore wind.	NO	YES	YES	YES
Port of Klaipeda	Lithuania	EU	Investigation of Effect on Environmental Performance of Using LNG as Fuel for Engines in Seaport Tugboats	NO	NO	NO	NO
Port of Jorf Lasfar, Safi, Agadir, Tan Tan, Laayoune and Dakhle.	Morocco	AF	1) Morocco is well suited to foster a green ammonia industry 2) Renewable resources and ambitions in Morocco	NO	NO	NO	YES
Port of Szczecin	Poland	EU	Seaports as Nodal Points of Circular Supply Chains: Opportunities and Challenges for Secondary Ports	NO	YES	NO	NO
Port of Malmo	Sweeden	EU	Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports—a case study in Copenhagen-Malmö Port (CMP)	NO	NO	NO	NO
Port of Benoa	Bali	AS	The Analysis of the Conceptual Framework of Green Port Implementation in Indonesia Using Circular Economy: The Case Study of Benoa Public and Fishing Terminals	NO	YES	NO	NO
Port of Aalborg	Denmark	EU	Optimal Configuration and Sizing of Seaport Microgrids including Renewable Energy and Cold Ironing—The Port of Aalborg Case Study	NO	YES	YES	YES
Port of Kapellskär	Sweeden	EU	Feasibility study of cold ironing from renewable sources in the	NO	YES	YES	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			Nordic region: case study : Port of Kapellskär in Stockholm				
Port of Heraklion	Greece	EU	Cold ironing feasibility study at the Heraklion Port	NO	NO	NO	NO
Iskenderun Port	Turkey	AS	Assessment of ship emissions through cold ironing method for Iskenderun Port of Turkey	NO	NO	NO	YES
Port of Nigeria	Nigeria	AF	Comparative study of alternative marine power (cold ironing) application as an air pollution mitigation technology in Nigeria seaports	NO	YES	NO	NO
Port of Trieste	Italy	AS	Environmental Assessment and Regulatory Aspects of Cold Ironing Planning for a Maritime Route in the Adriatic Sea	NO	NO	NO	NO
Port of Shanghai	China	AS	How would government subsidize the port on shore side electricity usage improvement?	NO	YES	NO	NO
No case specific			A bilevel hybrid economic approach for optimal deployment of onshore power supply in maritime ports	NO	NO	NO	NO
Port of Ancona	Italy	EU	Technical analysis and economic evaluation of a complex shore-to-ship power supply system	NO	YES	NO	NO
Port of Copenhagen	Denmark	EU	Optimal Sizing and Performance Evaluation of a Renewable Energy Based Microgrid in Future Seaports	NO	YES	NO	NO
Port of Civitavecchia	Italy	EU	Fuel saving and reduction of emissions in ports with cold ironing applications	NO	NO	NO	YES
Chinese ports	China	AS	Study of Safety and Economy of Utilizing Shore Power Supply System for Oceangoing Ship	NO	NO	NO	NO
Port of Barcelona	Spain	EU	Integration of Cold Ironing and Renewable Sources in the Barcelona Smart Port	NO	YES	NO	NO
Port of Mombasa	Kenya	EU	Ship-port interface: analysis of the cost-effectiveness of cold ironing at Mombasa Port	NO	NO	NO	NO
Port of Copenhagen	Denmark	EU	IS COLD IRONING HOT ENOUGH? An Actor Focus Perspective of On Shore Power Supply (OPS) at Copenhagen's Harbour	NO	YES	NO	NO
Spanish ports	EU	EU	OPS Master Plan for Spanish Ports Project. Study of potential acoustic benefits of on-shore power supply at berth	NO	YES	NO	NO
Chinese ports	China	AS	Analysis for Shore Power Economy in Preventing Air	NO	NO	NO	YES

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Aberdeen	Scotland	EU	Pollution of Vessels are Docked at the Berth Identifying the unique challenges of installing cold ironing at small and medium ports – The case of aberdeen	NO	YES	NO	NO
Chinese ports	China	AS	A Method for Determining the Required Power Capacity of an On-Shore Power System Considering Uncertainties of Arriving Ships	NO	YES	NO	NO
Port of Cartagena	Colombia	US	Renewable energy supply to ships at port	NO	YES	NO	NO
Port of Cartagena	Colombia	US	Implementing Onshore Power Supply from renewable energy sources for requirements of ships at berth	NO	YES	NO	NO
Port of Gävle	Sweeden	EU	Energy analysis and costs estimation of an On-shore Power Supply system in the Port of Gävle	NO	YES	NO	NO
Port of Shenzhen	China	AS	COSTS AND BENEFITS OF SHORE POWER AT THE PORT OF SHENZHEN	NO	YES	NO	NO
Port of Singapore	Singapore	AS	Optimal energy management and operations planning in seaports with smart grid while harnessing renewable energy under uncertainty	NO	YES	NO	NO
Finnish ports	Finland	EU	Technological trajectories and scenarios in seaport digitalization	NO	YES	NO	NO
Russian ports	Russia	AS	Sustainable digital transformation of the port equipment management system	NO	YES	NO	NO
Croatian ports	Croatia	EU	The Transition of Croatian Seaports into Smart Ports	NO	YES	NO	NO
Port of Klang	Malaysia	AS	An environmental management system in seaports: evidence from Malaysia	NO	YES	YES	NO
Italian ports	Italy	EU	Key performance indicators for developing environmentally sustainable and energy efficient ports: Evidence from Italy	NO	YES	NO	NO
Port Said	Egypt	AF	An analysis of wind power potential in PortSai ,Egypt	NO	YES	NO	NO
Port of Mytilene	Greece	EU	Abatement of air pollution at an aegean island port utilizing shoreside electricity and renewable energy	NO	YES	NO	NO
Cantabric and North-Atlantic coasts of Spain	Spain	EU	Economic Feasibility of Floating O shoreWind Farms in the North of Spain	NO	YES	NO	NO
Brazilian ports	Brazil	US	Selecting the most viable renewable energy source for Brazilian ports	NO	YES	YES	NO
South Korean ports	Korea	AS	using the FITradeoff method Site selection for offshore wind farms in the southwest coast of	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			South Korea				
European ports	Europe	EU	Organisation of the reception of ship-generated wastes and cargo residues illustrated by selected examples of European Union seaports	NO	YES	NO	NO
Port of Naples	Italy	EU	Management Control Systems in port waste management: Evidence from Italy	NO	YES	NO	NO
Croatian ports	Croatia	EU	Contribution to the implementation of "Green Port" concept in Croatian seaports	NO	YES	NO	NO
Adamas port	Greece	EU	Challenges of integrating hydrogen energy storage systems into nearly zero-energy ports	NO	YES	NO	NO
Trieste	Italy	EU	Multi-Objective Optimization of a Hydrogen Hub for the Decarbonization of a Port Industrial Area	NO	YES	NO	NO
No case specific			Advances in subsea carbon dioxide utilization and storage	NO	YES	NO	NO
Port of Koper	Slovenia	EU	Living with the green port: Environmental sustainability in the port of Koper SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Bar	Montenegro	EU	Green port transformation: Improvement of port's efficiency and environmental performance SUPAIR (Interreg Adrion)	NO	YES	YES	NO
Port of Durres	Albania	EU	Designing a Sustainable Eco-Friendly Port an approaching guide to regenerate the port-city link through a sustainable action plan SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Thessaloniki	Greece	EU	Strengthening the environmental and energy management of a port under development SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Venice	Italy	EU	North Adriatic Sea Port Authority (Ports of Venice and Chioggia) THE PORT OF VENICE IN NUMBERS SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Trieste	Italy	EU	Our Journey on the Waves of Sustainability PORT OF TRIESTE Port network Authority of the Eastern Adriatic Sea SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Piraeus	Greece	EU	SUPAIR (Interreg Adrion)	NO	YES	NO	NO
Port of Koper	Slovenia	EU	Solutions to improve freight connections between the port and its hinterland	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Ploče	Croatia	EU	upgrade of its Port Community Systems, thus allowing upgrading of communication interface and modules regarding services	NO	YES	NO	NO
Port of Igoumenitsa	Greece	EU	How the web-based platform and the mobile app work	NO	YES	NO	NO
Port of Bar	Montenegro	EU	upgrade of Port Community Systems to streamline freight flows transiting through the port and improve the attractiveness of the TEN-T corridor networks	NO	YES	NO	NO
Port of Venice	Italy	EU	A preliminary design for a new railway bridge in the port of Venice-Marghera	NO	YES	YES	NO
Port of Ancona	Italy	EU	"Implementation of artificial intelligence system in the Port of Ancona	NO	YES	YES	NO
Port of Ravenna	Italy	EU	A cost-benefit analysis of a new cargo rail from the port of Ravenna to its hinterland	NO	YES	NO	NO
Port of Igoumenitsa	Greece	EU	Feasibility Study	NO	YES	NO	NO
Port of Zagreb	Croatia	EU	Environmental assessment study of the construction of the Zagreb Deep Sea Container terminal, part of the "Rijeka Gateway Project"	NO	NO	NO	NO
Port of Bar	Montenegro	EU	Two technical studies have been carried out thanks to NewBrain Project: a) design for reconstruction of reinforced-concrete structure of the Volujica quay, b) detailed geotechnical investigation of the terrain for extension of the Volujica quay in port of Bar	NO	YES	NO	NO
Port of Verona	Italy	EU	Technical Economic Feasibility Project of public access roads and support for the development of the "Marangona" area	NO	YES	NO	NO
Port of Piraeus	Greece	EU	The TransBase intervention, a logistic community system based on the "single window" principle	NO	YES	YES	NO
Port of Valencia	Spain	EU	(i) the establishment of a LNG supply facility for vehicles at the port and (ii) the conversion of the engines of the Valencia Harbor's fleet to LNG powered ones.	NO	YES	NO	NO
Port of Koper	Slovenia	EU	Implementation of an intelligent energy management system at the Fruit Terminal	NO	YES	NO	NO
Port of Rijeka	Croatia	EU	PV Solar Plant plant installation	NO	YES	NO	NO
Port of Livorno	Italy	EU	Electrification of the docks (Cold-ironing)	NO	YES	NO	NO
Port of Marseille	France	EU	Port of Marseille-Fos proposes an energy plan will reduce operating	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
			costs and enable to provide environmental sustainable services to port community				
Port of Venice	Italy	EU	electric mobility solution for passengers and work together with local SMEs for assessing its potential.	NO	YES	NO	NO
Port of Bordeaux	France	EU	interoperable IoT platform: new modelling and predictive algorithms developed with the data and knowledge	NO	YES	NO	NO
Port of Monfalcone	Italy	EU	interoperable IoT platform: new modelling and predictive algorithms developed with the data and knowledge	NO	YES	NO	NO
Port of Thessaloniki	Greece	EU	interoperable IoT platform: new modelling and predictive algorithms developed with the data and knowledge	NO	YES	NO	NO
Port of Piraeus	Greece	EU	interoperable IoT platform: new modelling and predictive algorithms developed with the data and knowledge	NO	NO	YES	YES
Port of Antwerp	Belgium	EU	Several demos are planned in the port	NO	YES	NO	YES
Port of Antwerp	Belgium	EU	dual-fuel hydrogen straddle carrier	NO	NO	NO	YES
Port of Barcelona	Spain	EU	Several demos are planned in the port	NO	NO	NO	NO
Port of Venlo	Netherlands	EU	Several demos are planned in the port	NO	YES	NO	NO
Port of Piraeus	Greece	EU	5G technology in port operations	NO	YES	YES	YES
Port of Hamburg	Germany	EU	5G technology in port operations	NO	YES	NO	NO
Port of Koper	Slovenia	EU	5G technology in port operations	NO	NO	NO	YES
Port of Piraeus	Greece	EU	PREDICTOR Asset Management innovation has been implemented for the prediction of possible breakdowns of yard trucks and the Green Cookbook innovation for the energy assessment of the port. These two innovations and their implementation are presented in the following sections.	NO	YES	NO	NO
Port of Valencia	Spain	EU	Advanced Truck Appointment System (TAS)	NO	YES	NO	NO
Port of Antwerp	Belgium	EU	Brokerage Platform innovation	NO	YES	NO	NO
Port of Livorno	Italy	EU	PORTMOD innovation	NO	YES	NO	NO
Port Authority of Balearic Islands	Spain	EU	UC1: RoRo and Stowage Optimization □ UC2: Mafis' Working Hours Optimization	NO	YES	NO	NO

Port	Country	Region	Policies and incentives adherence to environmental legislation	Address impacts not covered by legislation	Collaboration among authorities and industry	Pair economic development with green objectives	Has this practice been monitored?
Port of Vigo	Spain	EU	UC3: Prediction of Port-City-Interaction UC4: Green Scheduling and Sustainability of Operations UC5: Port Pilot Assistance	NO	NO	NO	NO
Ports of Livorno and Piombino	Italy	EU	UC5: Port Pilot Assistance	NO	YES	NO	NO
Ports of Naples and Salerno	Italy	EU	UC6: Assistance to Goods and Inspection within Port Boundaries □ UC7: Monitoring of Port Performance	NO	YES	NO	NO
Port of Magdeburg	Germany	EU	UC8: Storage Area Monitoring □ UC9: Inter-Terminal Truck Tracking	NO	YES	YES	NO
				NO	YES	NO	NO
Port of Bremen	Germany	EU	#Spotlightproject DBU: "CLEAN – In-water hull cleaning"	NO	NO	NO	NO
Port of Bremen	Germany	EU	Binding regulations for the treatment of waste water from ships	NO	YES	NO	NO
Shannon Foynes Port Company	Ireland	EU	Air Quality	NO	YES	NO	NO
Shannon Foynes Port Company	Ireland	EU	Corporate Social Responsibility (CSR)	NO	YES	YES	NO
Shannon Foynes Port Company	Ireland	EU	VISION 2041	NO	YES	NO	YES
Shannon Foynes Port Company	Ireland	EU	Shannon Estuary Anti-Pollution Team Ltd	NO	NO	NO	YES
Shannon Foynes Port Company	Ireland	EU	Shannon Estuary Oil / HNS (Chemical) Spill Contingency Plan	NO	NO	NO	NO
Shannon Foynes Port Company	Ireland	EU	SFPC Waste Management Plan (WMP)	NO	YES	NO	NO
JadeWeserPort Realisierungs GmbH & Co. KG	Germany	EU	Demand-Driven (manual) Rail Switch Heating and Monitoring of the Switch Heaters	NO	YES	YES	YES
JadeWeserPort Realisierungs GmbH & Co. KG	Germany	EU	Charging Stations for Electric Passenger Cars at the Port Services Center	NO	YES	YES	YES
Port of Shoreham	UK	EU	Water Source Heat Pump	NO	NO	NO	NO
Port of Shoreham	UK	EU	Emission Reduction	NO	NO	NO	YES
Port of Shoreham	UK	EU	Seabin Installation - Lady Bee Marina	NO	YES	NO	NO
port of Den Oever-Hollands Kroon	Netherlands	EU	The new doc	NO	YES	NO	NO
port of Den Oever-Hollands Kroon	Netherlands	EU	Change XL	NO	YES	YES	NO

Table 27. Operational and Implementation Dimensions of Green Port Practices

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Los Angeles	United States	US	YES	YES	YES	Shortly after implementation, the process, known as the Alternative Maritime Power program, resulted in the decline of 14 tons of diesel particulate matter, as well as 123 tons of nitrogen oxide emissions. Buoyed by this early success, on Jan. 1, 2014, the State of California established a new regulation that requires container and refrigerated ship fleets to plug into shore-side power. Since 2006, the Port of Los Angeles has invested more than \$180 million in shore power infrastructure, which includes shore-power capable berths at the port's eight marine container terminals, as well as its cruise passenger and ferry terminals. As a result, the port currently has more shore-power capable berths than any other port in the world	Since 2006, the Port of Los Angeles has invested more than \$180 million in shore power infrastructure, which includes shore-power capable berths at the port's eight marine container terminals, as well as its cruise passenger and ferry terminals. In the past 10 years, the port has spent more than \$350 million on environmental initiatives
Ports of Brunswick and Savannah	Georgia, United States	US	NO	YES	YES	Transition of rubber-tired gantry cranes (RTGs) from diesel to electric power. Because the electric RTGs only use diesel power when they move between container rows, they operate on electric power more than 90 percent of the time. The GPA has also installed 104 electrified refrigerated container racks. Because they do not require the use of diesel generators, the racks currently save 5.6 million gallons of fuel annually. In addition, the GPA uses electrified ship-to-shore cranes, which capture energy—enough to power themselves for 18 minutes of each operating hour—as they lower container boxes	The GPA has also installed 104 electrified refrigerated container racks. Because they do not require the use of diesel generators, the racks currently save 5.6 million gallons of fuel annually Installed new computer-controlled, photosensitive lights at the 1,200-acre Garden City Terminal, reducing 3,569 metric tons of CO2 emissions annually Reducing emissions: By retrofitting 20 RTGs with electric power, the GPA reduced emissions by roughly 1,800 tons. The GPA also retrofitted 11 locomotives with automatic engine stop-start devices, ultimately leading to an annual emissions decline of 18 tons RTG retrofitting project alone has cost \$20.6 million
Port of Antwerp	Belgium	EU	YES	YES	NO	Air Plus Powerpack will be unloaded at the terminal. This powerpack will be used in a test setting where electric cars are being charged during their inspection at import. This way, the cars are fully charged with the green energy from the wind turbines and the energy produced is used locally. This also results in a significant CO2 reduction in the "well to wheel" of the electric cars.	
Port, City and Borough of Juneau, Vancouver Fraser Port Authority, and Leading	global	global	NO	NO	NO	The collaborative effort is aimed at exploring the feasibility of a green corridor that could accelerate the deployment of zero greenhouse gas emission ships and operations between Alaska, British Columbia, and Washington.	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Global Cruise Lines							
C40 Green Ports Forum	global	global	YES	YES	NO	The C40 Green Ports Forum is focused on connecting port cities and ports around the world to implement policies and programmes that mitigate air pollution and greenhouse gas emissions from ports, shipping and supply chains.	
PSA International	Singapore	AS	NO	YES	YES	Opt-E-Arrive will be complementary to CMA CGM's existing Fleet Centers, which can be described as vessel control towers with smart decision support tools for the Group's 566 vessels and their crews. Backed by 26 team members in Marseille, Miami and Singapore, the Fleet Centers provide round the clock support to ensure the safety of the Group's crew, vessels and cargoes, and also offer real time data to adapt vessels' routes and speed to reduce greenhouse gas emissions.	This innovative solution is set to reduce greenhouse gas emission through further optimisation of bunker consumption. An annualised bunker savings of 4 % to 7 % for CMA CGM vessels arriving in Singapore is expected to be achieved with the digital solution.
American Association of Port Authorities	United States	US	NO	YES	YES	AAPA says that for maritime shipping, electric battery power will be insufficient in eliminating the use of fossil fuels, but hydrogen can serve as an alternative because it can power combustion engines "When used in a fuel cell or a mono-fuel internal combustion engine, it is a zero-carbon fuel. Alternatively, when it is used in a dual fuel combustion engine, carbon emissions are significantly reduced compared to pure fossil fuels," AAPA said in its first in the series of spotlights on alternative fuels.	The AAPA said that the bill would establish a grant programme that allocates US\$100,000,000 for each fiscal year from 2022-2026 to provide competitive grants for the purchase, installation, construction, facilitation, maintenance and/or operation of hydrogen or ammonia-fueled technology. Eligible projects would include cargo-handling equipment, maritime vessels, shore power, onsite power generation and fuel storage and fueling. The Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law, or BIL) has created a new Department of Energy (DOE) programme to establish regional clean hydrogen hubs across the country with the end goal of creating a national network of green hydrogen
Port of Baltimore	United States	US	YES	YES	YES	the Port of Baltimore currently offers a Dray Truck Replacement Program that allows truck owners and operators to trade in their old model trucks for newer models that reduce air emissions. Since the port enacted the program in 2012, nearly 135 trucks have been replaced. As a result, emissions have steadily declined, as truck turn times were reduced by 6.6 percent in 2014 alone. In addition, the port strives to improve the water quality and energy conservation of its facilities. For example, it installed a variety of vaults that treat stormwater, and upgraded its lighting and mounted solar panels on a cruise terminal and transit shed. These projects not only increased environmental sustainability, but also improved the productivity of port operations.	135 trucks have been replaced. As a result, emissions have steadily declined, as truck turn times were reduced by 6.6 percent in 2014 alone. Reducing emissions: Thus far, the Dray Truck Replacement Program has diminished 2,076 tons of nitrogen oxides, 81 tons of fine particulate matter, and 520 tons of carbon monoxide. Equipment operators saved thousands of dollars thanks to the truck replacement program, which has also decreased fuel by 502,065 gallons of diesel over the lifetime of the truck that has been replaced.
Port of Long Beach	United States	US	YES	YES	YES	In 2015, the Port of Long Beach constructed four new buildings on a recently redeveloped marine terminal	From 2005 to 2014, diesel particulate emissions, nitrogen oxides, sulfur oxides,

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						located at the 170-acre Middle Harbor. The buildings, which conserve energy and water, have received a gold level certification from the Leadership in Energy and Environmental Design (LEED). Of equal importance, the terminal itself is also environmentally friendly. Its cranes and cargo moves run on electricity, resulting in nearly zero emissions compared to traditional terminals.	and greenhouse gases declined—by 85, 50, 97, and 21 percent, respectively. Since 2005, the port has spent approximately \$500 million to implement the Green Port Policy; it spent about 40 percent of this total on shore power
Port of Oakland	United States	US	YES	YES	YES	With nearly 19 miles of waterfront on the San Francisco Bay, the Port of Oakland is committed to protecting its surrounding wildlife from the transmission of harmful pollutants. To help diminish air pollution from mobile and stationary on-, near-, and off-shore areas, the port has created a Maritime Air Quality Improvement Plan (MAQIP). Among other goals, the plan's key objective is to reduce diesel particulate matter emissions by 85 percent by 2020, when compared to 2005 levels. In response, the port's maritime area offers shore power to ships so they can plug into electric grids while they are docked. Through an electric grid connection, the docked vessels help the port achieve another sustainability goal: the State of California Air Resources Board's requirement to reduce the aggregate of air pollutants emitted from ships by 80 percent by 2020.	From 2005 to 2012, the port reduced diesel particulate matter, carbon monoxide, nitrogen oxides, and sulfur oxides by 70, 33, 15, and 80 percent, respectively; it will measure emissions inventory again in 2016. Among other expenses, the port has spent about \$60 million on its shore power project
Port of Portland	United States	US	NO	YES	YES	In 2012, the port began to replace the Oregon's (a dredge that it owns and operates) 1960s-era engine with a modern, more efficient engine; it completed the project in 2013. Since then, the vessel's diesel particulate emissions have declined by 88 percent. The Port of Portland has also purchased certified Renewable Energy Credits for 100 percent of its electricity consumption, and invested in new energy-efficient LED lighting for its maintenance facilities, marine terminals, and roadways, along with the Portland International Airport's parking lots. It will complete the two-year project in 2017. In addition, the Port of Portland installed 35 acres of porous pavement at one of its terminals. Aside from increasing vehicle storage space, the pavement also infiltrates 100 percent of stormwater into the site's subsurface to naturally break down pollutants.	Since 2009, the port has decreased greenhouse gas and diesel particulate matter by 67 and 73 percent, respectively. At what cost: The port has invested \$3.5 million toward energy efficiency improvements port-wide; it has also spent \$5.1 million on the Oregon's engine replacement.
Port of San Diego	United States	US	NO	NO	YES	In 2013, the Port of San Diego's Board of Port Commissions created a seven-year and 22-year Climate Action Guide. With a focus on long-term environmental sustainability, the port established two main objectives—to reduce greenhouse gases by 10 percent by 2020 and 25 percent by 2035, using 2006 statistics as a reference point. To achieve these goals, the board also outlined six emission reduction strategies, including water and energy conservation. Although the port has reduced water usage by 47 percent since 2008, it will continue to implement new tactics for further conservation, including discontinuing repetitive power washing and	Since 2008, the port has reduced greenhouse gas emissions by approximately 24 percent. At what cost: Within the past 10 years, the port's environmental fund committed \$8.5 million to support 75 projects

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
South Carolina Port Authority	United States	US	YES	NO	YES	decreasing irrigation. The port has also installed 10 public electric vehicle-charging stations around port tidelands, so that vessels can receive shore power and plug into electric grids while they are docked.	
						to reduce emissions, the SCPA has replaced traditional diesel conveyors with electrified ones, and upgraded its terminal equipment, including fully electrified ship-to-shore and rubber-tired gantry cranes.	Since 2005, truck emissions have declined by more than 50 percent, as a result of local, state, and federal regulatory programs supported by the SCPA. Ocean-going vessel emissions of particulate matter have decreased by 80 percent since 2011.
						In March 2016, the SCPA publicized plans to install solar panels on the warehouse rooftops of two of its terminals, resulting in the generation of 3.7 megawatts of electricity. Furthermore, the SCPA has dedicated \$5 million to the conservation of the Cooper River Corridor's Francis Marion National Forest, in Huger, S.C.	At what cost: The SCPA, along with its local, state, and federal partners, has spent more than \$20 million on environmental protection and emission reduction efforts.
Port Authority of New York and New Jersey	United States	US	YES	YES	YES	The Port Authority of New York and New Jersey has undertaken a variety of initiatives to improve air, land, and water quality. For example, since 2001, the Port Authority acquired nearly 400 acres of property within the Hudson-Raritan Estuary to preserve open space for conservation and ecological development. Additionally, it restored several Jamaica Bay marsh islands, using the clean dredge material it acquired by deepening its harbor by 50 feet, an accommodation for larger, deeper-draft vessels. The Port Authority has also introduced a Clean Air Strategy, a set of voluntary actions that will reduce emissions through initiatives such as installing shore power capability at the Brooklyn Cruise Terminal, modernizing cargo handling equipment, and replacing old trucks. In doing so, the Port Authority is committed to annually decreasing criteria air pollutants and greenhouse gases by 3 and 5 percent, respectively, resulting in an eventual 80-percent decline in greenhouse gases by 2050.	Maritime-related air pollution in the Puget Sound region has decreased by upwards of 40 percent since 2005. At what cost: Although expenditures have not yet been measured, the alliance's budget allocates \$1.7 million for its air quality and sustainable practices program in 2016.
Ports of Seattle and Tacoma	United States	US	YES	YES	YES	To unify the management of their marine cargo terminals and achieve their goals of emission reduction more efficiently, the ports of Seattle and Tacoma formed a partnership known as The Northwest Seaport Alliance. The alliance is committed to ensuring sustainable growth that will not only protect the environment, but also the public health of each port's surrounding communities. Prior to this alliance, the two ports had already joined forces in 2008, collaborating with Port Metro Vancouver, British Columbia, to develop a variety of short- and long-term emission reduction goals, via a policy known as the Northwest Ports Clean Air Strategy. Among other key goals, the strategy, which was updated in 2013, is particularly focused on reducing two emissions by 2020: Diesel particulate matter emissions per ton of cargo by 80 percent and greenhouse gas emissions per ton of cargo by 15 percent.	From 2006 to 2014, the Port Authority's Criteria Air Pollutant emissions decreased by 41.5 percent. At what cost: Since 2006, the Port Authority spent approximately \$42 million on air emission reduction initiatives

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Ports of Antwerp and Zeebrugge	Belgium	EU	YES	NO	YES	To maximize the added value of a unified port, the Port of Antwerp-Bruges as it will now be known will seek to develop and make optimum use of the interconnectivity between the two ports. The transportation of goods by rail between the two sites will be bundled, estuary traffic by inland vessels on the North Sea will be optimized, and pipeline connections will also be on the list of priorities. Committed strategic investments, such as the new sea lock in Zeebrugge and the additional container capacity in Antwerp, will go ahead. Future investments will be evaluated from a unified operational perspective so that both port platforms will benefit, and the port continues to meet its customers' expectations. As part of a joint plan, the two ports have defined three strategic priorities – sustainable growth, resilience, and leadership in the energy and digital transition – for their future priorities. Focusing on sustainability and the ongoing transition in the industrial and maritime sectors, they will look to position the combined port as a hub for green hydrogen and the coming hydrogen economy. They believe the area with its industrial cluster in the Antwerp-Zeebrugge will play a key role in the future energy challenges in the Flanders region and the broader Benelux area. They will also continue their efforts to examine will examine methods of applying CCUS (Carbon Capture, Utilization & Storage) to contribute to the transition towards a low-carbon port.	more than 12,000 pieces of corals were moved and resettled as well as more than 14,000 square metres of coral reefs for the project. Also programs were set to enrich the area with nearly 32,000 of mangroves and seedlings to provide food and environment necessary for marine life to flourish
Port of Hamad	Qatar	AS	NO	YES	NO	Sharing some other details of steps taken to preserve the environment while developing Hamad Port, Mwani Qatar had also talked about relocation of 14,300 square metres of seaweeds and 31,700 marine seedlings and avicennia trees providing shelter and nourish countless sea creatures.	
Port of Ain Sokhna	Egypt	AF	YES	YES	YES	Owned, built and operated by a consortium comprising the Sovereign Fund of Egypt, Fertiglabe, Scatec and Orascom, Egypt Green will be the first integrated green hydrogen plant in Africa, delivering around 15,000 tonnes of the fuel as feedstock for up to 90,000 tonnes of green ammonia annually	The 100 MW of electrolyzers, powered by 260 MW of solar and wind, are located at Ain Sokhna which is perfectly positioned close to Suez opening up the possibility of using renewable electricity to develop an industrial hub near global shipping lanes.
Port of Gandia	Spain	EU	YES	YES	YES	The Port Authority of Valencia has awarded the contract worth €1.7 million to Electromur to install and maintain the plant. Construction is expected to take eight months with a maintenance period of 52 months	Both are already in the tendering process and will enable the Valencian precinct to produce 14% of the electrical energy it needs
Port of Aberdeen	Scotland	EU	YES	YES	YES	The funding for the 'Port Zero' feasibility study will analyse future port power demands, assess low carbon energy sources for equipment and quayside infrastructure and help develop a roadmap to decarbonise port operations	CMDC2 was launched in May 2022, funded by the Department for Transport and delivered in partnership with Innovate UK. As part of the CMDC2, the Department allocated over £14m to 31 projects supported by 121 organisations from across the UK to deliver feasibility studies and collaborative R&D projects in clean maritime solutions

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Long Beach	United States	US	YES	YES	YES	This multi-year conversion project has resulted in the largest deployment of eRTGs in North America and represents 100% of the RTG fleet at the Port of Long Beach Pier J terminal.	The multi-million-dollar project was supported by a US\$9.7 million grant from the California Energy Commission. The Pier J eRTG project is estimated to eliminate consumption of diesel fuel by 225,000 gallons per year, reducing emissions of criteria air pollutants and greenhouse gases from SSA Marine's operation
Port of Galveston	Texas, United States	US	YES	NO	YES	"Cleaner energy sources and air quality initiatives are just two examples," says Mr Rees. Green Marine's environmental programmes are guiding the port as it plans for cruise growth. In November, we will open our third cruise terminal. In 2023, we are forecasting a record year with 360 cruise ships and more than 1 million passengers	When operational, the terminal located in the southern province of Ba Ria Vung Tau, will boast the capacity of one million tonnes per year in 2022 and three million tonnes per year in the second phase of development
Seattle-Tacoma & Busan	Washington State, South Korea	US	YES	NO	NO	Initiated by the United States and Norway, the Green Shipping Challenge encourages governments, ports and companies to prepare commitments to spur the transition to greener shipping.	
Port of Gothenburg	Sweden	EU	YES	YES	NO	"Green connection program" implementation accelerating the green transition. Provides infrastructure for production of green molecules (hydrogen, LNG, LPG, ammonia, methanol) & business model for decarbonization of transport going through the port - carbon neutral in the port and port terminals since 2021. Try to stop do business with "grey" vessels and trucks	
Port of Barcelona	Spain	EU	YES	YES	NO	Energy transition is the main port's pillar, decarbonise the seaside, the yard and the hinterland	
Port of Antwerp	Belgium	EU	YES	YES	NO	Develop a specific area at ports where circular activities will take place. Fully recycle the plastics generated from the port as well as from ship waste	
Port of Antwerp	Belgium	EU	YES	NO	YES	Measures to eliminate congestion that disrupts the supply chain by optimizing the existing capacities, better traffic management systems, predictive models,	
Barcelona Europe South Terminal	Spain	EU	YES	YES	YES	The terminal already uses mostly electric cranes and is working with the Barcelona Port Authority to electrify its quay and provide shore-based power for visiting vessels. This solar panel initiative is part of BEST's sustainability strategy and reinforces its commitment to the United Nations Sustainable Development Goal 7 of the 2030 Agenda on 'Affordable and Clean Energy	The 1,832 panels are capable of generating 1.18 GWh of electricity, enough to power around 200 homes for a year.
Port of Antwerp	Belgium	EU	YES	NO	YES	The conversion of a Port of Antwerp-Bruges tug to methanol has been launched with the first engine installed in mid-November. A second dual-fuel engine is set to be installed this week week enabling the vessel to run both on methanol and conventional fuels, according to the port authority	The Hydrotug consists of two BeHydro V12 dual fuel medium speed engines that can run on both hydrogen and traditional fuel. It can store 415kg of compressed hydrogen in six stillages installed on deck and eliminates the emission's equivalent of 350 cars
Port of Vancouver	Canada	US	YES	YES	YES	Canada's largest port is testing a variety of low and zero-emission fuels and technologies in order to create a zero-emission port by 2050	Through the Low-Emission Technology Initiative, a joint initiative between the port authority and the Province of British

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							Columbia, the port authority and the province have each committed CAN\$1.5 million in funding to support the port community's transition to low-emission energy, including the testing of battery-electric-powered terminal tractors; 100% biodiesel on commercial ferries; a hydrogen-powered crane; and 100% renewable diesel on a terminal locomotive and one of the port authority's patrol boats.
Pilbara Ports	Australia & Japan	global	YES	NO	NO	Pilbara Ports Authority (PPA) and Port of Himeji have teamed up to boost the green energy trade between Western Australia (WA) and Japan	
Port of Bellingham	US	US	NO	NO	NO	Port of Bellingham will assess its environmental performance through indicators that address such issues as greenhouse gases, underwater noise, spill prevention, community impacts, community relations, waste management, and environmental leadership	
Port of Corpus Christ	US	US	YES	YES	YES	The port's two supported projects involve the geologic data collection in two strategic locations: one is onshore under port territory and the other is at state-owned offshore tracts	The U.S. Department of Energy's Carbon Storage Assurance Facility Enterprise (CarbonSAFE) has awarded \$16.4 million to the Port of Corpus Christi to evaluate the economic and technical feasibility of permanently storing captured carbon dioxide (CO2) from industrial operations.
Port of San Diego	US	US	NO	YES	YES	The recent addition of the new station along with the initial one installed in 2010 make it possible for the port to reduce harmful air pollutants by 90% while cruise ships are docked	The recent addition of the new station along with the initial one installed in 2010 make it possible for the port to reduce harmful air pollutants by 90% while cruise ships are docked
Port of Hamburg	Germany	EU	YES	YES	NO	Hamburg Port Consulting (HPC) is to scope out the commercial suitability of Helgoland as a potential location for a hydrogen bunker station on the North Sea.	
Virginia Inland Port	US	US	YES	YES	YES	Virginia Inland Port (VIP) is fulfilling all of its operational electricity needs from clean-energy resources moving the Port of Virginia closer to carbon-neutrality by 2040.	This year work begins on a US\$15 million capacity expansion that will create more capacity and efficiency. When the work is complete, the terminal will retire straddle carriers and begin using rubber-tire gantry cranes to move containers from railcars to trucks.
Pilbara Ports	Australia	AU	YES	NO	NO	Pilbara Ports Authority (PPA) and Port of Himeji have teamed up to boost the green energy trade between Western Australia (WA) and Japan	
Port of Shoreham	UK	EU	YES	NO	NO	Shoreham Port has secured an eight-figure package with HSBC UK to consolidate existing facilities and fund future sustainable growth	
Port of Oakland	US	US	YES	YES	YES	The move dates back to March 2017, when the port approved an US\$8.9 million deal to buy 11,000-megawatt hours of electricity power annually from the solar farm.	The move dates back to March 2017, when the port approved an US\$8.9 million deal to buy 11,000-megawatt hours of electricity power annually from the solar farm.
							Oakland's commitment is equivalent to

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							using about 50 acres of the 1300-acre solar array.
Port of Mombasa	Kenya	AF	YES	YES	YES	A study is assessing the possibility of solar farms capable of generating shore-based power at two brownfield sites at the Port of Mombasa in Kenya	ABL has explored whether a 5-10 MWp solar plant could supply enough shore-based power to meet likely demand in a cost-effective way compared with heavy fuel oils.
Port of Tianjin	China	AS	YES	YES	NO	The terminal's solar power system includes photovoltaic panels that have been installed on top of the terminal's covered parking lot	
Port of Gothenburg	Sweeden	EU	YES	NO	NO	The Port of Gothenburg has deployed two Skaraslättens Transport electric trucks with a third to join them shortly	
Port of Stockholm	Sweeden	EU	YES	YES	YES	Port of Stockholm has joined eight other Baltic sea ports in applying for EU grant funding to develop onshore power infrastructure to help lower emissions.	joint application for the grant from the EU Connecting Europe Facility (CEF)
Port of Leith	Scotland	EU	NO	YES	NO	The Port of Leith has become the first large mainland commercial port in Scotland to provide a shore power connection	
Port of Southampton	UK	EU	YES	YES	YES	DP World's container terminal at Southampton, UK has enjoyed its greenest ever year in 2022 after delivering a 55% reduction in net carbon emissions.	DP World is investing up to US\$500 million over the next five year to cut carbon emissions across all its operations. The expected reduction of 700,000 tonnes represents a 20% cut from 2021 and will come through electrification, renewables and alternative fuels
Port of Liverpool	UK	EU	YES	YES	NO	Where cruise facilities are embedded in the heart of a major city, sustainability goals need to take into account the high visibility of the cruise business and its perceived impacts on the life of the city and wider region	
Kotug Canada Inc	US	US	NO	NO	YES	Towage provider Kotug is using an innovative marine coating to help reduce underwater noise created by one of it's vessels	These coatings will enhance the reduced impact with the additional benefits of considerably improving fuel efficiency and decarbonisation. It is expected that this vessel will significantly reduce CO2 emissions over the next five years
Port of Los Angeles, Port of Shanghai, and C40 Cities	global	global	YES	NO	NO	Key decarbonisation goals for the Green Shipping Corridor partnership include: The phasing in of low, ultra-low, and zero-carbon fuelled ships through the 2020s, with the world's first zero-carbon trans-Pacific container ships introduced by 2030 by qualified and willing shipping lines. The development of best management practices to help reduce emissions and improve efficiency for all ships using this international trade corridor. Reducing supply chain emissions from port operations, improving air quality in the ports of Shanghai and Los Angeles and adjacent communities	
Portsmouth Port	England	EU	YES	YES	YES	Portsmouth International Port's (PiP) Port Energy Systems Optimisation (PESO) project has demonstrated how ports can use smart grid technology to decarbonise	These include high cost of battery storage, the need to collaborate more widely along the value chain for maritime logistics and much needed policy developments on electricity pricing and

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							public investment in the transmission and distribution networks
22 countries	global	global	YES	NO	NO	Clydebank Declaration for green shipping corridors	
Port of Gothenburg	Sweeden	EU	YES	NO	NO	Electric trucks now have priority passage and handling in the container terminal at the Port of Gothenburg. Around 1,000 trucks pass through APM Terminals Gothenburg daily but only a small fraction is electric. This is set to change when logistics company DFDS begins deploying 20 electric trucks on 3 March.	
Port of Gothenburg	Sweeden	EU	NO	NO	NO	DFDS is launching a new fleet of 20 electric trucks in Gothenburg, the single biggest delivery of heavy electric trucks in the Nordic region	
Haropa Port	France	EU	YES	YES	YES	SOGEPPE operates a storage depot for liquid energy products on six hectares in Gennevilliers' port area. It's the first Paris area depot to invest in river logistics for the development of biobased, sustainable liquid energy products. This strategic choice is very much in line with the energy transition that has now begun along the Seine Axis as a whole.	Management of the construction of the required river infrastructure was entrusted to Haropa. The port provided €1.1m in funding to build the jetty and €2.65m for modification of the riverbanks in its vicinity. The cost of the jetty superstructure required for operations was borne by SOGEPPE.
Port of London Authority	England	EU	YES	NO	YES	The Port of London Authority (PLA) has reached a major milestone, halving its carbon emissions in 2022 and making strong progress on its Net Zero programme.	With more than 20 vessels in its fleet, the PLA has invested over £120,000 in new steel fuel tanks to store biofuel at three of its bases along the river.
Associated British Ports	England	EU	YES	YES	NO	Associated British Ports (ABP) new sustainability strategy is backed by a plan to invest around GB£2 billion in decarbonising its own operations by 2040.	
Port of Aberdeen	Scotland	EU	YES	NO	YES	A zero-emissions consortium has been awarded a multi-million pound UK government grant to help decarbonise the maritime sector. establish a green shipping corridor between Aberdeen and the Orkney and Shetland Islands, with the world's first hydrogen-powered autonomous surface ships being used to transport cargo	The Hydrogen Innovation – Future Infrastructure & Vessel Evaluation and Demonstration (HI-FIVED) consortium will receive over £3.8m of funding to build and showcase autonomous vessel and bunkering infrastructure technologies for liquid hydrogen.
Port of Kembla	Australia	AU	NO	YES	NO	the project is to support the State's growing renewable energy demand and will capitalise on the port's favourable location.	
Port or Portsmouth	England	EU	NO	YES	YES	Portsmouth International Port is piloting a new smart energy system as part of its strategy to significantly decarbonise operations at the port and further afi eld. the Port Energy Systems Optimisation (PESO) system involves using a dual chemistry battery and a multi-level control system that utilises AI-based capabilities. The control system learns from historic energy consumption profiles to ensure that the battery can deliver as much stored energy as possible when demand is high.	This project is co-funded by Innovate UK, an agency that works to show how port infrastructure can meet the UK Government's 'Clean Maritime Plan.'
Port Everglades	US	US	NO	YES	YES	In the US, Port Everglades (FL) has completed a study assessing the capacity of the existing electrical grid and the required upgrades to deliver shore power to eight cruise terminals.	If fully implemented, this shore power and electrifi cation initiative will remove 11,366 metric tons of CO2 while also reducing NOx by 75 per cent and SO2 emissions by 51 per cent – or "The study found that signifi cant reduction in the local burning

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							of heavy fuel oils can be secured from the use of cold ironing [shore power], resulting in an improvement to local air quality," explained Aimee Besant, Energy Storage Lead, ABL Group, adding that a 5–10 MW peak solar plant energy system could be harnessed to support a green energy shore power system. The project was commissioned following the proposed introduction of the Green Ports Policy by the Kenyan Ports Authority which plans for all vessels at the port of Mombasa to turn off onboard generators and operate from shore power. equivalent to taking 2470 cars off the road annually, according to the port authority.
Virginia Inland Port	US	US	NO	YES	YES	The inland port gets its power from Rappahannock Electric Cooperative and through a new agreement the utility company will provide clean electricity to VIP from Virginia-based solar installations to all six of its general cargo terminals	This year work begins on a US\$15 million capacity expansion that will create more capacity and efficiency. When the work is complete, the terminal will retire straddle carriers and begin using rubber-tire gantry cranes to move containers from railcars to trucks
Port of Gothenburg	Sweeden	EU	YES	NO	YES		By 2030 the Port of Gothenburg have set out the ambitious target to reduce shipping emissions by 70% within the port area. One key step to reach this goal is to provide a variety of shipping fuels that contribute to bring down emissions – in the port as well as on a global scale. Many initiatives are taken around the world with net zero vessels now in the order books
Port of Antwerp	Belgium	EU				Construction of a demonstration plant at the INOVYN site in Antwerp is scheduled to start by 2022, with the aim of producing 8000 tonnes of sustainable methanol annually, thus avoiding at least an equivalent volume of CO2 emissions. This methanol will be produced from captured CO2 and sustainably generated hydrogen. The carbon dioxide is captured by means of Carbon Capture and Utilisation (CCU), through which CO2 emissions are partially recovered and then combined with hydrogen generated on the basis of green energy produced from renewable electricity.	
Port of Singapore	Singapore	AS				Type of Concession Criteria: 20% Concession for Container Ships Declaration of purpose code 1 (Loading/Discharging of Cargo), Port stay does not exceed 4 days, 30% Concession for Green Port Programme, Use zero carbon fuel in the Port of Singapore, Port stay does not exceed 4 days, 25% Concession for Green Port Programme , Use LNG as marine fuel in the Port of Singapore, or, Use low carbon fuel in the Port of Singapore, EEDI reduction exceeds the IMO Phase 3	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						EEDI requirement by 10% or more, Port stay does not exceed 4 days, 10% Concession for Green Port Programme vessels that engage LNG-fuelled, low or zero carbon fuelled harbour craft for port operations , Applicable to GPP-registered vessels that engage an LNG-fuelled harbour craft for operations, or, GPP-registered vessels that are serviced by low or zero, carbon fuelled MPA licensed harbour craft, Port stay does not exceed 4 days, 20% Rebate for Vehicle Carrier Operators , Port stay does not exceed 4 days	
Port of Kapellskär	Sweeden	EU				A Swedish port has installed shore power in order to service a fl eet of green new-build ferries. The Port of Kapellskär has introduced shore power and auto-mooring at the quay to service two brandnew Finnlines Superstar-class vessels on the Kapellskär-Långnäs-Naantali route	
Port of Kapellskär	Sweeden	EU				Hyster aims to off er electric container handlers powered by integrated lithium-ion batteries with achoice of charging options and for operations with higher power consumption and extremely heavyduty cycles, they can be equipped with hydrogen fuel cells. Hydrogen and grid power providecomplementary power solutions for operations. Where the requirements to power a fl eet of electric BigTrucks are likely to exceed the power capabilities of the grid, hydrogen may provide operations withreadily available energy without a requirement for a high-capacity electric charging infrastructure	
Port of Ipswich	UK	EU				Two fully electric-powered hydraulic cranes are arriving at the Port of Ipswich, helping further reducecarbon emissions. The Mantsinen model 95ER cranes are amongst the fi rst of their kind in the UK andare the latest in a series of sustainable measures from Associated British Ports which have contributedto a 36% decrease in greenhouse gas emissions since 2014	
Trondheim Port Authority	Norway	EU				Access to attractive shore power and battery charging facilities is central to achieving the objectives forthe reduction of emissions from maritime transport. The development of such facilities is underway, butthe utilisation rate is low. This is partly due to a non-optimised use of available power and energy, andpartly due to uncertainties regarding the technical solutions. ElMar will investigate how integrated energy systems and new business models can make it moreattractive to develop, operate and utilise shore power and battery charging facilities. Furthermore, ElMarwill break down technical barriers through increasing the understanding of how such facilities aff ect theelectricity grid and its components.	
San Francisco bay	California	US				The San Francisco Bay will soon have a new fossil fuel-free ferry fl oating in its waters, propelledcompletely by hydrogen fuel cells, and offi cials hope it heralds change on the high seas.Aptly	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						named SeaChange, the 70-foot (21-meter), 75-passenger ferry will service multiple stops along San Francisco's waterfront. It was built at All American Marine shipyard in Bellingham, Washington, and was undergoing tests with the U.S. Coast Guard in nearby Puget Sound.	
Port of Barcelona	Spain	EU				The port is developing pilot projects that demonstrate and promote the viability of LNG as a mobility fuel, both for boats and for trucks and terminal machinery. These initiatives are outlined in the port's Improvement Plan for Air Quality, which aims to minimize the impact of port activity in the environment.	
	Groningen	EU				The terminal, near Groningen, has two Floating Storage Regasification Units (FSRUs) that Gasunie leased at the request of the Dutch government. Until this year, the Netherlands only had an LNG terminal in the port of Rotterdam. The expansion in the Eemshaven and the optimization of the terminal in Rotterdam will double the import capacity for LNG. The LNG terminal in the port of Eemshaven will operate floating FSRUs (floating storage and regasification units), the Exmar S188 and the Golar Igloo. Together, the two FSRUs have a throughput capacity of approximately 8 bcm per year, which can contribute significantly to ensuring the security of supply and reducing dependence on Russian gas.	
Port Coronel	Chile	US				The port purchased the forklift cranes with minimum noise generation to mark the beginning of its Puerto Verde programme, that aims to progressively incorporate electric equipment and increase the use of more environmentally friendly technologies. The three Linde High Lift e50L cranes will allow a saving of 80% in energy compared to the port's existing cranes.	
Port of Antwerp	Belgium	EU					
Port of Rotterdam	Netherlands	EU				The construction of a hydrogen plant with a capacity of 1GW is the next leap in scale in the production of green hydrogen. Several companies are now building, or have advanced plans to build, electrolyzers with a capacity of 200 to 250 MW at the Maasvlakte	Making hydrogen directly on the coast is appealing, since it does not require additional high-voltage cables on land. It is also attractive to produce where the main customers are industry.
Gothenburg	Sweden	EU				The fuel supplier Bunker One has launched its first methanol-ready bunker tanker in the strait between Denmark and Sweden allowing for last-mile refuelling of ships.	
Tauranga	New Zealand	EU				New Zealand's Port of Tauranga has ordered four new Kalmar hybrid straddle carriers to help achieve its carbon neutral ambitions	Our hybrid straddle carriers, which can cut fuel consumption by up to 40% compared to equivalent diesel-powered machines, will have an important role in helping the port both meet its tough

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							carbon-reduction targets and fulfil its ambitious growth plans
European Ports		EU					
Klaipeda port	Lithuania	EU				The Lithuanian port of Klaipėda is working with the methanol supplier Proman to transition into an "energy port"	
Port of Vancouver	Vancouver	US				The Provincial Government of British Columbia is providing CAN\$4 million financial support for a project which will help ween B.C.'s port industries off carbon by introducing hydrogen fuel-cell powered truck	
Port of Stephenville	Canada	US					
Port of Detroit	Canada	US				The Detroit Wayne County Port Authority has begun a year-long project to reach net-zero carbon emissions for port activities by 2040	
Kalmar company						The global port equipment manufacturer has announced big steps forward in its electrical offering.	
						Kalmar is securing more orders on the back of the launch of its Charge Family range, which comprises of battery technologies, charging solutions and software.	
port Wallhamn	Sweeden					Swedish port Wallhamn AB is to benefit from a new facility for local energy production which uses non-recyclable waste to produce electricity and green methanol.	
Freeport Texas	USA					BASF and Yara Clean Ammonia are collaborating on a joint study to develop and construct another world-scale blue ammonia production facility in the USA	
Port of Valencia	Spain					Valenciaport has shared its current projects exploring the use of hydrogen at a meeting in Brussels of the Clean Hydrogen Alliance.	
						The event aims to identify viable projects to drive the adoption of green hydrogen across the European Union and help decarbonise the maritime industry.	
Fjords	Norway					A collaborative project will create one of the largest hydrogen production facilities in the Nordic region.	
						The collaborative agreement between Provaris Energy Ltd and Norwegian Hydrogen AS will jointly progress the next phase of development for the FjordH2 project, located at Ørskog in the Ålesund municipality, Norway.	
Port of Brownsville	Texas, United States					A new business park at the only deepwater port on the US/Mexico border will help support industry in the region	
						The Port of Brownsville on the US/Mexico border in Texas has held a groundbreaking ceremony for a new 118 acre (315 ha) business park.	
						The port says this latest project will provide local	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Singapore	Asia					manufacturers and industries with storage capabilities combined with access to multimodal transport.	
						The Ever Ulysses has taken on board ExxonMobil marine biofuel at the Port of Singapore	
						The Port of Singapore has played host to the latest successful ship-to-ship biofuel bunkering.	
DP World Yarimca	Asia					On 1 April 2023 Evergreen Line's vessel, Ever Ulysses, received ExxonMobil's marine biofuel oil blend via a ship-to-ship transfer in Singapore waters before heading to the discharge port.	
						DP World Yarimca has reportedly become the first port in Türkiye to integrate remote-controlled electrified cranes in its operations.	
Port of Auckland	Californian					The move is part of the terminal's 'Zero Tolerance' safety project which the port says has yielded a significant reduction in workplace accidents, halving lost time incidents since 2018	
						A Californian port has committed to 12 years' worth of geothermal energy, providing 10% of the port's energy needs	
Stockholm	Sweeden					The Ports of Stockholm is on target to achieve its solar ambitions two years early Ports of Stockholm is building six new rooftop solar systems, increasing the company's production by 55%. The operator currently has five solar cell system installations with a total production capacity of 995 MWh per year.	
						A new solar farm at an Estonian port is already powering two warehouses with plans for expansion	
Port of Muuga	Estonia					Hamburger Hafen und Logistik subsidiary, HHLA TK Estonia, has built reportedly the largest solar park at the Port of Muuga – with plans for further expansion.	
						The first phase of the new solar power park has been installed on top of two warehouses and is already in operation.	
Port of Vigo	Iraðu					The Port of Vigo launched, pioneeringly in Europe, the implementation of a Blue Growth strategy through a participatory methodology to promote competitiveness, efficiency, and sustainability in all port-related activities. One of the key focus areas of the Port of Vigo's Blue Growth strategy is humanization. Port of Vigo aims to position itself as an inclusive port, dedicated to people and committed to the training of new professions, social cohesion of sectors and individuals associated with the sea, and social innovation initiatives, in line with the United Nations' 2030 Agenda for Sustainable Development.	
						The port sector is facing a fundamental challenge, which is to move to a new level of development by giving greater priority to "Soft" actions, through the	
National Ports	Morocco						

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Agency of Morocco						overhaul and optimization of port processes, taking advantage of Innovation, new technological resources and the digital revolution. To tackle this challenge, the National Ports Agency of Morocco (ANP) has embarked on a voluntary, inclusive and creative approach involving all stakeholders in the port ecosystem, placing the economic operator at the heart of the various projects.	
Fiji Ports	Fiji					Fiji Ports has obtained the Integrated Management System (IMS) Certification which ensures the company's Quality, Environmental and Occupational Health & Safety management systems are in line with international standards. This has enabled the company to improve its performance, provide better quality service, reduce risk, enhance workplace safety, continually improve processes and be innovative. Employee well-being is one of the six corporate values adopted by Fiji Ports. Fiji Ports shows its commitment to Health & Safety by maintaining this certification for the past four (4) years and shall continue to uphold the stringent requirements of this health & safety standard.	
Port of Long Beach Board	USA					Since adoption of the landmark Green Port Policy by the Port of Long Beach Board of Harbor Commissioners in 2005, the Port of Long Beach (POLB) has continued to lead the industry on environmental initiatives. One important aspect of the Green Port Policy is water quality. The POLB has made significant improvements to our receiving water quality through reductions in stormwater pollutants and remedial dredging to address legacy sediment contamination.	
Port of Santa Cruz	Tenerife					Tenerife Port ZERO is at the forefront of sustainable port innovation, incorporating a wide range of pioneering projects to drive environmental stewardship and energy efficiency. Our commitment to renewable energy is evident in initiatives such as the OPS Masterplan, which enables shoreside power supply to vessels during their docking periods. By utilizing clean energy sources like offshore wind turbines and implementing intelligent lighting systems, we significantly reduce emissions and create a greener port environment.	
Port of Vienna	Austria	EU	YES	YES	YES	The preparatory work of the exploratory study is structured along three pillars: Analysis of basics principles and implementation potential Stakeholder analysis & network development Result utilization & monitoring The project will be taking place from April 2022 to March 2023 with a budget of 306.939 €, 62% of which is funded by the Austrian Research Promotion Agency	The project will be taking place from April 2022 to March 2023 with a budget of 306.939 €, 62% of which is funded by the Austrian Research Promotion Agency

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Solomon Ports	Honiara	AU	YES	YES	NO	As part of the extension of our port-community dialogue through this Green Port Project, Solomon Ports embarked on this new project to support rural communities by providing sustainable energy for those who previously could not access any form of energy. With the aim of becoming a Zero Emission Port by 2030, Solomon Ports has endeavored to promote and build a social cohesion towards establishing renewable energy for rural communities in the Solomon Islands. Solomon Ports also take pride in investing in its communities to achieve this goal by assisting them with solar outfits, installation and maintenance and creating awareness on the importance of using renewable energy for a sustainable community	
Port of Rotterdam	Netherlands	EU	YES	YES	YES	The aim of our program is to raise awareness among companies of the potential threats created by climate change and how, in partnership, we can manage the risk of flooding to an acceptable level together. The development of adaptation strategies was done in close cooperation with a large number of companies and stakeholders. By considering various climate change scenarios, we developed adaptation strategies for coping with flood risk in collaboration with the companies and public organizations. We have mapped out the probabilities and consequences of flooding, assessed these risks with an assessment framework, specifically developed for our port, and listed and selected appropriate measures.	The development of adaptation strategies was done in close cooperation with a large number of companies and stakeholders. With the aim of Joint Fact Finding, dozens of workshops were organized in which potential risks were discussed and measures were combined into widely agreed adaptation strategies.
Port of London Authority	UNITED KINGDOM	EU	YES	YES	NO	The Port of London Authority (PLA) is leading a new consortium aiming to develop a UK hydrogen highway network which consists of land, sea and ports. The hydrogen highway could significantly support the integration of hydrogen technologies into a range of different sectors with six projects planned for the highway. The six projects cover energy diversity research, trialing hydrogen power generation for vessels based at the PLA's Denton Wharf, establishing the business case for back hauling hydrogen into central London, ship design and health & safety requirements.	
Port of Amsterdam	Netherlands	EU	YES	YES	NO	Achieving Zero-waste status by 2050 (becoming fully circular) is one of the main innovation goals of the Port of Amsterdam. To have a fully circular economy model, manufacturers have to be able to design their products in a way that mostly uses secondary materials as input, and that after the products lifecycle, the materials could be salvaged to be reused.	
Port of Seattle	Canada	US	YES	NO	YES	the Port formally recognized the effects of ocean acidification (OA) on the maritime industry and marine environment and committed to addressing OA through the creation of an Ocean Acidification Action Plan. The plan serves as a framework that highlights	The Port works to ameliorate OA through habitat, stormwater, and clean air and energy initiatives. The Maritime Climate and Air Action Plan describes the Port's plan to reduce GHG emissions to 50% of

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						the Port's current initiatives to combat OA and recommends next steps.	baseline by 2030 and become carbon neutral by 2050
North Sea Port	Belgium	EU	YES	YES	YES	The installation of solar panels on the roofs of the warehouses at Verbrugge Scaldia Terminals (VST) and Verbrugge Zeeland Terminals (VZT) is nearing completion. More than 140,000 panels are almost installed, with a total capacity of 50 million watts in 2021	More than 140,000 panels are almost installed, with a total capacity of 50 million watts in 2021. This is enough to yield more than 16 million kWh of energy a year, generated by the Zeeland sun. This amount can supply power to approximately 5500 households. Moreover, it will result in a CO2 reduction of 10,200 tons a year
Port of Busan	Republic of Korea	AS	YES	YES	YES	installation of 8, innovative devices at the port which automatically sort and clean PET plastics. The plastics are then transferred by partner organizations to be decompressed, before being manufactured into recycled and upcycled goods such as duvets, and eco-bags	14,000 bottles have been recycled so far via these devices at Busan Port facilities, creating enough recycled material for 10,000 eco-bags. A total of 220kg of plastic has been collected and recycled, resulting in an estimated 526kg reduction in greenhouse gasses. Over \$8,400 USD (10 million KRW) in social welfare support has been generated as a result of the upcycling program. In addition, collaboration with local government is seeing the creation of 80 jobs for local, elderly citizens within the upcycling program.
Flinders Port Holdings	Australia	AU	YES	NO	YES	FPH recognized the port infrastructure of tomorrow will need to be built to higher specifications of resilience and to achieve net-zero emissions. This is a sizeable challenge that FPH is embracing. FPH will also play an integral role in achieving improved outcomes for coastal ecosystems and local communities by adopting a sustainable approach to the ongoing development of our ports.	
Port of Baku	Azerbaijan	AS	YES	NO	NO	The Port of Baku (PoB) has been developed as a green port and logistic center by adhering to international standards and using contemporary technology in various aspects such as energy, waste management, air quality, digitalization, automation, as well as sustainable business practices.	
Port of Igoumenitsa	Greece	EU	YES	YES	YES	The main scope of the ALFION project (ALternative Fuel Implementation in igOumeNitsa), co-financed by the Connecting Europe Facility of the European Union, is to transform the Port of Igoumenitsa into an energy hub in the Adriatic-Ionian Sea, providing sustainable solutions based on the requirements of the port's marine and vehicle traffic	co-financed by the Connecting Europe Facility of the European Union
RAK Ports	Arab Emirates	AS	YES	YES	YES	Saqr Port implemented Dynamic Under Keel Clearance System (DUKC®) on January 1st 2020. The average increase in sailing draft realized to date by Saqr Port with DUKC® is 0.67m, thereby allowing ships to sail with more cargo whilst reducing risk. By increasing the tonnes lifted by every vessel, the per tonne-km CO2 emissions are reduced.	With DUKC®, Saqr Port has delivered record sailing drafts and tonnages, and a reduction in CO2 emissions of 100,617 tonnes in the first 23 months across 369 transits (~6.8%), equivalent to: GHG emissions from 406,955,509 km driven by the average passenger vehicle; CO2 emissions from 12,239,318,159

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							smart phone recharges or 18,276 homes electricity use for 1 year; or CO2 sequestered by 1,663,723 tree seedlings grown for 10 years, or 123,274 acres of forests in 1 year.
Port of Amsterdam	Netherlands	EU	YES	YES	NO	strive to become a Multi Fuel Port, meaning that we must facilitate the safe and efficient bunkering of clean fuels – even of fuels that we do not yet have full knowledge on. In collaboration with our partners, we offer shore power and mobile power with floating batteries. We also prevent emissions due to unnecessary sailing movements and berthing.	
Fiji Ports	FIJI	US	YES	YES	YES	Fiji Ports play an important role in trade, logistics and the survival of many Pacific Island nations. Understanding the Port's significance and impact, the Green Port Master Plan 2019-2023 has been launched, aligning to the Port's vision of being the Smart, Green Gateway for trade in the Pacific Region, which outlines the pathway to reduce its environmental footprint and combat climate change	As a result, Fiji Ports have achieved 11% average reduction of GHG emissions over the last 5 years. It is further intended to reduce its carbon footprint by 220 tonnes of carbon emissions by 2023 with a goal to reach carbon neutral status with respect to energy usage by 2027
Port of Puna	Ecuador	US	YES	YES	YES	This program aims to create blue carbon ecosystems through mangroves in Ecuador with the aim of capture CO2 emissions and minimizing DP World's environmental impact. The ability of these vegetated ecosystems to remove carbon dioxide (CO2) from the atmosphere makes them significant net carbon sinks.	The company delivered the first 65 ha of mangroves (more than 150,000 Red Mangroves) in September 2021 to the Ecuadorian Minister of Environment, and to reach the goal of 105ha of mangrove, DPWP started the sowing of 115,000 additional mangroves seeds since November 2020. Until date 35,000 Red Mangroves seedlings have been planted. DPWP for 2024 estimates a reduction of 3.125.000kg of CO2 from the 100Ha of Red Mangrove Planting
Port of Vigo	Spain	EU	YES	YES	YES	catalyze a fundamental change in the Coastal and Marine Infrastructure (CMI) industry's operations by shifting away from obsolete "grey" construction and towards nature-inclusive infrastructure with structural, environmental, and socio-economic co-benefits.	330m ² EONcrete sea wall and an underwater monitoring and community outreach deck developed by Cardama Shipyard to show the citizens that "the blue change" is possible and build awareness accordingly; The floating deck will be supported by five EONcrete bio-enhancing moorings; 100 EONcrete Coastalock units will provide coastal stabilization as well as habitat creation and ecological uplift.
Port of Colombo	Sri Lanka	AS	YES	YES	NO	SLPA has undertaken various initiatives targeting increasing the efficiency of port call and operations, including investments in digitalization and infrastructure, electrifying port equipment, using solar energy to power the port authority offices, committing to carbon footprint monitoring and reporting, as well as investigating and planning the provision of onshore power supply to vessels as berth	Therefore the Sri Lanka Ports Authority with collaboration with the other terminal operators and port stakeholders have taken joint measures
Port of Gothenburg	Sweeden	EU	YES	YES	YES	The Port of Gothenburg and Norwegian energy company Statkraft are planning to construct a hydrogen production facility at the port, with operations due to commence in 2023. When	The planned facility will have an initial capacity of four MW, producing up to two tonnes of hydrogen per day. This is equivalent to 2,200 litres of diesel and

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						hydrogen is produced using fossil-free power sources, such as hydropower or wind power, the hydrogen would also be fossil free	could help reduce carbon emissions by at least 4 tonnes every day. The capacity can be expanded if demand increases, and new areas of use emerge.
Port of Yokohama	Japan	AS	YES	YES	NO	The Port of Yokohama is working to become a Carbon Neutral Port by improving port functions with consideration for decarbonization to implement the low-cost import of large-volumes of next-generation fuel such as hydrogen, ammonia, and carbon-neutral methane	
Port of Los Angeles	US	US	YES	YES	YES	One of the key technology development activities underway at the Port of Los Angeles is the demonstration of how zero emission technologies will be able to handle cargo as it is unloaded from a ship, moves through a terminal, and ultimately is transferred off terminal and on to its final destination.	Another element of this pathway is featured in our "Shore to Store" project where we are working with a truck manufacturer, Kenworth, to develop ten zero-emission Class 8 hydrogen fuel cell electric trucks that include Toyota's fuel cell drive technology
Port of Kaohsiung	Taiwan	AS	YES	YES	NO	The master-plan demonstrates how to achieve economic development while encompassing climate and environmental considerations through 2 major projects: the second phase of the Intercontinental Container Terminal Project and the Port Reinvention Project.	
Port of Antwerp	Belgium	EU	YES	NO	NO	Emissions and consumption by investing in energy-efficient ships, focus on alternative fuels and improve processes to reduce consumption, Ergonomics and well-being on board by focusing on people and staff, providing a safe and ergonomic working environment and focusing on training, Improving services by digitizing and innovating	
Port of Guangzhou	China	AS	YES	NO	YES	The port shore power project of Guangzhou China Resources Thermal Power Co., Ltd. has a design capacity of 1,000kVA, an output of high voltage of 6.6kV(60Hz) and 6kV(50Hz), an output of low voltage of 440V/(60Hz) and 400V(50Hz), and several power connection modes. It can meet the demands of power supply during the berthing and operation of a 50,000-ton ship	The shore power facilities can replace 211.82 tons of standard oil per year and the annual carbon dioxide emission reduction is 656.32 tons. The port shore power project of Guangzhou China Resources Thermal Power Co., Ltd. has a design capacity of 1,000kVA, an output of high voltage of 6.6kV(60Hz) and 6kV(50Hz), an output of low voltage of 440V/(60Hz) and 400V(50Hz), and several power connection modes. It can meet the demands of power supply during the berthing and operation of a 50,000-ton ship.
Port of Gothenburg	Sweden	EU	YES	NO	YES	The aim behind CinfraCap is to produce a more comprehensive picture of the logistics chain required to transport captured carbon dioxide from different industrial facilities in western Sweden, from liquefaction and intermediate storage, through to distribution to ships and onward transport to the repository site.	transport two million tonnes of captured carbon dioxide per year from our quayside facility and to do so we must have an efficient infrastructure
Port of Gothenburg	Sweden	EU	NO	YES	NO	The latest shoreside power facility was installed in the Ro-Ro Terminal and started operations in January	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						2021. This time it was the shipping company DFDS that had adapted their ships to shoreside power, and their vessel Flandria Seaways was the first to connect to the new facility	
Ports of Auckland	New Zealand	EU	YES	YES	NO	trialing 2nd Generation Biofuel, a Renewable Diesel made from residual waste streams, fully operational hydrogen refueling facility on port now, trialing hydrogen container handling equipment in the future	
Guangzhou Container Terminal	China	AS	YES	YES	YES	A project was initiated to replace all 40 existing dPM with electric ones over the course of 5 years	A project was initiated to replace all 40 existing dPM with electric ones over the course of 5 years. In December 2020, the first batch of 10 electric prime movers (ePM) became operational. The adoption of ePM will reduce carbon emissions by about 52% compared to using dPMs. Annually, this will help abate over 1,780,000 kg CO ₂ e of carbon emissions by 2026
Port of Gothenburg	Sweeden	EU	NO	YES	YES	Gothenburg Port Authority to plant 1.7 hectares of eelgrass to compensate for the eelgrass that will disappear during construction	To date, 4,300 square meters of eelgrass have been planted and based on the excellent results that have emerged and new findings in this relatively unexplored area, the project is now set to move to the next level
PSA Marine	Singapore	AS	NO	NO	YES	Both tugs can operate in either diesel or LNG mode, carry up to 25 cubic meters of LNG in a Type C tank located within the vessel body.	To date, 4,300 square meters of eelgrass have been planted and based on the excellent results that have emerged and new findings in this relatively unexplored area, the project is now set to move to the next level
Port of Seattle, Port of Tacoma, Northwest Seaport Alliance, and Vancouver Fraser Port Authority	Canada	US	YES	NO	NO	Engagement: The ports worked together for over two years while engaging industry, government, and community partners to shape the Strategy and cultivate broad buy-in for the vision	
Port of Valencia	Spain	EU	YES	NO	NO	The main objectives of the Strategy include: Promoting the decarbonization of the Spanish port system, including the incorporation of the circular economy in port construction projects and port operations. Fostering the digital transformation of the Spanish port system.	
Port of Marseille	France	EU	YES	YES	YES	HyAMMED project led by Air Liquide is implementing an hydrogen motorization technology that aims to make the transition from road transport of various polluting heavy vehicles to responsible, innovative and environmentally friendly mobility. The project	The project will reduce CO ₂ emissions by more than 1,500 tons of CO ₂ per year, the equivalent of more than 2 million kilometers traveled by truck.

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Taipei	Taiwan	AS	YES	YES	YES	includes the construction of Europe's first high-pressure hydrogen station for long-distance trucks Reclamation construction utilizes dredging in the port area and accepts spoil disposal from public constructions in the Greater Taipei area as material for the port's reclaimed land. This solves the problem of spoil disposal from construction projects, while also increasing national land assets and areas of green space	About 43 hectares of land in the logistics and warehousing areas are planned to be developed as windbreaks, where about 64,000 trees can be planted, which can absorb nearly 34,000 tons of CO2.
Port of Amsterdam	Netherlands	EU	NO	NO	YES	the Port of Amsterdam is building an innovative hydrogen powered port vessel, the first ship in the world that will sail on Sodium Borohydride (NaBH4)	As for the reuse of construction fencing, the construction materials from constructed fencing at the Port of Taipei for all phases are recycled to reduce environmental resource consumption, including 42 caissons, over 4,700 miscellaneous leftover blocks, and around 70,000 cubic meters of building stones for reuse in subsequent construction, which can effectively reduce spending, saving about NT\$560 million
Port of Algeiras	Spain	EU	YES	NO	NO	The Port of Algeiras Bay Authority has been leading huge efforts framed in the Strategic Plan and, particularly, in its Digital and Innovation Program to enhance processes and operations' efficiency and become more environmentally sustainable, that is to become a Digital and Green Next Generation Port.	
Port of Marseille	France	EU	YES	YES	YES	In the port of Marseille, the pilot station simulator allows pilots to perfect their maneuvers on all types of vessels and in all types of conditions. It performs a large number of calculations on a digital model, whose behavior it reproduces in real time. A lot of data can be extracted apart from fuel consumption values.	The simulations carried out using the Friend Ship Solution highlight possible gains in consumption during the maneuvering phase. With a 200-meter ferry, fuel savings of more than 10% are immediately calculated in metric tons. The same applies to the reduction of polluting emissions, given the large number of calls operated by these vessels.
Port of Marseille	France	EU	YES	YES	YES	The generator consumes hydrogen and oxygen and produces heat, water and electricity. It is a modular solution, easily transportable, that can power up to 32 refrigerated containers, without any polluting emissions.	The generator consumes hydrogen and oxygen and produces heat, water and electricity. It is a modular solution, easily transportable, that can power up to 32 refrigerated containers, without any polluting emissions. A resolutely eco-responsible solution that avoids the emission of atmospheric pollutants and several thousand tons of CO2 per port terminal and per year. In addition, a digital tool is also studied to allow remote monitoring of the solution.
Solomon Ports	Solomon Islands	AU	YES	NO	NO	It saves energy and natural resources, helps to reduce pollution and reduces the need for landfill. The 3R concept introduces a sequence of steps on how to manage waste properly.	
Port of Marseille	France	EU	NO	YES	NO	The technology makes it possible to avoid the use of chillers, limiting the energy consumption of buildings and their carbon footprint. This solution is thirty times	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						more energy efficient than a conventional cooling solution.	
Port of Marseille	France	EU	YES	YES	YES	It is a modular solution that combines a membrane ultrafiltration system with a heat recovery system and thus makes it possible to produce reusable water and heat from wastewater generated by cruise ships. This solution is based on a wastewater collection system using a mobile hydrogen barge combined with a fixed system underground wastewater recycling & thermal recovery system.	100% of the wastewater can therefore be recycled and reused for any non-potable use, such as cleaning water, irrigation water or for flushing toilets. From an energy point of view, 50% of the thermal energy of the wastewater can be reused on board for preheating of domestic hot water. Overall, this solution reduces water consumption on board by 60% and the associated energy bill and CO2 emissions by 40%.
Port of Brisbane	Austratlia	AU	NO	NO	NO	The Climate Change Module (in use) delivers a modelling tool that allows PBPL to determine, on an 'as needs' basis, the risk of various climate change parameters (sea level, flood level and severity, storm severity, and storm surge impacts) on physical port infrastructure.	NCOS Online has delivered significant environmental outcomes with the technology supporting substantial UKC improvements and playing a pivotal role in increasing in the capacity of the Port of Brisbane's navigational channel that include: increasing vessel LOA by 13.6% to 350 metres and vessel beam by 11.1% to 50m potentially delaying significant capital dredging projects enabled PBPL to accommodate larger vessels at the Port of Brisbane, resulting in reduced transit times and improved shipping efficiency for customers and the subsequent reduction in vessel emissions providing a greater level of accuracy in vessel behaviour for the Harbour Master.
Port of Rotterdam	Netherlan ds	EU	NO	NO	NO	a platform for optimizing port calls to reduce CO2 emissions globally in shipping	
Port of Vigo	Spain	EU	YES	NO	NO	In this context, the project "Sunset Dock" was created. Planned on 4 stages, Sunset Dock includes a set of actions to develop innovative practices that allow achieving sustainability objectives by: Recovering the good state of marine ecosystems in the port area Promoting awareness of ecosystem conservation in the port area Reducing carbon emissions through CO2 capture techniques	
Port of Helsinki	Finland	EU	YES	YES	YES	9 berths with new OPS capability, auto-mooring installations will be added for speedier calls, supporting ship owners transitioning into biofuels, by carrying part of the price difference for fuels used in harbor, solar plants on the buildings under Port ownership	By committing to this action plan, the Port of Helsinki will cut harbor area CO2 emissions by over 30 %, even though the port's own emissions only constitute 5 % of total area emissions.
Port of Huelva	Spain	EU	NO	YES	YES	The Ecological Recover project positioned the Port of Huelva as an international example of good environmental practice	Through concentrated efforts for over 10 years and a total investment of 27 million euro, the project addressed the environmental recovery of the degraded

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							left bank of the Odiel estuary and the conservation of habitats and their environmental values. The environmental work was complemented with the construction of a boulevard along 1 km of the Odiel estuary, and a 4 km pedestrian path
European ports	global	EU	YES	NO	YES	PASSport solution is about to complement already operational platforms extending the surveillance perimeter using a fleet of drones to provide innovation and operational support to the safety and security aspects of daily operations	PASSport will be validated via five specifically designed case studies in the ports of Hamburg, Le Havre, Kolobrzeg, Ravenna and Valencia.
Port of Hamburg	Germany	EU	NO	NO	NO	One robot identifies litter using deep-learning artificial intelligence trained to differentiate between marine wildlife and debris. The collection is performed by a larger robot that navigates to the location where waste has been found and removes it using a gripper-suction device. This process is carried out in strict compliance to nature conservation standards.	
North Sea Port	MALAYSIA	AS	YES	NO	NO	Throughout the journey, Northport has embarked on various HSE initiatives which include: Establishment of Business Continuity Plan to ensure adequate measures are in place for Northport's operational and business continuity throughout the COVID-19 pandemic. Strengthen our port's security with the use of drone and closed-circuit surveillance system. Northport is the first port in Malaysia to use drones for security and	
Port of Long Beach	US	US	YES	NO	YES	The demonstration will include three never-before-tested battery-electric top handlers and feature a unique, head-to-head comparison of a hydrogen fuel cell yard truck versus a battery-electric yard truck.	This project will help test the performance of clean technologies that could play a role in meeting the zero-emissions goals. The California Air Resources Board awarded a \$5.3 million grant to fund the demonstration, known as the Commercialization of POLB OffRoad Technology Demonstration, or C-PORT.
Port of Bari	Italy	EU	YES	NO	NO	The platform aims at monitoring environmental pollutants generated by traffic within the port area (ships, ferries, cargos, vehicles) and at evaluating the impact on the port itself and on its urban surroundings (city of Bari)	
Port of Genoa	Italy	EU	NO	YES	YES	A twofold medium voltage distribution network has been realized inside the port area (at 15kV, 50Hz and at 6,6/10/11kV at 60Hz based on a 10MW 50/60Hz ICBT converter) able to provide high electricity outputs by ensuring as well the maximum of flexibility to power cruise ships	In order to facilitate feeding operations for docked ships, a mobile structure was implemented that can be easily moved and positioned into different quays. A SCADA system to monitor and control the overall electrical plants and a high-band fiber optic data network are also relevant components of the project
Tenerife Port	Spain	EU				Tenerife Port ZERO is at the forefront of sustainable port innovation, incorporating a wide range of pioneering projects to drive environmental stewardship and energy efficiency. Our commitment to renewable energy is evident in initiatives such as	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						the OPS Masterplan, which enables shoreside power supply to vessels during their docking periods. By utilizing clean energy sources like offshore wind turbines and implementing intelligent lighting systems, we significantly reduce emissions and create a greener port environment.	
Port of Long Beach	Canada	US				Since adoption of the landmark Green Port Policy by the Port of Long Beach Board of Harbor Commissioners in 2005, the Port of Long Beach (POLB) has continued to lead the industry on environmental initiatives. One important aspect of the Green Port Policy is water quality. The POLB has made significant improvements to our receiving water quality through reductions in stormwater pollutants and remedial dredging to address legacy sediment contamination.	
Port of Acu	Berazil	US				Ports around the world are already experiencing the consequences of air and water temperature increases, rising sea levels and changes in seasonal precipitation, wind, and wave patterns. From a global perspective, the climate change effects associated with global warming are projected to escalate in coming decades and already represent a significant risk to business, operations, safety, and infrastructure. Therefore, is an urgent matter for ports to act to strengthen resilience and adapt to future climate conditions	
Port of Brisbane	Australia	AU				In response to increasing concerns around climate change impacts and following the development of our own Climate Change Risk Assessment, PBPL implemented an Energy Transition Plan in 2020. Aligned with the Science Based Targets initiative (SBTi), the Plan committed to achieving net zero carbon emissions (Scope 1 and 2) by 2030. It set a pathway to achieve this through the transition from carbon intensive electricity/fuels to more energy efficient technology and zero emission fuels and aligns with Queensland Government priority areas and the 2015 Paris Agreement.	
New Owendo International Port	Gabon	AF				New Owendo International Port (NOIP) has committed to having carbon-neutral operations on its lines of business. Following this commitment, we planned in 2020 to first tackle our scope 1 and 2 emissions by decarbonizing and reducing our fuel consumption. NOIP is thus steering a range of ambitious initiatives: these include investing in the electrification of cranes, improving energy efficiency, and developing waterway transport of containers to reduce fuel consumption by shifting transport operations from road to barge.	
NSW Ports – Offshore wind energy hub	Australia	AU				In 2023 NSW Ports released concept plans for a large-scale port facility at the Port Kembla Outer Harbour which demonstrate how the port can be used to support the rapidly emerging offshore wind industry over the coming years. Situated in an area identified	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						by the New South Wales State Government as a designated Renewable Energy Zone (REZ), the project firmly positions Port Kembla as a key enabler in the Illawarra region's transition to a net zero emissions, clean energy future.	
Port of Kapellskär	Sweeden	EU	NO	YES	YES	installed onshore power supply (OPS) and automooring at the quay to service two newbuild Finnliness vessels on the Kapellskär-Långnäs-Naantali route. automooring helps sustainable development at the port by reducing the time the vessel spends in the port, as well as saving on fuel	The facility at Port of Kapellskär is funded at 30% by the EU project "Upgrade of the Baltic Sea Bridge Kapellskär-Långnäs-Naantali".
Port of Antwerp	Belgium	EU	NO	NO	YES	detects floating debris with a drone and intends to have it flying over the port several times a day. Cleaning it helps reduce water pollution as well as negative impact on biodiversity and damage to ships. These drones can also improve safety as the port is close to the city and a fire can be detected by the thermal camera to help the fire brigade.	Around 50 tonnes of debris, made up of plastics, wood, cardboard, organic material, and mooring lines, are being collected from the docks every year.
Port of Antwerp	Belgium	EU	YES	YES	YES	The 88-hectare NextGen District at the Port of Antwerp, deliberately chosen because of its proximity to Europe's largest chemical cluster, will become home to manufacturers keen to explore circular carbon solutions and renewable energy technologies.	Two companies (Triple Helix for polyurethane products and Bolder Industries for tyres) have already signed up, bringing €100 million in investment and at least 70 new jobs.
Port of Vlissingen	Netherlands	EU	NO	NO	YES	industrial plant for chemical recycling of plastic waste will be built at North Sea Port in Vlissingen, contributing to the further development of circular economy in the port.	It will have an annual processing capacity of about 55,000 tons of mixed plastic waste.
Port of Valencia	Spain	EU	NO	NO	NO	A new pilot project aims to supply water to the port terminals employees in the Port of Valencia, which would allow to save a million plastic bottles per year	
Port of Valencia	Spain	EU	NO	NO	NO	Fundación Valenciaport coordinates a new project called LOOP-Ports to facilitate this transition in ports through the creation of an innovative Circular Economy Network.	
Port of Kiel	Germany	EU	NO	YES	NO	The investment comprises the construction of quay-side pressure pipes leading into storage tanks equipped with technology for analysis and treatment. The connection to the municipal wastewater system has been established using pump stations and further pressure pipes	
Port of Antwerp	Belgium	EU	YES	YES	YES	Port of Antwerp is taking steps to recover waste heat from a waste incineration facility and connect it for district heating.	This project would be the biggest hot water network in Flanders, with a yearly reduction of 20,000 tons of CO2. As well as support from partners including the City of Antwerp, Indaver and Fluvius, the Flemish government will provide the project with an investment support of €15.7 million
Port of Algeciras	Spain	EU	YES	YES	NO	Installation of water jets in offices, and of glass jugs in meeting rooms instead of plastic single-use bottles. Placement of 80-liter containers for the deposit of single-use plastic containers use, and its collection in all buildings managed by the Port Authority;	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Barcelona	Spain	EU	YES	NO	YES	In order to contribute to the elimination of the use of plastic containers, an initiative was launched in 2019 by the Port of Barcelona to replace plastic bottles used by the Port Authority workers with a system of water sources with water treatment located in the common spaces and in the offices of the organisation's buildings	So far, 30 water sources have been installed, leading to a saving of 118,680 plastic water bottles. The Port hopes to consolidate and extend this scheme, reducing waste directly at the source without needing to implement reuse or recycling initiatives
Port of Vigo	Spain	EU	YES	NO	NO	The ML-Style project of the Port of Vigo aims to develop a comprehensive management system for waste from fishing ports (including food plastics, polystyrene boxes, disused gear and marine litter). This involves the installation of waste collection facilities and campaigns to communicate their work on waste collection to stakeholders and the local community.	
Port of Amsterdam	Netherlands	EU	YES	NO	NO	The Port of Amsterdam aims to become a hotspot for the circular economy in Europe. To this end, the Port has been active in establishing a strategy to attract businesses and entrepreneurs. The Port has actively sought out organisations that are passionate about transforming society and the ways we use resources. The Port links those organisations to existing industries and activities, e.g. the city waste cluster, energy production, biorefineries, chemicals and liquid terminals	
Port of Nakskov	Denmark	EU	YES	NO	YES	While searching for a novel, innovative idea to improve sustainability in the port, the Port of Nakskov has decided to apply circular economy principles to key port equipment, namely red beacons. The red beacons get faded by the sun through time, meaning that they must be discarded. The Port of Nakskov has found a way to grind the beacon and repaint it, allowing it to be reused.	The project boasts huge potential – Nakskov alone has about 60-70 beacons placed in the water, and each cost about €9,300
Port of Santander	Spain	EU	NO	YES	YES	A system of gathering rainwater from warehouse roofs and storing it in two deposits of 160 m3 and 935 m3 was put in place. This water is then used to clean the port area, to dampen dusty materials, and in case of emergencies such as fire. The system was also digitalised so that tap water could be used if there was a lack of rainwater and to monitor the overall consumption of both rain and tap water.	A system of gathering rainwater from warehouse roofs and storing it in two deposits of 160 m3 and 935 m3 was put in place
Port of Dover	UK	EU	NO	YES	YES	Dover introduced its Safety Environment Awareness (SEA) Award in 2017 to acknowledge outstanding performance on recycling rates and waste procedure compliance.	Within just one year, the percentage of recycling of cruise ship waste increased from 23% to 40%.
Port of Ipswich	UK	EU	NO	YES	YES	The Port of Ipswich received two fully electric-powered hydraulic cranes as part of many other sustainable measures from Associated British Ports which have contributed to a 36% decrease in greenhouse gas emissions since 2014	These new electric hydraulic cranes are estimated to save up to 5,275 tonnes of CO2 over their lifetime and can be powered by solar energy generated at the port from the approximately 4,000 rooftop solar arrays.
Port of Hamburg	Germany	EU	NO	NO	NO	The Port of Hamburg is now equipped with two new firefighting diesel-electric hybrid vessels. This will allow for cleaner operations at the port. Its five-pillar concept looks, among others, at alternative fuels,	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						retrofitting of existing ships and the efficiency of ship operations	
Port of Barcelona	Spain	EU	NO	YES	YES	Since 2017, 544 LNG supply operations have been carried out at the Port of Barcelona, with 152,000m3 of LNG supplied, both in truck-to-ship (TTS) and ship-to-ship (STS) operations, with 46 STS LNG supply operations carried out on Carnival Group cruise vessels and 498 TTS LNG operations carried out on the Balearia ferries	The use of LNG allows the reduction of almost 100% of SOx and PM emissions, about an 80% of NOx emissions, depending on the type of engine, and between 20-25% of CO2 emissions, and it is easily substitutable by Bio-LNG or e-LNG, zero or almost zero emissions fuels.
Port of Marseille	France	EU	NO	YES	YES	The first ship-to-containership LNG bunkering operation in the Port of Marseille Fos was completed this year alongside the Eurofos container terminal, while the containership carried out cargo operations simultaneously. Marseille is the first LNG bunkering hub in France	BioLNG will be produced by converting the biodegradable part of household waste from Marseille Provence region.
Port of Bilbao	Spain	EU	YES	YES	NO	The Port of Bilbao will soon have an LNG bunkering terminal, built by the Spanish energy company Repsol. The facility will be used to supply marine LNG to Brittany Ferries' gas-powered Salamanca and Santoña, which will begin operations in 2022 and 2023 respectively	
Port of Mukran	Germany	EU	NO	YES	NO	The German Mukran Port has been chosen as the base port for the 'Arcadis Ost 1' 257MW offshore wind farm, located in the Baltic Sea, approximately 19 kilometers northeast of the island Rügen. The port's experience with offshore projects makes it the ideal location for the operations centre of this first offshore wind farm in Germany.	
Port of Wilhelmshaven	Germany	EU	YES	YES	YES	Offshore wind with hydrogen on a large scale will be developed at the Port of Wilhelmshaven following a Uniper and Ørsted memorandum of understanding (MoU), with TenneT as transmission system operator (TSO). Wilhelmshaven could develop into a hydrogen centre for Lower Saxony and serve as an example for similar projects.	Uniper began developing the "Wilhelmshaven Green Hydrogen" project in 2020. It is expected that an electrolysis plant with a capacity of 70MW will be installed from 2025, to be expanded to 410MW by 2030. Any power grid bottlenecks can be avoided thanks to the direct conversion of renewable electricity into green hydrogen
Port of Rotterdam	Netherlands	EU	YES	YES	YES	The Port of Rotterdam Authority and Energy company Uniper have signed an MoU for developing the production of green hydrogen at the Uniper location on Maasvlakte, making Rotterdam an international hub for hydrogen production and import and for the transit of hydrogen to other countries in Northwestern Europe. These plans build on the findings of a recent feasibility study showing that the location on Maasvlakte is ideally suitable for large-scale production of green hydrogen with the use of power generated by North Sea wind farms	Specifically, the project is to be one of the largest hydrogen plants in the world with a capacity of 200 MW based on its large-scale 20 MW alkaline water electrolysis module.
Port of Kiel	Germany	EU	YES	YES	YES	The Port of Kiel aims to reduce all of its carbon dioxide emissions to zero by 2030. The path to climate neutrality is described in a three-step plan that concretises the port's BLUE PORT concept initiated in 2018, covering 60% of the energy requirements of ships calling at Kiel with green electricity already in 2022.	Moreover, the energy demand at the terminals has been sustainably reduced by switching to economical LED technology as well as increasing energy efficiency, while photovoltaic systems supply approximately 290,000 kilowatt hours of solar energy every year. More

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							than 6,200 tonnes of CO2 have already been saved at the Port of Kiel in 2020
Port of Felixstowe	UK	EU	YES	YES	YES	The Port of Felixstowe has placed orders for 48 battery-powered terminal tractors and 17 zero-emission remote controlled Electric Rubber-Tyred Gantry cranes (ReARTGs).	This technological innovation will save 6,662 tonnes of CO2 and 59.38 tonnes of NOx emissions every year at the port. It will help the port to reach its target of a further 20% reduction over the next five years, whereas it has already reduced its carbon footprint by 30% since 2015
Port of Hamburg	Germany	EU	YES	YES	NO	The Hamburg Port Authority (HPA) will have the first shore power systems for container ships that will supply container ships with green electricity during their berthing time at the Burchardkai and Tollerort terminals in an initial test phase. This will start in 2023. Each of the terminals will be equipped with an extraction point from the public grid, a converter station and the respective ship connection systems at the quay wall.	
North Sea Port	Belgium and the Netherlands	EU	YES	YES	NO	At North Sea Port, the 'Hydrogen Delta Network NL', a transport network for hydrogen, will build on Zeeland's existing position for hydrogen and is intended to take shape over the coming years. Via an 'Expression of Interest', the specific activities, wishes and requirements for supply and demand are being identified in terms of capacity and volume. This will help to inform the choice of pipeline capacity, dimensioning and routing.	
Port of Genoa	Italy	EU	YES	YES	NO	Thanks to an EU CEF Transport-funded project, Ports of Genoa can now provide onshore electricity. The Port is located very close to urban areas and will see a reduction in air pollutants and noise as a result of this. The project is included in a Global Project aiming to improve the environmental performance of the port through two elements: the provision of shore-side electricity and an ex post climate change impact assessment. In the long run, the project will support good port-city relationships and sustainable growth for the port.	The project began in July 2015 and was completed in December 2021. Almost 2,5 million were funded by the EU
Shoreham Port	UK	EU	YES	YES	YES	Shoreham Port entered into partnership with H2 Green, an infrastructure developer, to create a hydrogen hub in the port combined with onshore wind and solar power. With this agreement, 100% green hydrogen and renewable electricity will be produced, which will be used by heavy forklift trucks and HGVs entering and in the port during the first phase of the partnership. This would result in a significant reduction of emissions of up to 45,000 tonnes of CO2 per year and less noise pollution.	This would result in a significant reduction of emissions of up to 45,000 tonnes of CO2 per year and less noise pollution. In addition, an ammonia importation facility is also planned in the agreement
Port of Gothenburg	Sweden	EU	YES	YES	YES	Together with Norwegian energy company Statkraft, the Port of Gothenburg has started plans to construct a hydrogen production facility in the port area.	With a capacity of 4 MW, up to 2 tonnes of hydrogen will be produced every day in the new facility. Hydrogen could replace fossil-based fuels of different equipment in the port, and there is already a high demand for hydrogen-powered equipment in and around the port.

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Antwerp	Belgium	EU	NO	NO	NO	The Port of Antwerp and the Port of Montreal signed a cooperation agreement at the COP26 to see the creation of the first green shipping corridor in the North Atlantic.	
Ports of Stockholm, Helsinki, and Tallinn	Sweeden	EU	NO	YES	NO	The three Baltic Sea ports of Stockholm, Helsinki, and Tallinn have agreed on standards and now all provide onshore power for ferries operating between the three capitals.	200 cargo-loaded ferries sail every week between the three ports, transporting about 4,500,000 tonnes of freight, or 380,000 haulage vehicles/trailers and 12 million passengers.
Port of Valencia, Port of Hamburg	Europe	EU	NO	NO	NO	The Port Authority of Valencia and Hamburg Port Authority, together with the Valenciaport Foundation, have signed an agreement around the development of hydrogen projects applied in the maritime sector, in line with their commitment to fight climate change. Following this agreement, both ports will work together on projects around the generation of hydrogen, storage stations, use of hydrogen in terminals and machinery, and supply and transport to the hinterland.	The collaboration between the two ports also intends to involve their port and logistics communities to foster competitiveness and innovation
Port of Antwerp	Belgium	EU	NO	NO	NO	The Ports of Antwerp and Zeebrugge have signed a Memorandum of Understanding with the Chilean Ministry of Energy during the COP26 in Glasgow in November 2021. Through this agreement, the three parties commit to working together towards creating a green hydrogen corridor between Chile and Western Europe	
Port of Rotterdam	Netherlan ds	EU	YES	YES	YES	The Port of Rotterdam is investigating the possibility of installing shore-side power at its ECT and APMT2 terminals. Providing shore-side power to vessels berthing at the Port would allow them to be able to turn off their engines, which would lead to a reduction in CO2 emissions and would improve air quality.	the Port is also looking into the possibility to install shore-based power at the terminals of Vopak and Cruiseport Rotterdam. In total, this could result in a 200,000 tonnes reduction in CO2 emissions by 2030. The ongoing investigation is partly subsidised by EU funds
Port of Rotterdam	Netherlan ds	EU	YES	NO	YES	Electric sailing can be used to reduce CO ₂ emissions in inland shipping. On 2 June 2020, Zero Emission Services B.V. (ZES) was launched: a new company co-founded by the Port that helps increase the sustainability of the inland shipping sector by leasing exchangeable battery containers (known as ZES-Packs) to businesses in the sector.	The HEINEKEN beer company has entered into an agreement with ZES, who will be providing emission-free beer transports from the brewery in Zoeterwoude to Moerdijk for ten years.
Port of Gothenburg	Sweeden	EU	YES	NO	NO	In Gothenburg, the first high voltage shoreside power facility was installed in 2001, and since then the number of power facilities has grown year by year, with an average of one third of ship calls now having access to a shoreside power facility. The latest shoreside power facility was installed in the Ro-Ro Terminal and started operations in January 2021.	
Port of Gothenburg	Sweeden	EU	YES	YES	NO	In an effort to speed up the transition to fossil-free fuels in the transport sector, the Port of Gothenburg has partnered with Volvo Group, Scania, and Stena Line, to bring about a significant reduction in carbon emissions. The aim is to cut carbon emissions generated from transports to and from the Port of Gothenburg by 70% by 2030.	Volvo and Scania will put commercial offerings in place for their heavy truck customers, ensuring that in time, land transport becomes fossil free in accordance with the goals laid down by the port

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Kiel	Germany	EU	YES	YES	YES	Kiel's first shore power supply plant has been in operation at the Norwegenkai Terminal since May 2019, supplying the ferries of the Color Line shipping company. This facility supplies the ships with 10kV and 50Hz of power and delivers around 4 million kWh of shore power on an annual basis	The dimension of the facility with an 110kV cable connection, its own port owned-substation, the dimension of 16 megavolt ampere and the possibility of parallel provisioning of shore-side power built according to the applicable ISO standards is unique for Germany to date.
Port of Rotterdam	Netherlands	EU	YES	NO	YES	The Port of Rotterdam has signed a memorandum of understanding with Horisont Energi to set up a corridor to transport blue ammonia from Norway to Rotterdam. With this agreement, blue ammonia produced in Northern Norway from natural gas with carbon capture and storage would be shipped to the Port of Rotterdam, where it would then be distributed in the North-West of Europe.	The final investment decision for the production of blue ammonia at Horisont Energi's project is expected at the end of 2022 and blue ammonia could be shipped to Rotterdam by 2025. 3000t of ammonia will be produced per day
Port of Antwerp	Belgium	EU	YES	NO	YES	For the first time ever, a tugboat will be converted to methanol propulsion in the Port of Antwerp. The resulting "methatug" is part of the EU Horizon 2020-funded Fastwater project, aiming to showcase the feasibility of methanol as a sustainable marine fuel to reach carbon-neutral shipping. The project is expected to be operational in early 2022 and will enable the Port to continue its transition towards becoming CO2-neutral.	Methanol was until then forbidden as a marine fuel by the Central Commission for Navigation the Rhine (CCNR), but the Port of Antwerp's project received the European Commission's green light after 18 months of negotiations
Port of Antwerp	Belgium	EU	YES	YES	NO	The ports of Antwerp, Bremen, Hamburg, HAROPA and Rotterdam have signed a Memorandum of Understanding on 21 June 2021 to facilitate the implementation of Onshore Power Supply (OPS). With this new agreement, these North European ports want to pave the way towards zero-emission shipping and send a strong message of fair competition, clean shipping, and clean supply chains. The main points of the MoU concern a clear regulatory framework for the use of shore power (or equivalent alternative), an equivalent valuation of fuels, and sufficient availability of public funds to implement these projects. With this MoU the ports hope to set an example for other ports, terminals and shipping segments to follow.	
Port of Rotterdam	Netherlands	EU	YES	NO	YES	Hydrogen could be the way forward for road transport. Air Liquide and the Port of Rotterdam Authority are working together to enable 1,000 hydrogen-powered zero-emission trucks on the roads connecting the Netherlands, Belgium, and West Germany by 2025. Several partners representing the whole supply chain, from truck manufacturers to transport companies as well as leading fuel cell suppliers are part of the project.	This is one of the largest projects in Europe for the development of hydrogen trucks and related infrastructure and will contribute to improve air quality by reducing CO2 emissions by an estimated amount of more than 100,000 tonnes per year, which is equivalent to 110 million kilometres driven
Port of Rotterdam	Netherlands	EU	YES	YES	NO	Sea-going vessels that arrive in Rotterdam need power at the quay for the power supply on board. Currently, diesel generators are usually used for this. Every year, sea-going vessels moored along Rotterdam's quays consume as much electric power as 250,000 to 300,000 households. And in the process, they release various harmful emissions into the atmosphere.	To increase the possibilities for shore-based power, the Municipality of Rotterdam and the Port of Rotterdam Authority are working together on a series of projects that are intended to accelerate and scale up the adoption of shore-based power. By 2030, this could result in

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							carbon savings of approximately 200,000 tonnes per year
Associated British Ports	UK	EU	YES	NO	NO	Building on its achievement of reducing its carbon emissions by 35% since 2014, the Associated British Ports (ABP) has continued to decarbonise its operations throughout the last year, gaining ISO 14001 Certification for Environmental Management for all 21 ports. Green initiatives this year have included the opening of the GB£55m shore power-enabled Horizon cruise terminal at ABP's Port of Southampton. In 2020, ABP's Port of Hull completed the UK's largest commercial rooftop solar array	
Port of Rotterdam	Netherlands	EU	YES	NO	YES	The Port of Rotterdam Authority has set up an incentive scheme to support innovative projects involving alternative fuels in sea-going shipping. The scheme started on 21 January 2019 and will continue until 31 December 2022. The aim is to considerably reduce CO2 emissions and to give a boost to projects that are perhaps difficult to get off the ground without financial support	The alternative fuel should result in a CO ₂ reduction of over 50% compared with the current gas oil and diesel oil
Associated British Ports	UK	EU	YES	NO	YES	The port could become a model for other ports, making the most of the decarbonisation potential of hydrogen. Green hydrogen could be produced at the port by electrolysis, using a renewable energy supply such as offshore wind.	Associated British Ports (ABP), together with Uniper, Siemens Energy and Toyota Tsusho, submitted a joint bid to the Clean Maritime Fund for matched funding to develop their project of getting an initial c.20MW supply of green hydrogen to the Port of Immingham by 2025
Port of Gdynia	Poland	EU	YES	YES	NO	The Polish Port of Gdynia Authority S.A. is preparing to be a future offshore wind hub, supporting the attractiveness of the port to project developers. With a strong port infrastructure, Poland can become an export hub for the offshore wind supply industry, as it has announced a target to deliver 11GW of offshore wind by 2040.	
North Sea Port	Belgium and the Netherlands	EU	YES	YES	YES	North Sea Port is supporting efforts to increase the sustainability of Zeeland's energy supply with the construction of a 60MW solar farm at Valuepark Terneuzen that will generate solar power for over 14,000 households. The farm will generate more than 56 million kWh per year, which equates to 22,600 tonnes of CO2 saved annually, and will be the largest in Zeeland and in the North Sea Port area.	The farm should be operational in November 2021 and, together with the energy transition and climate objectives, will anchor business activity and employment in the port area
Port of Copenhagen	Denmark	EU	YES	YES	YES	An initiative to make port activities in Copenhagen greener has led the way for a joint collaboration between Copenhagen Malmö Port (CMP) and ferry company DFDS, to establish an onshore power facility at the DFDS terminal in Copenhagen	The OPS facility is expected to be operational from late summer 2021, and will deliver up to 10 kV with 50 Hz for DFDS' ferries Crown Seaways and Pearl Seaways while in the port.
Port of Amsterdam	Netherlands	EU	YES	YES	NO	The Port of Amsterdam will be the location for the new biofuel plant Advanced Methanol Amsterdam (AMA) of GIDARA Energy. The plant will produce around 87,5 kilotons per annum of renewable methanol each year, which amounts to the waste produced by 290,000 households. This renewable methanol, which is a sustainable alternative to	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						methanol produced from fossil fuels, will contribute to reducing carbon emissions.	
Port of Bilbao	Spain	EU	YES	YES	YES	One of the projects of the port of Bilbao aiming at reducing greenhouse gas emissions concerns a green hydrogen production plant which uses renewable electricity as a power source. The plant is set to be operational in 2024	The e-fuel plant will have a production capacity of 8.000 litres/day, enabling renewable energy to be stored on a large scale. Planned investment stands at EUR 67 million.
Port of Gdynia	Poland	EU	YES	YES	YES	The new Public Ferry Terminal of the Port of Gdynia will open in June 2021. The biggest project of the Port in nearly 50 years, the new modern terminal will allow the possibility to provide OPS to ferries calling at the port.	By powering ships using OPS, no exhaust fumes are released in the air. Ten hours of power use in a port by a large cruise ship allows to save 22 tons of CO2.
Port of Lowestoft	UK	EU	YES	YES	NO	ABP will develop a new green infrastructure at the Port of Lowestoft in Suffolk over the next five year. The Lowestoft Eastern Energy Facility (LEEF) will enable the port to accommodate new, modern offshore support vessels and will allow for Operations & Maintenance (O&M) activities and construction support activities to be carried out in the port, thereby supporting the production of offshore energy of the wind farms in Barrow, Grimsby and Lowestoft.	
Port of Kiel	Germany	EU	YES	NO	NO	In the context of the 2015 increase air emissions standards in the Baltic Sea emissions control area (ECA), the Port of Kiel and its partners looked to the use of cleaner fuels. Methanol does not contained sulphur - so passes the ECA criteria - and emits a reduced amount of NOx, PM and CO2 compared to traditional fuel.	
Port of Piombino	Italy	EU	NO	YES	NO	In recent years, the Port of Piombino has been redesigning its maintenance and service projects with a view to upgrading the energy efficiency of its plants while maintaining the high quality of the services they provide and getting as close as possible to zero harm. To this end, all public lighting systems under the port's jurisdiction are being progressively replaced, using new generation lighting and LED technology to reduce energy consumption	
Port of Antwerp	Belgium	EU	YES	YES	NO	Alongside partners including Air Liquide, BASF, Borealis, ExxonMobil, INEOS, Fluxys, Total & VLAO, the Port of Antwerp is investigating the technical and economic feasibility of building CCUS (Carbon Capture Utilisation & Storage) infrastructure. The partners are currently carrying out a feasibility study with the support of the Flemish Agency for Innovation & Enterprise to study the possibility of building a central "backbone" in the form of a pipeline along the industrial zones on both the Right and Left banks of the Scheldt, along with various shared processing units, a shared CO2 liquefaction unit, interim storage facilities and cross-border transport of CO2, both by ship and by pipeline.	
Port of Valencia	Spain	EU	YES	YES	NO	The H2Ports project, funded by the Fuel Cells and Hydrogen Joint Undertaking and coordinated by Fundación Valenciaport, aims to boost the transition	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						of the European port industry towards an effective zero-emission and safe operative model.	
Port of Valencia	Spain	EU	YES	YES	NO	The Valenciaport cluster has been actively involved for almost a decade in energy efficiency projects aiming to reduce fuel consumption. In cooperation with leading equipment manufacturers such as Terberg, Hyster-Yale, and Paceco, the terminals in the Port of Valencia, the Port Authority of Valencia and Fundación Valenciaport have developed a range of energy efficient designs, including prototypes of LNG and electrified terminal tractors, eco-diesel RTG and reach stackers, a terminal carbon footprint sensor network, HDG RTG, hybrid full LNG-electric reach stackers, automated lighting systems and more besides.	
Port of Marseille	France	EU	NO	NO	NO	Since 2019, JUPITER 1000 has produced hydrogen through water electrolysis. Situated on the Piicto platform in Marseille Fos' industrial zone, JUPITER 1000 is the first "power to gas" unit connected to the gas transport network in France. Supported by GRTGaz, seven industrial partners and financed by local, national and European authorities, this innovative technology consists in converting surplus renewable electricity to gas (hydrogen and synthetic methane), before storing it in existing gas networks.	
Port of Marseille	France	EU	YES	YES	YES	The port had already installed 3 OPS facilities for the ferries serving Corsica.	In 2019, the Port of Marseille Fos approved a new investment of €20 million dedicated to the OPS facilities at the port (Connexion Electrique des Navires A Quai, CENAQ) for maritime passenger transport.
Port of Barcelona	Spain	EU	NO	YES	YES	Looking to further boost its green credentials, the Port of Barcelona has investigated the possibility of renewable energy generation within the port area. While the potential of solar energy is promising, the investigation found wind generation impossible in the port the height limitation imposed by the nearby airport.	An initial study found that the photovoltaic generation potential of all the port area is around 92 MWp and its annual electricity generation could reach up to 120,000 GWh.
Port of Barcelona	Spain	EU	YES	YES	YES	As part of its ambitious emissions reduction strategy, the Port of Barcelona approved an OPS project consisting of the electrification of its main piers and docks for cruise ships, container ships, ferries and car carriers.	The project is expected to reduce 50% of NOx emissions and 25% of PM-10 in the port by 2030 compared to estimated emissions in 2017.
Port of Vigo	Spain	EU	YES	YES	NO	In order to improve energy efficiency of the harbour market – and thus reduce energy costs – the Port Authority of Vigo has renovated the fish market building, insulating it and fitting it with energy efficient LED lighting. Likewise, a smart grid system for managing electrical efficiency has been implemented, and a photovoltaic renewable energy system has been installed to provide clean energy.	
Port of Rotterdam	Netherlands	EU	YES	YES	YES	The Port of Rotterdam has invested in energy infrastructure for residual heat, steam, and CO2. There is a clear benefit of collecting residual heat produced by industry, as it can be used in heating for	Moreover, the Port, the Gasunie and Energie Beheer Nederland (EBN) are jointly exploring the realisation of Porthos, an infrastructure project that aims to

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						households in neighbouring cities such as Rotterdam, the Hague and Leiden.	collect CO2 emissions in the Rotterdam port area to be stored in empty gas fields under the North Sea. In 2019, ExxonMobil, Shell Air Liquide and Air Products reached an agreement regarding Porthos to start preparatory work on the project.
Port of Klaipeda	Lithuania	EU	YES	YES	NO	Responding to the need for innovation solutions to make alternative fuels easily available, Klaipėda Terminal has installed the first floating LNG import terminal in the world. The facility ensures flexibility by providing services to multiple consumers at the same time. In 2017, Independence became the world's first floating terminal not only to supply degassed LNG to the gas transmission system, but also to reload LNG to smaller gas carriers for further distribution in the Baltic Sea region. As part of this process, Lithuania has become the 12th largest country for LNG re-exports	
Port of Valetta	Malta	EU	YES	NO	NO	The Maltese Transport Authority is a project partner in the WestMOPoCo Project and IMAROS Project. The West MOPoCo initiative supports the states of the western Mediterranean in strengthening their cooperation in the field of preparedness for and response to oil and highly noxious substances marine pollution	
Port of Esbjerg	Denmark	EU	NO	YES	NO	The Port of Esbjerg is equipped with new shore power units using renewable electricity from offshore wind turbines. Their impact is monitored through a special programme developed in partnership with Honeywell.	
Port of Esbjerg	Denmark	EU	NO	YES	NO	The Port of Esbjerg is a market leader when it comes to handling and shipment of windmills. More than 2/3 of all offshore wind capacity in Europe is shipped from the Port of Esbjerg. But the Port has recently been looking at further increasing its ambitions in support to the green economy. Within the next five years, an additional 1 million square meters for storage of the windmill parts needed for shipment will be established. This will allow the Port to continue to serve the growing demand for offshore wind power.	
Port of Hirtshals	Denmark	EU	YES	YES	NO	At the end of 2019, four wind turbines were put up at the Port of Hirtshals. The turbines were established without any public subsidies and are run solely on commercial terms. Only a month after being put into use, they indicated a positive electricity curve for the port and the town. In certain periods, the electricity production has even been 50% higher than usage. The port is thus contributing directly to greener electricity production.	
North Sea Port	Belgium and the Netherlands	EU	NO	YES	YES	North Sea Port will replace existing street lighting with LED lighting in the entire Belgian part of the port in the next three years. This is a first step in the implementation of the Canal Zone Lighting Plan	This is a first step in the implementation of the Canal Zone Lighting Plan (drawn up in 2011) with the various partners and municipalities.

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						(drawn up in 2011) with the various partners and municipalities.	
North Sea Port	Belgium and the Netherlands	EU	YES	YES	YES	North Sea Port is working with its partners in the ports to build up its renewable energy capacity and ensure the greenest mix of energy possible coming from the port. Recently, North Sea Port has invested in creating a strong offshore field in Vlissingen with 50 wind farms currently operating. A further 100 wind turbines are in operation across the port area, jointly generating 280 megawatts each year, equivalent to the power needed to provide 180,000 households with a year's worth of power.	North Sea Port has installed solar panels and parks at Zonneburg in Ghent and at the Scaldia solar park in Vlissingen and Terneuzen, to generate a total of 110 megawatts of power, equal to the annual consumption of 28,000 households
Port of Stockholm	Sweden	EU	YES	YES	YES	As part of its commitment to renewable energy, Ports of Stockholm inaugurated a new rooftop solar cell facility on a large warehouse at Stockholm Norvik Port in September 2021. The 3,600 square metre solar cell system is one of the biggest in Sweden and is able to produce up to 560 MWh of solar electricity each year, which represents the energy requirements of about 25 detached houses. The facility generates a significant part of Ports of Stockholm's power requirements, and this within its port area. This results in important savings for the Ports, both financially as well as environmentally. This is not the first solar cell system owned by Ports of Stockholm, which already has five other similar facilities, the first one dating from 2013.	The facility generates a significant part of Ports of Stockholm's power requirements, and this within its port area. This results in important savings for the Ports, both financially as well as environmentally.
Port of Gothenburg	Sweden	EU	NO	YES	NO	The Port of Gothenburg has a number of financial incentives to incentivise vessels to connect to an onshore power supply. There is no charge for the power provided – on the contrary, vessels connected to an onshore power supply score higher in the indexes on which the environmentally discounted port charge is based. Tax on onshore power has been reduced substantially in Sweden for a number of years and is currently 0.5 öre (around 0.05 cent) per kilowatt-hour. The Port has also been working actively to promote the use of liquefied natural gas (LNG) as a marine fuel. Since 2015, vessels can fill their tank with LNG in the Port of Gothenburg	
Port of Tallinn	Estonia	EU	YES	NO	YES	In a continuation of its efforts to increase its use of renewable energy, the Port of Tallinn will now only consume green electricity produced in Estonia. This is an important step forward to achieve the Port's ambition to reduce its ecological footprint and to become climate-neutral.	A new agreement between the Port and Eesti Energia foresees the supply of 10 GWh of renewable electricity in 2021 to the Port, which will allow to save 7,000 tons of CO ₂ , which would otherwise have been released in the air.
Port of Tallinn	Estonia	EU	YES	YES	NO	The Port of Tallinn has set itself the goal of increasing energy efficiency and the use of renewable energy, while keeping an eye on the sustainable use of all natural resources. In planning buildings and infrastructure, the Port has implemented Digital Building Information Modelling (BIM), which facilitates the improvement of the functionality of the facilities	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						and implements sustainable solutions in the design phase.	
North Adriatic Sea Port	Italy, Slovenia, Croatia, Albania	EU	YES	YES	YES	Conscious of its role as a role-model, the North Adriatic Sea Port Authority (NASPA) has, since 2009, been looking into ways to reduce its carbon footprint through energy efficiency improvements throughout the authority's premises. Given that lighting represents a fifth of consumed electricity, a number of projects have been implemented to improve energy efficiency in areas directly managed by NASPA. These include a new LED lighting system on the public road and a new LED lighting system supported by solar panels along 15km of one of the main port canals, the Malamocco-Marghera canal	The result of these measures are a reduction of around 70% of electricity use
Port of Rotterdam	Netherlands	EU	NO	NO	YES	The Port of Rotterdam Authority and BigMile are developing a digital platform to identify transport-related emissions in the port, providing insight into emissions at a business location, for example, and which should also provide companies with more details on carbon and other emission levels in their total transport chain	The goal for the coming six months is to include emissions from supply chains en route to and leaving the port of Rotterdam in order to clarify transport emissions from door to door. In the first project phase, the focus is on the port of Rotterdam area, from 60 kilometres offshore to the Brienenoordbrug.
Port of Rotterdam	Netherlands	EU	YES	YES	YES	The Port of Rotterdam is working towards achieving a carbon-neutral and circular port in three steps: Step 1 Efficiency & infrastructure: reusing port heat, and capturing and storing CO2 under the North Sea; Step 2 Energy transition: industry will switch to electricity, hydrogen and green hydrogen; Step 3 New materials and fuel system: replacing fossil raw materials by sustainable alternatives.	The Port of Rotterdam and Gasunie are working together to reuse this residual heat as a replacement for natural gas in households and greenhouses. CO ₂ emissions will be reduced, and less gas will be needed from Groningen. At the moment 16,000 Rotterdam households are being heated using residual heat from a refinery in Pernis.
Port of Rotterdam	Netherlands	EU	YES	NO	YES	As part of its commitment to GHG emissions reduction, the Port of Rotterdam has established a start-up called PortXchange. PortXchange originates from Pronto – a collaborative vessel and terminal planning platform – designed by the port. Pronto has been used in Rotterdam since 2018, and various pilots have been conducted, with fantastic results.	Together with strategic partners Shell and Maersk, PortXchange successfully conducted several pilots outside Rotterdam. As of 2020, PortXchange is used by more than 50 parties to support over 100 000 port calls
Port of Bergen	Norway	EU	YES	NO	NO	Taking an important step towards an emission-free port, the Port of Bergen acquired a new workboat, Sydnese, meeting environmental credentials thanks to a battery pack. Using batteries only will give the boat a two-hour range at 4-5 knots. Running conventional engines gives a further 5 hours of sailing at 27 knots.	
Port of Hamburg	Germany	EU	YES	NO	NO	The Hamburg Port Authority (HPA) will soon acquire an unusual hybrid workboat, named Chicago, who will be significantly more efficient than its 60-year-old predecessor and also an extremely eco-friendly boat which will tackle most of Hamburg's underwater levelling work	
Port of Valencia	Spain	EU	YES	YES	YES	The Port of Valencia has just installed its third cabin to monitor air quality and other environmental factors at the Port of Segunto. The 3 booths can record up to	The two cabins which were already in the Port of Valencia are part of the GREEN C PORTS project, coordinated by the

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						8 different gases and particles which allows for a precise analysis of air quality around the port. Using the latest technology, the cabin can measure in real time the concentration of sulphur dioxide (SO ₂), nitrogen oxides (NO ₂ /NO/NO _x), ozone (O ₃), carbon monoxide (CO) and PM ₁₀ and PM _{2.5} particles.	Valenciaport Foundation and co-financed by the European Union
Port of Oostende	France	EU	YES	YES	NO	The Port of Oostende is the lead partner of a new project developed together with 15 different partners in the EU, France, the Netherlands and Flanders, including shipowners, shipyards, research institutions, energy producers and ports. The shipping industry is currently responsible for 3% of all greenhouse gases. Shipping industries and port authorities need to invest in decarbonisation and zero-emission technologies, which include biofuels, fuel cells and batteries, and hydrogen-based fuels. the ISHY project intends to achieve the following objectives: develop tools to implement and support the transition to hybrid and hydrogen technologies in vessels and ports; demonstrate the use and effectiveness of these technologies in new and retrofitted vessels; establish a hydrogen bunkering station at the Port of Oostende to show the feasibility of H ₂ bunkering facilities in ports; and increase the acceptance of low and zero-carbon technologies with high impact potential and cost-effectiveness in the longer term.	
Port of Helsinki	Finland	EU	NO	YES	YES	The amount of heavy capacity OPS connection points in Port of Helsinki is being increased. Until now, only one OPS connection has been in use since 2012 in Katajanokka harbour. The Port is also increasing automooring to make port operations faster and more sustainable. The automooring system contributes significantly to CO ₂ emissions reduction by optimising ship speed and reducing the time spent waiting, and mooring and unmooring vessels.	The completion of all planned connection points will make it possible to use heavy capacity OPS on 10 quays in the Port of Helsinki. The plan is to achieve this by the end of 2026.
Port of Valencia	Spain	EU	YES	YES	YES	As part of the net-zero emissions strategy of the Valenciaport cluster, led by the Port Authority of Valencia, Fundación Valenciaport and the Port Authority of Valencia are working together on the GREEN C Ports project to pilot the use of sensors, big data and artificial intelligence in the Port of Valencia to reduce the impact of port operations on the city, monitor emissions from ports and vessels and optimise performance of port operations.	The project aims to decrease port traffic congestion and reduce CO ₂ emissions by 10% from trucks in the Port. Further benefits will be the monitoring and prediction of air quality and noise levels to generate notifications to government institutions when certain levels will be exceeded
Port of Rotterdam	Netherlands	EU	YES	YES	NO	The Port Authority of Rotterdam has taken strong measures to reduce its carbon footprint. A third of patrol vessels runs 100% on biofuel. We are also stimulating employees to travel by public transport or bicycle. For lease car drivers, a CO ₂ standard of 59 g/km applies. The office uses heat from the port and green electricity. And throughout the port, the Port Authority is replacing the public lighting with LED.	
Port of Valetta	Malta	EU	YES	YES	YES	The Maltese Transport Authority (the port authority of the Port of Valetta) has launched an ambitious project to reduce air pollution from passenger ships	The project will amount to just under €50 million and is projected to cut over 90% of

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						and eventually Ro-Ro vessels in the port. The project will amount to just under €50 million and is projected to cut over 90% of the air pollution from cruise liners and Ro-Ro ships.	the air pollution from cruise liners and Ro-Ro ships
Port of Tallinn	Estonia	EU	YES	YES	NO	To ensure that outdoor air in the Port's locations of operation is clean and of high quality, the Port of Tallinn has employed a number of innovative solutions in close cooperation with its customers and partners	
Port of Dover	UK	EU	YES	YES	YES	The Port of Dover is working hard to make its existing and new operations sustainable, aiming to reduce its carbon footprint by 5% each year towards a net zero carbon future.	The Port has been successful in achieving a 49% carbon reduction since 2007, more than double relevant British and European targets. 4,837 individual photovoltaic panels have been installed on the roof of the new Dover Cargo Terminal West, with an additional 933 panels installed at the former Eastern Docks
Port of Venice	Italy	EU	YES	YES	YES	With the aim of reducing emissions around Venice, the North Adriatic Sea Port Authority (NASPA) instituted the Venice Blue Flag (VBF) agreement in 2007. The agreement brings together the main cruise companies, the Venice Harbour Master, the Venice Municipality and NASPA itself to promote the adoption of fuels with low-sulphur content	The benefits of the VBF are clear: as well as a clear improvement in the air quality in the bay area, the reduction in terms of marginal external costs has been estimated at €2 million, clearly outweighing the increase in costs related to the adoption of distillate fuel (between €1.1 million and €1.5 million).
Port of Vigo	Spain	EU	YES	NO	YES	The Port of Vigo will be implementing the LIVING PORTS, an EU Horizon 2020 funded project, to shift the Coastal and Marine Infrastructure (CMI) industry's operations away from obsolete construction toxic to many marine organisms and requiring expensive maintenance and towards nature-inclusive infrastructure with structural, environmental, and socio-economic co-benefits. The project is part of the port integral program of actions "Sunset Dock".	The benefits of the VBF are clear: as well as a clear improvement in the air quality in the bay area, the reduction in terms of marginal external costs has been estimated at €2 million, clearly outweighing the increase in costs related to the adoption of distillate fuel (between €1.1 million and €1.5 million)
Port of Rotterdam	Netherlands	EU	YES	YES	NO	The Park Maashaven at the Port of Rotterdam Authority combines the dynamism of the port and river with a big public park that features two large slopes, lawns, a public square and a boulevard. The area allows for the residents of surrounding neighbourhoods and other Rotterdam citizens to stroll, sunbathe, play, or have a picnic. A new 7-ha meeting point with room for inland shipping will be created. Plans include a tidal park where plants pop into view twice a day.	
Port of Stockholm	Sweden	EU	YES	YES	YES	In collaboration with Finnish company Arctia-Meritaito and the Port of Naantali, Ports of Stockholm is testing a solar-powered smart buoy, with the aim of improving efficiency of service and maintenance in a sustainable way. This unique buoy, which has a twin at the Port of Naantali, is equipped with solar cells to charge its batteries, which only need to be replaced every seven to ten years, much less frequently than current buoys whose batteries have a lifetime of one year.	The project is part of the Intelligent Sea EU project, funded by the CEF programme.

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Tallinn	Estonia	EU	YES	YES	NO	The Port of Tallinn opened a brand new cruise terminal for the 2021 cruise season. In line with the Port's aims to be a front runner in sustainable terminals and to improve the environmental footprint of its activities, the new modern, multifunctional terminal has been built with a view to reducing its negative impact on the environment. The environmental sustainability of the new terminal was a key priority during its construction	
Port of Malmö	Copenhagen	EU	NO	YES	YES	Copenhagen Malmö Port and By & Havn have reached an agreement on a new container terminal at Ydre Nordhavn. The construction of the new terminal takes account of the environment and environmental approvals have been granted for the project. Thanks to its location close to Copenhagen, delivery of goods will be possible with minimal emissions and congestion on Danish roads.	The new terminal will be bigger than the existing terminal at Levantkaj, with around 165.000m ² , compared to 140.000m ² currently. In addition, two new container cranes will be installed. In total, the length of the quay will be of 550m, and water depth will go down to 12,5m.
Port of Helsinki	Finland	NO	NO	NO	NO	Environmentally influenced financial incentives play an important part of the Port of Helsinki's role of green facilitator. The Port offers environmental discounts on vessel fees for Environmental Ship Index (ESI) points, noise level in downtown harbour and for environmental investments. The Port also offers cruise ships a discount on waste fees, if they leave their wastewater in port reception facilities. Reviewing the results of these fees, the Port has found that the waste fee discount for cruise ships has been particularly effective.	
Port of Algeciras	Spain	EU	NO	NO	NO	The Port Authority of Algeciras will renew 36 of the 57 vehicles in its fleet in the coming months following the acquisition of electric and hybrid vehicles. Among them are 12 patrol cars and 6 Port Police motorcycles. Added to this, is the incorporation of 5 new electric vehicles into the fleet of the port body.	
Port of Amsterdam	Netherlands	NO					
North Sea Port	Belgium and the Netherlands	EU	NO	NO	NO	North Sea Port is committed to ensuring the greenest possible modal share. The port has invested heavily in shifting container transport off the road onto inland waterways (saving around 30 trucks for each inland vessel that carries 30 containers). Currently, over 50% of transport between the port and the hinterland is conducted via inland shipping.	
Port of Antwerp	Belgium	EU	NO	YES	YES	The Port of Antwerp-Bruges redeveloped Fort Sint-Filips polluted site to restore valuable habitat and provide flood protection. The site was polluted through years of dumping oil waste and the contamination was stored on site within an underground, watertight wall of bentonite cement to avoid unnecessary transport to a treatment centre	
Port of Sevilla	Spain	EU	YES	YES	YES	The Port of Sevilla has recovered a 275-meter-long stretch of the right bank of its Guadalquivir River, where the Doñana National Park's coastline is located. The area had been affected by erosion due to recent storms, high tides and flooding.	The regeneration of the Doñana's beaches began in November 2021 and was achieved through the deposit of 62.000 m ³ of sand extracted during

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							maintenance dredging of the navigation channel
Port of Tarifa	Spain	EU	NO	YES	NO	The Port of Tarifa breakwater restoration project aims to maintain the port infrastructure and the integrity of the Port of Tarifa itself. The presence of specimens of <i>P. ferruginea</i> (species protected as it is in danger of extinction) in this dock depends on its own integrity, so its restoration is necessary not only to meet the first goal mentioned but also to guarantee the survival of the population of <i>P. ferruginea</i> .	
Port of Algeciras	Spain	EU	YES	NO	NO	The Port Authority of the Bay of Algeciras (APBA) promotes scientific studies aimed at understanding the evolution and risks of the reproductive expansion of <i>Rugulopteryx Okamurae</i> , better known as invasive algae, and assessing the risks of possible future associated biological invasions to the port infrastructures of the Bay of Algeciras and Tarifa, as well as its early detection and its eradication.	
Port of Riga	Latvia	EU	NO	NO	NO	The Freeport of Riga Authority, together with PurOceans Technology and SIA "OVI", is testing an environmentally friendly method for collecting historical pollution in the port water area. The solution is for non-invasive soil (of lakes, rivers, seas and oceans) cleaning to remove oil sludge, microplastics, chemicals and other pollutants. It is based on the so-called flotation method, which does not involve chemicals, electrical impulses or dredging, thus reducing damage to flora and fauna.	
Port of Bremen	German	EU	YES	NO	NO	The first German guidelines for granting permits for underwater hull cleaning at the Bremen and Bremerhaven ports have been published as a result of the 'CLEAN' project, with the aim of reducing pollutants into port waters thanks to proactive cleaning on abrasion-resistant, biocide-free coatings for the shipping business.	
Port of Roenne	Denmark	EU	NO	YES	NO	Having entered a climate partnership agreement in 2020, the Port of Roenne A/S on Bornholm will plant 14,000 trees in Kannikeskoven near Åkirkeby in 2021, surpassing its annual target of 10,000 trees for the next 10 years. In total, this corresponds to 25 hectares or an area the size of 35 football fields.	
North Sea Port	Belgium and the Netherlands	EU	NO	NO	NO	North Sea Port is actively involved in the 'Internet of Water' project initiated by imec, VITO, Vlakwa, Vlaamse Milieu Maatschappij, De Watergroep and Aquafin with the support of the Flemish Agency for Innovation and Entrepreneurship (VLAIO). Within this four-year research project, which was launched in 2019, Flanders is rolling out a dense network of smart sensors to monitor the water quality in the Ghent-Terneuzen canal.	
Port of Algeciras	Spain	EU	YES	NO	NO	The Port Authority of Algeciras is undertaking an intensive cleaning campaign of its shores, thanks to the initiative promoted by its Sustainability Area. These initiatives are part of the Green Strategy of the Port Authority of the Bay of Algeciras with which the	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						institution is aligned with the Sustainable Development Goals of the UN 2030 Agenda.	
Port of Le Havre	France	EU	YES	NO	NO	Port of Le Havre, together with the company Paysages de l'Estuaire, has installed nest boxes near the buildings and green spaces of the port area to help the animals looking for a nesting place. The 20 nest boxes that have been installed (10 for swallows and 10 for bats) have different shapes and sizes to accommodate a wide diversity of animals.	
Port of Livorno	Italy	EU	YES	NO	NO	As a result of cleaner waters caused by the COVID-19 lockdown, local residents and the local newspaper Il Tirreno launched a campaign to carry out a concerted, comprehensive cleaning of Livorno's canals, while the rubbish was clearly visible. In its role in charge of the Canals, the North Tyrrhenian Ports Network teamed up with Labmare (dealing with cleaning operations), Sub Sea (a team of underwater divers) and ISPRA (monitoring ecological risk) in a spirit of collaboration inspired by the epidemic to take on the issue free of charge.	
Port of Cava	Spain	EU	NO	NO	NO	With the objective of protecting and increasing the amount of wildlife around the port of Cava, the Port Authority begun a project to obstruct dragnet fishing. The port used the columns from the landing stage to create physical barriers against this illegal activity. The project required the mapping of the phytozoobenthotic presence, which showed that there was general degradation of the seabed but that there were numerous areas suitable for deterrents against illegal fishing.	
Port of Piombino	Italy	EU	NO	NO	NO	Over the last years, the Port of Piombino has taken care to ensure the constant cleaning of the beaches that fall under the jurisdiction of the Port Network Authority's Territorial Office in Piombino. This has involved the removal and disposal of all materials that the sea periodically washes up.	
Port of Antwerp	Belgium	EU	YES	NO	NO	Together with the partners in the Great Saeftinghe nature park, a green area straddling the border between Belgium and the Netherlands, the Port of Antwerp has issued a Request for Proposals aimed at farmers on the left bank of the Scheldt, as part of a drive to promote nature-inclusive agriculture.	
Port of Algeciras	Spain	EU	NO	NO	YES	This project of the Port Authority of Algeciras aims to recuperate the local Patella Ferruginea population, an endemic Mediterranean gastropod, currently listed as an endangered species. The projects consists in the translocation of some specimens of the species from Melilla to Algeciras, located with the help of the 3D print technology technology AIMS (Artificial Inert Mobile Substrat). Since the project began in 2016, two translocations have been carried out, with a survival rate of 90%.	Since the project began in 2016, two translocations have been carried out, with a survival rate of 90%.
Port of Valencia	Spain	EU	NO	NO	NO	The EU-funded HiSea Project offers ports high resolution data for water quality forecasts, met-ocean and bathymetry monitoring.	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						The information and forecasts are presented in a clear, visual, digestible way, presenting flexible layers for port authorities and managers. Near-real-time data based on analysis of satellite images provides accurate, reliable and high-resolution information that will make port operation more cost-effective. The innovative HiSea Platform incorporates, and processes data obtained through the marine, land and climate service COPERNICUS (the EU Earth Observation and Monitoring service), local monitoring data and advanced modelling.	
Port of Marseille	France	EU	NO	NO	YES	This water segregation system collects contaminated water, treats it by decantation and filtration before releasing it into the marine environment. This system will be a first in the Mediterranean. The start of the works is scheduled for the end of 2020 and will last around five years. The result of the system will be a reduction of discharges into the sea and the improvement of the water quality in the Bay of Marseille.	The Port of Marseille Fos is dedicating €12 million to equip its 10 types of ship repair with a system for water treatment
Port of Vigo	Spain	EU	NO	NO	NO	This Sunset Dock project of the Port of Vigo includes a set of actions to increase biodiversity in the port area and reduce emissions. At first, studies were made to look at how to project biodiversity in the port waters. Then, structures built to foster growth of flora and fauna in the port waters were designed and installed. Following the success of these structures, further initiatives are being implemented to increase biodiversity in the port. The final objective of the project is to build the 'sunset dock' for recreational use by the local community, where a local eco-reserve is on show.	
Port of Rotterdam	Netherlands	EU	YES	YES	NO	Rotterdam's port area is rich in animal and plant life, an aspect of the local environment the port has been active in investing in. The nearby Maasvlakte contains a wealth of nature, including the recently inaugurated Bird Valley, covering over 21 hectares of land. The Bird Valley has diverse islands, large water bodies and a wall where sand martins can breed. It is a safe, enclosed area where birds can rest, eat and breed, after they have flown in exhausted from the sea.	
Port of Gothenburg	Sweden	EU	YES	NO	NO	The establishment of the wetland is a voluntary undertaking of the Port of Gothenburg to compensate for the harbour's expansion in the immediate area around the Torsviken wetland. The project has identified important measures and, in collaboration with the Gothenburg Ornithological Association, has created a habitable wetland environment, whose aim is to promote biodiversity by creating habitat for local bird life and other wildlife.	
Port of Dover	UK	EU	YES	NO	NO	Every September a beach clean is organised by the Port of Dover and a local charity, White Cliffs of Dover Partnership. Shakespeare Beach is on the Dover-Folkestone Heritage Coast and is formed	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						mainly of vegetated shingle. In 2020, 74 volunteers from Dover and the surrounding areas took part in the beach clean and collected 38.5 bags (144kg) of rubbish. Vegetated shingle has been identified as an important habitat within the port, not only due to its scarcity (it is a UK priority habitat subject to a habitat Biodiversity Action Plan (BAP)) but also due to its importance for birds of conservation concern ('red-listed birds').	
North Adriatic Sea Port		EU	YES	NO	NO	Mindful that emissions reductions targets must address all forms of pollution, the North Adriatic Sea Port Authority (NASPA) launched a series of projects to monitor and reduce noise pollution, working alongside academics from the University of Padua	
Port of Koper	Slovenia	EU	NO	NO	NO	Case studies of proposed green activities in scientific literature	
Port of Rotterdam	Netherlands	EU	YES	YES	NO	Case studies of proposed green activities in scientific literature	
Port of Gävle	Sweden	EU	YES	YES	YES	Port of Gävle in Sweden, where the port has used dredged contaminated material to create entirely new land to expand the existing footprint of two areas of the port, including expanding the port's cargo terminal outward into a deepened shipping channel	
Port of Barcelona	Spain	EU	YES	NO	NO	study the effect produced by discharging this residual water on the acidity level (pH) of Barcelona port water. This objective was achieved through the periodical sampling and analysis of Barcelona port water in collaboration with the IDAEA (CSIC) laboratory	
Port of Izmit Bay	Turkey	AS	NO	NO	NO	This study evaluated the emission reduction rates when Automatic Mooring System (AMS) and Cold Ironing (CI) methods were applied separately, and together at a port in Izmit Bay. We used Entec and EPA methodologies to estimate ship-borne emissions	
Port of Casablanca	Morocco	AF	NO	NO	NO	The present paper aims to reduce unclean production of CO2 emission of port crane and improve the clean air gains, so authors studies the case of the most relevant Atlantic port located in Casablanca at Morocco and uses its operational data about daily energy of 11 RTGs crane collected for the last two years.	
Port of Valparaiso	Chile	US	NO	YES	YES	The paper presents a complete value chain for the use of green hydrogen in a port facility. The main objective was to propose the sizing of the main components that make up green hydrogen to ensure the supply of 1 MWe in replacing the diesel generator	
Port of Aberdeen	Scotland	EU	YES	YES	YES	Therefore, this study examines the feasibility of installing cold ironing	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						in a medium sized port with several small berths, based on the case of Aberdeen.	
Mediterranean ports	Europe	EU	YES	NO	NO	This study focuses on the state port reception facilities (PRF) in the case of the second biggest cruise region of the world, the Mediterranean and its adjoining seas. In particular, it sheds light on the extent that the current practices of cruise ports have achieved a satisfactory level of compliance to the emerging environmental related international regulatory framework.	
Port of Djibouti	Africa	AF	YES	YES	NO	The purpose of this study is to identify the most critical barriers that hinder the deployment of shore power supply in the container terminals of Djibouti. To achieve this aim, this study consults professional experts and experienced managers working in the maritime industry	
Port of Mongla	Bangladesh	AS	NO	YES	NO	Mainly Cutter Suction Dredger and Trailing Suction Hopper Dredger used at Mongla Port dredging works. All the dredged material was dumped on land and all of the low land of port area has filled up. To keep the port operational in connection with the market demand, huge amount of dredging will be required in upcoming years.	
Port of Bangladesh	Bangladesh	AS			NO	The findings reveal that capital cost, alternative energy price, and safety are the most important factors for alternative energy transition in Bangladesh. Apart from the benchmark HFO, Liquefied Natural Gas (LNG), HFO-Wind, and LNGWind hybrids are considered the most viable alternatives.	
Port of Amsterdam	Netherlands	EU			YES	The Port of Amsterdam region also host considerable demand for hydrogen – some 50PJh – even though hydrogen required for the production of bunker fuels (some 20PJh) for the shipping industry is not accounted for. A large share of this hydrogen will most likely be supplied by hydrogen produced from the regular seasonal surpluses of green power, which are typical for this region and result from seasonal supply overshooting demand. The development of green hydrogen facilities, with a minimal spatial footprint of 14ha. is needed to cover the summer-winter spread of the offshore wind coming to shore.	There is clear evidence that a close collaboration between the three harbours is likely to generate serious synergy benefits. Our modelling suggests that, depending on the scenario, these benefits can amount to anywhere between €100 – €300 million per annum for the three harbours combined. These synergies seem to be strongly dependent on a hydrogen backbone grid connecting the three harbours, such that hydrogen flows can easily be exchanged and collectively transmitted further into the hinterland. By collaborating via the backbone, the harbours will be able to act as a flexibility provider to the energy system: because hydrogen can be easily transported back and forth, a stable energy supply can be guaranteed. This is crucial for the overall energy market' security of supply and some specific destinations such as dedicated industrial activities in particular
Port of Den Helder	Netherlands	EU			YES	The scenario analysis unfold that connecting Den Helder to the backbone enables the benefit of full	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						synergies between the three ports. To gain these significant benefits a minor extension of the backbone with a 35-40km pipeline section to Den Helder is required. This backbone connection is very important for the three harbour regions to generate comparative advantages for scaling up specific additional economic activity. The re-use of exiting offshore exploration pipelines (three in total) combined with the proximity to large CO2 injection fields and to offshore wind location provides a competitive edge for hydrogen production in the Den Helder region, as a recent feasibility study has shown.	
The Groningen Seaports	Netherlands	EU			YES	Until 2030, the landfall of electricity from the Gemini Wind Park is already planned in or near the Groningen province, either via Eemshaven, or via Vlieter, or via Bergum in Friesland (20)23. The region has the potential to host multiple GW offshore wind capacity, but this will require a strong build-up of electric infrastructure in the region as well of the integration of these capacities via a transport corridor through the international recognized Waddensea area.	
Port of Klaipeda	Lithuania	EU			YES	The study of the environmental impact of shipping became a little-studied fleet of tugboats in the Baltic Sea region. The ecological impact of CO2, SO2, and NOx emissions assessment. was performed in two cases when diesel engines were replaced by natural gas-powered engines: using actual engine load data of typical tugboat KLASCO-3 and all the tugboats in the region of Baltic Sea based on statistical data of tugboat engine power	The study showed that a 33% fuel costs savings can be achieved each year. Based on the approved methodology, an ecological impact assessment was conducted for the entire fleet of tugboats operating in the Baltic Sea ports if the fuel type was changed from diesel to natural gas. The results of the assessment showed that replacing diesel fuel with natural gas achieved 78% environmental impact in terms of NOx emissions according to MARPOL 73/78 Tier III regulations.
Port of Jorf Lasfar, Safi, Agadir, Tan Tan, Laayoune and Dakhle.	Morocco	AF				The total potential for offshore wind along Morocco's coastline is reportedly 250GW [11], which is about 25 times the current total power plant capacity in the country and would provide enough electricity (770 terawatt-hours (TWh)) annually assuming a 35% capacity factor) to produce green ammonia for about a third of the international shipping fleet2	
Port of Szczecin	Poland	EU			YES	Our study showed that the secondary ports lacking technical conditions to serve large vessels, but with available space to develop their transshipment, storage, industrial, distribution, and logistics activities, may become major participants in circular supply chains. Taking advantage of the opportunities associated with participating secondary ports in the circular supply chain requires facing a number of challenges identified in the current literature, such as	ervices. Some of the sea-land circular supply chains analysed in this article require a broader range of time-consuming additional logistics services provided by port enterprises in addition to the basic transshipment services. The cargo types flowing in the circular supply chains are characterised by considerable diversity, while their

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						return-flow uncertainty, transport and infrastructure, the availability of suitable supply chain partners, coordination and information sharing, product traceability, and cultural issues	annual volumes are relatively low (50–300 thousand tonnes). Consequently, they are not attractive to stevedores operating in large primary ports, who are interested in serving larger cargo flows under long-term contracts.
Port of Malmo	Sweeden	EU			YES	The innovative state-of-art model introduced in this research deals with the feasibility of a closed loop, based on the circular economy, to give added value to a large amount of the waste generated from shipping activities in the Copenhagen-Malmö Port. The proposed model includes key elements such as waste management, biogas plant and cold ironing. Two scenarios are compared, first is the current condition and the second one is assumed with the established circular economy model by the port authority. paper. The above framework consisted of three main parts in line. Part a of the proposed framework illustrates the circular economy model with four main elements of the ship waste management, port ship management, port-owned biogas plant and cold-ironing facility to close the loop in the port. It shows how the organic wastes of the ships could be used to produce electrical power and give it back to the birthed cruise ships. In part b of the framework, the research methodology for the proposed model is shown in the block diagram. It describes both quantitative and qualitative methods result in the economic feasibility of the proposed circular economic model at a port. Involvement and cooperation of multiple. Finally, in part c is the recommendation which is the higher level port decision-making with recommendations.	Costs and benefits of both scenarios are analysed.
Port of Benoa	Bali	AS				It is important to note that the liquid waste from fish processing activity can be reused after being treated while vessel parking management can be used to ensure the safety of vessel traffic and increase the efficiency of fish landing. Moreover, it is possible to regulate the activities of fishermen toward recycling their fishing gears, implement reusable products around public terminals, and ensure terminal operators provide an adequate location for street/stand vendors. Every Sustainability 2022, 14, 6083 4 of 14 waste generated from surrounding activities can also be recycled by the port and city management instead of transporting them directly to landfills in order to provide certain benefits for both the entities of the port and the city. It is important to note that the current waste disposal system in Denpasar City is in the form of a landfill.	
Port of Aalborg	Denmark	EU			YES	This paper aims to design a hybrid system for a seaport microgrid with optimally sized	a grid/PV/wind/converter configuration with a

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						components. The selected case study is the Port of Aalborg, Denmark. The proposed grid-connected structure consists of renewable energy sources (photovoltaic system and wind turbines), an energy storage system, and cold ironing facilities. The seaport architecture is then optimized by utilizing HOMER to meet the maximum load demand by considering important parameters such as solar global horizontal irradiance, temperature, and wind resources.	250 kW-PV, 25,100 kW-WTs, and a 90 kW converter with an NPC of USD 4,718,247 is the best seaport microgrid design to serve the given ship's load at the target port. More than 80% of electricity was generated from RESs, whereas only 14.7% of energy was purchased from the main grid. The proposed seaport microgrid was also able to sell a considerable amount of energy back to the main grid. In terms of emissions, the optimal design could offer a significant reduction in CO₂, SO₂, and NO_x emissions, with a total reduction of 82.51%, 74.98%, and 74.98%, respectively. Emission reduction and cost-effectiveness of the optimal design of the seaport microgrid results in a promising solution for electrification of the future seaports following green maritime goals and the sustainable energy systems paradigm
Port of Kapellskär	Sweeden	EU			YES		Results of the simulations showed that the annual energy requirements of ships while at berths can be covered by installing three 660 kW Wind turbines representing the cost-effective solution taking the cost of emissions saving in consideration. With this configuration, the ships' electricity demand exceeds the renewable energy production between June and September, thus, a costly battery storage system is not effective to off-set the variation in wind energy. In this way, significant emission reductions occur through a viable renewable energy solution ensuring a cleaner and healthier environment
Port of Heraklion	Greece	EU			YES	The port is also a hub for multiple smaller ships, professional fishing ships and vessels that perform relatively small trips on a tight and dense schedule.. Because of their schedule, those vessels are not ideal for receiving electrical power from the shore due to them spending little time at berth. Another category that would not be fit for cold ironing is aging ships, because the cost of the modifications required would be too high considering their reduced operational life, making it an unattractive investment. Therefore, this analysis is	Nonetheless, another drawback of the old thermal plants of Crete, will be their non-competitiveness from economic perspective, when Cretan entities start participating in the Greek Power Exchange (Electricity Market). The analysis above demonstrates that only a trivial portion (<3%) in the energy production mix will be coming from thermal plants in the island of Crete in the next years.. With the use of shore-side

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						going to be focused on recently constructed and relatively bigger ships with significant power demand at berth time	power, ship owners can achieve a reduction of 65.48% in CO ₂ , 96.49% in SO _x , 90.67% NO _x and 96.38% in PM emissions in 2024. The use of shore power would positively affect air quality in the urban areas near the port and significantly ameliorate the life of the citizens
Iskenderun Port	Turkey	AS			YES		In Iskenderun Port Area, external cost of burned fuels are much higher than the total cost of consumed fuel. In case of meeting electricity energy demand by renewable sources, it would be possible to eliminate the approximately \$23 million of external emission costs per year. Adaptation of a cold ironing system requires both ports and shipping companies to invest in power transmission equipment.
Port of Nigeria	Nigeria	AF			YES	This study therefore is on comparative study of shore base marine power application as an air pollution mitigation technology in Nigeria seaports. Research objectives and hypotheses were formulated, data were sources from many sources and analyzed. The results of the analysis indicated available air mitigation technology for vessels, it also showed that the cost of cold ironing in Nigeria seaport when compared with the cost of electricity in other countries is significant; recommendations were made based on the results and findings	The study noted that Nigeria stands a better chance in adopting CI technique in terms of cost and benefits associated with the technology when compared with other African countries and global ports of Asia, Europe and USA.
Port of Trieste	Italy	AS				This paper aims to unpack and analyze the economic, regulatory, and environmental factors that can foster cold ironing as a standard installation in the Mediterranean Sea. Based on a model design for the port of Trieste (Italy) as applied to a cluster of target ports in the Adriatic Sea (in Italy, Croatia, and Greece), this article evaluates the cold ironing payback period by comparing costs of shore side-plants with environmental externalities and O&M costs. Moreover, the paper addresses key regulatory bottlenecks arising in different European jurisdictions with regard to the setting-up and development of cold ironing, while appraising the legal and economic consequences of deploying cold ironing in light of the future inclusion of the maritime sector in the EU Emission Trading System.	
Port of Shanghai	China	AS				The aim of this research is to propose a framework of optimizing government subsidy structure to achieve the maximized subsidy efficiency of at-berth emission reduction per monetary unit. The problem is formulated as a mathematical model that 2 types of government subsidy to the port have been taken into	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						consideration, that are the subsidy on SSE construction and subsidy on SSE operations. The port of Shanghai is selected for case study. Results show that the optimized government subsidy structure emerges when port's SSE supply capacity and ships' SSE demand meet an equilibrium, then the subsidy efficiency (g/USD) also could achieve the utmost level. It also indicates that in the beginning of SSE promotion, the government should subsidize more to the port on facility construction, then subsidize more on the SSE operations in later years for better usage of SSE and emission reduction	
No case specific						This paper proposes a novel bilevel hybrid economic approach to jointly aid both the regulatory agency and the port entity to holistically increase OPS uptake. In the proposed model, the regulatory authority on the upper level acts first and develops the optimal hybrid incentive policy to minimize the negative environmental impacts caused by ships at berth. The port entity on the lower level then decides the most financially favorable and economically viable investment decisions regarding the selection and installation of OPS.	
Port of Ancona	Italy	EU			YES	This paper, taking as a case study the port of Ancona, provides a methodology to evaluate the energy demand of ships at berth and to produce electricity through a highly efficient cogeneration plant. In this way ships can shut down their auxiliary engines, which are a great cause of pollution due to the sulphur content of fuels, with a consequent important reduction in the emission of pollutants in the port area.	for overall optimization. At last, the economical aspect has been evaluated to prove the feasibility of the whole system. The results, for the case of the port of Ancona, show that a 1.5 MW and 2 MW cogenerator covers the 83.05% and 92.5% of the electrical need of ships respectively, and the 61% and 74% of the thermal need of buildings over the period analysed. The coverage of the CAES system is not influenced by the rated power.
Port of Copenhagen	Denmark	EU				This paper presents the optimal design and specifies the dimension, energy planning and evaluates the performance of a microgrid to supply the electricity to the load by using integrated microgrid. The integrated system consists of PV, wind turbine and a battery for grid-connected. This paper also analyzes the performance of the designed system based on seaport located in Copenhagen, Denmark as a case study	
Port of Civitavecchia	Italy	EU			YES		The various shore-side power systems and their barriers were introduced. The direct annual cost for onboard generation of electricity was compared to that from the shore-side electricity

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							systems. Ro/ro pax and High Speed Craft were also investigated as cases study for the applicability of shore-side power concept while berthed at Civitavecchia and at Ancona ports. The results prove the national
Chinese ports	China	AS			YES		In accordance with the analysis of this paper, the cost of shore power supply system has no advantage compared with the cost of ship generating electricity. But the utilization of shore power can achieve power replacement of fuel and power consumption extension. Power supply enterprises not only exploit the power market, but also increase the power sales revenue. Therefore, the power supply enterprises shall make concessions in reducing the cost of power capacity expansion, and introduce preferential policies on shore power price in order to promote the utilization of shore power.
Port of Barcelona	Spain	EU				the study proposes the use of a cold ironing system in the port of Barcelona, where the power generation is entirely given by renewable energy systems (wind turbines and photovoltaic panels). The idea is to contribute to the wide spread of cold ironing within smart port microgrids to achieve the goal of zero emissions from berthed ships	
Port of Mombasa	Kenya	EU			YES		The main objective of the study was to assess the cost-effectiveness of cold ironing at the port of Mombasa. From the findings of the study, it is evident that the cost of the cold ironing system greatly depended on the amount of time ships stayed at berth. Currently the average port time for container ships at Mombasa port was 3.1 days which is quite high compared to the time spent by ships in other ports. This delay can be attributed to the inefficient port operations and gaps during ship port interface. The OPEX for ship owners also depended on the cost of electricity which for Kenya is at 0.15 USD/kWh, a price considered to be high when compared to other regions and countries such as South Africa. When cold ironing was compared with the

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							alternative of the use of auxiliary engines with residual oil at 2.7% Sulphur content, there was a gap in the OPEX, economically favoring the use of fuel oil, and that gap became higher considering scenarios where all ships will be required to use 0.5% Sulphur fuel oil from 2020 under the MARPOL convention, and under a scenario where the Kenyan government adopted a policy making it mandatory for ships to use 0.1% LSFO while at berth.
Port of Copenhagen	Denmark	EU			YES		The OPS technology and the related market are proven and mature enough to become of wide use and the environmental benefits that can be generated are several. However, the spread of an on shore power supply culture struggles to take off. Thus, there is a need for an actor that takes the lead paving the way of this transition. The role of the municipality was considered crucial in this shift and ergo the range of its intervention was explored in order to discover how it could be amplified. The research looks into the current situation at Copenhagen's harbour, as well on how OPS has developed in some other Baltic Sea ports, with the intention of providing concrete examples to formulate suggestions
Spanish ports	EU	EU			YES		Noise levels emitted by berthed ships using the Cold Ironing system can be significantly reduced depending on the type of vessel. This benefit can be perceived at night and at locations close to the port; in other cases, it may be masked by the port activity or other surrounding noise sources.
Chinese ports	China	AS			YES		Infrastructure investment and equipment purchase expense of port shore power and vessel power-receiving facilities are both relatively high and service charge of shore power and shore power expense paid by vessel enterprise are opposite expenses. At present, because fuel price is low, shore power expense paid by vessel enterprise is larger than expense for vessel power generation, vessel enterprise are unwilling to use shore power. Port

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							maintenance expense is very important to restrict shore power use of port and vessel and a price recognized by both parties of the vessels and the port must be determined to facilitate shore power use by the vessels and ports.
Port of Aberdeen	Scotland	EU			YES		it is feasible to install cold ironing technology in a medium sized port for vessels which are smaller than those traditionally connected to shore power. It was calculated that if all the ships using this area were able to connect to shore power then 108 tons of NOx, 2.7 tons of PM and 4767 tons of CO2 emissions could be saved annually, equating to £1.3m of external costs. The system would require considerable financial investment with a cost of approximately £6.6 m; however, in the best case scenario the substantial external cost benefits would return the system capital and operating costs in only 7.0 years, or 3.5 years if subsidised 50% by the EU.
Chinese ports	China	AS			YES	This paper was concerned more about how to determine the required power capacity of the OPS to meet total power demand of all arriving ships, considering the stochastic nature of arriving ships. Therefore, this paper does not consider the power standardization between the shore and ships and introduces the hypothesis that the OPS and handling equipment works well in operational stages	Considering all arriving ships use shore power, the required power capacity of the OPS reduces correspondingly with the arrival intervals of ships increasing. When arrival intervals range from 1 to 10 h, the allocated capacity is the largest, which lies between 6000 and 7000 kW. When the arrival intervals of ships are between 60 and 100 h, the required power capacity remains stable around 2300 kW.
Port of Cartagena	Colombia	US				Related to particular case discussed, the geographic and orographic environment of the Port of Cartagena allow to install the OPS system entirely from renewable sources. In addition, the port traffic features lead to implement this strategy progressively, guiding the first implementation phase to those ships in which the state of the technology is fully developed. The implementation would be a significant	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						environmental benefit both to port workers and to the population of Cartagena and adjoining areas, even in the immediate phase with a reduction of 10% of emissions generated by fossil fuels	
Port of Cartagena	Colombia	US			YES	As indicated in the text, several international initiatives for the implementation of the OPS philosophy at ports have been carried out, and in some countries significant progress has been made. Focusing attention on Spain, different studies have been carried out for analyzing the feasibility of the OPS implementation in coastal ports, having encountered different difficulties (www.inovalabs.com, for instance). Two main reasons can explained why this system is not universally installed today in Spanish ports: • The first consists of the installed electrical network does not have enough capacity for providing the required power to the ships in most of ports, and it does not usually reach the connection point at the port. • The second is that a considerable amount of ships are not adapted to be connected during the berth	The necessary enlargement of the electrical networks is expensive in most cases, and the adaptation of ships, although of relatively small importance, also requires investment by the shipowners. Actually, the Spanish Government applies a 50% bonus on the coastal port rate for vessels that use electricity supplied from the port during berthing (from 2016 Spanish General State Budgets). However, it seems that this initiative is insufficient, and more fiscal incentives would be necessary, as well as appropriate technical assessments, adapted to the different operational conditions.
Port of Gävle	Sweeden	EU			YES	analysed input data with regard to vessels calling at the Port of Gävle: power systems, fuel consumption and emissions, among others. According to available input data, the OPS system and the estimations have only been considered in the Container terminal, putting the Energy terminal on the back burner. 12 container ships stay alongside the quay during 90,1% of the time; therefore, a reasonable decision for a potential OPS system would be to retrofit only these vessels. A typical call lasts 30,9 h on average, seldom less than 20 h, which means that the time required to carry out the connection procedure is negligible.	3984 kg of MGO (<0,1% S) are saved per call on average, which implies that energy costs decrease by 71% at berth (from 19919 SEK to 4022 SEK) in an OPS system. MGO and electricity prices are constant for those calculations: 500 \$/ton and 0,70 SEK/kWh, respectively; a trend for future prices could not be found due to high variations during the past years. Looking over the investment costs, yearly costs result in 620.000 SEK/year for a typical container ship calling at the Port of Gävle (1500 kVA), considering an interest rate of 6% and a depreciation of 10 years
Port of Shenzhen	China	AS			YES		on information provided by various ports, CARB estimated the cost to modify each berth at a terminal to be about \$5 million. We used this as the baseline cost for each berth. This figure does not take into account other infrastructure investments that may be needed, including costs related to improving existing electrical infrastructure.

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							We then adjusted the cost downward by 20% because relatively low labor and raw material costs in China, along with the experience learned from onshore power projects elsewhere, should reduce capital overlays
Port of Singapore	Singapore	AS			YES	The positive impact of harnessing renewable energy in ports is quantified. The case study in this paper is inspired by ports in Singapore, namely Port of Singapore and Jurong Port. These ports have invested into Photovoltaic (PV) infrastructure for renewable energy generation to utilize Singapore's sunlight-rich potential [8]. Ultimately, ports are large scale end-users in energy supply networks and Port of Singapore has a sizeable portion of Singapore's daily energy demand. Therefore, investments for smart energy management, including demand response mechanisms (including smart meters, energy-management controller, etc.), energy storage and PV infrastructure are worthy to be investigated	On average, total cost saving of 3.2 MW energy storage with demand response management in a port microgrid is 18.5% and 21.0% for 30 and 40 ships compared to single price conventional setting. When a battery of 9.6 MW is used in microgrid setting, total saving rises to 19.6% and 21.9% for 30 and 40 ships compared to conventional setting. Installment of extra battery units brings further total cost savings for all instances of microgrid case. However, the marginal increase in the cost saving reduces as the storage capacity of battery increases.
Finnish ports	Finland	EU			YES	The results support the primacy of cyber security and trust before other developments are able to root and take hold of the system level management. As such, cloud and mobile services (easy information transfer regardless of location or users) are currently considered major trends too. The scenarios expect that ports are moving from static information applications to dynamic real-time cargo and transport data sourcing. Data driven application modeling enables both visualization and content combination creating 'virtual ports' that can be managed from remote locations. Examples of these developments are fully autonomous port quays that may be governed from remote locations (e.g. collective data management centers possibly located several kilometers from the actual loading areas)	
Russian ports	Russia	AS				1. Analysis of the level of digital transformation in the management of port equipment and seaports in general. 2. Identifying trends in the digitalization of seaports. 3. Highlighting the main advantages and disadvantages of digital transformation. 4. Consideration of examples of digital transformation of seaports and their management systems, in particular.	
Croatian ports	Croatia	EU				In port of Ploče, the objectives are: integration of PCS system with other systems (TOS, CIMIS and others); development of ports logistics center and enabling	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						the automated data exchange based on the concept of Single Window. A well digitalized port allows access to a common business application system intended for port management. There is no doubt that this is a strategic move in which the efficiency of business is at the forefront. The port of Rijeka possesses many advantages such as its position and the depth of the sea at the terminals, but adequate capacities are essential to meet the potential demand. Therefore, PCS ICT solution in port of Rijeka will enable the optimization of business processes, timely and reliable data exchange as well as simplified and accelerated business processes among all stakeholders.	
Port of Klang	Malaysia	AS				This paper has focused on two models related to: 1) the factors influencing Port Klang becoming a green port hub in Malaysia and 2) the impact of its role as a green hub on seaport competitiveness. AHP methods have been applied for developing both models in order to identify the weights and rankings attached to each criterion in the model on the basis of a 'global weight' calculation. The AHP results suggest that maritime experts in Malaysia believe that these indicators play a part in promoting green port development, giving evaluations of 'Extremely Important' to 'Weakly Important' for each of the indicators, which have then been numerically assigned to a scale of 1 to 9 for the purposes of the model.	
Italian ports	Italy	EU				This paper has focused on managerial KPIs for environmental sustainability and energy efficiency in the port industry, drawing from the primary contributions in the research and practice on the topic. We observed and described the main KPIs provided from research and practice for PAs in achieving environmentally sustainable and energy efficient behaviours, outlining the gap still existing both in the literature and practice, i.e., effective managerial KPIs have been missing	
Port Said	Egypt	AF				wind technology applications in the coastal location Port Said City at Suez Canal–Mediterranean intercept in the near future.	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Mytilene	Greece	EU				These emissions could be reduced by providing electricity to the ships from a hybrid renewable energy system with wind turbines and photovoltaics, connected to the grid. Simulationsshowedthatthetotalenergyrequirementsof heshipsintheportof Mytilene couldbecoveredbyfour1.5MWwindturbinescombinedwitha5MWphotovoltaics.With this configuration,renewableenergywillexceedtheships'electricityneedsformostofth timeinorder not toincreasethepowerstation'sload.Theexcessenergycouldbefedtotheislands'grid, oacostly battery storagesystemisnotnecessarytohandlethevariationsof alternativeenergy.	
Cantabric and North-Atlantic coasts of Spain	Spain	EU				This paper assesses the economic feasibility of o shore wind farms installed in deep waters considering their internal rate of return (IRR), net present value (NPV), and leveled cost of energy (LCOE).	
Brazilian ports	Brazil	US			YES	This study uses a multicriteria decision model to solve a problem of energy source selection in order to identify which type of renewable energy is the most viable for Brazilian ports to invest in. This research considers wind energy, photovoltaic energy, and wave energy from a multicriteria perspective	After the decision maker answered elicitation questions, the FITradeoff decision support system identified photovoltaic energy as the most viable source for Brazilian ports. This energy source performed best on sixteen of the twenty criteria evaluated. Since efficiency is often the only attribute that decision makers consider when deciding between renewable energy systems, it should be noted that photovoltaic energy is not the most efficient among the potentially optimal alternatives.
South Korean ports	Korea	AS			YES	This study is to provide guidance for selecting sites suitable for offshore wind farm developments with lower social, economic, and environmental impacts in the South Korea southwest coastal area with its complicated shoreline configuration, large ecologically important tidal flats, and various marine-based human activities.	Harvestable energy of a 60-MW wind farm was calculated for the entire southwest coastal area using offshore wind speed, generation capacity of turbines, number of turbines, and other parameters to analyze economic feasibility. Expected wind power generation was calculated based on harvestable wind energy ranges between 42,315 MWh/year (generation efficiency: 8.05%) and 222,583 MWh/year (generation efficiency: 42.3%) that is highly dependent on the location of wind farms. The net present value of the 60-MW wind farm was calculated by integrating harvestable wind energy, grid connection, electricity transmission cost, and

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
							operation and maintenance costs during the expected operation lifetime. It is interesting to note that NPV varies significantly based on grid connection point showing the importance of grid connection
European ports	Europe	EU				In view of the envisaged increase of cargo carried by sea within the European Union, the problem of proper management of ship-generated waste and cargo residues can be expected to aggravate. The strengthening of legislation in this area has led European Union Member States to look for optimum system solutions for waste management in ports. The analysis carried out has shown that EU ports use very diverse economic solutions for the reception of waste and cargo residues from ships, which may indicate that an optimum model for the calculation of the environmental fee has not yet been found.	
Port of Naples	Italy	EU				This study highlights the need to respond to international, European and national regulations in terms of waste management, but, unfortunately, there is still a lack of an integrated MCS for sharing and managing information and data between all the players to manage the waste emissions in compliance with effectiveness and efficiency performance criteria. The waste management process is performed by other actors on the basis of elements of trust through reports not completely formalised and other players with high risks of conflict of interests, conflicting roles or opportunistic behaviours	
Croatian ports	Croatia	EU				a general model relevant for the implementation of the concept of "green" port development has been created. The main activities of the proposed theoretical model related to the analysis of the current situation of environmental protection in the Croatian seaports refer to the definition of the Master Plan. The Master Plan defines the conditions of purchase and installation of the equipment relevant to the implementation of the environmental protection system. These activities include the creation of a particular information system and a test in real conditions. The analysis refers to the state of the infrastructure, the implementation and training of responsible internal staff. The Master Plan needs to define the waste management system in the Croatian seaports	
Adamas port	Greece	EU					

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Trieste	Italy	EU				Multi-objective optimization is performed to determine the optimal levelized cost of hydrogen in environmental and technoeconomic terms. A Polymer Electrolyte Membrane (PEM) electrolyzer powered by a grid-integrated photovoltaic (PV) plant, a compression station and two-pressure level storage systems are chosen to provide hydrogen to a hydrogen refueling station for a 20-car fleet and satisfy the demand of the hydrogen batch annealing in a steel plant. The	
No case specific						This paper provides an overview of carbon dioxide storage and utilization mechanism in the seabed, analyzes key technical and economic issues, and summarizes existing research on safety risks, monitoring technologies, and investment and operating cost control to identify remaining knowledge gaps. This is followed by an overview of global engineering practice to update on current progress.	
Port of Koper	Slovenia	EU	YES	YES	YES	• Upgrade of the equipment for monitoring of emissions and consumptions • Investment in green technology through the switch to electricity • Detection of vessels' pollution • Share of measurements information through the portal • Investment in efficient solutions for the Municipality. Exchanging best practices with other ports will also allow the development of solutions for port's sustainability in line with citizens' expectations	
Port of Bar	Montenegro	EU	YES	NO	YES	Strategic planning: • Highlighting the relevance of the plan • Understanding of existing conditions, development of stakeholder strategy • Establishment of vision and goals Operational planning: • Development of evaluation framework • Identification of sustainability actions • Definition of deployment strategy plan • Definition of monitoring progra	
Port of Durres	Albania	EU	YES	YES	YES	Revitalization of Green Spaces within and outside the port areas • A Recycling Plan for a Sustainable Port, including actions such as: recycling seminars, vessels waste fee reductions and a waste management plan • A Mobility Plan for Durres Port staff to increase the use of green transport modes • Clean Energy Investment (renewable), including conversion of port cranes and vehicles from diesel engine to electrical ones, installation of photovoltaic plant system and deployment of the on-shore power supply	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Thessaloniki	Greece	EU	NO	NO	NO	• Energy Management Plan • Energy Management Database • Truck flow management plan	
Port of Venice	Italy	EU	NO	NO	NO	Pilot intervention 1 - Design and implementation of a Smart Traffic Management Tool to improve the port performances landside Pilot intervention 2 - Certification of energy performance of NASPA buildings Pilot intervention 3 - Development, dissemination and data collection by means of a questionnaire aimed at gathering specific data about each specific terminal set of activities carried out in the Port of Venice	
Port of Trieste	Italy	EU	YES	NO	NO	Creation of an emissions inventory consisting in a catalogue of the various port related emissions sources • Analysis of the available innovative technologies useful to ensure an improvement of port the environmental performance • Strengthening the cooperation with local, regional, national and international maritime stakeholders to share relevant experiences and evaluate commonly implementation planning strategies	
Port of Piraeus	Greece	EU	YES	YES	YES	Air quality real-time monitoring system - Use of alternative fuels (LNG) - LED lighting for indoor and outdoor lighting - use of electric eco-buses - Installation of cold ironing - Micro-mobility measures	
Port of Koper	Slovenia	EU	YES	YES	YES	The hybrid system ACAR allows the registration and the booking of the arrivals/departures of trucks transporting cars in/from the port of Koper The Vehicle Booking System (VBS) is an online platform that allows checking the cargo status and scheduling plans The EDI (Electronic Data Interchange) systems are specific tools for the registration of containers entering/leaving the port.	
Port of Ploče	Croatia	EU	YES	YES	YES	procedures and processes within new entrance terminal (that includes the extension of the expressway to the port thus connecting the port to the "A1" Motorway) will be included in delivery of services for upgrade of PCS system which will improve traffic flows and optimize business processes to the satisfaction of all port users and members of the port community	
Port of Igoumenitsa	Greece	EU	YES	YES	YES	A web-based platform for PCS flows' analysis about sea and road transport flows. A virtual navigation mobile app, addressed mainly to vehicle drivers	
Port of Bar	Montenegro	EU	YES	NO	NO	Module "control center" allows the stakeholder the use of the reports and statistical data related to the role they have in the port community. Module Customs allows The Customs Administration of Montenegro in the monitoring of cargo movement i.e., connecting customs documents/declarations with port documentation.	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						Truck Module allowing to regulate entering/exiting of trucks and cars into/from the Port of Bar and requirements related to safety shall be met (ISPS regulation).	
Port of Venice	Italy	EU	YES	YES	NO	(the activities within the scope of infrastructure and market improvement requirements of railway freight connections undertaken by NASPA. This in line with the contents stated in the Strategic Plan for Port and Logistics activities, as a part of the Operational Program 2018 – 2020	
Port of Ancona	Italy	EU	NO	YES	YES	A very innovative investment aimed at setting up an artificial intelligent system to track and trace trucks embarking and disembarking the port of Ancona. The action promotes the efficiency of maritime traffic operations thanks to the digitalization of custom and maritime formalities, and contributes to increase the security of port operations thanks to the tracking system applied to all trucks movements in the port areas	
Port of Ravenna	Italy	EU	NO	YES	YES	This complex project consists of two parts: 1) the construction of a new terminal inside the Parmafreight village; 2) the organization and management of a new cargo rail mission from the port of Ravenna to the Freight Village of Parma. The construction of the infrastructure would allow to move part of the flow of goods from road to rail between the port of Ravenna and the Parma freight village. This project could contribute to reduce road congestion, providing a contribution to the reduction of harmful emissions deriving from road freight transport	
Port of Igoumenitsa	Greece	EU	YES	YES	NO	Link Projects refer to road and rail connections among involved nodes which will enhance hinterland intermodal connections. Node Projects refer to interventions identified on the ports	
Port of Zagreb	Croatia	EU	YES	YES	YES	The main goal is to develop the Port of Rijeka as one of the most important transit ports in the northern Adriatic for European markets which naturally gravitate toward it	
Port of Bar	Montenegro	EU	NO	YES	YES	Preconditions for attracting new cargo flows and creating conditions for new investments in various segments of the port system are being met by improving the condition of the existing infrastructure and creating a new one	
Port of Verona	Italy	EU	YES	YES	YES	(The main objective of the Feasibility Project is to prepare the plan of the infrastructural works necessary for the development of the area. These works are appropriately linked to the main viability and to the local road network, and already in place according to recent directives and policy from European Commission). A software platform that allows parties involved in trade and transport to lodge standardized information and allows a sound cooperation and communication between multiple logistic nodes, initially port of Piraeus and port of	
Port of Piraeus	Greece	EU	YES	NO	YES		

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						Lavrion	
Port of Valencia	Spain	EU	YES	YES	YES	develop a blueprint for the use of LNG technology in the Port of Valencia and in particular a supply station for vehicles	
Port of Koper	Slovenia	EU	NO	YES	YES	The Port of Koper actively supervised the implementation of the pilot project and prototype, which focused on the Fruit Terminal, aiming to demonstrate the potentials that can be achieved in terms of energy savings thus compiling lessons learned from the working relations between participating SMEs and end-users.	
Port of Rijeka	Croatia	EU	NO	YES	YES	Port of Rijeka has made an excellent report about the application of PV Solar Plant divided in three parts: The first part is a description of a plant P.V. in general terms, the second part shows a detailed application at Rijeka Port, economic study included, and the third part the pilot project is described the manner concise and very clear, as following	
Port of Livorno	Italy	EU	NO	YES	YES	The Port Authority of Livorno has recently planned a project of wharf electrification. The construction of the "On Shore Power Connection" intend to supply electrical power to cruise ships and ferries hotelling, at Calata Sgarallino, directly from dock rather than through the engine on-board. The plant will feed electrically vessels that require, in general, a maximum power which varies between 5 and 15 MW with a power factor between 0.6 and 0.9.	
Port of Marseille	France	EU	NO	YES	YES	The Marseille Port considers that the next step of Greenberth project will provide an opportunity to consider new technologies such as LNG, hydrogen, smart grids, etc...	
Port of Venice	Italy	EU	YES	NO	YES	Taking into account the characteristics of the port of Venice, one important issue that should be considered is the increased cruise traffic and the externalities of the touristic activities especially with regard to the city's historic center.	
Port of Bordeaux	France	EU			NO	To improve the access to IoT devices and big data calculations to increase the number of physical measurements in ports. This includes setting up an (open) IoT platform and connecting existing and new sensors. 2. To raise awareness and to provide decision tools about port operations and port development thanks to the integration of PIXEL components (advanced port statistics analysis) to PCS (Port Community Systems) and to "big data calculations". This implies developing an API (Application Programming Interface) between VIGIEsp and PIXEL in order to exchange data in standardized formats. Some PIXEL components could be integrated into VIGIEsp to give an appropriate end-user experience. 3. To develop a methodology to assess the opportunity to supply local renewable energies to the port's customers at a	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						competitive price. This will include the design of simulation algorithms for: a. estimating the real-time quantity of energy consumed during port operations depending on the type of cargos and vessels, and to size the electricity network needed in the port area to encourage self-consumption b. estimating port traffic evolution 4. To measure the green policy outcomes of a port (for instance, LNG dredge, energy efficiency actions, comprehensive environmental and energy transition strategy) thanks to PEI	
Port of Monfalcone	Italy	EU			NO	Data sharing between the Port of Monfalcone and SDAG to reduce bottlenecks and congestions in port areas and to promote the use of railways where necessary. 2. Reinforce the safety related to ADR transport through the operability of data with regional stakeholders and in connection with SILI. 3. Collect data on Regional logistic flows to support the activities of the Regional Environment and Health Observatory (REHO). Here the objective is to give the REHO the possibility to monitor the flows on the road. Within the ARPA (Regional Environmental Agency of Friuli Venezia Giulia), the REHO structure has the aim to put in relation health population status and environmental factors. Moreover, there are air data pollution in open data format available on the ARPA website. 4. Collect and analyse data on Regional logistic flows to support the activities of the Regional Government (another public entity) to evaluate specific programs to promote rail logistic solutions as well as the implementation/expansion of other logistic infrastructures. This objective refers specially to the side study of slabs traffic from the port of Monfalcone to the regional iron mills. If the externalities related to the slabs transport by truck are measured, it is possible to promote the rail transport mode for this traffic and specific economic bonus for operators that use rail instead of trucks	
Port of Thessaloniki	Greece	EU			NO	The use case of the Port of Thessaloniki focuses on the interoperability of city and port in freight traffic and in pollution impact towards the city. The expectations from THPA for the project and the particular execution of its use case are the following: 1. To optimize the traffic between the city and the port area and thus alleviate congestion or bottlenecks, caused by its operations. 2. To measure air and noise pollution thus being able to establish mitigation actions to reduce its environmental impact while at the same time, strengthen its relationships with the city of Thessaloniki. 3. To integrate existing systems and devices (already installed and new) with the broader platform of PIXEL	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
Port of Piraeus	Greece	EU			NO	PIXEL will enable the end-to-end visibility of the port's operations that relate to the cruises operations and capacity resources, mainly focusing on passengers and barge transportation plans and execution monitoring, delivering state of the art Planning as a Service, facilitating online access to schedules and allowing PPA to accurately plan, and inform on goods and capacities to their existing and new clients	
Port of Antwerp	Belgium	EU			NO	Energy generation from water currents Hydrogen refuelling infrastructure modular docking stations for containerw Battery storage and smart management Hydrogen heating for buildings local resource recovery for green circular concrete Carbon Capture and Storage Automated container shuttle solutions for port operations Automated vessels	
Port of Antwerp	Belgium	EU				This action has already been implemented	CMB.TECH, an Antwerp-based cleantech company specialized in developing and building hydrogen and ammonia-powered large marine and industrial applications, was responsible for integrating the technology and related expertise to design and build this first prototype, in collaboration with ATS and equipment manufacturers. The dual fuel technology is able to replace 70% of diesel consumption with hydrogen on new straddle carriers, with the eventual goal of 100 percent hydrogen injection
Port of Barcelona	Spain	EU			NO	Multimodal access to port using MaaS Maritime 5G for intelligent vessel location containers transport forecast	
Port of Venlo	Netherlands	EU			NO	modular docking stations for containerw electric green last mile	
Port of Piraeus	Greece	EU				At Piraeus port, real-time traffic regulation and coordination over a fleet of 5G connected trucks will be realized through low-latency transmissions and enhanced localization services, while also telemetry data from a set of diverse on-truck sensors will be utilized	
Port of Hamburg	Germany	EU				are aimed at collecting Floating Truck & Emission data (FTED) by 5G IoT devices, on-board units and nomadic devices, whereas use case 11 will use this data for sustainable traffic management purposes. Analysing FTED data according to the ISO-23795 standard [2] leads to microscopic emission models per vehicle for the air pollutants CO ₂ , NO _x , PM and noise, all directly linked to acceleration and energy	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						performance index (API, EPI). Overall, 5G-LOGINNOV at Athens LL will optimise port operations through a diverse set of use cases, including the optimal assignment of container jobs based on localisation (and other) data of internal 26 trucks, improvement of personnel safety through analytics of 4K video streams, predictive maintenance of yard equipment and reduction of the environmental footprint in port operations. This will be achieved by the deployment of a 5G network and installation of 5G access points on yard trucks connected to the engine CAN-Bus and truck sensors, the deployment of the envisioned 5G-IoT devices as well as the deployment of 4K surveillance cameras on the quay side and the rail terminal.	
Port of Koper	Slovenia	EU				The Koper Living Lab targets implementation of novel 5G technologies (MANO-based services and network orchestration, Industrial IoT, AI/ML based video analytics, drone-based security monitoring etc.) and cutting-edge prototypes tailored to be operated in port environment	
Port of Piraeus	Greece	EU				The use case of PREDICTOR involves the yard trucks of Piraeus Container Terminal. The fleet involves 170 internal trucks. Its purpose is to train the developed algorithm based on historical maintenance and breakdown data in order to predict future breakdowns of yard trucks as well as the parts that will be affected and relative spare parts required for the maintenance aims at optimizing road transport processes and ensure optimal operations. To achieve this objective, the TAS is based on predefined time slots for container delivery/pick-up operations that allow terminal operators to define the capacity for the land operations. With this system, logistics operators, shipping agents and truck companies can plan their operations and select the most suitable time slot to perform them	
Port of Valencia	Spain	EU				The final version enables fully fledged marketplace customized for ports operations. Terminals offering their assets describe them in the shared database and keep their records updated so that no overlaps with their operations occur. Terminals willing to rent assets can search them using categories, filter them on the updated map. It is also available to book the assets automatically exchanging a csv file from the TOS used in the terminal. Assets equipped with their own GPS system generate location data automatically so that the map is updated on real-time basis.	
port of Antwerp	Belgium	EU					Aims to reduce the idle times in terminals
port of Livorno	Italy	EU				focuses on the efficient management of containers at the CT Lorenzini in terms of container terminal layout and the way containers	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						are moved within the considered container terminal area.	
Port Authority of Balearic Islands	Spain	EU			All the use cases defined above have been thought to be applied jointly in any medium-sized landlord port. In order to explain the possible interactions between them, the use cases are listed below:		
Port of Vigo	Spain	EU					
Ports of Livorno and Piombino	Italy	EU				will provide port pilots with assisted reality sensors, by means of smart glasses, to know in real time the sea conditions, wind speed, gusts and other possible hazards to navigation. These information will be retrieved by the already existing platform MONICA, which is in turn linked to the sea traffic monitoring system run by the Italian Coast Guard. This platform will therefore give data on speed, course and direction of the vessel, and the use case will consequently assess and test how to provide this information to pilots on the bridge	
Ports of Naples and Salerno	Italy	EU				The present use case is aimed, through the identification of appropriate technologies, at maintaining a high level of competitiveness of the port. MAR.TE., the lead partner for the use case, will focus on a number of closely interlinked issues, such as: ☐ Logistics and multimodal relations with the surrounding environment. ☐ Optimisation of freight management including access to and share of smart information (e.g. expected flows of goods, control phases, etc.) at appropriate levels. D1.2 – Use case restrictions & requirements PortForward Version 2.0 Page 82 of 97 This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 769267. ☐ Access to data related to the environmental and social impact of port activities on the surrounding areas, with specific regard to densely inhabited areas; reduction of environmental impact through the implementation of appropriate actions and plans.	
Port of Magdeburg	Germany	EU				Two different Smart Logistics use cases are planned for the Port of Magdeburg and will be further described below. These use cases will be based on	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						IoT- and camera-based data gathering in different port environments and address: □ the monitoring of defined multi-purpose storage areas to automatically document their occupancy and the handled goods. □ the monitoring of external transportation traffics (on public roads) between the different terminals of the port as data basis for a future slot management. Both use case applications shall be integrated into the virtual port model by implementing the port specific digital twin. By that, process related real-time data will be directly entered into the digital and virtual model of the port.	
Port of Bremen	Germany	EU				Guidelines published for granting permission for inwater cleaning of ship hulls First German guidelines for issuing permits for inwater hull cleaning as a result of the CLEAN project, partly funded by the Deutsche Bundesstiftung Umwelt, have been stated binding regulations for hull cleaning with the aim of reducing the introduction of pollutants into the waters of the ports of Bremen	
Port of Bremen	Germany	EU				marine "litterbin" has a capacity of 20 litres, removes up to four kilos of plastic a day and filters particles with a size of 2mm or more out of the water.	
Shannon Foynes Port Company	Ireland	EU				SFPC have implemented a programme of dust monitoring at operations in Foynes, and more recently in Limerick, to establish overall levels of dust generations associated with cargo handling operations	
Shannon Foynes Port Company	Ireland	EU				The SFPC Corporate Social Responsibility Policy is a publically available document, approved by the Board of the Company, which sets out the Company's CSR Policy Objectives (http://www.sfpc.ie/about-us/corporate-governance/).	
Shannon Foynes Port Company	Ireland	EU				SFPC has undertaken the preparation of a Masterplan in order to promote and support the provision of port infrastructure and services in the Shannon Estuary over the next 30 years	
Shannon Foynes Port Company	Ireland	EU				SFPC has been instrumental in the formation and operation of an Oil Pollution Consortium known as the Shannon Estuary Anti-Pollution Team Ltd. (SEA-PT) (http://www.seapt.ie/).	
Shannon Foynes Port Company	Ireland	EU				SFPC have developed a Contingency Plan to address a major oil/HNS spill (or potential spill) within the Estuary	
Shannon Foynes Port Company	Ireland	EU				SFPC have prepared a comprehensive and detailed Waste Management Plan (WMP) (http://www.sfpc.ie/about-	

Port	Country	Region	Has this practice promote the collaboration between private and public sector?	Has this practice included advances in port or port restructuring?	Comments on feasibility of measures adopted	Comments	Comments on feasibility
						us/environment/waste-management/) which has been approved by the Marine Transport Division of the Irish Department of Transport, Tourism & Sport.	
JadeWeserPort Realisierungs GmbH & Co. KG	Germany	EU				In order to secure usability and functionality of the rail switches at the staging/shunting yard, the switches are heated at night, when there is frost in the forecast. This is done 'by hand' at JadeWeserPort through the colleagues from the rail switch tower	
JadeWeserPort Realisierungs GmbH & Co. KG	Germany	EU				publicly accessible charging station for electric passenger cars at the Services Center. This way, JadeWeserPort actively supports and enables their own employees, but also the employees of commercial settlement companies, to charge their e-vehicles during working hours or during their stay at JadeWeserPort	
Port of Shoreham	UK	EU				One of our key emission reduction initiatives is to install a renewable energy powered Marine Source Heat Pump (MSHP) with associated abstraction and rejection plant.	
Port of Shoreham	UK	EU				By replacing two thirds of our vans with new fully electric vehicles (EV's) the Port has been able to reduce carbon emissions by 6 tonnes of CO2 per year.	
Port of Shoreham	UK	EU				two Sea Bins as part of the redevelopment of our Lady Bee Marina pontoons. Water is sucked in from the surface by a pump capable of displacing 25,000 litres per hour and passes through a catch bag inside the bin	
port of Den Oever-Hollands Kroon	Netherlands	EU				In recent years, the Waddenpoort project is developed to support the fisheries and companies around the port. This makes the move and realization of the new ship dock an important link. The current doc in the port of Den Oever does not comply with the objectives mentioned in Water Framework Directive. Due to the replacement of the doc it will be possible to collect waste material easier which will result in a cleaner and better (working) environment	
port of Den Oever-Hollands Kroon	Netherlands	EU				All ships in the port of Den Oever switched to the new ChangeXL fuel on the first of June 2019. This results in a reduction of 1,292 tonnes of CO2 emission for the port. The fuel contains no metals, chemical components and ash. As a result, in addition to reducing CO2 emissions, NOx emissions and soot / particulate matter emissions are also reduced	

Table 28. Sources of Green Port Practices

Port	Country	Region	Source	Year	Type of measure	Key word assigned
Port of Los Angeles	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Technical	Onshore Power supply
Ports of Brunswick and Savannah	Georgia, United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Technical	fleet replacement programmes
Port of Antwerp	Belgium	EU	https://pioneers-ports.eu/portfolio-item/energy-pioneers-in-the-port-of-antwerp/	2022	Technical	electrification
Port, City and Borough of Juneau, Vancouver Fraser Port Authority, and Leading Global Cruise Lines	global	global	https://www.portseattle.org/news/port-city-and-borough-juneau-vancouver-fraser-port-authority-and-leading-global-cruise-lines	2022	Initiative/ Policy	green shipping corridors
C40 Green Ports Forum	global	global	https://www.c40.org/privacy-policy/	2022	Initiative/ Policy	decarbonisation
PSA International	Singapore	AS	https://www.globalpsa.com/wp-content/uploads/nr220511.pdf	2021	Technical	digital solutions
American Association of Port Authorities	United States	US	https://www.portstrategy.com/story.aspx?storyCode=1470637&preview=1&hash=33AE84FA347B2F2BA0CDFAAF913968A9	2022	Technical	hydrogen
Port of Baltimore	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Initiative/ Policy	fleet replacement programmes
Port of Long Beach	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Strategy/ Plan	decarbonisation
Port of Oakland	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Technical	Onshore Power supply
Port of Portland	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Technical	Onshore Power supply
Port of San Diego	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Strategy/ Plan	Nature and habitat
South Carolina Port Authority	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Technical	fleet replacement programmes
Port Authority of New York and New Jersey	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Initiative/ Policy	Nature and habitat
Ports of Seattle and Tacoma	United States	US	https://www.inboundlogistics.com/articles/10-greenest-ports-in-america/	2016	Strategy/ Plan	decarbonisation
Ports of Antwerp and Zeebrugge	Belgium	EU	https://www.maritime-executive.com/article/belgium-s-antwerp-and-zeebrugge-seaports-agree-to-merge-operations	2021	Initiative/ Policy	hydrogen
Port of Hamad	Qatar	AS	https://www.hellenicshippingnews.com/qatar-hamad-port-is-one-of-worlds-largest-green-projects/#:~:text=Hamad%20Port%20is%20the%20largest,on%20its%20Twitter%20handle%20yesterday	2020	Initiative/ Policy	Nature and habitat
Port of Ain Sokhna	Egypt	AF	https://www.portstrategy.com/greenport/egypt-green-hydrogen/1478159.article	2022	Technical	hydrogen
Port of Gandia	Spain	EU	https://www.portstrategy.com/greenport/gandia-solar-energy-plant/1478234.article	2022	Technical	solar plants/ farms
Port of Aberdeen	Scotland	EU	https://www.portstrategy.com/greenport/clean-fuel-funding/1478244.article	2022	Strategy/ Plan	decarbonisation
Port of Long Beach	United States	US	https://www.portstrategy.com/greenport/crane-conversion-project/1478324.article	2022	Technical	fleet replacement programmes
Port of Galveston	Texas, United States	US	https://www.portstrategy.com/greenport/integrated-berthing/1478553.article	2022	Initiative/ Policy	infrastructure
Seattle-Tacoma & Busan	Washington State, South Korea	US	https://green-marine.org/stayinformed/news/northwest-seaport-alliance-announces-decarbonization-partnership-with-busan-port-authority/	2022	Initiative/ Policy	decarbonisation
Port of Gothenburg	Sweeden	EU	https://smartports.tv/decarbonization-business-model	2022	Initiative/ Policy	Alternative fuels
Port of Barcelona	Spain	EU	https://smartports.tv/decarbonization-business-model	2022	Initiative/ Policy	decarbonisation
Port of Antwerp	Belgium	EU	https://smartports.tv/high-level-roundtable	2022	Technical	circular economy
Port of Antwerp	Belgium	EU	https://smartports.tv/high-level-roundtable	2022	Initiative/ Policy	digital solutions

Barcelona Europe South Terminal	Spain	EU	https://www.portstrategy.com/greenport/solar-panel-installation/1478740.article	2022	Technical	solar plants/ farms
Port of Antwerp	Belgium	EU	https://www.portstrategy.com/greenport/alternative-fuelled-tugs/1478761.article	2022	Technical	fleet replacement programmes
Port of Vancouver	Canada	US	https://www.portstrategy.com/greenport/zero-emission-testing/1479157.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_e8b5952973c51f6fd9ffb0ed08ee6834&utm_source=Email%20marketing%20software&utm_term=Zero-emission%20testing	2022	Initiative/ Policy	Alternative fuels
Pilbara Ports	Australia & Japan	global	https://www.portstrategy.com/environment-and-sustainability/pilbara-ports-and-japan-team-up-on-green-energy/1480614.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_929ba6bbae49af3bcfc5d78e9bf65401&utm_source=Email%20marketing%20software&utm_term=Pilbara%20Ports%20and%20Japan%20team%20up%20on%20green%20energy	2023	Initiative/ Policy	hydrogen
Port of Bellingham	US	US	https://green-marine.org/stayinformed/news/the-port-of-bellingham-prepares-for-green-marine-s-certification/	2023	Initiative/ Policy	Nature and habitat
Port of Corpus Christ	US	US	https://green-marine.org/stayinformed/news/the-port-of-corpus-christ-is-awarded-16-4-million-to-capture-carbon/	2023	Initiative/ Policy	carbon capture and storage
Port of San Diego	US	US	https://green-marine.org/stayinformed/news/two-cruise-ships-use-shore-power-simultaneously-at-the-port-of-san-diego-for-the-first-time/	2023	Technical	Onshore Power supply
Port of Hamburg	Germany	EU	https://www.portstrategy.com/environment-and-sustainability/fuelling-the-need-for-north-sea-hydrogen-bunkering/1480675.article	2023	Strategy/ Plan	hydrogen
Virginia Inland Port	US	US	https://www.portstrategy.com/environment-and-sustainability/renewables-help-us-port-achieve-carbon-neutrality/1480626.article	2023	Technical	electrification
Pilbara Ports	Australia	AU	https://www.portstrategy.com/environment-and-sustainability/pilbara-ports-and-japan-team-up-on-green-energy/1480614.article	2023	Initiative/ Policy	hydrogen
Port of Shoreham	UK	EU	https://www.portstrategy.com/greenport/financing-green-growth/1479438.article	2023	Initiative/ Policy	hydrogen
Port of Oakland	US	US	https://www.portstrategy.com/environment-and-sustainability/port-turns-solar-power-supplier/1480454.article	2023	Technical	solar plants/ farms
Port of Mombasa	Kenya	AF	https://www.portstrategy.com/environment-and-sustainability/kenyan-shore-based-power-study/1480307.article	2023	Strategy/ Plan	solar plants/ farms
Port of Tianjin	China	AS	https://www.portstrategy.com/greenport/solar-and-wind-takes-off-at-tianjin-port/1480192.article	2023	Technical	solar plants/ farms
Port of Gothenburg	Sweeden	EU	https://www.portstrategy.com/greenport/gothenburg-expands-electric-truck-fleet/1480078.article	2023	Technical	fleet replacement programmes
Port of Stockholm	Sweeden	EU	https://www.portstrategy.com/greenport/baltic-ports-tackle-emissions-with-onshore-power/1480017.article	2023	Technical	Onshore Power supply
Port of Leith	Scotland	EU	https://www.portstrategy.com/greenport/shore-power-electrifies-leith/1479959.article	2023	Technical	Onshore Power supply
Port of Southampton	UK	EU	https://www.portstrategy.com/greenport/biofuel-used-in-race-to-meet-carbon-targets/1479793.article	2023	Technical	biofuels
Port of Liverpool	UK	EU	https://www.portstrategy.com/greenport/planning-for-green-cruise-growth/1479430.article	2023	Initiative/ Policy	infrastructure
Kotug Canada Inc	US	US	https://www.portstrategy.com/environment-and-sustainability/fighting-underwater-noise-using-green-vessel-coatings/1480820.article	2023	Technical	Nature and habitat
Port of Los Angeles, Port of Shanghai, and C40 Cities	global	global	https://www.c40.org/news/la-shanghai-green-shipping-corridor/	2022	Initiative/ Policy	green shipping corridors
Portsmouth Port	England	EU	https://www.portstrategy.com/environment-and-sustainability/using-smart-grid-technology-to-decarbonise/1481586.article	2023	Initiative/ Policy	decarbonisation
22 countries	global	global	https://rightship.com/insights/digital-revolution-tackle-air-quality-ports?utm_source=PTI&utm_medium=PaidMedia-eshot&utm_term=MEP_Green_Corridors_Foleon	2023	Initiative/ Policy	digital solutions
Port of Gothenburg	Sweeden	EU	https://www.portstrategy.com/environment-and-sustainability/priority-for-electric-trucks-at-gothenburg/1481396.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_9b173759a31c68a2467d9866a8125b60&utm_source=Email%20marketing%20software&utm_term=Priority%20for%20electric%20trucks%20at%20Gothenburg	2023	Initiative/ Policy	decarbonisation
Port of Gothenburg	Sweeden	EU	https://www.portstrategy.com/environment-and-sustainability/electric-truck-fleet-breaks-nordic-records/1481559.article	2023	Technical	fleet replacement programmes
Haropa Port	France	EU	https://www.portstrategy.com/environment-and-sustainability/france-ramps-up-its-biofuels-logistics-chain/1481558.article	2023	Technical	infrastructure
Port of London Authority	England	EU	https://www.portstrategy.com/environment-and-sustainability/pla-in-net-zero-milestone/1481535.article	2023	Technical	biofuels
Associated British Ports	England	EU	https://www.portstrategy.com/environment-and-sustainability/abp-plans-for-the-energy-transition-and-net-zero/1481389.article	2023	Strategy/ Plan	infrastructure
Port of Aberdeen	Scotland	EU	https://www.portstrategy.com/environment-and-sustainability/worlds-first-h2-shipping-project/1481148.article	2023	Technical	hydrogen
Port of Kembla	Australia	AU	https://issuu.com/mercatormedia/docs/port_strategy_march_2023_flipbook?fr=sNmYyYTU4NDEwOTg	2023	Technical	Wind farms
Port or Portsmouth	England	EU	https://issuu.com/mercatormedia/docs/port_strategy_march_2023_flipbook?fr=sNmYyYTU4NDEwOTg	2023	Technical	digital solutions

Port Everglades	US	US	https://issuu.com/mercatormedia/docs/port_strategy_march_2023_flipbook?fr=sNmYyYTU4NDEwOTg	2023	Technical	Onshore Power supply
Virginia Inland Port	US	US	https://www.portstrategy.com/environment-and-sustainability/renewables-help-us-port-achieve-carbon-neutrality/1480626.article	2023	Technical	solar plants/farms
Port of Gothenburg	Sweeden	EU	https://www.portofgothenburg.com/news-room/press-releases/the-port-of-gothenburg-is-ready-for-methanol-bunkering-ship-to-ship/	2022	Technical	Alternative fuels
west European routes	Norway	EU	https://www.portstrategy.com/environment-and-sustainability/green-hydrogen-milestone-for-short-sea-feeder-vessels/1481981.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_19d9f690b45a2f65a9662760517ab812&utm_source=Email%20marketing%20software&utm_term=Green%20hydrogen%20milestone%20for%20short%20sea%20feeder%20vessels	2023	Technical	hydrogen
Port of Antwerp	Belgium	EU	https://newsroom.portofantwerpbruges.com/new-milestone-in-sustainable-methanol-production-in-the-port-of-antwerp	2022		
Port of Singapore	Singapore	AS	https://www.mpa.gov.sg/finance-e-services/tariff-fees-and-charges/ocean-going-vessels/port-dues-concessions	2023		
Port of Kapellskär	Sweeden	EU	https://www.docksthefuture.eu/electrification-of-the-ports-infrastructure-and-equipment/	2023		
Port of Kapellskär	Sweeden	EU	https://www.docksthefuture.eu/electrification-of-the-ports-infrastructure-and-equipment/	2023		
Port of Ipswich	UK	EU	https://www.docksthefuture.eu/electrification-of-the-ports-infrastructure-and-equipment/	2023		
Trondheim Port Authority	Norway	EU	https://www.docksthefuture.eu/elmar-electrification-of-maritime-transport-and-the-ports-of-the-future/	2023		
San Francisco bay	California	US	https://www.docksthefuture.eu/innovative-hydrogen-powered-vessels/	2023		
Port of Barcelona	Spain	EU	https://www.greenport.com/news/101/lng/lng-cruise-ship-bunkered-at-barcelona	2023		
	Groningen	EU	https://maritimeducation.com/fi rst-lng-tanker-docks-at-new-dutch-fl oating-terminal/ (https://maritimeducation.com/fi rst-lng-tanker-docks-at-new-dutch-fl oatingterminal/)	2023		
Port Coronel	Chile	US	https://www.greenport.com/news/101/Products-and-Services/zero-emissionequipment-drive-for-chile-port	2023		
Port of Antwerp	Belgium	EU	https://newsroom.portofantwerpbruges.com/new-milestone-in-sustainable-methanol-production-in-the-port-of-antwerp	2023		
Port of Rotterdam	Netherlands	EU	https://www.portstrategy.com/environment-and-sustainability/green-hydrogen-production-from-windfarms/1482880.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_8d7e420c26e8e00f7d9b5f5d2653c340&utm_source=Email%20marketing%20software&utm_term=Green%20hydrogen%20production%20from%20windfarms	2023		
Gothenburg	Sweeden	EU	https://www.portstrategy.com/environment-and-sustainability/scandinavia-ups-the-ante-in-methanol-bunkering/1484469.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_0bef54b0a13249efdf4b65fc158d1074&utm_source=Email%20marketing%20software&utm_term=Scandinavia%20ups%20the%20ante%20in%20methanol%20bunkering	2023		
Tauranga	New Zealand	EU	https://www.portstrategy.com/environment-and-sustainability/tauranga-takes-the-hybrid-approach-to-getting-greener/1484507.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_0bef54b0a13249efdf4b65fc158d1074&utm_source=Email%20marketing%20software&utm_term=Tauranga%20takes%20the%20hybrid%20approach%20to%20getting%20greener	2023		
European Ports		EU	https://www.portstrategy.com/environment-and-sustainability/european-ports-join-forces-to-create-hydrogen-corridors/1484886.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_fa8fef300cee0603d3593fdec2c5aac&utm_source=Email%20marketing%20software&utm_term=European%20ports%20join%20forces%20to%20create%20hydrogen%20corridors	2023		
Klaipeda port	Lithuania	EU	https://www.portstrategy.com/environment-and-sustainability/klaipda-to-transition-into-an-energy-port/1484670.article	2023		
Port of Vancouver	Vancouver	US	https://www.portstrategy.com/environment-and-sustainability/vancouver-to-use-hydrogen-trucks-to-decarbonise/1484659.article	2023		
Port of Stephenville	Canada	US	https://www.portstrategy.com/environment-and-sustainability/canadian-energy-firm-acquires-key-hydrogen-port/1484466.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_0bef54b0a13249efdf4b65fc158d1074&utm_source=Email%20marketing%20software&utm_term=Canadian%20energy%20firm%20acquires%20key%20hydrogen%20port	2023		
Port of Detroit	Canada	US	https://www.portstrategy.com/environment-and-sustainability/detroit-begins-work-on-net-zero-plan/1484441.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_0bef54b0a13249efdf4b65fc158d1074&utm_source=Email%20marketing%20software&utm_term=Detroit%20begins%20work%20on%20net-zero%20plan	2023		
Kalmar company			https://www.portstrategy.com/environment-and-sustainability/kalmar-charges-ahead-with-electric-equipment-roll-out/1485147.article?utm_medium=email&utm_campaign=Weekly%20Greenport%20%20Weekly%20Newsletter&utm_content=Weekly%20Greenport%20%20Weekly%20Newsletter+CID_37bf25b56b8c34cf8c866616f12d1665&utm_source=Email%20marketing%20software&utm_term=Kalmar%20charges%20ahead%20with%20electric%20equipment%20roll-out	2023		
port Wallhamn	Sweeden		https://www.portstrategy.com/environment-and-sustainability/recycling-waste-into-green-methanol-for-port-use/1485374.article	2023		
Freeport Texas	USA		https://www.portstrategy.com/environment-and-sustainability/usa-fixes-sights-on-blue-ammonia-production/1485369.article	2023		
Port of Valencia	Spain		https://www.portstrategy.com/environment-and-sustainability/valencia-shares-hydrogen-ambitions/1485238.article	2023		

Fjords	Norway		https://www.portstrategy.com/environment-and-sustainability/norwegian-fjords-transition-into-h2-hub/1485198.article	2023		
Port of Brownsville	Texas, United States		https://www.portstrategy.com/world/port-of-brownsville-business-park/1485169.article	2023		
Port of Singapore	Asia		https://www.portstrategy.com/environment-and-sustainability/singapore-plays-host-to-biofuel-bunkering/1485137.article	2023		
DP World Yarimca	Asia		https://www.portstrategy.com/operations/turkish-port-in-remote-control-crane-first/1485115.article	2023		
Port of Auckland	Californian		https://www.portstrategy.com/environment-and-sustainability/oakland-invests-in-geothermal-energy/1485113.article	2023		
Stockholm	Sweeden		https://www.portstrategy.com/environment-and-sustainability/new-solar-farms-at-ports-of-stockholm/1484894.article	2023		
Port of Muuga	Estonia		https://www.portstrategy.com/environment-and-sustainability/solar-farm-opens-at-estonian-port/1484852.article	2023		
Port of Vigo	Italy		https://sustainableworldports.org/project/port-of-vigo-welfare-committee/	2023		
National Ports Agency of Morocco	Morocco		https://sustainableworldports.org/project/national-ports-agency-of-morocco-smart-port-innovation-approach/	2023		
Fiji Ports	Fiji		https://sustainableworldports.org/project/fiji-ports-integrated-management-system-certification/	2023		
Port of Long Beach Board	USA		https://sustainableworldports.org/project/port-of-long-beach-water-quality-programs-result-in-port-biodiversity/	2023		
Port of Santa Cruz	Tenerife		https://sustainableworldports.org/project/port-authority-of-santa-cruz-de-tenerife-tenerife-port-zero/	2023		
Port of Vienna	Austria	EU	https://sustainableworldports.org/project/port-of-vienna-h2-meets-h2o-project/	2022	Strategy/ Plan	hydrogen
Solomon Ports	Honiara	AU	https://sustainableworldports.org/project/solomon-islands-ports-authority-renewable-energy-for-a-sustainable-community/	2021	Initiative/ Policy	solar plants/farms
Port of Rotterdam	Netherlands	EU	https://sustainableworldports.org/project/port-of-rotterdam-flood-risk-management-programme/	2021	Initiative/ Policy	Nature and habitat
Port of London Authority	UNITED KINGDOM	EU	https://sustainableworldports.org/project/port-of-london-authority-hydrogen-highway-project/	2021	Technical	hydrogen
Port of Amsterdam	Netherlands	EU	https://sustainableworldports.org/project/port-of-amsterdam-upcycle-factory/	2020	Strategy/ Plan	circular economy
Port of Seattle	Canada	US	https://sustainableworldports.org/project/port-of-seattle-ocean-acidification-action-plan/	2020	Strategy/ Plan	Nature and habitat
North Sea Port	Belgium	EU	https://sustainableworldports.org/project/north-sea-port-solar-park/	2021	Technical	solar plants/farms
Port of Busan	Republic of Korea	AS	https://sustainableworldports.org/project/busan-port-recycling-of-plastic-waste/	2021	Technical	circular economy
Flinders Port Holdings	Australia	AU	https://sustainableworldports.org/project/flinders-port-holdings-climate-adaptation-strategy/	2021	Strategy/ Plan	Nature and habitat
Port of Baku	Azerbaijan	AS	https://sustainableworldports.org/project/port-of-baku-climate-strategy-2035/	2021	Strategy/ Plan	Infrastructure
Port of Igoumenitsa	Greece	EU	https://sustainableworldports.org/project/port-of-igoumenitsa-alfion-project/	2022	Technical	Onshore Power supply
RAK Ports	Arab Emirates	AS	https://sustainableworldports.org/project/rak-ports-channel-optimization-with-dukc/	2020	Technical	decarbonisation
Port of Amsterdam	Netherlands	EU	https://sustainableworldports.org/project/port-of-amsterdam-multi-fuel-port-spatial-safety/	2021	Strategy/ Plan	alternative fuels
Fiji Ports	FIJI	US	https://sustainableworldports.org/project/fiji-ports-green-port-initiative/	2019	Strategy/ Plan	decarbonisation
Port of Puna	Ecuador	US	https://sustainableworldports.org/project/dp-world-posorja-mangrove-reforestation-project/	2020	Strategy/ Plan	Nature and habitat
Port of Vigo	Spain	EU	https://sustainableworldports.org/project/port-of-vigo-living-ports/	2021	Technical	Nature and habitat
Port of Colombo	Sri Lanka	AS	https://sustainableworldports.org/project/port-of-colombo-ghg-emission-reduction-project/	2021	Strategy/ Plan	electrification
Port of Gothenburg	Sweeden	EU	https://sustainableworldports.org/project/port-of-gothenburg-hydrogen-production-facility-and-filling-station/	2021	Technical	hydrogen
Port of Yokohama	Japan	AS	https://sustainableworldports.org/project/port-of-yokohama-hydrogen-supply-chain-joint-study/	2021	Strategy/ Plan	alternative fuels
Port of Los Angeles	US	US	https://sustainableworldports.org/project/port-of-los-angeles-zero-emissions-pathway/	2021	Technical	fleet replacement programs
Port of Kaohsiung	Taiwan	AS	https://sustainableworldports.org/project/port-of-kaohsiung-master-plan-2017-2021/	2021	Strategy/ Plan	Infrastructure
Port of Antwerp	Belgium	EU	https://sustainableworldports.org/project/port-of-antwerp-renewing-greening-and-optimizing-the-ports-fleet/	2021	Initiative/ Policy	alternative fuels
Port of Guangzhou	China	AS	https://sustainableworldports.org/project/port-of-guangzhou-improving-the-rate-and-reliability-of-onshore-power-supply/	2018	Technical	Onshore Power supply
Port of Gothenburg	Sweeden	EU	https://sustainableworldports.org/project/port-of-gothenburg-cinfracap-carbon-infrastructure-capture/	2020	Technical	carbon capture and storage
Port of Gothenburg	Sweeden	EU	https://sustainableworldports.org/project/port-of-gothenburg-frontrunner-on-onshore-power-supply-for-vessels/	2021	Technical	Onshore Power supply
Ports of Auckland	New Zealand	EU	https://sustainableworldports.org/project/ports-of-auckland-ghg-emission-reduction-pathway/	2018	Strategy/ Plan	alternative fuels

Guangzhou Container Terminal	China	AS	https://sustainableworldports.org/project/guangzhou-container-terminal-electric-prime-movers/	2020	Technical	fleet replacement programmes
Port of Gothenburg	Sweeden	EU	https://sustainableworldports.org/project/port-of-gothenburg-large-scale-planting-of-eelgrass-meadows/	2018	Initiative/ Policy	Nature and habitat
PSA Marine	Singapore	AS	https://sustainableworldports.org/project/psa-marine-lng-dual-fuel-tugs/	2019	Technical	fleet replacement programmes
Port of Seattle, Port of Tacoma, Northwest Seaport Alliance, and Vancouver Fraser Port Authority	Canada	US	https://sustainableworldports.org/project/collaborative-project-2020-northwest-ports-clean-air-strategy/	2021	Strategy/ Plan	decarbonisation
Port of Valencia	Spain	EU	https://sustainableworldports.org/project/port-of-valencia-strategy-towards-zero-emissions-by-2030/	2020	Strategy/ Plan	decarbonisation
Port of Marseille	France	EU	https://sustainableworldports.org/project/port-of-marseille-hyammed/	2019	Technical	hydrogen
Port of Taipei	Taiwan	AS	https://sustainableworldports.org/project/port-of-taipei-eco-resilient-future/	2020	Technical	Nature and habitat
Port of Amsterdam	Netherlands	EU	https://sustainableworldports.org/project/port-of-amsterdam-h2ships-project/	2021	Technical	hydrogen
Port of Algeiras	Spain	EU	https://sustainableworldports.org/project/port-of-algeiras-portxchange/	2020	Technical	digital solutions
Port of Marseille	France	EU	https://sustainableworldports.org/project/port-of-marseille-friend-ship-solution/	2020	Technical	digital solutions
Port of Marseille	France	EU	https://sustainableworldports.org/project/port-of-marseille-green-mobile-energy-for-reefer-containers/	2020	Technical	hydrogen
Solomon Ports	Solomon Islands	AU	https://sustainableworldports.org/project/solomon-ports-3r-reduce_reuse_recycle-campaign/	2021	Initiative/ Policy	waste management
Port of Marseille	France	EU	https://sustainableworldports.org/project/port-of-marseille-river-cooling/	2020	Technical	circular economy
Port of Marseille	France	EU	https://sustainableworldports.org/project/port-of-marseille-energy-recovery-from-cruise-ships-wastewater/	2020	Technical	waste management
Port of Brisbane	Australia	AU	https://sustainableworldports.org/project/port-of-brisbane-ncos-online/	2019	Technical	digital solutions
Port of Rotterdam	Netherlands	EU	https://sustainableworldports.org/project/port-of-rotterdam-portxchange-pronto/	2019	Technical	digital solutions
Port of Vigo	Spain	EU	https://sustainableworldports.org/project/port-of-vigo-sunset-dock-project/	2019	Strategy/ Plan	Nature and habitat
Port of Helsinki	Finland	EU	https://sustainableworldports.org/project/port-of-helsinki-carbon-neutral-port-2035/	2019	Strategy/ Plan	Onshore Power supply
Port of Huelva	Spain	EU	https://sustainableworldports.org/project/port-of-huelva-ecological-recovery-project/	2016	Initiative/ Policy	Nature and habitat
European ports	global	EU	https://sustainableworldports.org/project/collaborative-project-passport/	2020	Initiative/ Policy	Nature and habitat
Port of Hamburg	Germany	EU	https://sustainableworldports.org/project/port-of-hamburg-seaclear-project/	2020	Initiative/ Policy	Nature and habitat
North Sea Port	MALAYSIA	AS	https://sustainableworldports.org/project/northport-malaysia-bhd-journey-towards-hse-excellence/	2020	Initiative/ Policy	digital solutions
Port of Long Beach	US	US	https://sustainableworldports.org/project/port-of-long-beach-c-port-zero-emissions-demonstration-project/	2019	Technical	fleet replacement programmes
Port of Bari	Italy	EU	https://sustainableworldports.org/project/port-of-bari-artificial-intelligence-for-environmental-monitoring-and-prediction/	2019	Technical	digital solutions
Port of Genoa	Italy	EU	https://sustainableworldports.org/project/port-of-genoa-onshore-power-supply-to-vessels/	2019	Technical	Onshore Power supply
Tenerife Port	Spain	EU	https://sustainableworldports.org/project/port-authority-of-santa-cruz-de-tenerife-tenerife-port-zero/	2023		
Port of Long Beach	Canada	US	https://sustainableworldports.org/project/port-of-long-beach-water-quality-programs-result-in-port-biodiversity/	2023		
Port of Acu	Brazil	US	https://sustainableworldports.org/project/port-of-acu-climate-resilience/	2023		
Port of Brisbane	Australia	AU	https://sustainableworldports.org/project/port-of-brisbane-net-zero-emissions-scope-1-2/	2023		
New Owendo International Port	Gabon	AF	https://sustainableworldports.org/project/new-owendo-international-port-decarbonization-initiatives/	2023		
NSW Ports – Offshore wind energy hub	Australia	AU	https://sustainableworldports.org/project/nsw-ports-offshore-wind-energy-hub/	2023		
Port of Kapellskär	Sweeden	EU	https://www.espo.be/practices/port-of-kapellskar-offers-onshore-power-supply-ops	2022	Technical	Onshore Power supply
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/the-port-of-antwerp-bruges-detects-floating-debris	2022	Technical	waste management
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/circular-economy-hotspot-nextgen-district-at-the-p	2022	Technical	circular economy
Port of Vlissingen	Netherlands	EU	https://www.espo.be/practices/chemical-recycling-of-plastic-waste-at-north-sea-p	2022	Technical	circular economy
Port of Valencia	Spain	EU	https://www.espo.be/practices/port-of-valencia-gets-rid-of-plastic-bottles	2021	Technical	circular economy
Port of Valencia	Spain	EU	https://www.espo.be/practices/loop-ports	2021	Strategy/ Plan	circular economy

Port of Kiel	Germany	EU	https://www.espo.be/practices/waste-heat	2021	Technical	waste management
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/waste-heat	2021	Technical	circular economy
Port of Algeciras	Spain	EU	https://www.espo.be/practices/plastics-reduction-campaign	2021	Technical	circular economy
Port of Barcelona	Spain	EU	https://www.espo.be/practices/elimination-of-plastic-bottles	2021	Initiative/ Policy	circular economy
Port of Vigo	Spain	EU	https://www.espo.be/practices/ml-style	2021	Initiative/ Policy	waste management
Port of Amsterdam	Netherlands	EU	https://www.espo.be/practices/circular-economy	2021	Strategy/ Plan	circular economy
Port of Nakskov	Denmark	EU	https://www.espo.be/practices/port-of-nakskov-applying-circular-economy-principles	2021	Technical	circular economy
Port of Santander	Spain	EU	https://www.espo.be/practices/use-of-rainwater-for-cleaning	2021	Technical	Water quality
Port of Dover	UK	EU	https://www.espo.be/practices/the-dover-sea-award-for-cruise-waste-management	2021	Initiative/ Policy	waste management
Port of Ipswich	UK	EU	https://www.espo.be/practices/electric-hydraulic-cranes-at-the-port-of-ipswich	2021	Technical	electrification
Port of Hamburg	Germany	EU	https://www.espo.be/practices/hybrid-port-vessels-at-the-port-of-hamburg	2022	Technical	electrification
Port of Barcelona	Spain	EU	https://www.espo.be/practices/use-of-lng-at-the-port-of-barcelona	2022	Technical	LNG in port
Port of Marseille	France	EU	https://www.espo.be/practices/lng-bunkering-operation-at-the-port-of-marseille	2022	Technical	LNG in port
Port of Bilbao	Spain	EU	https://www.espo.be/practices/new-lng-bunkering-terminal-at-the-port-of-bilbao	2022	Technical	LNG in port
Port of Mukran	Germany	EU	https://www.espo.be/practices/offshore-wind-farm-at-germanys-mukran-port	2022	Technical	Wind farms
Port of Wilhelmshaven	Germany	EU	https://www.espo.be/practices/hydrogen-production-at-wilhelmshaven	2022	Technical	Wind farms
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/hydrogen-production-at-the-port-of-rotterdam	2022	Technical	hydrogen
Port of Kiel	Germany	EU	https://www.espo.be/practices/port-of-kiel-blue-port-measures	2022	Initiative/ Policy	electrification
Port of Felixstowe	UK	EU	https://www.espo.be/practices/battery-powered-vehicles-at-the-port-of-felixstowe	2022	Technical	electrification
Port of Hamburg	Germany	EU	https://www.espo.be/practices/onshore-power-for-container-ships-at-the-port-of-hamburg	2022	Technical	Onshore Power supply
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/hydrogen-network-for-north-sea-port	2022	Initiative/ Policy	hydrogen
Port of Genoa	Italy	EU	https://www.espo.be/practices/onshore-electricity-at-ports-of-genoa	2022	Technical	Onshore Power supply
Shoreham Port	UK	EU	https://www.espo.be/practices/development-of-a-hydrogen-hub-at-shoreham-port	2022	Technical	hydrogen
Port of Gothenburg	Sweeden	EU	https://www.espo.be/practices/hydrogen-production-facility-at-the-port-of-gothenburg	2022	Strategy/ Plan	hydrogen
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/ports-of-antwerp-and-montreal-to-create-green-ship	2022	Initiative/ Policy	green shipping corridors
Ports of Stockholm, Helsinki, and Tallinn	Sweeden	EU	https://www.espo.be/practices/onshore-power-for-ferries-between-ports-of-stockholm-helsinki-and-tallinn	2022	Technical	Onshore Power supply
Port of Valencia, Port of Hamburg	Europe	EU	https://www.espo.be/practices/new-agreement-around-hydrogen-between-the-port-of-valencia-and-the-port-of-hamburg	2022	Technical	hydrogen
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/port-of-antwerp-port-of-zeebrugge-and-chile-collaboration	2022	Technical	hydrogen
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/shore-based-power-at-the-port-of-rotterdam	2022	Technical	Onshore Power supply
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/port-of-rotterdam-sustainable-inland-shipping	2021	Technical	electrification
Port of Gothenburg	Sweeden	EU	https://www.espo.be/practices/onshore-power-supply-at-the-port-of-gothenburg	2021	Technical	Onshore Power supply
Port of Gothenburg	Sweeden	EU	https://www.espo.be/practices/tranzero-initiative-of-the-port-of-gothenburg	2021	Initiative/ Policy	electrification
Port of Kiel	Germany	EU	https://www.espo.be/practices/shore-power-for-cruise-ships-and-ro-ro-ferries-at-the-port-of-kiel	2021	Technical	Onshore Power supply
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/port-of-rotterdam-signs-mou-for-transport-of-blue-ammonia	2021	Initiative/ Policy	Blue ammonia
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/first-tugboat-using-methanol-to-be-used-in-port-of-antwerp	2021	Technical	fleet replacement programmes
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/onshore-power-supply-in-the-ports-of-antwerp-bremse	2021	Initiative/ Policy	Onshore Power supply
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/hydrogen-powered-trucks-in-the-port-of-rotterdam	2021	Technical	fleet replacement programmes

Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/shore-power-in-the-port-of-rotterdam	2021	Technical	Onshore Power supply
Associated British Ports	UK	EU	https://www.espo.be/practices/abp-has-stepped-up-its-sustainability-efforts-for-	2021	Technical	Onshore Power supply
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/port-of-rotterdam-incentive-scheme-climate-friendl	2021	Initiative/ Policy	alternative fuels
Associated British Ports	UK	EU	https://www.espo.be/practices/joint-bid-for-a-low-carbon-hydrogen-supply-to-abps	2021	Initiative/ Policy	hydrogen
Port of Gdynia	Poland	EU	https://www.espo.be/practices/port-of-gdynia-to-become-an-offshore-wind-hub	2021	Technical	Wind farms
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/construction-of-a-solar-farm-at-valuepark-terneuze	2021	Technical	Wind farms
Port of Copenhagen	Denmark	EU	https://www.espo.be/practices/onshore-power-supply-ops-facility-at-the-dfcs-ferr	2021	Initiative/ Policy	Onshore Power supply
Port of Amsterdam	Netherlands	EU	https://www.espo.be/practices/methanol-produced-from-non-recyclable-waste-at-the	2021	Technical	biofuels
Port of Bilbao	Spain	EU	https://www.espo.be/practices/green-hydrogen-production-plant-in-the-port-of-bil	2021	Technical	hydrogen
Port of Gdynia	Poland	EU	https://www.espo.be/practices/first-onshore-power-supply-ops-charging-station-in	2021	Technical	Onshore Power supply
Port of Lowestoft	UK	EU	https://www.espo.be/practices/lowestoft-eastern-energy-facility-leef	2021	Technical	Wind farms
Port of Kiel	Germany	EU	https://www.espo.be/practices/methanol-alternative-marine-fuel	2021	Strategy/ Plan	methanol
Port of Piombino	Italy	EU	https://www.espo.be/practices/energy-efficiency	2021	Strategy/ Plan	LED technology
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/antwerpc	2021	Technical	carbon capture and storage
Port of Valencia	Spain	EU	https://www.espo.be/practices/h2ports	2021	Technical	hydrogen
Port of Valencia	Spain	EU	https://www.espo.be/practices/energy-efficiency-projects	2021	Initiative/ Policy	fleet replacement programmes
Port of Marseille	France	EU	https://www.espo.be/practices/jupiter-1000-hydrogen-electrolysis	2021	Technical	hydrogen
Port of Marseille	France	EU	https://www.espo.be/practices/comprehensive-electrification-of-the-port	2021	Technical	Onshore Power supply
Port of Barcelona	Spain	EU	https://www.espo.be/practices/renewable-energy-plan	2021	Strategy/ Plan	solar plants/ farms
Port of Barcelona	Spain	EU	https://www.espo.be/practices/comprehensive-electrification	2021	Strategy/ Plan	Onshore Power supply
Port of Vigo	Spain	EU	https://www.espo.be/practices/fish-market-40	2021	Technical	LED technology
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/energy-infrastructure	2021	Technical	carbon capture and storage
Port of Klaipeda	Lithuania	EU	https://www.espo.be/practices/the-worlds-first-floating-lng-terminal	2021	Technical	LNG in port
Port of Valetta	Malta	EU	https://www.espo.be/practices/westmopoco-imaros	2021	Technical	water quality
Port of Esbjerg	Denmark	EU	https://www.espo.be/practices/port-of-esbjerg-monitoring-energy-consumption-and-	2021	Technical	Onshore Power supply
Port of Esbjerg	Denmark	EU	https://www.espo.be/practices/port-of-esbjerg-consolidating-market-leadership-in	2021	Strategy/ Plan	Wind farms
Port of Hirtshals	Denmark	EU	https://www.espo.be/practices/port-of-hirtshals-commercial-and-sustainable-energ	2021	Technical	Wind farms
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/upgrading-building-infrastructure-to-the-highest-e	2021	Technical	LED technology
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/working-to-boost-renewable-energy-infrastructure	2021	Technical	Wind farms
Port of Stockholm	Sweeden	EU	https://www.espo.be/practices/developing-rooftop-solar-cell-systems	2021	Technical	solar plants/ farms
Port of Gothenburg	Sweeden	EU	https://www.espo.be/practices/facilitating-and-encouraging-the-uptake-of-alterna	2021	Initiative/ Policy	Onshore Power supply
Port of Tallinn	Estonia	EU	https://www.espo.be/practices/locally-produced-green-energy	2021	Technical	electrification
Port of Tallinn	Estonia	EU	https://www.espo.be/practices/energy-efficiency-and-sustainable-use-of-natural-r	2021	Technical	solar plants/ farms
North Adriatic Sea Port	Italy, Slovenia, Croatia, Albania	EU	https://www.espo.be/practices/increasing-energy-efficiency-in-port-and-terminal-	2021	Technical	LED technology
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/digital-platform-to-identify-port-of-rotterdams-em	2021	Technical	decarbonisation
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/port-of-rotterdam-co2-neutral-in-3-steps	2021	Strategy/ Plan	decarbonisation
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/port-of-rotterdam-digital-solutions-for-sustainabl	2021	Technical	decarbonisation

Port of Bergen	Norway	EU	https://www.espo.be/practices/battery-run-workboat-for-the-port-of-bergen	2021	Technical	electrification
Port of Hamburg	Germany	EU	https://www.espo.be/practices/new-hybrid-workboat-for-the-hamburg-port-authority	2021	Technical	electrification
Port of Valencia	Spain	EU	https://www.espo.be/practices/cabins-to-control-air-quality-and-environmental-fa	2021	Technical	decarbonisation
Port of Oostende	France	EU	https://www.espo.be/practices/ishy-project-implementation-of-hybrid-shipping	2021	Technical	decarbonisation
Port of Helsinki	Finland	EU	https://www.espo.be/practices/ops-and-automooring-systems	2021	Technical	Onshore Power supply
Port of Valencia	Spain	EU	https://www.espo.be/practices/green-ports-digital-tools-towards-sustainability	2021	Strategy/ Plan	decarbonisation
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/carbon-footprint-of-the-port-authority	2021	Technical	biofuels
Port of Valetta	Malta	EU	https://www.espo.be/practices/grand-harbour-clean-project	2021	Technical	Onshore Power supply
Port of Tallinn	Estonia	EU	https://www.espo.be/practices/clean-air-projects-in-the-port-of-tallinn	2021	Initiative/ Policy	decarbonisation
Port of Dover	UK	EU	https://www.espo.be/practices/achieving-emissions-reductions-targets-through-sol	2021	Initiative/ Policy	solar plants/ farms
Port of Venice	Italy	EU	https://www.espo.be/practices/achieving-emissions-reductions-through-dialogue-wi	2021	Initiative/ Policy	alternative fuels
Port of Vigo	Spain	EU	https://www.espo.be/practices/living-ports-infrastructure-project-at-the-port-of	2022	Technical	Nature and habitat
Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/new-park-at-maashaven-port-of-rotterdam	2022	Technical	Nature and habitat
Port of Stockholm	Sweeden	EU	https://www.espo.be/practices/solar-powered-smart-buoys-tests-at-the-ports-of-st	2022	Technical	solar plants/ farms
Port of Tallinn	Estonia	EU	https://www.espo.be/practices/new-sustainable-cruise-terminal-opens-at-port-of-t	2021	Initiative/ Policy	solar plants/ farms
Port of Malmo	Copenhagen	EU	https://www.espo.be/practices/new-green-container-in-copenhagen-malmo-port	2021	Technical	infrastructure
Port of Helsinki	Finland	NO	https://www.espo.be/practices/environmental-incentives	2021		
Port of Algeciras	Spain	EU	https://www.espo.be/practices/the-apba-replaces-more-than-60-of-its-mobile-fleet	2021	Technical	fleet replacement programmes
Port of Amsterdam	Netherlands	NO				
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/ensuring-staff-have-the-greenest-options-on-their-	2021	Initiative/ Policy	green modal share
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/the-port-of-antwerp-bruges-redevelops-polluted-sit	2022	Technical	Nature and habitat
Port of Sevilla	Spain	EU	https://www.espo.be/practices/regeneration-of-the-donana-coastline-at-the-port-o	2022	Technical	Nature and habitat
Port of Tarifa	Spain	EU	https://www.espo.be/practices/pilot-project-for-the-repositioning-of-rocky-block	2022	Technical	Nature and habitat
Port of Algeciras	Spain	EU	https://www.espo.be/practices/early-detection-of-potentially-invasive-algae-at-t	2022	Strategy/ Plan	Nature and habitat
Port of Riga	Latvia	EU	https://www.espo.be/practices/freeport-of-riga-authoritys-soil-remediation-techn	2022	Technical	Nature and habitat
Port of Bremen	German	EU	https://www.espo.be/practices/port-of-bremens-clean-project	2022	Technical	water quality
Port of Roenne	Denmark	EU	https://www.espo.be/practices/port-of-roenne-is-planting-trees-on-bornholm	2021	Initiative/ Policy	Nature and habitat
North Sea Port	Belgium and the Netherlands	EU	https://www.espo.be/practices/water-quality-monitoring-at-the-ghent-terneuzen-se	2021	Technical	water quality
Port of Algeciras	Spain	EU	https://www.espo.be/practices/cleaning-of-the-algeciras-coastline	2021	Initiative/ Policy	Nature and habitat
Port of Le Havre	France	EU	https://www.espo.be/practices/nest-boxes-for-birds-and-bats	2021	Initiative/ Policy	Nature and habitat
Port of Livorno	Italy	EU	https://www.espo.be/practices/livorno-new-venice-canals	2021	Initiative/ Policy	Nature and habitat
Port of Cava	Spain	EU	https://www.espo.be/practices/elba-island-repopulation-of-protected-species	2021	Initiative/ Policy	Nature and habitat
Port of Piombino	Italy	EU	https://www.espo.be/practices/beach-clean	2021	Initiative/ Policy	Nature and habitat
Port of Antwerp	Belgium	EU	https://www.espo.be/practices/agriculture-innovation-fund-to-stimulate-nature-in	2021	Initiative/ Policy	Nature and habitat
Port of Algeciras	Spain	EU	https://www.espo.be/practices/life-remopaf-project	2021	Initiative/ Policy	Nature and habitat
Port of Valencia	Spain	EU	https://www.espo.be/practices/hisea	2021	Technical	water quality
Port of Marseille	France	EU	https://www.espo.be/practices/water-treatment-system	2021	Technical	waste management
Port of Vigo	Spain	EU	https://www.espo.be/practices/sunset-dock	2021	Initiative/ Policy	Nature and habitat

Port of Rotterdam	Netherlands	EU	https://www.espo.be/practices/nature-in-the-port-the-bird-valley	2021	Initiative/ Policy	Nature and habitat
Port of Gothenburg	Sweeden	EU	https://www.espo.be/practices/ensuring-port-expansion-minimises-biodiversity-loss	2021	Initiative/ Policy	Nature and habitat
Port of Dover	UK	EU	https://www.espo.be/practices/annual-beach-clean	2021	Initiative/ Policy	Nature and habitat
North Adriatic Sea Port		EU	https://www.espo.be/practices/investigating-how-to-reduce-ship-noise-pollution-p	2021	Initiative/ Policy	Noise
Port of Koper	Slovenia	EU	https://www.researchgate.net/publication/321246833_An_Evaluation_of_Marine_Sediments_in_Terms_of_their_usability_in_the_Brick_Industry_Case_Study_Port_of_Koper	2017	Technical	Nature and habitat
Port of Rotterdam	Netherlands	EU	https://www.mdpi.com/2071-1050/10/7/2558	2018	Strategy/ Plan	alternative fuels
Port of Gävle	Sweeden	EU	https://www.sciencedirect.com/science/article/pii/S0025326X18300766	2018	Technical	circular economy
Port of Barcelona	Spain	EU	https://upcommons.upc.edu/bitstream/handle/2117/366076/water-14-01146.pdf?sequence=1	2022	Technical	carbon capture and storage
Port of Izmit Bay	Turkey	AS	https://www.tandfonline.com/doi/full/10.1080/18366503.2022.2038465	2022	Technical	digital solutions
Port of Casablanca	Morocco	AF	https://www.sciencedirect.com/science/article/pii/S0959652621004893	2021	Technical	digital solutions
Port of Valparaiso	Chile	US	https://www.researchgate.net/publication/356992696_Green_Hydrogen_Value_Chain_in_the_Sustainability_for_Port_Operations_Case_Study_in_the_Region_of_Valparaiso_Chile	2021	Technical	hydrogen
Port of Aberdeen	Scotland	EU	https://www.sciencedirect.com/science/article/pii/S1361920917309124	2018	Technical	Onshore Power supply
Mediterranean ports	Europe	EU	https://spoudai.unipi.gr/index.php/spoudai/article/view/2572	2017	Technical	waste management
Port of Djibouti	Africa	AF	https://link.springer.com/article/10.1007/s10098-019-01706-z#:~:text=One%20can%20deduce%20that%20power,power%20in%20Djibouti's%20container%20terminals.	2019	Technical	Onshore Power supply
Port of Mongla	Bangladesh	AS	http://www.iccesd.com/proc_2020/Papers/WRE-4824.pdf	2020	Technical	Nature and habitat
Port of Bagladesh	Bangladesh	AS	https://www.sciencedirect.com/science/article/pii/S0308597X23001069	2023		
Port of Amsterdam	Netherlands	EU	Jepma_2020	2020		
Port of Den Helder	Netherlands	EU	Jepma_2020	2020		
The Groningen Seaports	Netherlands	EU	Jepma_2020	2020		
Port of Klaipeda	Lithuania	EU	Lebedas_2020	2020		
Port of Jorf Lasfar, Safi, Agadir, Tan Tan, Laayoune and Dakhle.	Morocco	AF	Ash_2019	2019		
Port of Szczecin	Poland	EU	Mankowska_2020	2020		
Port of Malmo	Sweeden	EU	Kirampour_2019	2019		
Port of Benoa	Bali	AS	Ballini_2017	2017		
Port of Aalborg	Denmark	EU	Abu Bakar_2022	2022		
Port of Kapellskär	Sweeden	EU	Abdaoui_2021	2021		
Port of Heraklion	Greece	EU	Karapidakis_2022	2022		
Iskenderun Port	Turkey	AS	Kilic_2020	2020		
Port of Nigeria	Nigeria	AF	Anyanwu_2022	2022		
Port of Trieste	Italy	AS	Picolli_2021	2021		
Port of Sanghai	China	AS	Wang_2021	2021		
No case specific			Wang_2021	2021		
Port of Ancona	Italy	EU	Collarosi_2020	2020		
Port of Copenhagen	Denmark	EU	Ahamad_2018	2018		
Port of Civitavecchia	Italy	EU	Coppola_2014	2014		
Chinese ports	China	AS	Feng_2017	2017		
Port of Barcelona	Spain	EU	Rolan_2019	2019		
Port of Mombasa	Kenya	EU	Ssali_2018	2018		
Port of Copenhagen	Denmark	EU	Zaneti_2013	2013		
Spanish ports	EU	EU	Santander_2018	2018		
Chinese ports	China	AS	Haibo_2018	2018		

Port of Aberdeen	Scotland	EU	Innes_2018	2018	
Chinese ports	China	AS	Peng_2018	2018	
Port of Cartagena	Colombia	US	Perez_2015	2015	
Port of Cartagena	Colombia	US	Romero_2019	2019	
Port of Gävle	Sweeden	EU	Saenz_2019	2019	
Port of Shenzhen	China	AS	Wang_2015	2015	
Port of Singapore	Singapore	AS	Iris_2020	2020	
Finnish ports	Finland	EU	Inkinen_2021	2021	
Russian ports	Russia	AS	Zaychenko_2021	2021	
Croatian ports	Croatia	EU	Kavran_2019	2019	
Port of Klang	Malaysia	AS	Jeevan_2022	2022	
Italian ports	Italy	EU	Di Vaio_2018	2018	
Port Said	Egypt	AF	Lashin_2012	2012	
Port of Mytilene	Greece	EU	Kotkla_2017	2017	
Cantabric and North-Atlantic coasts of Spain	Spain	EU	Castro-Santos_2020	2020	
Brazilian ports	Brazil	US	Fossile_2020	2020	
South Korean ports	Korea	AS	Kim_2018	2018	
European ports	Europe	EU	Deja_2013	2013	
Port of Naples	Italy	EU	Di Vaio_2019	2019	
Croatian ports	Croatia	EU	Badurina_2017	2017	
Adamas port	Greece	EU	Vichos_2022	2022	
Trieste	Italy	EU	Pivetta_2023	2023	
No case specific			Luo_2023	2023	
Port of Koper	Slovenia	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Bar	Montenegro	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Durres	Albania	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Thessaloniki	Greece	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Venice	Italy	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Trieste	Italy	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Piraeus	Greece	EU	https://supair.adrioninterreg.eu/library	2020	multiple actions in port
Port of Koper	Slovenia	EU	https://adripass.adrioninterreg.eu/category/library-archive/page/3	2022	multiple actions in port
Port of Ploče	Croatia	EU	https://adripass.adrioninterreg.eu/category/library-archive/page/4	2022	digital solutions
Port of Igoumenitsa	Greece	EU	https://adripass.adrioninterreg.eu/category/library-archive/page/5	2022	digital solutions
Port of Bar	Montenegro	EU	https://adripass.adrioninterreg.eu/category/library-archive/page/6	2022	digital solutions
Port of Venice	Italy	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	infrastructure
Port of Ancona	Italy	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	digital solutions
Port of Ravenna	Italy	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	infrastructure
Port of Igoumenitsa	Greece	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	infrastructure
Port of Zagreb	Croatia	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	multiple actions in port
Port of Bar	Montenegro	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	multiple actions in port
Port of Verona	Italy	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	multiple actions in port
Port of Piraeus	Greece	EU	https://newbrain.adrioninterreg.eu/activities-archive/newbrain-action-plans	2019	digital solutions
Port of Valencia	Spain	EU	Deliverable not publicly available	2015	LNG in port
Port of Koper	Slovenia	EU	Deliverable not publicly available	2015	digital solutions
Port of Rijeka	Croatia	EU	Deliverable not publicly available	2015	solar plants/ farms

ANNEX V: The entire list of model's variables and equations

Variable name	Equation	Type	Units
new funding approvals	10000000	Constant	euros/year
available capital budget	INTEG (new funding approvals - annual capital allocation , 60e6)	Level	euros
total annual spending	annual budget for ops + annual budget for charging + annual budget for grid + annual budget for GSV + annual budget for electric cranes	Auxiliary	euros/year
annual capital allocation	total annual spending	Auxiliary	euros/year
allocation share for GSV	0.175	Constant	Dmnl
annual budget for GSV	(available capital budget * allocation share for GSV)/ allocation time	Auxiliary	euros/year
allocation time	1	Constant	year
allocation share for OPS	0.4	Constant	Dmnl
annual budget for OPS	(available capital budget * allocation share for OPS)/ allocation time	Level	euros/year
allocation share for charging hubs	0.125	Constant	Dmnl
annual budget for charging hubs	(available capital budget * allocation share for charging hubs)/ allocation time	Auxiliary	euros/year
allocation share for electric cranes	0.2	Constant	Dmnl
annual budget for electric cranes	(available capital budget * allocation share for charging hubs)/ allocation time	Auxiliary	euros/year
allocation share for grid	0.1	Constant	Dmnl
annual budget for grid	(available capital budget * allocation share for grid)/ allocation time	Auxiliary	euros/year
gsv adopted	(new gsv adopted-gsv retirement)	Level	vehicles

new gsv adopted	(annual budget for gsv/capex per gsv)*implementation efficiency gsv*saturation factor gsv	Auxiliary	vehicles/year
gsv retirement	gsv adopted*retirement rate gsv	Auxiliary	vehicles/year
capex per gsv	150000	Constant	euros/vehicles
implementation efficiency gsv	0.8	Constant	Dmnl
max gsv capacity	60	Constant	Vehicles
retirement rate gsv	0.05	Constant	1/year
saturation factor gsv	$\text{MAX}(0, \text{MIN}(1, (\text{max gsv capacity} - \text{gsv adopted}) / \text{saturation normalizer gsv}))$	Auxiliary	Dmnl
saturation normalizer gsv	max gsv capacity	Auxiliary	vehicles
ops units installed	(annual budget for ops/capex per berth) * implementation efficiency ops * saturation factor ops	Auxiliary	berths/year
ops infrastructure deployed	ops units installed - ops retirement	Level	berths
ops retirement	ops infrastructure deployed * retirement rate ops	Auxiliary	berths/year
saturation factor ops	$\text{MAX}(0, \text{MIN}(1, (\text{max ops capacity} - \text{ops infrastructure deployed}) / \text{saturation normalizer ops}))$	Auxiliary	Dmnl
capex per berth	6000000	Constant	euros/berths
implementation efficiency ops	0.9	Constant	Dmnl
retirement rate ops	0.05	Constant	1/year
max ops capacity	12	Constant	berths
saturation normalizer ops	5	Constant	berths
charging units deployed	(new charging units installed - chargers retirement)	Level	chargers
new charging units installed	(annual budget for charging/capex per charger)*implementation efficiency charging	Auxiliary	chargers/year

	unit*saturation factor charging unit		
chargers retirement	charging units deployed*retirement rate charging unit	Auxiliary	chargers/year
capex per charger	150000	Constant	euros/chargers
implementation efficiency charging unit	0.85	Constant	Dmnl
saturation normalizer charging unit	max charging unit capacity	Auxiliary	chargers
saturation factor charging unit	MAX(0 , MIN(1 , (max charging unit capacity - charging units deployed) / saturation normalizer charging unit))	Auxiliary	Dmnl
retirement rate charging unit	0.07	Constant	1/year
max charging unit capacity	40	Constant	chargers
new electric cranes installed	(annual budget for electric cranes/capex per crane)*implementation efficiency cranes*saturation factor cranes	Auxiliary	cranes/year
electric cranes deployed	(new electric cranes installed - electric crane retirement)	Level	cranes
electric crane retirement	electric cranes deployed * retirement rate cranes	Auxiliary	cranes/year
retirement rate cranes	0.03	Constant	1/year
capex per crane	3000000	Constant	euros/cranes
saturation normalizer cranes	12	Constant	cranes
saturation factor cranes	MAX(0,MIN(1,(max cranes capacity-electric cranes deployed)/saturation normalizer cranes))	Auxiliary	Dmnl
implementation efficiency cranes	0.8	Constant	Dmnl
max cranes capacity	12	Constant	cranes

grid capacity installed	(new grid capacity installed- grid capacity retirement, 20)	Level	mw
new grid capacity installed	(annual budget for grid/capex per mw grid)*implementation efficiency grid*saturation factor grid	Auxiliary	mw/year
grid capacity retirement	grid capacity installed*retirement rate grid	Auxiliary	mw/year
saturation factor grid	MAX(0,MIN(1,(max grid capacity - grid capacity installed)/saturation normalizer grid))	Auxiliary	Dmnl
retirement rate grid	0	Constant	1/year
saturation normalizer grid	max grid capacity	Auxiliary	mw
max grid capacity	80	Constant	mw
implementation efficiency grid	0.3	Constant	Dmnl
capex per mw grid	1000000	Constant	euros/mw
capital overspend indicator	MAX(0 , annual capital allocation - (available capital budget / allocation time))	Auxiliary	euros/year
capital budget violation	MIN(0, available capital budget)	Auxiliary	euros

ANNEX VI: System Dynamics Model Specification (.mdl file extract)

```
{UTF-8}
ops units installed=
    (annual budget for ops/capex per berth)*implementation efficiency ops*saturation factor ops\
    *grid readiness factor ops
    ~      berths/year
    ~      |

grid headroom for ops=
    MAX(0, grid capacity installed - nonops port load)
    ~      mw
    ~      |

grid readiness factor ops=
    MAX(0,MIN(1,grid headroom for ops/(ops power required + small number mw)))
    ~      Dmnl
    ~      αυτός ο ορισμός κάνει το readiness να \
    μειώνεται όσο μεγαλώνει η απαιτούμενη ops \
    ισχύς και να αυξάνει όσο αυξάνει το headroom. \
    Είναι "soft constraint"
    |

nonops port load=
    15
    ~      mw
    ~      "άλλα φορτία λιμένα" (φωτισμός, κτήρια, \
    λοιπές υποδομές κ.λπ.).
    |

ops power requirement per berth=
    2
    ~      mw/berths
    ~      είναι η ισχύς που "δεσμεύει" ένα berth με \
    ops (aggregate/representative)
    |

ops power required=
    ops infrastructure deployed*ops power requirement per berth
    ~      mw
    ~      |

small number mw=
    0.001
    ~      mw
    ~      μόνο για αποφυγή διαίρεσης με 0
    |

implementation efficiency cranes=
    0.8
    ~      Dmnl
    ~      |

capex per gsv=
    150000
    ~      euros/vehicles
    ~      |

max charging unit capacity=
    40
    ~      chargers
```

```

~      |

max cranes capacity=
12
~      cranes
~      |

max grid capacity =
80
~      mw
~      |

max gsv capacity=
60
~      vehicles
~      |

charging units deployed= INTEG (
    (new charging units installed-chargers retirement),
    0)
~      chargers
~      |

new charging units installed=
    (annual budget for charging/capex per charger)*implementation efficiency charging unit\
    *saturation factor charging unit
~      chargers/year
~      |

new electric cranes installed=
    (annual budget for electric cranes/capex per crane)*implementation efficiency cranes\
    *saturation factor cranes
~      cranes/year
~      |

grid capacity installed= INTEG (
    (new grid capacity installed-grid capacity retirement),
    20)
~      mw
~      |

new grid capacity installed=
    (annual budget for grid/capex per mw grid)*implementation efficiency grid*saturation factor grid
~      mw/year
~      |

new gsv adopted=
    (annual budget for gsv/capex per gsv)*implementation efficiency gsv*saturation factor gsv
~      vehicles/year
~      |

gsv retirement=
    gsv adopted*retirement rate gsv
~      vehicles/year
~      |

implementation efficiency charging unit=
0.85
~      Dmnl
~      |

capex per charger=

```

```

150000
~      euros/chargers
~      |

capex per crane=
3e+06
~      euros/cranes
~      |

retirement rate charging unit=
0.07
~      1/year
~      |

capex per mw grid=
1e+06
~      euros/mw
~      |

capital budget violation=
MIN( 0, available capital budget )
~      euros
~      ~      :SUPPLEMENTARY
~      |

capital overspend indicator=
MAX( 0 , annual capital allocation - ( available capital budget / allocation time ) \
)
~      euros/year
~      ~      :SUPPLEMENTARY
~      |

chargers retirement=
charging units deployed*retirement rate charging unit
~      chargers/year
~      |

saturation factor charging unit=
MAX( 0 , MIN( 1 , ( max charging unit capacity - charging units deployed ) / saturation normalizer charging unit\
))
~      Dmnl
~      |

electric crane retirement=
electric cranes deployed * retirement rate cranes
~      cranes/year
~      |

electric cranes deployed= INTEG (
(new electric cranes installed - electric crane retirement),
0)
~      cranes
~      |

saturation factor gsv=
MAX( 0 ,MIN( 1 ,( max gsv capacity - gsv adopted ) / saturation normalizer gsv ) )
~      Dmnl
~      |

grid capacity retirement=
grid capacity installed*retirement rate grid
~      mw/year

```

```

~      |
gsv adopted= INTEG (
    (new gsv adopted-gsv retirement),
    0)
~      vehicles
~      |

saturation normalizer cranes=
    12
~      cranes
~      |

saturation normalizer grid=
    max grid capacity
~      mw
~      |

implementation efficiency grid=
    0.3
~      Dmnl
~      |

implementation efficiency gsv=
    0.8
~      Dmnl
~      |

saturation factor grid=
    MAX(0,MIN(1,( max grid capacity - grid capacity installed)/saturation normalizer grid\
    ))
~      Dmnl
~      |

retirement rate cranes=
    0.03
~      1/year
~      |

retirement rate grid=
    0
~      1/year
~      |

retirement rate gsv=
    0.05
~      1/year
~      |

saturation factor cranes=
    MAX(0,MIN(1,(max cranes capacity-electric cranes deployed)/saturation normalizer cranes\
    ))
~      Dmnl
~      |

saturation normalizer charging unit=
    max charging unit capacity
~      chargers
~      |

saturation normalizer gsv=
    max gsv capacity

```

```

~      vehicles
~      |

ops retirement=
ops infrastructure deployed*retirement rate ops
~      berths/year
~      |

ops infrastructure deployed= INTEG (
ops units installed-ops retirement),
0)
~      berths
~      |

saturation factor ops=
MAX(0,MIN(1,(max ops capacity-ops infrastructure deployed)/saturation normalizer ops\
))
~      Dmnl
~      |

capex per berth=
6e+06
~      euros/berths
~      |

implementation efficiency ops=
0.9
~      Dmnl
~      |

max ops capacity=
12
~      berths
~      |

retirement rate ops=
0.05
~      1/year
~      |

saturation normalizer ops=
5
~      berths
~      |

annual capital allocation=
total annual spending
~      euros/year
~      |

total annual spending=
annual budget for ops + annual budget for charging + annual budget for grid + annual budget for gsv\
+ annual budget for electric cranes
~      euros/year
~      |

available capital budget= INTEG (
( new funding approvals - annual capital allocation),
)
~      euros
~      |

```

annual budget for electric cranes=
 (available capital budget * allocation share for electric cranes)/ allocation time
 ~ euros/year
 ~ |

annual budget for grid=
 (available capital budget * allocation share for grid)/ allocation time
 ~ euros/year
 ~ |

annual budget for gsv=
 (available capital budget * allocation share for gsv)/ allocation time
 ~ euros/year
 ~ |

annual budget for ops=
 (available capital budget * allocation share for ops)/ allocation time
 ~ euros/year
 ~ |

allocation time=
 1
 ~ year
 ~ |

annual budget for charging=
 (available capital budget * allocation share for charging hubs)/ allocation time
 ~ euros/year
 ~ |

allocation share for charging hubs=
 0.1
 ~ Dmnl
 ~ |

allocation share for electric cranes=
 0.1
 ~ Dmnl
 ~ |

allocation share for grid=
 0.35
 ~ Dmnl
 ~ |

allocation share for gsv=
 0.15
 ~ Dmnl
 ~ |

allocation share for ops=
 0.3
 ~ Dmnl
 ~ |

new funding approvals=
 1e+07
 ~ euros/year
 ~ |

.Control

*****~

Simulation Control Parameters

|

FINAL TIME = 30

~ year
~ The final time for the simulation.
|

INITIAL TIME = 0

~ year
~ The initial time for the simulation.
|

SAVEPER =

TIME STEP

~ year [0,?]
~ The frequency with which output is stored.
|

TIME STEP = 0.25

~ year [0,?]
~ The time step for the simulation.
|

\\--// Sketch information - do not modify anything except names

V300 Do not put anything below this section - it will be ignored

*View 1

\$-1--1--1,0,10|-1--1|-1--1|-1--1|-1--1|-1--1|-1--1|-1--1|96,96,66,2
10,1,available capital budget,541,918,55,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
10,2,annual budget for ops,884,722,51,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
10,3,annual budget for charging,843,870,62,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
10,4,annual budget for grid,858,1038,51,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
11,5,0,665,933,6,8,2,3,0,0,1,0,0,0,0,0,0,0,0
11,6,0,665,933,6,8,2,3,0,0,1,0,0,0,0,0,0,0,0
11,7,0,629,1019,8,6,1,3,0,0,1,0,0,0,0,0,0,0,0
12,8,48,230,915,25,15,0,3,0,0,-1,1,0,0,0,0,0,0,0
1,9,11,8,100,0,0,22,0,192,0,-1--1--1,,1|(300,915)|
1,10,11,1,4,0,0,22,0,192,0,-1--1--1,,1|(421,915)|
11,11,0,351,915,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
10,12,new funding approvals,351,945,52,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
10,13,total annual spending,1346,831,42,23,8,3,0,0,-1,1,0,0,0,0,0,0,0
1,14,2,13,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
1,15,3,13,1,0,0,0,0,192,0,-1--1--1,,1|(1093,830)|
1,16,4,13,1,0,0,0,0,192,0,-1--1--1,,1|(1128,995)|
10,17,allocation share for ops,1137,573,54,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
1,18,17,2,1,0,0,0,0,192,0,-1--1--1,,1|(996,581)|
10,19,allocation share for electric cranes,-185,675,62,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
10,20,allocation share for charging hubs,1458,751,44,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
10,21,allocation share for grid,1305,1163,54,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
10,22,allocation share for gsv,-211,1269,56,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
1,23,20,3,1,0,0,0,0,192,0,-1--1--1,,1|(1200,654)|
1,24,21,4,1,0,0,0,0,192,0,-1--1--1,,1|(1067,1152)|
1,25,1,2,1,0,0,0,0,192,0,-1--1--1,,1|(649,771)|
1,26,1,3,1,0,0,0,0,192,0,-1--1--1,,1|(708,853)|
1,27,1,4,1,0,0,0,0,192,0,-1--1--1,,1|(671,1026)|
10,28,annual budget for gsv,145,1155,53,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
1,29,1,28,1,0,0,0,0,192,0,-1--1--1,,1|(408,1100)|
1,30,22,28,1,0,0,0,0,192,0,-1--1--1,,1|(-28,1265)|
1,31,28,13,1,0,0,0,0,192,0,-1--1--1,,1|(800,1200)|
10,32,annual budget for electric cranes,263,644,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
1,33,19,32,1,0,0,0,0,192,0,-1--1--1,,1|(15,611)|

1,34,1,32,1,0,0,0,0,192,0,-1--1--1,,1|(437,786)|
 1,35,32,13,1,0,0,0,0,192,0,-1--1--1,,1|(786,633)|
 10,36,allocation time,750,1302,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,37,36,4,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 1,38,36,3,1,0,0,0,0,192,0,-1--1--1,,1|(982,1076)|
 1,39,36,28,1,0,0,0,0,192,0,-1--1--1,,1|(433,1336)|
 1,40,36,2,1,0,0,0,0,192,0,-1--1--1,,1|(604,1009)|
 1,41,36,32,1,0,0,0,0,192,0,-1--1--1,,1|(48,1302)|
 12,42,48,1667,911,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,43,45,1,100,0,0,22,0,192,0,-1--1--1,,1|(837,911)|
 1,44,45,42,4,0,0,22,0,192,0,-1--1--1,,1|(1366,911)|
 11,45,0,1085,911,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,46,annual capital allocation,1085,941,56,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 1,47,13,46,1,0,0,0,0,192,0,-1--1--1,,1|(1193,855)|
 10,48,ops infrastructure deployed,415,479,42,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
 12,49,48,76,479,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 12,50,48,793,479,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,51,53,48,100,0,0,22,0,192,0,-1--1--1,,1|(531,479)|
 1,52,53,50,4,0,0,22,0,192,0,-1--1--1,,1|(693,479)|
 11,53,0,612,479,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,54,ops retirement,612,509,42,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 10,55,capex per berth,186,234,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,56,implementation efficiency ops,445,309,59,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,57,retirement rate ops,745,219,44,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,58,max ops capacity,971,354,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,59,saturation normalizer ops,950,18,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,60,57,54,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 10,61,saturation factor ops,307,35,48,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,62,59,61,1,0,0,0,0,192,0,-1--1--1,,1|(638,149)|
 1,63,58,61,1,0,0,0,0,192,0,-1--1--1,,1|(709,98)|
 1,64,66,49,100,0,0,22,0,192,0,-1--1--1,,1|(166,479)|
 1,65,66,48,4,0,0,22,0,192,0,-1--1--1,,1|(308,479)|
 11,66,0,237,479,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,67,ops units installed,237,509,42,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 1,68,2,67,1,0,0,0,0,192,0,-1--1--1,,1|(572,577)|
 1,69,55,67,1,0,0,0,0,192,0,-1--1--1,,1|(159,368)|
 1,70,56,67,1,0,0,0,0,192,0,-1--1--1,,1|(296,365)|
 1,71,61,67,1,0,0,0,0,192,0,-1--1--1,,1|(81,245)|
 1,72,48,54,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 1,73,48,61,1,0,0,0,0,192,0,-1--1--1,,1|(328,265)|
 10,74,charging units deployed,407,1671,55,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
 12,75,48,37,1666,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,76,78,75,100,0,0,22,0,192,0,-1--1--1,,1|(134,1666)|
 1,77,78,74,4,0,0,22,0,192,0,-1--1--1,,1|(285,1666)|
 11,78,0,213,1666,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,79,new charging units installed,213,1696,61,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 12,80,48,913,1671,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,81,83,74,100,0,0,22,0,192,0,-1--1--1,,1|(562,1671)|
 1,82,83,80,4,0,0,22,0,192,0,-1--1--1,,1|(781,1671)|
 11,83,0,669,1671,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,84,chargers retirement,669,1701,55,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 10,85,capex per charger,-22,1914,55,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,86,implementation efficiency charging unit,150,1999,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,87,saturation factor charging unit,570,1927,59,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,88,retirement rate charging unit,918,1935,55,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,89,saturation normalizer charging unit,354,2081,49,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,90,max charging unit capacity,805,2041,62,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,91,74,84,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 1,92,88,84,1,0,0,0,0,192,0,-1--1--1,,1|(843,1822)|
 1,93,85,79,1,0,0,0,0,192,0,-1--1--1,,1|(28,1780)|
 1,94,87,79,1,0,0,0,0,192,0,-1--1--1,,1|(471,1771)|
 1,95,86,79,1,0,0,0,0,192,0,-1--1--1,,1|(250,1864)|

1,96,3,79,1,0,0,0,0,192,0,-1--1--1,,1|(397,1260)|
 1,97,74,87,1,0,0,0,0,192,0,-1--1--1,,1|(404,1874)|
 1,98,89,87,1,0,0,0,0,192,0,-1--1--1,,1|(473,2059)|
 1,99,90,87,1,0,0,0,0,192,0,-1--1--1,,1|(704,2036)|
 10,100,capital budget violation,-423,94,80,36,8,3,0,58,-1,1,0,0,0-0-0-0-0,Arial|12||251-2-7,0,0,0,0,0,0
 1,101,1,100,1,0,0,0,0,192,0,-1--1--1,,1|(-430,673)|
 10,102,capital overspend indicator,-290,255,62,22,8,3,0,18,-1,1,0,0,0-0-0-0-0,||B|251-2-7,0,0,0,0,0,0
 1,103,46,102,1,0,0,0,0,192,0,-1--1--1,,1|(-240,869)|
 1,104,1,102,1,0,0,0,0,192,0,-1--1--1,,1|(-350,853)|
 10,105,electric cranes deployed,-939,858,56,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
 12,106,48,-1271,853,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,107,109,106,100,0,0,22,0,192,0,-1--1--1,,1|(-1186,853)|
 1,108,109,105,4,0,0,22,0,192,0,-1--1--1,,1|(-1055,853)|
 11,109,0,-1121,853,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,110,new electric cranes installed,-1121,883,45,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 12,111,48,-598,858,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,112,114,105,100,0,0,22,0,192,0,-1--1--1,,1|(-821,858)|
 1,113,114,111,4,0,0,22,0,192,0,-1--1--1,,1|(-685,858)|
 11,114,0,-753,858,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,115,electric crane retirement,-753,888,56,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 10,116,capex per crane,-973,650,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,117,implementation efficiency cranes,-879,1073,61,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,118,max cranes capacity,-1134,1115,48,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,119,saturation normalizer cranes,-697,523,49,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,120,saturation factor cranes,-640,701,54,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,121,retirement rate cranes,-1121,485,51,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,122,32,110,1,0,0,0,0,192,0,-1--1--1,,1|(-350,1020)|
 1,123,116,110,1,0,0,0,0,192,0,-1--1--1,,1|(-1085,742)|
 1,124,117,110,1,0,0,0,0,192,0,-1--1--1,,1|(-1027,1000)|
 1,125,120,110,1,0,0,0,0,192,0,-1--1--1,,1|(-899,735)|
 1,126,105,115,1,0,0,0,0,192,0,-1--1--1,,1|(-843,912)|
 1,127,121,115,1,0,0,0,0,192,0,-1--1--1,,1|(-837,589)|
 1,128,105,120,1,0,0,0,0,192,0,-1--1--1,,1|(-768,797)|
 1,129,118,120,1,0,0,0,0,192,0,-1--1--1,,1|(-549,1074)|
 1,130,119,120,1,0,0,0,0,192,0,-1--1--1,,1|(-628,599)|
 1,131,36,102,1,0,0,0,0,192,0,-1--1--1,,1|(-406,1133)|
 10,132,gsv adopted,-709,1481,42,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
 12,133,48,-1048,1480,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,134,136,133,100,0,0,22,0,192,0,-1--1--1,,1|(-952,1480)|
 1,135,136,132,4,0,0,22,0,192,0,-1--1--1,,1|(-810,1480)|
 11,136,0,-876,1480,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,137,new gsv adopted,-876,1510,42,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 12,138,48,-422,1483,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,139,141,132,100,0,0,22,0,192,0,-1--1--1,,1|(-609,1483)|
 1,140,141,138,4,0,0,22,0,192,0,-1--1--1,,1|(-493,1483)|
 11,141,0,-546,1483,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,142,gsv retirement,-546,1513,42,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 10,143,capex per gsv,-1115,1637,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,144,implementation efficiency gsv,-1201,1796,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,145,saturation factor gsv,-923,1833,47,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,146,saturation normalizer gsv,-609,1751,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,147,max gsv capacity,-435,1846,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,148,132,142,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 1,149,28,137,1,0,0,0,0,192,0,-1--1--1,,1|(-452,1245)|
 1,150,143,137,1,0,0,0,0,192,0,-1--1--1,,1|(-1029,1553)|
 1,151,144,137,1,0,0,0,0,192,0,-1--1--1,,1|(-1007,1699)|
 1,152,145,137,1,0,0,0,0,192,0,-1--1--1,,1|(-867,1692)|
 10,153,retirement rate gsv,-292,1660,44,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,154,153,142,1,0,0,0,0,192,0,-1--1--1,,1|(-468,1693)|
 1,155,147,145,1,0,0,0,0,192,0,-1--1--1,,1|(-653,1949)|
 1,156,146,145,1,0,0,0,0,192,0,-1--1--1,,1|(-743,1882)|
 1,157,132,145,1,0,0,0,0,192,0,-1--1--1,,1|(-764,1685)|

1,158,147,146,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 10,159,grid capacity installed,1448,1489,50,22,3,3,0,0,-1,1,0,0,0,0,0,0,0
 12,160,48,1081,1491,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,161,163,160,100,0,0,22,0,192,0,-1--1--1,,1|(1176,1491)|
 1,162,163,159,4,0,0,22,0,192,0,-1--1--1,,1|(1328,1491)|
 11,163,0,1252,1491,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,164,new grid capacity installed,1252,1521,61,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 12,165,48,1789,1489,25,15,0,3,0,0,-1,0,0,0,0,0,0,0,0
 1,166,168,159,100,0,0,22,0,192,0,-1--1--1,,1|(1561,1489)|
 1,167,168,165,4,0,0,22,0,192,0,-1--1--1,,1|(1700,1489)|
 11,168,0,1631,1489,6,8,34,3,0,0,1,0,0,0,0,0,0,0,0
 10,169,grid capacity retirement,1631,1519,54,22,40,3,0,0,-1,1,0,0,0,0,0,0,0
 10,170,capex per mw grid,1198,1675,43,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,171,implementation efficiency grid,1531,1778,58,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,172,max grid capacity,1834,1859,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,173,saturation normalizer grid,1834,1658,59,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,174,saturation factor grid,1559,1303,48,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,175,4,164,1,0,0,0,0,192,0,-1--1--1,,1|(937,1374)|
 1,176,159,169,0,0,0,0,0,192,0,-1--1--1,,1|(0,0)|
 10,177,retirement rate grid,1893,1290,44,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,178,177,169,1,0,0,0,0,192,0,-1--1--1,,1|(1747,1385)|
 1,179,174,164,1,0,0,0,0,192,0,-1--1--1,,1|(1346,1372)|
 1,180,159,174,1,0,0,0,0,192,0,-1--1--1,,1|(1551,1408)|
 1,181,172,174,1,0,0,0,0,192,0,-1--1--1,,1|(2042,1364)|
 1,182,173,174,1,0,0,0,0,192,0,-1--1--1,,1|(1734,1459)|
 1,183,170,164,1,0,0,0,0,192,0,-1--1--1,,1|(1262,1632)|
 1,184,171,164,1,0,0,0,0,192,0,-1--1--1,,1|(1434,1607)|
 1,185,172,173,1,0,0,0,0,192,0,-1--1--1,,1|(1784,1764)|
 1,186,90,89,1,0,0,0,0,192,0,-1--1--1,,1|(593,2143)|
 10,187,ops power requirement per berth,1440,304,62,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,188,ops power required,1355,112,45,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,189,nonops port load,1219,213,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,190,grid headroom for ops,1381,403,51,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,191,small number mw,1554,190,42,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 10,192,grid readiness factor ops,1608,568,57,22,8,3,0,0,-1,1,0,0,0,0,0,0,0
 1,193,48,188,1,0,0,0,0,192,0,-1--1--1,,1|(811,150)|
 1,194,187,188,1,0,0,0,0,192,0,-1--1--1,,1|(1413,204)|
 1,195,159,190,1,0,0,0,0,192,0,-1--1--1,,1|(1899,868)|
 1,196,189,190,1,0,0,0,0,192,0,-1--1--1,,1|(1246,319)|
 1,197,190,192,1,0,0,0,0,192,0,-1--1--1,,1|(1421,524)|
 1,198,191,192,1,0,0,0,0,192,0,-1--1--1,,1|(1622,380)|
 1,199,188,192,1,0,0,0,0,192,0,-1--1--1,,1|(1543,312)|
 1,200,192,67,1,0,0,0,0,192,0,-1--1--1,,1|(523,419)|
 \\\--/// Sketch information - do not modify anything except names
 V300 Do not put anything below this section - it will be ignored
 *View 2
 \$-1--1--1,0,|10||-1--1--1|-1--1--1|-1--1--1|-1--1--1|96,96,100,2
 \\\--/// Sketch information - do not modify anything except names
 V300 Do not put anything below this section - it will be ignored
 *View 3
 \$-1--1--1,0,|10||-1--1--1|-1--1--1|-1--1--1|-1--1--1|96,96,100,2
 ///--\\\

```

:GRAPH ops_deployment
:TITLE ops deployment
:SCALE
:VAR available capital budget
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR annual capital allocation to projects for ops
:DATASET
:LINE-WIDTH 1
  
```

```

:SCALE
:VAR ops infrastructure deployed
:DATASET
:LINE-WIDTH 1

:TABLE budget_values_
:TITLE budget_values_
:FONT Vensim Sans|12||0-0-0
:VAR available capital budget for ops
:DATASET
:VAR annual capital allocation to projects for ops
:DATASET

:GRAPH B1_OPS_base_case
:TITLE B1_OPS_base case
:SCALE
:VAR available capital budget for ops
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR annual capital allocation to projects for ops
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET
:LINE-WIDTH 1

:GRAPH ops_deployment_-_scenario_1:_pessimistic
:TITLE scenario1_pessimistic
:X-AXIS Time
:SCALE
:VAR ops infrastructure deployed
:Y-MIN 0
:Y-MAX 60
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR annual capital allocation to projects for ops
:Y-MIN 0
:Y-MAX 3
:DATASET
:LINE-WIDTH 1

:GRAPH ops_deployment_-_baseline_scenario
:TITLE ops deployment – baseline scenario
:SCALE
:VAR ops infrastructure deployed
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR annual capital allocation to projects for ops
:DATASET
:LINE-WIDTH 1

:GRAPH electrification_baseline_outputs
:TITLE electrification_baseline_outputs
:X-AXIS Time
:NO-LEGEND 16
:SCALE
:VAR ops infrastructure deployed
:DATASET *

```

```

:LINE-COLOR 255-0-31
:LINE-WIDTH 1
:SCALE
:VAR ops units installed
:DATASET *
:LINE-COLOR 49-102-255
:LINE-WIDTH 1

:GRAPH Capital_budget_constrains
:TITLE Budget for OPS
:STAMP jhvjh
:X-AXIS Time
:SCALE
:VAR available capital budget for ops
:DATASET integrated scenario_baseline5.vdxf
:LINE-WIDTH 2
:VAR annual capital allocation to projects for ops
:DATASET integrated scenario_baseline5.vdxf
:LINE-WIDTH 2
:VAR new funding approvals for ops
:DATASET integrated scenario_baseline5.vdxf
:LINE-WIDTH 2

:GRAPH attempt2
:TITLE attempt2
:SCALE
:VAR new funding approvals for ops
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 2
:VAR available capital budget for ops
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 2
:VAR annual capital allocation to projects for ops
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 2

:GRAPH grid_readiness
:TITLE Grid readiness
:SCALE
:VAR Grid readiness for ops
:DATASET integrated scenario_baseline5.vdxf
:LINE-WIDTH 3
:SCALE
:VAR grid upgrade projects
:DATASET
:LINE-WIDTH 3

:GRAPH ops_infrastructure_deployed_baseline3
:TITLE ops infrastructure deployed_baseline3
:SCALE
:VAR ops infrastructure deployed
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 1
:VAR available capital budget for ops
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 1
:VAR annual capital allocation to projects for ops
:DATASET integrated scenario_baseline3.vdxf
:LINE-WIDTH 1

:GRAPH TEST
:TITLE TEST

```

```
:SCALE
:VAR available capital budget for ops
:DATASET integrated scenario_baseline5.vdfx
:LINE-WIDTH 3
:VAR new funding approvals for ops
:DATASET integrated scenario_baseline5.vdfx
:LINE-WIDTH 3
:VAR annual capital allocation to projects for ops
:DATASET integrated scenario_baseline5.vdfx
:LINE-WIDTH 3
```

```
:GRAPH Available_capital_budget
:TITLE Available capital budget
:SCALE
:VAR available capital budget
:DATASET
:LINE-WIDTH 2
:SCALE
:VAR total annual spending
:DATASET
:LINE-COLOR 255-98-255
:LINE-STYLE DASHDOTDOT
:LINE-WIDTH 1
:SCALE
:VAR annual capital allocation
:DATASET
:LINE-STYLE DOT
:LINE-WIDTH 3
```

```
:GRAPH Both_stocks_ops_chargers
:TITLE Both stocks ops_chargers
:SCALE
:VAR ops infrastructure deployed
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR charging units deployed
:DATASET
:LINE-WIDTH 1
```

```
:GRAPH OPS_stock_flow
:TITLE OPS_stock_flow
:SCALE
:VAR ops infrastructure deployed
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR ops units installed
:DATASET
:LINE-WIDTH 1
```

```
:GRAPH grid_capacity
:TITLE grid capacity
:SCALE
:VAR grid capacity installed
:DATASET
:LINE-WIDTH 1
:SCALE
:VAR grid capacity retirement
:DATASET
:LINE-WIDTH 1
:SCALE
```



```

:VAR new grid capacity installed
:DATASET
:LINE-WIDTH 1

:GRAPH SSE-OPS_deployment
:TITLE SSE-OPS deployment
:SCALE
:VAR ops infrastructure deployed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET electric cranes_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET grid_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET ops priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET gsv_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET charging hubs_priority.vdxf
:LINE-WIDTH 1

:GRAPH OPS_UNDER_CONSTRAINTS
:SCALE
:VAR ops infrastructure deployed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET ops priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET grid_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET gsv_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET electric cranes_priority.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET charging hubs_priority.vdxf
:LINE-WIDTH 1

:GRAPH ALL_STOCKS_BASELINE
:SCALE
:VAR ops infrastructure deployed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1

```

```

:SCALE
:VAR charging units deployed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:SCALE
:VAR electric cranes deployed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:SCALE
:VAR grid capacity installed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:SCALE
:VAR gsv adopted
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1

:GRAPH GRID_CAPACITY_INSTALLED_ALL_SCENARIOS
:SCALE
:VAR grid capacity installed
:DATASET Baseline scenario_main.vdxf
:LINE-WIDTH 1
:VAR grid capacity installed
:DATASET grid_priority.vdxf
:LINE-WIDTH 1
:VAR grid capacity installed
:DATASET ops_priority.vdxf
:LINE-WIDTH 1

:GRAPH Diagram_4
:SCALE
:VAR ops infrastructure deployed
:DATASET Baseline scenario_main_constraints.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET grid_priority_constraints.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET ops_priority_constraints.vdxf
:LINE-WIDTH 1

:GRAPH 3_runs_stress_tests
:SCALE
:VAR ops infrastructure deployed
:DATASET delayed_investment.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET low_budget.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET high_capex.vdxf
:LINE-WIDTH 1
:SCALE
:VAR ops infrastructure deployed
:DATASET Baseline scenario_main_constraints.vdxf
:LINE-WIDTH 1
:L□<%^E!@
1:Baseline scenario_main.vdxf

```

4:Time
5:new funding approvals
9:constraints/grid_priority_constraints
19:66,0
24:0
25:30
26:30
23:0
15:0,0,0,0,0,0
27:0,
34:0,
42:0
72:0
73:0
95:0
96:0
97:0
77:0
78:0
102:0
93:0
94:0
92:0
91:0
90:0
87:0
75:
43:
103:2,11,8,3,8
105:0,0,0,0,0,0,0,0,0
104:Arial|10||0-0-0|0-0-0|-1--1--1|0-0-255|192-192-192|-1--1--1