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Work Package 3

Best practices for sustainable goals in the port services sector: case studies and impact analysis

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Disclaimer:

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Executive summary

This report, developed within Work Package 3 (WP3 - "Raw data analysis for curriculum development") of the GREENPORT Alliances project (Erasmus+ Call: ERASMUS-EDU-2023-PI-ALL-INNO), presents an in-depth analysis of sustainable practices in the technical-nautical services sector of ports. The objective is to identify innovative, effective, and replicable solutions that support emission reduction and improve environmental performance in port operations. This document falls within the scope of Task 3.4, "Publication of research paper and industry report for public dissemination", and represents the first output of the WP3, named "Industry report on emissions within the port services sector". This is a public document that presents the results of the scientific activities carried out in Task 3.1, "Cross-sectoral identification of best practices", and Task 3.2, "Scientific analysis".

These activities, conducted between months 10 and 15 of the project, are based on the data collected in WP2 and focus on the identification and analysis of best practices through a scientific approach that evaluates practices first through different perspectives of analysis and then, in the specific case of this report, through empirical evidence. With reference to the latter objective, a key methodological tool - the Case Study Identification Sheet - was used to collect and document 18 case studies provided by the project partners. These case studies represent different geographical and operational contexts and reflect a wide range of technological, behavioural and management innovations.

The analysis revealed two main strategic paths toward sustainability in port services:

1. Technological innovation, including the use of alternative fuels, digital monitoring systems, and energy-efficient propulsion technologies.
2. Human-centered initiatives, such as continuous training, awareness programs, and collaborative governance.

Case studies demonstrate that while advanced technologies can significantly reduce emissions and increase efficiency, their effectiveness depends on the engagement and training of human actors — pilots, tug operators, port

authorities — who are key to integrating these solutions into operational routines.

The findings provide a strong foundation for designing targeted training programs, supporting policy recommendations, and promoting a culture of innovation and environmental responsibility in port services. Ultimately, this work contributes to the broader goal of making port ecosystems more resilient, digitalized, and sustainable.

Introduction

This report was created with the aim of analysing how different working methods can influence the emission of harmful gases, highlighting the need for behavioural training. The different approaches and working methods are the subject of the 18 case studies provided by the project partners. As we will see, this empirical evidence has allowed us to highlight essential recommendations for the development of training paths identified as drivers for the ecological transition of the technical-nautical services sector.

This study is part of the WP3 of the Greenport Alliance project. The study and analysis activities of the work package (T3.1 and T3.2), carried out between months 10 and 15 of the project, aimed at identifying and analysing the most sustainable business practices within the sector. Starting from the data collected in WP2 ('Analysis of needs and business drivers'), the studies conducted in the first WP3 activities identified and validated 17 best practices. Subsequently, 18 case studies were identified as empirical evidence of best practices. The analysis of the case studies, which is the subject of this report, allowed us to derive useful information for developing training courses based on sustainability principles aimed at operators and stakeholders in the sector.

The analysis was also structured with the aim of highlighting the main operational factors that influence emission levels in port operations. By evaluating these parameters, the study highlights the strategic role of training and behavioural awareness in guiding the transition towards more environmentally friendly practices. As already mentioned, the analysis is based on the identification and scientific evaluation of representative case studies. These cases reflect concrete practices currently implemented in different ports and geographical contexts, offering insights into their effectiveness in reducing environmental impact and how contextual factors can influence their adoption and scalability. The results provide a solid basis for the development of more sustainable, replicable and scalable operational solutions. These solutions will ultimately contribute to the broader goal of improving the environmental performance of the port services sector through the implementation of adequate and comprehensive training programs.

As part of this activity, MAR.TE. carried out an in-depth review of the Case Study Identification Sheets submitted by project partners. This review assessed the relevance, quality, and potential impact of each proposed practice in relation to the overarching goals of the GREENPORT Alliances project. The resulting matrix (Table 25) provides a comprehensive overview of partner contributions, illustrating the diversity of initiatives and highlighting the multidimensional nature of the sustainability challenges faced in port operations.

The study consolidates technical knowledge, behavioural insights, and governance strategies into an integrated framework for sustainability. It sets the stage for cross-case comparisons and the dissemination of best practices that can inform both policy recommendations and targeted training actions, in alignment with the project's commitment to supporting greener and more resilient port ecosystems.

The structure of this report is designed to guide the reader through a progressive understanding of the research objectives, the methodological approach adopted, the case studies analysed, and the resulting implications for curriculum development and training design. Chapter 1 introduces the concept of best practices in the port services sector, highlighting the dual pathway—technological and human-driven—through which sustainability goals are pursued. Chapter 2 presents the methodological framework, with a specific focus on the Case Study Identification Sheet developed to ensure the systematic and comparable collection of data across diverse port contexts. Chapter 3 offers a detailed description of the 18 case studies gathered from project partners, illustrating their key features, implementation processes, and strategic objectives. Each case relates the implementation of innovative solutions by highlighting the combination of drivers, constraints and impacts identified through the Identification sheet. Chapter 4 provides an analytical summary of the case studies, identifying common trends, key enablers and areas of convergence between technological and non-technological dimensions. This section also describes the implications of the findings, essentially identifying the skills needed for widespread adoption of sustainable practices by proposing training content and recommendations for curriculum development. The report ends with the conclusion section laying the foundation for the next steps of the GREENPORT Alliances project, aimed at supporting a sustainable transition in the port services sector.

1 Best practices for sustainable goals in the port services sector

Ships can be viewed as mobile industrial units that produce pollution by impacting the environmental compartments of air and water. Engines, generators, boilers, and other ship operations are sources of harmful emissions, noise pollution, and various kinds of waste. The increase in greenhouse gas emissions and the resulting global warming have intensified the effects of climate change. This has prompted institutions at the international, European, and national levels to take action and identify measures that are stringent and binding. The goal is to encourage the port and maritime transport sector to participate in reducing the impact on air quality and global warming in a concrete and effective way. Although this mode of transportation is efficient and less polluting, particularly on medium and long distances, it still generated 885 million tonnes of CO2 emissions globally in 2023 (SRM, 2023).

Reducing the environmental impact of transport and, thus, shipping is among the priorities of both the UN, through the IMO (International Maritime Organisation), and the European Union.

The measures issued by the IMO include short-term (2018-2023), medium-term (2023-2030), and long-term (beyond 2030) actions to achieve these targets.

Some short-term measures concern (www.imo.org):

- the aim is to enhance the current energy efficiency framework, with a specific focus on Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP);
- technical and operational measures for improving energy efficiency in existing ships will be developed (i.e., the three-step approach will be considered to identify and enhance the energy efficiency performance of shipping, which includes the Annual Efficiency Report (AER), Energy Efficiency per Service Hour (EESH), Individual Ship Performance Indicator (ISPI), and Fuel Oil Reduction Strategy (FORS);
- Analyze the use of speed optimization and speed reduction, taking into consideration safety issues, the distance covered, market or trade

distortion, and the fact that this measure should not affect the ability of maritime transport to serve remote geographic areas;

- consider and analyse measures to address methane emissions and further improve measures to address volatile organic compound emissions;
- Continue and enhance technical cooperation and capacity-building activities under the ITCP,
- Consider and analyze measures to encourage global port developments and activities to facilitate the reduction of greenhouse gas emissions from shipping (e.g., electricity supply to ships and coasts/shorelines from renewable sources, infrastructure to support the collection of low-carbon and zero-carbon alternative fuels);
- Consider and analyze measures to encourage global port developments and activities to facilitate the reduction of greenhouse gas emissions from shipping (e.g., electricity supply to ships and coasts/shorelines from renewable sources, infrastructure to support the collection of low-carbon and zero-carbon alternative fuels);
- Undertake research and development on marine propulsion, low-carbon and zero-carbon alternative fuels, and innovative technologies to further improve the energy efficiency of ships, and establish an International Maritime Research Council to coordinate and oversee these research and development efforts;
- develop an implementation programme for the effective adoption of low-carbon and zero-carbon alternative fuels.

Medium-term measures include implementing programs to adopt low-carbon and zero-carbon alternative fuels effectively, updating national action plans, new emission reduction mechanisms to incentivize GHG emission reductions, and development a feedback mechanism to collect lessons learned on the implementation of measures to be collected and shared through a possible exchange of information on best practices.

Finally, some long-term measures are to pursue the development and supply of carbon-neutral or fossil-free fuels to enable the shipping industry to assess and consider decarbonization in the coming years.

In subsequent consultations about emissions from shipping, the MEPC adopted several measures to support the achievement of the targets set out in the initial IMO strategy for reducing greenhouse gas (GHG) emissions. Existing ships will be required to implement energy efficiency management plans, which include enhancements in voyage planning, more frequent maintenance, and the adoption of technical measures such as residual heat recovery systems or the use of advanced propellers. Short-term measures to enhance ship efficiency, while awaiting the construction of new-generation ships (such as electric, hybrid, or hydrogen-powered vessels), may include optimizing sailing speeds and utilizing biofuels. To facilitate the transition to zero-emission shipping, infrastructure development and logistics optimization strategies are also in the works. Moreover, International Maritime Organization promotes collaboration between the port and maritime sectors to contribute to the reduction of greenhouse gas emissions from ships. This collaboration involves operational, technical, and economic actions, including the provision of shore-based power preferably from renewable sources, port incentives, the promotion of sustainable zero-emission maritime transport, and the optimization of port operations (www.imo.org).

In the European context, the principal regulations issued to combat emissions from maritime transport are listed below; the table (**Hata! Başvuru kaynağı bulunamadı.**) briefly outlines their contents.

- Directive on the deployment of alternative fuels infrastructure, (AFID 2014/94/EU)
- Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting, and verification of carbon dioxide emissions from maritime transport ('EU MRV', Regulation 2015/757/EU)
- Directive (EU) 2016/802 of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels (codification)

- Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).

Table 1 - The principal European regulations issued to combat emissions from maritime transport

EUROPEAN REGULATIONS	
AFID 2014/94/EU	Adopted in 2014, the directive sets targets and standards to ensure the availability of infrastructure, such as refuelling stations for alternative fuels such as natural gas, hydrogen and electric vehicles. The main objective is to facilitate the transition to more sustainable and low-carbon forms of transport in the European Union.
'EU MRV,' Regulation 2015/757/EU	The regulation requires shipping companies to monitor and report their CO2 emissions from shipping activities. The main objective is to promote transparency and energy efficiency in the maritime transport sector, contributing to the EU's efforts to reduce greenhouse gas emissions.
Directive (EU) 2016/802 relating to a reduction in the sulphur content of certain liquid fuels (codification)	The Directive concerns reducing sulphur content in certain liquid fuels and is primarily concerned with codifying provisions on this issue. The main objective is to establish transparent and standardised rules for reducing the sulphur content in certain liquid fuels.
Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources	Approved in 2018, this directive sets binding targets for the share of renewable energy to be achieved by 2030 in the European Union. The main objective is to foster the transition to a more sustainable, low-carbon energy system by promoting the adoption of renewable energy sources such as solar, wind and hydro.

Source: Our elaboration

The European Commission later implemented concrete actions and specific initiatives related to the Green Deal. On 14 July 2021, the package known as “Fit for 55” was adopted, which aims to reduce greenhouse gas emissions by 55% by 2030. As regards the ports and maritime transport sectors, the package includes (www.consilium.europa.eu):

- A proposal to include maritime transport emissions in the EU Emissions Trading Scheme for the first time (COM(2021)0551).
- A proposal concerns the revision of the Alternative Fuels Infrastructure Regulation, intending to ensure that ships have access to clean electricity in significant ports (COM(2021)0559).
- A proposal concerning using renewable and low-carbon fuels in the maritime transport sector (FuelEU Maritime), which also involves amendments to Directive 2009/16/EC (COM/2021/0562).

The Emission Trading Scheme (ETS) regulatory system operates as a control and trading mechanism in which actors are required to comply with an emissions cap and may acquire or receive emission allowances free of charge. This cap is subject to a gradual reduction over time, aiming to incentivize the adoption of technologies with a reduced environmental impact and gradually make fossil fuels less competitive.

The Alternative Fuels Infrastructure Regulation aims to ensure the availability of adequate infrastructure networks for charging or refuelling road vehicles and ships using alternative fuels, both for citizens and businesses. In March 2023, an agreement was reached between the European Parliament and the European Council on a new Alternative Fuels Infrastructure Regulation (AFIR), which includes shore-side electricity supply in ports serving large passenger and container ships. In addition to bunkering infrastructure, efforts will be needed to establish the entire fuel supply chain, including production, transport, distribution and storage. The proposal aims to increase the presence of LNG refuelling stations by 2025 and to ensure access to electricity in major EU ports by 2030. It also sets targets for infrastructure deployment, addresses interoperability and aims to simplify the use of services.

The FuelEU Maritime initiative was conceived with the main objective of reducing the intensity of greenhouse gas emissions from energy used on board ships by 80 percent by 2050 by promoting the adoption of more environmentally friendly fuels by ships. This regulation sets progressively decreasing targets for reducing greenhouse gas (GHG) emissions from energy used on board ships arriving in, anchored in, or departing from ports under the jurisdiction of Member States. The European Parliament and the European Council established that ships will be required to progressively reduce their greenhouse gas emissions, starting with a 2% reduction by 2025, and reaching 80% reduction by 2050 in accordance with this reduction plan (SRM, 2023).

The regulation will apply to ships with a gross tonnage exceeding 5,000 tons, which are, in principle, responsible for 90% of CO2 emissions for 100% of the energy used within or between EU ports, as well as 50% of the energy used on journeys where the departure or arrival port is outside the EU. It also promotes the adoption of shore-side power in EU ports. Taken together, these measures, with varying deadlines up to 2030, aim to reduce GHG emissions in the EU maritime sector by at least 80% by 2050 (www.consilium.europa.eu). In this scenario, the port sector is pushed towards a redefinition of economic activities by strongly promoting the use of 4.0 technologies and new practices to support the transition and the reduction of environmental impact. The technical-nautical services sector, which is an essential component of the port ecosystem, must actively and responsibly engage in the ecological transition process. While the regulations mentioned earlier primarily focus on the technical specifications of ships related to maritime transport, they can also serve as an incentive for the technical-nautical services sector to enhance their operational methods. This improvement can be achieved by integrating efficiency, safety, and sustainability.

Even today innovation processes in ports seem to proceed slowly and with a low level of conviction about the relevance of port innovation. Literature studies identify the reason as the conservative nature of the sector. However, there may also be other factors to evaluate the nature of the innovation process and the way it is applied in the transport and logistics industry. In fact, some works (Acciaro et al., 2014a; Arduino et al., 2014) focused the attention on the role of interactions among the participants in the innovation process trying to identify the characteristics that can ensure a successful innovation path. However, ports need to implement new management practices to improve port competitiveness, especially regarding sustainability, to respond to increasingly stringent and ambitious environmental regulations set at international and European levels.

The case studies under analysis illustrate and describe the implementation of green practices identified during the research activities conducted in WP2 and the initial actions of WP3. The process of identifying and selecting practices aimed at reducing emissions and the environmental impact generated by the technical-nautical services sector was structured in three phases.

In the first phase of the process, existing practices aimed at reducing emissions and environmental impact within the reference sector were studied and identified. The relevance of these practices was then analysed and assessed through the research activities carried out by ETA within Work Package 2. In the second phase, as part of the initial activity of WP3—Task 3.1 "Cross-sectoral identification of best practices"—a further investigation was carried out by the

MARTE working team. This activity marked the beginning of the selection process for the most promising practices among those previously identified. During this phase, the initial set of practices was expanded, ultimately leading to the identification of 17 potential best practices. Finally, in the third phase, conducted within Task 3.2 "Scientific analysis" these 17 practices were systematically evaluated and validated as the most effective and relevant. The assessment process was based on a set of predefined criteria applied across key dimensions of analysis:

- Environmental perspective, to assess the effectiveness of each practice in reducing emissions and minimizing ecological impact;
- Economic perspective, to evaluate cost-efficiency and overall financial sustainability;
- Social perspective, focusing on the implications for workers, communities, and broader societal benefits;
- Technical perspective, to examine feasibility and ease of integration into existing operations;
- Institutional and governance perspective, assessing the alignment with regulatory frameworks and the level of support or involvement required from public authorities and institutions.

This multidimensional approach ensured a robust and holistic evaluation, facilitating the identification of practices with the highest potential for impact, scalability, and replicability within the technical-nautical services sector.

In the Table 2 each best practice is accompanied by a brief description that provides essential information and key elements to help understand how it contributes to reducing the environmental impact generated by the sector.

Table 2 - The best practices

Practice 1: Active involvement of pilots in the planning of port initiatives
Involve pilots and other stakeholders in the planning and implementation of sustainability initiatives at the port level. This may include designing greener infrastructure and adopting eco-friendly operational practices.
Practice 2: Active participation of pilots in research and development projects for new green technologies
Directly involve pilots in R&D initiatives to contribute to the development and implementation of innovative ecological technologies that can reduce the environmental impact of the maritime sector.
Practice 3: Behavioral change through training and awareness
A proposal for training programs to promote behavioral change by raising awareness among operators about the environmental impact of their actions. These programs include ongoing training, visual reminders, and incentives to adopt sustainable behaviors.
Practice 4: Collaboration among stakeholders for real-time data sharing
Improving operational efficiency through real-time information sharing between different actors, such as port authorities, shipping companies, and terminals, to reduce delays and optimize the supply chain, thus reducing emissions.
Practice 5: Collaboration with other ports to exchange information and green solutions
Create networks of collaboration between ports to share best practices, technologies, and innovative strategies aimed at reducing emissions and promoting environmental sustainability in port operations.
Practice 6: Continuous monitoring of emissions during operations
Implement monitoring systems to track emissions of CO2, SO2, and other pollutants, using advanced technologies to collect accurate data.
Practice 7: Continuous training and updates for pilots
Regularly organize training sessions for Tug Masters and engineers on sustainability and ecological practices, emphasizing the importance of reducing emissions.
Practice 8: Implementation of eco-friendly propulsion systems
Invest in green technologies such as hybrid propulsion systems, electric engines, and other innovations to reduce environmental impact.
Practice 9: Supply chain optimization
It is essential for achieving operational efficiency and the sustainable use of resources. A key element of this optimization is logistical coordination between the various stakeholders (transporters, shipping companies) to ensure that operations are carried out within the required timeframes. This ensures, for example, that waiting times for ships or goods to be loaded (export cycle) are reduced, thereby improving the efficiency of pilots and tugboats while preventing congestion and operational overloads
Practice 10: Minimization of engine running time
Minimize engine idle times when not necessary by turning off engines or using alternative power systems when possible.
Practice 11: Optimization of operation speed
Implement eco-speed practices during transit, adjusting vessel speed to minimize fuel consumption without compromising operations.
Practice 12: Periodic publication of reports on environmental performance
Regularly publish reports on environmental performance, including data on emissions and sustainability efforts, to promote transparency and improve corporate reputation.
Practice 13: Accurate route planning
This practice involves the development of optimized routes for tugboats, aiming to minimize both the distance travelled and the time required to complete operations. It is based on the analysis and definition of optimal routes before the commencement of activities, a crucial phase that significantly impacts the overall efficiency of the mission, laying the groundwork for operational success
Practice 14: Real-time navigation route optimization
Plan efficient routes to reduce fuel consumption and emissions, using advanced navigation software.
Practice 15: Regular maintenance of tugboat engines
Regularly perform maintenance and calibration of engines to ensure they operate efficiently, reducing emissions and fuel consumption.
Practice 16: Use of biofuels for tugboats
Use biofuels or low-emission fuels to reduce environmental impact compared to traditional fossil fuels.
Practice 17: Use of simulation tools to optimize maneuvers
Implement simulation software to test and optimize tugboat maneuvers, reducing fuel consumption and improving the efficiency of maritime operations.

An overview of the practices identified highlights how the technical-nautical services sector pursues sustainability goals through two main strategies: one technological and one human-oriented. On the one hand, the adoption of innovative technological solutions, including the use of low-emission vessels, digital systems for operational optimization, and environmental monitoring technologies; on the other, investment in human competencies through training activities, awareness-raising, and the promotion of an organizational culture focused on sustainability.

This dual approach demonstrates that improving environmental performance cannot rely solely on the technical evolution of equipment and infrastructure but also requires the activation of behavioural and managerial change processes within the organizations involved.

Technological approach	**Human approach**
Adoption of eco-friendly technologies	Involvement of pilots
Real-time data sharing	Collaboration between ports
Emission monitoring	Continuous training
Route optimization	Behavioral change
Use of biofuels	

Figure 1 - Practices for sustainable technical-nautical services

The image shown in Figure 1, for illustrative and explanatory purposes, presents some of the 17 practices analysed, categorized according to the two main distinguishing elements described above. It is possible to differentiate between practices that aim to reduce environmental impact and emissions using innovative technologies, and those that are expressions of human actions and decisions.

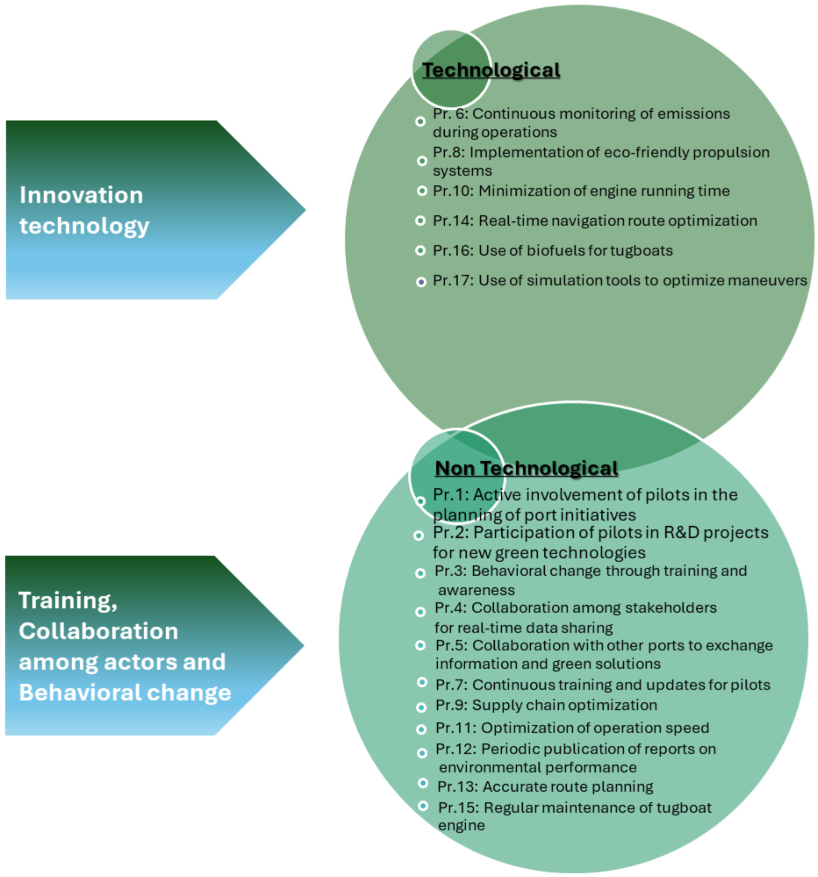


Figure 2 - Enabling factors for sustainable port service development

A more detailed analysis also reveals additional areas of interest within these two broad categories, emphasizing the complexity and complementarity of the various approaches to sustainability. Through the examination of these practices, we can identify the key drivers of sustainability: for technological best practices, the main driver is innovation, which is crucial for growth across all economic sectors while maintaining sustainability; for non-technological practices, the essential factors include training, collaboration among operators, and the evolution of human behaviour.

Technological best practices are based on the adoption or development of innovative solutions aimed at reducing environmental impact, improving process efficiency, and fostering economic growth within ecological limits. Digital technologies, environmental monitoring systems, renewable energy sources, automation, and artificial intelligence are examples of tools capable of generating sustainable value. Therefore, innovation represents the first driver for sustainable development. It enables structural changes in production, distribution, and consumption models, while maintaining both competitiveness and environmental responsibility.

In the case of non-technological best practices cultural and organizational change represent driving forces. Specifically, the key drivers are:

- **Training**, understood as the development of skills and awareness regarding sustainability;
- **Collaboration among operators**, which facilitates knowledge exchange and the creation of networks between different stakeholders (public, private, and local communities);
- **Behavioral evolution**, which refers to the adoption of daily practices and operational decisions oriented towards social and environmental responsibility.

These aspects, while less "tangible" than technology, ensure an effective and lasting sustainable transition, as they influence mindsets, habits, and inter-organizational relationships.

As will be demonstrated by the case study analysis, while technological innovation enables new operational solutions, the case studies reveal varying actions based on the human factor — with its knowledge, cooperation, and responsibility — creates the conditions for these solutions to be understood, accepted, and correctly applied. In non-technological best practices, in fact, sustainability requires a cultural shift, skill enhancement, and closer collaboration among the involved stakeholders. These drivers are complementary to technological innovation for ensuring the effective use of new solutions, contributing to making sustainability a shared goal that is fully integrated into daily decisions and actions.

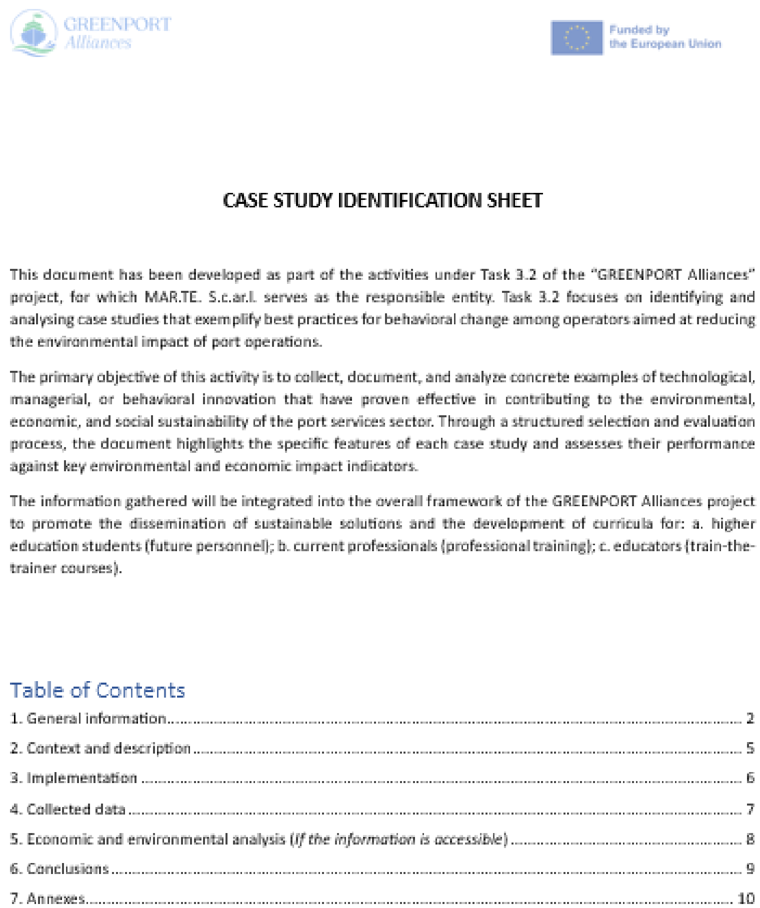
2 Methodology: The Case study identification sheet

The case studies allow for an in-depth observation of how sustainable strategies are introduced, adapted, and integrated into specific operational contexts, highlighting the concrete dynamics that either facilitate or hinder their success.

Case studies were identified based on the knowledge and experience of the project partners. Initially, MARTE, as leader of the activity, based on information that emerged in the first steps of WP3, formulated an allocation hypothesis by assigning each partner one or more practices on which to focus the search for case studies, while leaving the final choice to each partner. Therefore, the project partners provided one or more case studies based on their knowledge and experience. This led to a collection of in-depth information and experiences that concretely and comprehensively documented the implementation of each of the chosen practices.

Through a qualitative and context-specific approach, the analysis of concrete cases makes it possible to understand not only the outcomes achieved, but also the decision-making processes, the actors involved, the resources employed, and any resistance to change. This type of in-depth analysis is particularly useful for capturing the interactions between technological, organizational, regulatory, and cultural factors that influence the effectiveness and replicability of sustainable solutions. Moreover, case studies play a key role in knowledge dissemination and inter-organizational learning: the empirical evidence gathered can serve as an example for other stakeholders in the sector, encouraging processes of imitation, adaptation, and incremental innovation. The case study approach can be particularly effective in sectors where sustainability practices are still in an experimental phase: the documentation of pioneering experiences, the impact assessment and the identification of enabling factors and contextual conditions can foster a wider understanding and diffusion of green practices.

Within Task 3.2 "Scientific Analysis" of the GREENPORT Alliances project, MAR.TE. S.c.ar.l. developed the "Case study identification sheet" seto provide a concise and structured tool for the collection, documentation and analysis of good practices in the port services sector.



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CASE STUDY IDENTIFICATION SHEET

This document has been developed as part of the activities under Task 3.2 of the "GREENPORT Alliances" project, for which MAR.TE. S.c.ar.l. serves as the responsible entity. Task 3.2 focuses on identifying and analysing case studies that exemplify best practices for behavioral change among operators aimed at reducing the environmental impact of port operations.

The primary objective of this activity is to collect, document, and analyze concrete examples of technological, managerial, or behavioral innovation that have proven effective in contributing to the environmental, economic, and social sustainability of the port services sector. Through a structured selection and evaluation process, the document highlights the specific features of each case study and assesses their performance against key environmental and economic impact indicators.

The information gathered will be integrated into the overall framework of the GREENPORT Alliances project to promote the dissemination of sustainable solutions and the development of curricula for: a. higher education students (future personnel); b. current professionals (professional training); c. educators (train-the-trainer courses).

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Figure 3 - Case study identification sheet

It is a structured tool designed for the systematic collection of case studies relevant to the GREENPORT Alliances project. Its objective is to identify and analyze the implementation of best practices — already extensively examined in the earlier phases of WP3 — that can foster behavioral and operational change towards sustainability in ports. The main purpose of this tool is to highlight concrete cases of innovation — whether technological, managerial, or behavioural — that can significantly contribute to improving the environmental, economic, and social sustainability of technical-nautical services and port operations. The sheet provides a framework that standardizes the collection of information for the proposed case studies, in order to facilitate analysis and ensure that all relevant data are available to achieve the objectives set out in the project activity. Therefore, the “Case study identification sheet” allows to:

- describe the operational context and the actors involved;
- highlight the innovative elements introduced;
- assess the impact in terms of emission reduction, operational efficiency, or social benefits;
- support comparison among heterogeneous experiences and promote the replicability of the proposed solutions.

The first section, dedicated to general information, allows for the clear identification of the case study through its title, the selection of the implemented environmental practices (chosen from 17 predefined categories), the definition of specific objectives, the expected direct impacts, the geographical area, and the timeline.

The second section focuses on the operational context. It requires specifying the motivations that led to the implementation of the green practice, the main stakeholders involved, with particular attention to the role of pilots and tugs, in line with the focus of the project.

This is followed by a section dedicated to implementation, which describes how the practice was carried out, the technologies employed, and the skills required—thus allowing for an assessment of the solution’s transferability to other contexts. This section is one of the most crucial, as it was included to gather information useful for evaluating the applicability of the case study practice and, above all, to understand the training needs that may support its adoption and promote wider dissemination within the sector.

A distinctive feature is the section dedicated to data collection, which, where possible, requires a quantitative comparison between conditions before and after implementation. This is carried out through key indicators such as emissions, fuel consumption, operating costs, and hours of operation. Such data allow for an objective assessment of the effectiveness of the adopted practice.

If available, the subsequent economic and environmental analysis further completes the evaluation framework by identifying initial investments, generated savings, broader economic impact, and the contribution to environmental goals.

The conclusions section is divided into short sections highlighting lessons learnt, challenges encountered, training needs identified and recommendations for future applications or training developments. Finally, the annexes provide the opportunity to provide supporting documentation such as graphs, photographs, technical diagrams or direct testimonies, thus increasing the transparency and credibility of the case study. Overall, the sheet represents a solid methodological tool for mapping and benchmarking the identified best practices for impact reduction in the technical-nautical services sector.

The information collected through this tool, in line with the project's objectives, has served as a key element in developing an in-depth analysis aimed at supporting the dissemination of sustainable solutions within the port sector. Thanks to the systematic structure of the case study identification sheet, it was possible to gather comparable and meaningful data, which not only helped identify the most effective practices but also allowed for a better understanding of the conditions necessary for their applicability and transferability.

This analysis provided a solid foundation for the design of targeted educational content tailored to the needs of various audiences: university students, who require updated tools to grasp the challenges of sustainability in the sector; active professionals, who can benefit from practical insights and technical updates; and trainers, who can use validated material and real-life examples to enrich their teaching programs.

In this way, the tool has proven to be valuable not only for the evaluation of best practices but also as a driver for promoting a culture of sustainability and fostering continuous and cross-sectoral learning processes.

3 The case studies: key features and implementation

The case studies collected through the "Case study identification sheet" highlight a diverse range of approaches aimed at reducing the environmental impact of port operations, with a focus on behavioural, technological, and managerial innovation.

The implementation of the selected practices involves the adoption of advanced technologies or the redesign of operational procedures to minimise emissions. A key aspect of implementation lies in the ability of the actors involved to integrate environmental objectives with economic and operational constraints. Case studies reveal varying degrees of complexity. KPIs, where available, offer valuable insights into pre- and post-implementation performance, allowing for a more objective assessment of their environmental effectiveness. Overall, these case studies represent concrete examples of transition towards greener port operations; they represent a solid empirical basis for the development of targeted training programmes, knowledge transfer activities and policy recommendations within the GREENPORT Alliances project.

The matrix shown in the Figure 4 provides a summary of the case studies received, highlighting the practices examined by each partner:

- a total of 18 case studies were proposed, corresponding to 16 distinct practices;
- only one of the practices highlighted in red in the matrix has not yet been analysed.

The figure provides a clear overview of the distribution of the case studies and the practices addressed and shows the association between each partner and the practices analysed. This data suggests a good level of coverage of the identified themes, with active and diverse participation from the partners.

	Practice #1	Practice #2	Practice #3	Practice #4	Practice #5	Practice #6	Practice #7	Practice #8	Practice #9	Practice #10	Practice #11	Practice #12	Practice #13	Practice #14	Practice #15	Practice #16	Practice #17
MAR.TE.				Case #1							Case #14	Case #2		Case #1			
PIRI REIS UNIVERSITESI (PRU)							Case #8 Case #9	Case #10 Case #17									
UNIVER. MARITIMA DIN CONSTANTA (CMU)									Case #18	Case #13							
HOGERE ZEEVAARTSCHOOL (HZS)				Case #15													Case #16
NIKOLA VAPTSAROV NAVAL ACADEMY (NVNA)														Case #7			
SVEUCILISTE U RIJECI (UNIRI)						Case #3									Case #4		
EUROPEAN TUGOWNERS ASSOCIATION (ETA)																Case #5	
APA-ADMINISTRACAO DO PORTO DE AVEIRO (APA)		Case #11	Case #12		Case #11												
EUROPEAN MARITIME PILOTS ASS. (EMPA)	Case #6																

Figure 4 - Mapping of case studies provided by project partners in relation to the analysed practices

Furthermore, the analysis of the matrix reveals a heterogeneous participation from the partners: some contributed with multiple cases across different practices, while others provided specific experiences. As can be seen from the matrix, each case study focuses on the implementation of one practice; only in some cases we have two practices. For example, case no. 11, proposed by APA - Administração do Porto de Aveiro (APA), is associated with both Practice no. 1 and Practice no. 5. This suggests a possible integration between several operational dimensions. Overall, the variety of contributions reflects the diversity of approaches and contexts represented by the partners, providing a complete and comprehensive overview of best practices in the maritime and port sector. The sources used for the development of the case studies are mostly secondary in nature, based on existing documentation, public reports, publications and materials provided by the project partners; a part of the case studies is based on direct experiences, field observations or ongoing pilot projects. Finally, for the sake of completeness, it is highlighted that Practice #13 (Accurate route planning) has not been addressed in any of the case studies, probably due to the lack of documented experiences among the partners. However, this gap represents an opportunity to explore in the future.

In the following subsections, the description of the case studies is provided.

3.1 Case #1: AR Pilot Navigation Aid: enhancing efficiency and safety at the port of Livorno (MARTE)

The two most relevant practices for the AR Pilot Navigation Aid case study are stakeholder collaboration for real-time data sharing (Practice 4) and real-time navigation route optimization (Practice 14). The first practice involves the joint involvement of pilots, port operators and technology providers in the use of software platforms such as MONI.C.A. and the Tuscan Port Community System (TPCS). These systems promote effective communication and coordination with consequent operational advantages. The second consists in allowing pilots real-time access to information such as route, speed, position and characteristics of the vessel, allowing for quick and efficient navigation decisions. Together, these practices form the core of the case study.

Therefore, the case study describes how such technologies can support port pilots in their daily activities by promoting safety, improving working conditions and increasing operational efficiency. By using such systems, in fact, it is possible to increase navigation precision while optimally using the available resources. The added value is in particular provided by the application of augmented reality (AR) technologies that, appropriately integrated and in connection with port systems such as MONI.C.A. and the Tuscan Port Community System (TPCS), represent a valid support for the performance of technical-nautical services.

In terms of direct impacts, as we shall see, such systems improve communication between pilots and ground personnel, improve safety and decision-making, and increase operational efficiency by saving resources.

The Port of Livorno (Figure 5) is situated on the western coast of Italy, along the Ligurian Sea, which is part of the larger Tyrrhenian Sea.

Figure 5 - Location of the Port of Livorno

The AI-based system is called AR Pilot Navigation Aid and was born within the European project "PortForward". The system provides real-time information through augmented reality smart glasses, enabling more precise, efficient and environmentally friendly navigation that uses decision-making based on data from different sources.

The decision to adopt this system was born from three main objectives: improving safety during port maneuvers, optimizing the use of resources and reducing the likelihood of human error.

Its implementation aligns with broader digitalization efforts aimed at improving competitiveness, ensuring long-term economic viability and meeting environmental standards. The project developed in four main phases. In the initial phase, a detailed assessment of the operational requirements was carried out to determine the main functions of the system for safer and more effective navigation. Subsequently, the RealWear HMT-1 smart glasses (Figure 6) were integrated with existing digital platforms such as MONI.C.A. and the Tuscan Port Community System (TPCS), which allows immediate access to critical data. In the third phase, digital workflows were developed using TeamViewer tools to standardise and optimise piloting procedures. Finally, field tests on board the ‘Eco Valencia’ allowed real-life validation, gathering feedback from pilots to refine the system and ensure its functionality, safety and usability in daily port operations.

Figure 6 - RealWear HMT-1 Smart Glasses

The implementation of this innovation was supported by:

- the Port System Authority of the Northern Tyrrhenian Sea, which guaranteed the availability of infrastructure resources;
- the Port of Livorno pilots as the main recipients of the solution
- the technology provider TeamViewer, which ensured the correct integration of advanced digital tools and ease of use.

This multi-stakeholder involvement ensured technical feasibility and operational acceptance, paving the way for scalable and sustainable innovation in port services.

The AR Pilot Navigation Aid system is based on advanced technologies designed to assist pilots and tugboats in complex navigation operations in harbor waters. The innovative solution is the "RealWear HMT-1" smart glasses. The RealWear HMT-1 is an industrial-grade wearable device designed for workers who need hands-free access to digital information. The headset features an adjustable monocular display that can generate the effect of a seven-inch screen. The user views data from the headset and can access technical manuals or participate in remote assistance sessions without taking their eyes off their work. The integration of the RealWear HMT-1 smart glasses with digital platforms improves coordination between stakeholders and enables real-time navigation optimization. In addition, the adoption of this system generates a long-term impact on the approach to work of port operators and pilots. Furthermore, the system encourages a more structured and data-driven decision-making process, which reduces the dependency on individual expertise and complements it, enabling more efficient and sustainable operations. Ultimately, the goal is to achieve better operational efficiency, while contributing to safer and more environmentally friendly port management.

The implementation of the AR Pilot Navigation Aid system in the Port of Livorno required a comprehensive mix of technical, operational and environmental skills. On the technical side, operators had to manage augmented reality tools such as smart glasses and interpret GPS and sensor data to fully exploit the system's capabilities. On the operational side, specific training ensured that pilots were prepared to effectively use the devices and interact with real-time data within digital platforms such as MONI.C.A. and TPCS. Furthermore, the use of the described digital technologies provided pilots with greater environmental awareness: the project enabled them to see that informed management of operations can improve energy efficiency and reduce emissions. This integration of expertise has ensured not only the effective use of the system, but also its alignment with the broader objectives of innovation and environmental responsibility in port operations.

The case study does not include KPIs, which prevents a quantitative assessment of the effectiveness of the technologies adopted and limits the analysis to qualitative aspects or preliminary considerations. However, it is possible to reflect on the critical issues that existed prior to the introduction of the devices and the tangible benefits derived from their use.

Since the implementation of the AR Pilot Navigation Aid system, piloting and towage operations in the port of Livorno have seen significant improvements in efficiency, safety and sustainability. One of the most significant changes was the real-time access to critical navigation data through the use of augmented reality (AR) smart glasses. Pilots could instantly visualise essential information on ship size, speed, manoeuvrability and position, reducing reliance on rough estimates and improving the accuracy of decision-making.

Integration with the MONI.C.A. platform and the Tuscan Port Community System (TPCS) enabled smooth communication and real-time data exchange between pilots, tug crews and port operators. This improved situational awareness, reduced response times and minimised the risk of errors during manoeuvres. In addition, the hands-free operation enabled by the smart glasses optimised ergonomics and reduced distractions, allowing pilots to fully concentrate on navigation while receiving real-time guidance.

With reference to operational aspects, the system has allowed to reduce docking times, reducing operating costs and improving the reliability of port services. The adoption of augmented reality technology has also enabled training and knowledge sharing among pilots: the possibility of recording and analyzing real navigation scenarios has facilitated practical learning, allowing new pilots to familiarize themselves more quickly with port operations. For the implementation of the augmented reality (AR) pilot navigation assistance system, the Port of Livorno has prepared a detailed planning of the costs and resources needed. The main investments were concentrated in three areas: 1. augmented reality devices and hardware; 2. software development and technology integration; 3. staff training. In terms of equipment, the purchase of smart glasses and other essential hardware devices resulted in a total cost of approximately 25,000 euros; the software integration required a total investment of approximately 40,000 euros. This phase included the creation of digitalized workflows, the implementation of REST API interfaces to connect with the MONI.C.A. and TPCS platforms, and the integration of real-time data.

Finally, to ensure optimal use of the technology, a dedicated training program was conducted for the personnel involved, costing approximately 15,000 euros. The training program focused on: a. training pilots on the use of smart glasses; b. digital data management; c. interaction with the integrated platforms. Overall, the overall investment represented a significant but necessary commitment to improve the safety, efficiency and sustainability of port operations.

As already extensively described, the adoption of the technological innovations described optimises manoeuvring operations by reducing risks, wasted resources and operational costs. In addition, the optimisation of operations generates a reduction in consumption and consequently in emissions.

Although there is a lack of detailed secondary data on key performance indicators (KPIs), the qualitative evidence gathered indicates that the introduction of the system has had a positive impact not only on operations but also on the mental approach of operators. However, it is important to emphasise that the practice has required a change in the mode of operation and thus a significant behavioural change on the part of the operators. Therefore, we can state that the success of the system depended not only on the technical effectiveness of the tools used, but also on the ability of the operators to adopt new working methods and their predisposition to change. Therefore, the experience showed that the success of technological innovations depends on the diffusion of digital skills and an open mindset to change, to be cultivated through continuous training. The project also highlighted the value of joint work between engineers, software developers, pilots and port operators, fostering a more comprehensive and effective approach to technology implementation in which system flexibility is also a determining factor for the effectiveness of the solution. Only collaboration between the different actors can guarantee this by ensuring proper integration of the system into existing processes.

To improve the solution and its wider deployment, it would be desirable to envisage software integration, for instance, by developing dashboards for performance evaluation, and hardware integration, represented by the use of further IT and telecommunication technologies (e.g., 5G networks). Furthermore, the impact would increase if the system were replicated in other Mediterranean ports.

3.2 Case #2: Sustainability reporting as a driver for operational efficiency and environmental responsibility (MARTE)

The periodic publication of environmental performance reports is a key practice for promoting transparency, continuous improvement, and corporate accountability in the field of sustainability (Practice 12). The case study concerns the company Fratelli Neri Spa and has as its object the description of the reporting activity of the company's sustainability actions. Fratelli Neri S.p.A. operates in the port towage services, offshore terminal support and environmental protection sector mainly in the Italian ports of Livorno, Piombino and Marina di Carrara. The company has been preparing the sustainability report since 2021; the latest available document covers the year 2023 (from 1 January to 31 December). Fratelli Neri has prepared the report according to the standards of the Global Reporting Initiative (GRI). The company has decided to draft the Sustainability Report with the aim of providing clear and accessible information to stakeholders on the actions undertaken to achieve the United Nations Sustainable Development Goals (SDG). This choice reflects the company's proactive approach to market trends and regulatory developments in the maritime sector. The report not only strengthens trust with customers, partners and authorities, but also serves as an internal assessment and long-term strategic planning tool, supporting the monitoring of key sustainability performance indicators (KPIs). This practice, adopted voluntarily and consistently implemented over time, demonstrates a structured and continuously evolving commitment to sustainability.

The sustainability report represents a real tool for defining the company's strategy as it allows to measure performance through qualitative and quantitative indicators dictated by international standards (i.e.; the Global Reporting Initiative Standards), identify areas for improvement, strengthen stakeholder involvement through constant dialogue and always act in compliance with national and international regulations. The main impact generated by the publication of the Sustainability Report is the transparency and responsibility that the company achieves towards stakeholders. This increases the trust of customers, authorities, employees and local communities. Measuring the results achieved in terms of sustainability by enabling constant improvement of the actions undertaken allows for more efficient management of resources, with positive effects on operating costs and sustainability objectives. Furthermore, it is known that reporting helps to integrate sustainability principles into the corporate strategy, improving the reputation and competitiveness of the company in the medium-long term.

Fratelli Neri S.p.A. actively involves institutional stakeholders, customers, employees, suppliers and local communities in the reporting process through meetings, consultations and tools for collecting feedback. Although the report examined does not delve into the involvement of pilots and crews, it is inevitable that they also contribute indirectly to the reporting process as they represent the actors who concretely implement sustainable practices. Therefore, it is reasonable to assume that they provide data and information useful for reporting.

In line with traditional guidelines, Fratelli Neri also carried out a materiality analysis. The analysis is based on stakeholder involvement with the aim of identifying the most relevant social, environmental and governance issues. For the collection and validation of environmental, social and economic data, Fratelli Neri uses a cloud platform called ESGeo, certified by GRI. This software tool simplifies the management and continuous monitoring of information.

The adoption of this practice required technical skills for data analysis and reporting, operational capabilities for the interfunctional management of the process and a strong environmental awareness specific to the maritime sector. Therefore, staff were trained and actively involved, with dedicated company functions responsible for data collection, aggregation and traceability.

Case #2: Competencies required

- ***Technical expertise for data analysis and reporting***
- ***Operational capabilities for the cross-functional management of the process***
- ***Constant updates on laws and regulations on sustainability performance reporting***

The environmental sustainability report of Fratelli Neri S.p.A. presents a comparative analysis of the results achieved in 2023 compared to the previous year, with reference to the main ESG areas: governance, environment and social. This comparison allows us to evaluate the progress made. As previously explained, the drafting of the sustainability report does not produce a direct impact on the reduction of negative externalities. However, the reporting standards require the measurement of results achieved, typically across the areas of Environmental, Social, and Governance (ESG). The environmental area is monitored through indicators related to CO_2 emissions, energy consumption, and waste management.

Table 3 - Energy consumptions

Energy consumption for facilities	2023 (GJ)	2022 (GJ)
Of which diesel (operational use)	6,500	7,000
Of which marine diesel oil 0.1%	6,475,670.96	4,875,016.67
Total fuel consumption from non-renewable sources	-	-
Electricity purchased – from third parties	755,648	650,483
Of which from renewable sources (e.g., with guarantee of origin)	649,631.36	533,396
Energy consumption of company fleet	-	-
Diesel fuel – for company use	6,500	7,000
Company vehicles using diesel	6	6
Petrol – for company use	50.42	310
Company vehicles using petrol	1	1
LPG – for company use	0	0
Company vehicles using LPG	0	0
Diesel fuel – for mixed use	5,485.04	11,165
Mixed-use vehicles using diesel	6	5
Petrol – for mixed use	3,499.77	3,449
Mixed-use vehicles using petrol	3	3

Table 4 - Emissions

Emissions Category	2023 (tCO_2e)	2022 (tCO_2e)
Emissions from non-renewable fuel sources	0.04	0.11
Of which petrol	0.04	0.11
Of which LPG	-	-
Of which marine diesel	-	-
Of which operational diesel	-	-
Fugitive emissions	61.04	-
R22	-	-
R134A	-	-
R404A	-	-
R407C	-	-
R410A	-	-
R427A	6.00	12.14
R449A	35.00	48.90
Total Scope 1 emissions	41.04	122.19

Table 5 - Waste management

Waste Category (CER Code)	2023 (Kg)	2022 (Kg)
Sandblasting waste containing hazardous substances (CER 1210116)	0	680
Other motor and lubricant oils (CER 130208)	28,055	17,320
Paper and cardboard packaging (CER 150101)	370	450
Plastic packaging (CER 150102)	690	330
Wood packaging (CER 150103)	4,540	2,960
Packaging containing hazardous residues (CER 150110)	1,000	1,170
Absorbents and filtering materials contaminated by hazardous substances (CER 150202)	3,260	1,020
Oil filters (CER 160107)	2,530	210
Outdated equipment containing hazardous refrigerants (CER 160211)	120	410
Non-hazardous obsolete equipment (CER 160214)	90	653.20
Organic waste containing hazardous substances (CER 160305)	0	5,160
Lead batteries (CER 160601)	419	391
Waste containing oils (CER 160708)	2,830	0

The indicators calculated and compared with the previous year reveal an improvement or worsening of the results, highlighting the need for corrective actions. Regarding the social dimension, the sustainability report of Fratelli Neri S.p.A. describes several initiatives and indicators that measure the well-being and safety of employees (e.g., employees covered by a health and safety management system at work; accidents at work). Governance indicators measure the levels of integration of sustainability into their economic and financial processes by measuring circularity targets and monitoring the distribution of economic value, such as the economic value generated.

Fratelli Neri also carries out sustainable finance operations by making investments in line with the Sustainable Development Goals (SDG). Through the creation of an internally developed ad hoc indicator, "Economic CirculAbility", the company evaluates its ability to generate economic value while reducing the consumption of natural resources, in line with the principles of the circular economy. As demonstrated by the experience of the Fratelli Neri Group, reporting on sustainable actions allows for systematic monitoring of data and, although the effects are not always direct, this approach contributes to the continuous improvement of resource management and operational efficiency, also generating economic savings. For example, the reduction in energy consumption achieved by land-based power plants has led to a lower use of fuel and a reduction in maintenance costs. By systematically measuring environmental indicators for reporting sustainability results, such as CO_2 emissions, energy consumption and waste generation, the report supports the identification of critical areas and encourages the adoption of innovative solutions to reduce environmental impact. Among the most notable initiatives are the installation of electric charging stations for boats and investments in waste sorting and recovery, and alignment with scientific targets for emissions reduction.

It seems reasonable to state that the main challenges generated by the publication of a sustainability report are:

- Data collection and validation: collecting accurate and comprehensive sustainability data across multiple departments was initially challenging.
- Stakeholder engagement: ensuring consistent involvement and communication with a wide range of stakeholders, including clients, suppliers, and authorities, presented organizational difficulties.
- Adapting to international standards: aligning the report with GRI Standards posed methodological and compliance-related challenges.

The company has addressed these challenges by using digital reporting tools (e.g., the ESGeo cloud platform); establishing dedicated working groups; implementing stakeholder engagement mechanisms; adopting recognized frameworks (such as the GRI Standards) to facilitate standardization and comparability of reports.

These lessons highlight the importance of digital transformation, stakeholder engagement, and structured governance to coordinate sustainability reporting processes. Furthermore, the periodic publication of a Sustainability Report requires constant updates on laws and regulations on sustainability performance reporting. Therefore, it is essential to provide continuous training in this regard to company personnel involved in collecting and processing data and information to be included in the report.

For a more effective and complete publication of a sustainability report but above all to spread a greater sense of responsibility towards sustainability objectives, it would be useful to involve suppliers and service partners more actively in the reporting processes. Furthermore, it would be useful to introduce and emphasize the role of innovation in the sustainability path; this could happen by introducing in the reporting rules an area of indicators specifically dedicated to the measurement of these actions.

3.3 Case #3: Continuous monitoring of emissions during operations (UNIRI)

The third case study focuses on the implementation of Practice 6 "Continuous monitoring of emissions during operations" as it describes the use of advanced monitoring systems. These are Continuous Emission Monitoring Systems (CEMS) capable of detecting pollutants such as CO_2, SO_2 and NO_x.

Diesel engines of tugboats contribute to the emission of harmful substances such as carbon dioxide (CO_2), sulphur dioxide (SO_2) and other pollutants that have a negative impact on the environment and human health. Therefore, emission monitoring systems represent valid solutions to ensure compliance with international environmental standards and national regulations (e.g., the Air Pollution Control Programme for the period 2020-2029).

The main driving factor behind the adoption of emission monitoring systems on tugboats is compliance with environmental regulations. Stricter international and national standards, such as the MARPOL Convention and the Air Pollution Control Program (2020–2029), require shipping companies to monitor and reduce CO_2, SO_2, and NO_x emissions. By implementing advanced monitoring technologies, such as Continuous Emission Monitoring Systems (CEMS), drones with sensors, and mathematical models, operators can ensure compliance with regulations, avoid legal penalties, and contribute to environmental protection.

Additionally, reducing emissions enhances the company's reputation and supports global efforts in combating climate change.

Several technologies can be used for emission monitoring on tugboats. Continuous Emission Monitoring Systems (CEMS) are standard systems that provide real-time measurement of exhaust gas emissions from ship engines. These systems use sensors to detect and quantify the concentrations of CO_2, SO_2, NO_x, and other gases. The data is collected in real-time, enabling immediate analysis and response in case of exceeding the permitted limits.

CEMS are based on sensors to detect and quantify concentrations of CO_2, SO_2, NO_x and other gases.

Drones equipped with sensors have recently been introduced to detect pollutants emitted by ships in the air. This technology has been tested in a pilot project in the Port of Barcelona, where drones are used to monitor pollutant emissions and potential spills from ships. Furthermore, based on operational data and considering engine characteristics and fuel consumption, mathematical models can be used to estimate emissions based on operational data.

The implementation of an emission monitoring system first requires a detailed assessment of the current state of the tugboat. The assessment should consider the type and age of the engine, current fuel consumption and existing monitoring systems. After this assessment, the most suitable emission monitoring technology can be selected. For tugboats operating close to shore and in ports, CEMS systems can be ideal due to their accuracy and continuous monitoring capability. If the installation of CEMS systems is not technically or financially feasible, models that estimate emissions, supplemented by periodic measurements, can be used. After selecting the technology, the emission monitoring system needs to be integrated with the vessel's existing systems. This includes installing the sensors, defining communication channels for data transmission and implementing software solutions for analysis and reporting. Subsequently, it is necessary to calibrate the sensors and verify the correct execution of the system functions under real operating conditions.

The crew must be adequately trained in the correct use of the systems. Operators must be able to interpret the data and must be able to implement regular maintenance plans. The collected data should be regularly analyzed and compared with regulatory limits, and reporting systems must be established in compliance with national laws and international conventions such as MARPOL.

CO_2, SO_2 and NO_x emission monitoring systems are a fundamental step in the process of reducing emissions generated by technical-nautical services. The use of these technologies helps maritime operators to carry out operations in compliance with the regulations governing air pollution. Thanks to the combination of cutting-edge technologies, crew training and continuous monitoring, the actors operating in the sector will be able to contribute in a concrete and immediate way to the fight against climate change.

3.4 Case #4: Regular maintenance of tugboat engines (UNIRI)

The case study presented in this section focuses on Practice 15 “Tugboat engine routine maintenance”. Routine maintenance helps to maintain the correct functioning of the engines, ensure high performance and minimize fuel consumption by reducing harmful emissions. International regulations, such as MARPOL Annex VI, the Engine Technical File (ETF) and the Air Pollution Certificate (IAPP), require constant monitoring and maintenance of the engines to prevent excessive emissions of pollutants and preserve the useful life of the vessel. Periodic engine maintenance also reduces operating costs as it reduces the likelihood of failures that can lead to expensive repairs and delays in operations.

Therefore, planning and implementing regular maintenance and calibration of tugboat engines achieves objectives such as optimising fuel consumption, reducing harmful gas emissions and compliance international environmental regulations such as MARPOL Annex VI and the IAPP certificate.

The main driver behind the adoption of regular maintenance and calibration of tugboat engines is compliance with environmental regulations and cost optimization. International standards, such as MARPOL Annex VI and the IAPP certificate, require continuous monitoring and maintenance of engines to reduce CO_2, NO_x, and SO_2 emissions and ensure the environmental acceptability of the vessel. At the same time, proper maintenance and calibration reduce fuel consumption, increase engine reliability, and lower operational costs. By using digital monitoring systems and predictive analytics, operators can prevent costly failures, ensure engine longevity, and avoid legal sanctions, thus achieving long-term economic and environmental sustainability.

The main maintenance activities consist of monitoring and analyzing engine performance. The parameters are detected and analyzed by means of advanced sensor systems. Typical parameters are the temperature of the exhaust gases, the pressure in the cylinders and the air-fuel ratio. Finally, the actual performance is compared with the data in the Engine Technical File (ETF) to detect any deviations. Digital engine monitoring systems allow for automatic data logging and analysis using advanced algorithms. This enables predictive maintenance, reducing the need for emergency repairs and increasing engine reliability. Regular calibration and adjustment of engine components involves calibrating fuel injection and adjusting turbocharger operation. These operations help reduce fuel consumption and emissions by checking and adjusting combustion control systems and regularly replacing and cleaning filters, nozzles and other engine components. In addition to these basic tasks, exhaust gas analysis is recommended to ensure the engine is operating within its intended limits. The use of advanced diagnostic tools can help identify faults before they cause more serious problems.

MARPOL Annex VI sets maximum allowable emissions of NOx, SO_2 and CO_2 and requires maintenance and documentation of the engine's technical parameters. Regular maintenance and repairs must be recorded in the ETF to demonstrate compliance with the regulations. Tugboats exceeding certain emission thresholds must be equipped with emission control systems, such as SCR catalysts and scrubbers, to remain within the permitted limits. Maintenance of these systems is essential for their long-term efficiency.

The IAPP certifies that the vessel meets international emission standards. Maintenance and calibration documentation must be up to date and available during inspections, and the use of exhaust gas filtration and purification systems helps maintain certification. Regular inspections by authorized bodies ensure that vessels comply with stringent environmental standards. Improper maintenance or lack of documentation can lead to loss of certification and financial penalties, as well as operational restrictions.

The benefits of regular maintenance and calibration include reducing operational costs through optimal fuel consumption, reducing CO_2, NOx, and SO_2 emissions in accordance with international standards, extending engine life, and reducing the need for expensive repairs, increasing the safety and reliability of tugboat operations, avoiding legal issues and fines by complying with international regulations, and improving the company's image through responsible environmental practices.

For effective regular maintenance and calibration, it is recommended to develop a detailed maintenance plan with predefined service and inspection intervals, implement a digital data monitoring system with automatic logging of engine performance, train the crew to recognize potential issues, regularly analyze fuel with an emphasis on using high-quality fuels that can significantly reduce harmful emissions, and collaborate with certified service providers to ensure that all engine interventions are carried out according to manufacturer and regulatory standards.

Regular maintenance and calibration of tugboat engines are essential for reducing emissions, improving efficiency, and ensuring compliance with MARPOL Annex VI and the IAPP certificate. The implementation of modern technologies for monitoring and analyzing engines enables fuel consumption optimization and extends equipment lifespan, which contributes to ecologically sustainable and cost-effective operations in the long term. Systematic and precise maintenance reduces operational costs, increases engine reliability, and ensures regulatory compliance. The digitalization of maintenance processes and the use of predictive analytics further contribute to optimizing performance, reducing emissions, and maintaining high levels of safety on vessels.

Implement regular maintenance and calibration of tugboat engines to optimize fuel consumption, reduce harmful gas emissions, and ensure compliance with international environmental regulations such as MARPOL Annex VI and the IAPP certificate.

3.5 Case #5: Use of biofuels in tugboats by Svitzer and development of a new business model, EcoTow (ETA)

The case study provided by ETA focuses on practice 18 “Use of biofuels for tugboats”. The case describes Svitzer's decision to replace marine diesel (MGO) with a second-generation carbon-neutral biofuel.

Svitzer is a leading provider of maritime services worldwide and serves around 2,000 customers in 141 ports and 40 terminals in 37 countries through a fleet of 456 ships. Svitzer has its global headquarters in Copenhagen, Denmark and a presence in more than 35 countries (www.svitzer.com).

Svitzer has set a target of reducing the CO_2 intensity of its global fleet by 50% by 2030. Moreover, by 2040 the company´s global operations should be climate neutral. This switch to biofuels is one of the main measures implemented by the company to achieve them.

The main impact generated by adopting this practice is the certified reduction of emissions from towing operations provided to Svitzer's customers.

The pilot project took place in the second semester of 2021. Since then, a growing number of tugboats in the United Kingdom and in the European continent have switched to biofuel. Some United Kingdom´s terminals like London, Southampton, Medway, Felixstowe, etc. and now it is expanding to the European continent like the ports of Esbjerg, Gothenburg and Malmö.

To proceed with the substitution of marine diesel with a carbon-neutral second-generation biofuel, after securing the supply, conducting a pilot test, adapting the engines and converting the fleet to biofuel operation.

Although there are currently no specific environmental regulations aimed at decarbonising the sector, ports and companies operating in the sector are implementing plans to reduce their carbon footprint. In particular, there are funding programmes that promote the production, deployment and use of biofuels and there is a growing demand from customers for cleaner harbour towage services.

Svitzer published in May 2022 its decarbonization strategy and as part of it, it has been gradually adapting its fleets to run with biofuels. Once the London terminal had the capacity of bunkering and deploying a large amount of biofuel, the company run in 2021 a successful biofuel trial. This was completed in collaboration with CAT which adapted the engines and together with Svitzer crews and technicians developed maintenance guidelines and have been constantly monitoring fuel quality, fuel cleanliness, load response and overall engine health. This successful pilot exercise led to the conversion of an increasing number of tugs to biofuels in different British and EU ports.

Svitzer, which is the port operator and its technicians, crews and tugmasters that had to adapt to operate with biofuels, to learn to manage the software that helps the company collect and analyse data on fuel consumption and maintaining the engines. CAT an engineering equipment manufacturer, which developed new engines adapted to use biofuels and constantly monitor the performance of the tug and these engines. Biofuels producers expanding the production of standardised HVO and FAME biofuels. Port and governmental authorities supporting the deployment of biofuels in terminals. Tugmasters, crews and technicians play an essential role, adapting the way they operate the tugboat and implementing the recommendations on monitoring and maintenance. Svitzer published in May 2022 its decarbonization strategy and as part of it, it has been gradually adapting its fleets to run with biofuels. Once the London terminal had the capacity of bunkering and deploying a large amount of biofuel, the company run in 2021 a successful biofuel trial. This was completed in collaboration with CAT which adapted the engines and together with Svitzer crews and technicians developed maintenance guidelines and have been constantly monitoring fuel quality, fuel cleanliness, load response and overall engine health. This successful pilot exercise led to the conversion of an increasing number of tugs to biofuels in different British and EU ports.

Technologies used in the case study include the production, supply, certification and standardization of biofuels based on hydrotreated vegetable oil (HVO) and fatty acid methyl esters (FAME), adaptation of tugboats to run on 100% biofuel, with Cat® 3516C main engines and two C4.4 auxiliary engines. Monitoring of tugboat and engine performance using Caterpillar connectivity technology to help improve vessel efficiency and optimize fuel consumption.

Case #5 – Competencies required

- ***Adjusting tugboat operations to operate with biofuels***
- ***Operating following maintenance recommendations and guidelines for crews and technicians***
- ***Identifying and addressing abnormalities, component wear and enhance engine maintenance***

GREENPORT Alliances

Tugmasters and crews had to adjust their tugboat operations to operate with biofuels. CAT established maintenance recommendations and guidelines for crews and technicians, helping them identify and address abnormalities, component wear and enhance engine maintenance.

The use of these biofuels reduces carbon emissions by 100% on a tank-to-wake basis and about 90% on a well-to-wake basis compared to Marine Gas Oil. The switch to biofuels saw CO2 emissions reductions of more than 21,000 mt/year in 2022.

The use of these biofuels reduces carbon emissions by 100% on a tank-to-wake basis and about 90% on a well-to-wake basis compared to Marine Gas Oil. This enables Svitzer to offer its customers an opportunity to reduce their Scope 3 emissions and their environmental footprint, either by procuring towage services delivered by tugs fuelled with biofuel, or by 'insetting' carbon emissions from tug jobs elsewhere against savings generated in the British ports where they operate. Additionally, customers utilizing Svitzer's towing services will be subject to the Ecofriendly Bunker Adjustment Factor, which accounts for the cost differences associated with the shift to biofuels. Thus, Svitzer can now offer its customers the same service with an extra value that can contribute to lower their carbon footprint. The main environmental contribution is the reduction in carbon emissions of 100% from tank to wake and around 90% from well to wake compared to marine diesel. The switch to biofuels has led to a reduction in CO2 emissions of over 21,000 tonnes per year in 2022. Furthermore, the use of biofuels for harbour towage has supported their large-scale production, refuelling and deployment in UK ports, creating the demand needed to increase production of these green fuels. Finally, the use of biofuels in harbour towage operations is helping ports such as London to achieve their decarbonisation plans.

The outcomes have achieved the objectives; offering a quality service while reducing the tugboats emissions without major incidences. The expansion of this programme to other ports in the United Kingdom and the EU are a proof of it. The use of 2nd generation biofuels has helped Svitzer save millions of metric tons of CO2 emissions. These savings are the basis of EcoTow which provides Svitzer customers with audited and verified emission reductions and marginal abatement costs per ton of CO2 saved. These can be embedded into the company´s ESG reporting. Thus, Svitzer has been able to translate the decision of using biofuels into a business model that has the necessary demand to make it sustainable.

The trial of this practice has highlighted some important aspects that can be considered for the implementation and dissemination of this practice. This solution can be adopted where there is a steady supply of biofuels at reasonable prices and in sufficient quantities and there is a demand for greener harbour towage operations. It is essential to select the right type of engines to be used with biofuels. Continuous monitoring of fuel quality, cleanliness, load response and general engine health using digital tools is essential. Tug crews and skippers have had to adapt and modify their operations to switch from tugs running on marine diesel to those running on biofuel. Crews, together with marine engineers and technicians, have worked with CAT staff to assess the maintenance and repair needs of the engines and establish a set of guidelines to meet these requirements. Collaboration between the towing company, engine manufacturer, technicians and crews has been essential to optimise the use of biofuels in tugboats.

The company has been progressively adapting and will continue to adapt additional tugboats to operate on biofuels wherever available, as well as in terminals with a demand for green towage operations. This expansion is driven not only by customer demand but also by public policies that support the adoption of biofuels in terminals and the ports' decarbonization initiatives. Future implementations could include enhancing partnerships with port authorities to streamline 2nd and 3rd generation biofuel availability, expanding research into alternative sustainable fuels and exploring innovative technologies to further reduce emissions in towage operations.

3.6 Case #6: Energy efficient harbour towage and pilotage (EMPA)

This case study specifically focuses on Practice 1 “Active involvement of pilots in the planning of port initiatives”. In conjunction with the European Tug Owners Association, EMPA created a video issuing guidelines for energy efficient harbour towage. The aim of the video was to look at three distinct fields where we think gains can be made in emission reduction.

These three fields are:

1) Planning
2) Communication
3) Cooperation.

The primary objective of the project was to foster enhanced collaboration among a diverse group of stakeholders, including pilots, port authorities, tugboat operators, crew members, and other key players within the port community. By promoting closer cooperation and communication, the initiative aimed to refine and optimise the procedures that govern the safe and efficient movement of vessels in and out of the port. This collaborative effort was designed not only to streamline operations but also to reduce energy consumption and emissions, contributing to a more sustainable maritime industry.

The direct impact of this initiative is challenging to quantify due to its broad scope and the various factors involved. Nevertheless, as we distribute guidelines to our members and widely circulate this informative video, we aim to foster a positive influence on their work practices. By inspiring individuals to consider more efficient methods of operation, we believe this initiative will play a crucial role in advancing sustainability efforts. Emphasising efficiency not only reduces resource consumption but also promotes a culture of mindful and responsible work habits that benefit both the environment and the maritime industry stakeholders.

This video was widely shared among the members of ETA and EMPA, generating significant engagement across various social media platforms. As a result, it reached countless individuals not only within European countries but also in our neighbouring countries. The impact of this outreach was substantial, as it engaged thousands of viewers and sparked conversations online, nationally, and locally on the topic of energy efficient harbour towage and pilotage.

This video was shared in October 2023 and is still available on our website and social media channels.

The following sections describe the main phases, demonstrating how, through suitable operations and procedures, and thanks to the collaboration among the involved stakeholders, it is possible to operate while reducing emissions.

Planning

The pilot, the ship's master, and the tug operator collaboratively assess the requirements for the towage operation, determining the appropriate number and size of tugs based on factors such as the vessel's dimensions, weight, and prevailing environmental conditions. Together, they develop a comprehensive towing plan that outlines specific points along the route where the vessel will reduce its speed, where the tugs will secure their lines, and how the tugs will be used during the manoeuvre. This detailed plan ensures that all parties involved share a unified understanding of the operation, fostering effective communication and coordination throughout the process to ensure a safe and efficient towage manoeuvre.

Communication

By effectively communicating all relevant facts and parameters in advance, it becomes feasible to develop a comprehensive and actionable plan. Key factors to consider include weather conditions, which can greatly impact operations; berth availability, ensuring that the necessary docking space is available; tidal patterns, as they influence the timing and safety of ship movements; and anticipated traffic within the port. Additionally, the availability of tugs and pilots is crucial, as these resources are essential for safe navigation and docking. Finally, it is important to take into account the scheduled commencement of cargo operations, as this affects overall timelines and resource allocation. By addressing all these elements, we can ensure a smooth and efficient operation. Ship movements are inherently dynamic, and heavily influenced by various external factors, including changing weather and tidal conditions. These elements can significantly impact manoeuvrability and safety. To navigate these challenges effectively, it is essential to establish clear and precise communication between key parties, including the pilot, tug captains, and port authority (VTS). This collaborative approach ensures that all parties are aware of real-time conditions and can coordinate their efforts to promote not only safety but also the efficient use of resources and power during vessel operations. Communication protocols and thorough briefings can further mitigate risks, ensuring that every movement is executed smoothly and safely.

Cooperation

To optimise the efficiency of port operations and promote environmental sustainability, it is essential for pilotage authorities, tug operators, and port authorities to convene on a regular basis. These collaborative meetings should focus on establishing, reviewing, and refining best practices that address both operational effectiveness and environmental sustainability.

Energy conservation and emissions reduction extend beyond the scope of harbour towage. By fostering proactive cooperation with ship agents and cargo shippers/receivers vessels can be informed well in advance of predicted berth availability, port authorities can encourage ships to adjust their speeds. This approach allows vessels to adjust to eco speed, reducing the need for travelling at full speed and enabling them to arrive at the ports in time for berthing while significantly minimising fuel consumption.

By implementing these strategies, stakeholders can contribute to a more sustainable maritime industry, enhancing both the economic and environmental performance of port operations.

The initiative launched by EMPA and ETA stems from a deep commitment to environmental and social responsibility. ETA and EMPA firmly believe that passively waiting for technological advancements to address emission reduction is insufficient. Instead, we are taking proactive steps to implement meaningful changes today. Their goal is to create a sustainable framework that not only mitigates our ecological footprint but also inspires others to participate actively in this critical endeavour.

This initiative targets key stakeholders within the maritime industry, specifically pilots, tug operators, and individuals responsible for the coordination of ship operations and movements, including ship owners, agents, and shippers. The primary objective is to actively engage pilots and tug operators, as well as those who oversee and organise ship movements, in discussions and practices geared towards environmental sustainability. However, EMPA and ETA aim to take a more comprehensive approach by inviting all professionals in the maritime sector to reflect on their operational practices and the associated environmental impacts. We encourage each participant to examine how they can implement strategies to reduce their ecological footprint, ultimately fostering a culture of environmental responsibility through behavioural change throughout the industry.

This case study aims to promote greater awareness among industry members and stakeholders regarding the importance of considering emissions when planning ship movements. The objective is to encourage a more thoughtful and conscious approach to operations, highlighting how every use of ship, tug, or pilot boat engines contributes to overall emissions. While maintaining maritime safety as the top priority, environmental impact can be mitigated by optimising movement strategies to ensure they are both efficient and intentional. This involves minimising unnecessary trips and ensuring that all manoeuvres are carried out smoothly and purposefully. By adopting a more refined and deliberate operational approach, it is possible to contribute meaningfully to reducing the collective carbon footprint, without compromising the effectiveness of maritime activities.

At present, it is difficult to measure the actual success of this initiative, as no concrete data is yet available to support its evaluation. Nevertheless, the fact that the initiative has been widely discussed within EMPA, ETA, and among other industry stakeholders represents a significant initial outcome: it has at least succeeded in sparking a collective reflection on the importance of sustainability.

Driving behavioural change is not a simple process, especially in a context where climate change is increasingly becoming a political debate rather than a scientific discussion. This case study will serve as a valuable contribution to the development of a comprehensive training curriculum designed to address current gaps and support the evolution of the maritime sector. The training programme will focus on promoting sustainable practices and will aim to provide professionals with the knowledge and skills needed to operate more efficiently, responsibly, and consciously. The goal is to foster a culture of continuous learning and innovation, strengthening the workforce's competencies while simultaneously contributing to environmental protection within the sector.

A particularly interesting area to explore, in connection with the case study described, concerns the development of an in-depth study involving a cohort of pilots using ship-handling simulators. The aim of the research is to analyse in detail the behavioural characteristics related to manoeuvring, allowing for an examination of individual ship-handling styles and associated decision-making processes. Furthermore, the study will focus on identifying and documenting the practices adopted by pilots recognised for their energy-efficient management techniques, with the goal of highlighting exemplary operational models that can be shared and replicated.

3.7 Case #7: Sailing toward sustainability: green port of Varna (NVNA)

The case study proposed by the Nikola Vaptsarov Naval Academy focuses on the implementation of Practice 14: "Real-time navigation route optimization".

In recent decades, the reduction of emissions has become a global priority, with Europe leading efforts to implement sustainable policies. As part of the European Union, Bulgaria is committed to reducing emissions, particularly in its maritime sector, which is a key player in industrial emissions savings. The Port of Varna has been chosen for this case study due to its size, versatility, and strategic importance within the European transport network. Located on the Black Sea, Varna plays a crucial role in Bulgaria's trade and logistics, necessitating efforts to reduce emissions from port operations. The study highlights two primary methods of emission reduction: upgrading tugboats and pilot boats to more fuel-efficient models and optimizing operational logistics to minimize fuel consumption. Through coordinated planning among tug companies and port authorities, unnecessary vessel movements have been reduced, leading to lower fuel consumption and emissions. Additionally, Varna's pilot station has transitioned from steel boats to lighter fibre-reinforced constructions, resulting in a 25% fuel savings over the past 15 years. This case study explores the environmental and economic impact of these initiatives, emphasizing the importance of collaboration and regulatory support in achieving sustainable maritime operations.

This initiative aims to address key environmental and operational challenges within the maritime sector through a set of targeted objectives. A primary focus is the reduction of maritime emissions, with an emphasis on analysing and implementing strategies to lower CO_2 output from port operations—particularly those involving tugboats, pilot boats, and auxiliary vessels. A key component involves fleet modernization, assessing the benefits of replacing older, high-emission vessels with fuel-efficient or environmentally sustainable alternatives.

Efforts concentrate on operational optimization, improving coordination between pilot stations, tug operators, and port authorities to minimize unnecessary vessel movements, thereby reducing fuel consumption and emissions. In parallel, the initiative seeks to enhance fuel efficiency by evaluating consumption patterns and investigating the potential advantages of sourcing high-quality fuel directly from local refineries.

To ensure long-term success, collaboration among stakeholders—including port operators, tug companies, and logistics planners— is promoted to strengthen joint sustainability efforts. Furthermore, the project will involve an economic and environmental impact assessment, quantifying fuel savings, cost reductions, and emission decreases achieved through modernization and improved operational practices. Lastly, the identification of policy and regulatory support, such as financial incentives and enabling regulations, will play a crucial role in accelerating the adoption of green maritime technologies and practices.

The practice implemented at the Port of Varna, which began on February 3, 2025, focuses on reducing emissions and fuel consumption through fleet modernization and operational optimization. By integrating these two approaches, the Port of Varna has successfully lowered its harmful emissions while maintaining efficient port operations. The coordinated efforts ensure that vessels use the most direct and efficient routes, limiting fuel waste and reducing environmental impact.

The Port of Varna is a key maritime hub on the Black Sea, consisting of multiple terminals, shipyards, and quays spread over a vast area. The operational complexity arises from the need to move ships between these locations using tugboats and pilot boats. On a typical day, multiple vessel manoeuvres occur, requiring precise coordination to avoid delays and unnecessary fuel consumption. This geographical spread makes efficient planning essential to avoid redundant tug movements. Enhanced coordination between the pilot station, tug companies, and port traffic control led to strategic task-sharing among tug operators. Instead of moving boats over long distances for individual assignments, companies collaborated to utilize the nearest available tugs, reducing unnecessary fuel consumption and emissions. This practice demonstrates how logistical planning and inter-company cooperation can significantly improve port efficiency while contributing to environmental sustainability. The results include lower operational costs, reduced CO_2 emissions, and an overall improvement in green maritime practices.

The primary motivation behind implementing green practices at the Port of Varna is the major need to reduce maritime emissions, which contribute to both local air pollution and global climate change. Bulgarian Ports are high-traffic areas with significant fuel consumption from tugboats, pilot boats, and other auxiliary vessels. Since Varna's port is located near a major city, reducing emissions directly benefits urban air quality and public health. (https://aqicn.org/station/@96565/). Moreover, as part of the EU, Bulgaria complies with stringent environmental policies, including EU emission reduction targets and International Maritime Organization (IMO) regulations. These rules encourage ports to adopt cleaner technologies and optimize operations to lower CO_2, NOx, and SOx emissions. Implementing greener practices helps the Port of Varna align with EU Green Deal objectives and maintain regulatory compliance. Reducing fuel consumption is not only environmentally beneficial but also economically advantageous. Fuel is a major operating cost for tug and pilot boat companies. By optimizing vessel movements and replacing outdated, fuel-inefficient boats, companies lower operational expenses. The savings in fuel and maintenance costs provide a strong financial incentive to adopt green practices. Leading European ports are actively adopting sustainability initiatives, and the Port of Varna aims to stay competitive by following best practices in green maritime operations. Implementing fuel-saving and emission-reduction measures enhances the port's reputation as an eco-friendly logistics hub, attracting businesses and investors that prioritize sustainability. The initiative is driven by a collaborative effort between tug operators, pilot stations, and port authorities to improve efficiency. By better planning vessel movements, these stakeholders reduce idle passages and unnecessary fuel consumption, demonstrating how operational coordination can achieve both economic and environmental benefits. As stricter carbon regulations and emission limits emerge globally, ports must adapt to sustainable practices to avoid potential penalties or restrictions on operations. By proactively implementing these green initiatives now, the Port of Varna is positioning itself for a more sustainable and resilient future. In conclusion, these driving factors—environmental responsibility, regulatory compliance, economic benefits, competitive positioning, and operational optimization—serve as the core motivations behind the Port of Varna's adoption of green practices, ensuring both sustainability and long-term success in a rapidly evolving maritime industry.

The stakeholder involved in the implementation of this practice are:

- Port Fleet 99 AD: With over 50 years of experience, Port Fleet 99 operates a versatile fleet of seven tugboats, offering 24-hour manoeuvring and towing services within the port's waters (https://portfleet99.com/en);
- Navigation Maritime Bulgare (Navibulgar): As Bulgaria's largest shipping company, Navibulgar offers comprehensive tug services for all vessel types, including port manoeuvring in Varna, salvage operations, and supply services (http://www.navbul.com/)
- Varna Towage Company Ltd.: The company was founded in 2003 as Varna Towage Company ltd. Varna Towage Company ltd. began its operations with three brand new tugboats that were acquired from the leading tugboat builder Sanmar Shipyards. (https://www.vtc-bg.com/services.html);

- Varna Pilot Station: The primary organisation providing deep-sea and port pilotage from the approaches to the ports along the Northern Bulgarian Black Sea region - from cape Emine to the Romanian border. (https://varnapilots.com/aboutus_en.html).

The importance of emission reduction from ships and port operations comes mainly from the general importance of the world economy reductions but also from the proximity of ports near major cities. Both ports – Varna and Bourgas, are situated close to the two of the biggest cities in Bulgaria and the quality of the air in those cities depends upon the emissions from port operations. The proposed reduction of emissions near ports could be achieved in two main ways. The first one considers the use of more efficient tugs, pilot boats and other equipment which are sources of emissions. The second one is the proper organization of the port operations and adequate coordination in order to reduce the operational time of tugs, pilot boats and other equipment.

The port of Varna utilizes both ways depending upon the existing financing and state economic situation. During the last several years, the old tugs had been decommissioned and replaces by new ones with significantly less emissions. One of the existing tug companies replaced its three more than thirty years old tugs with newly built ones. The pilot station replaced the old steel pilot boats with second hand plastic ones thus reducing the consumption of fuel. Table one below shows the constructions in use by Varna Pilot Station Co.Ltd.

Table. 1

Pilot boat	Year build	Year of commencement of use	Year of decomissioning	Material
Nereida	1969	1969	2023	Steel
Fobos	1968	2011	2021	Steel
Pilot 2	1980	1995	2018	Steel
Pilot 1	2013	2013		Steel
Pilot 2 new	1996	2021		Fibre
Pilot 3	2003	2022		Fibre

Compared to ships, the consumption of pilot boats is significantly less and in that way the savings of fuel and emissions are disdainfully small. In polluted areas these are something in the big basket. For the last 15 years, change from steel to plastic boats reduced the consumption of fuel in Varna Pilot Station from 23 mt per year to 18 tons per year (25%). That is a good example how small size companies contribute to the green economy. The operational optimisation is more important at the moment as the other measures concern huge investments. The operational ones depend only upon better arrangement and management of the day-to-day work.

On 03rd of February 2025 there were more than usual moves in the port. There are three tug companies each of them having four tugboats. The port area includes more than 60 berths consisting of Varna East, terminals and shipyard quays along the old and the new canal, terminals in the lake of Varna, lake of Beloslav and Varna West and also Port of Balchik. The distance between quays is sometimes up to 12 miles. In addition, town port of Balchik is 17 miles from the other terminals. Since early morning it was clear that manoeuvres were expected in all the areas. The duty operator in Varna Pilot Station discussed with the tug companies the forthcoming moves. So, the tug companies agreed between themselves to exchange part of the tasks in order not to move their tugs from one area to the other. M/v "Tundra" was supposed to move from Shiprepair yard Odessos, quay 1 to the floating dock 3. For that manoeuvre four tugs are compulsory but the tug company in contract with the ship owner of "Tundra" had three available in the area. Instead of transferring the fourth one from Varna Port West (12 miles distance) they took the available tug from other tug company in the area. The same took place with the other manoeuvre in shiprepair yard "TEREM". M/v "Westford" was supposed to exit the floating dock with three tugs from one company but only two were available in that area. The third tug was arranged by the other tug operator which was in the vicinity thus saving move of one tug - 6 miles away. All that was possible because of the proper planning between the duty operators of the pilot station, the three tug-company management and Varna Vessel Traffic Service duty operator. In most cases the commercial reasons are stronger than ecological ones but all companies try to reduce the costs of operations. Reducing the idle passages of tugboats, tug companies save fuel consumption which is less emissions as well. During the manoeuvres mentioned above a total of 16 miles of idle passages had been saved. Bearing in mind the power of the tugs of 1500 HP that means about 235 KG of DO fuel saved and PM, NOx, CO_2, HCs emissions are reduced accordingly.

Another important issue is the quality of fuel used by the auxiliary ships, tugs and boats operating in the port area. In the pilot station comprehensive study was made about suppliers of fuel. As per the company's quality management system the review of suppliers is done annually and the company approved as main supplier the local refinery thus receiving the fuel directly from the producer and eliminating the possibility to worsen the quality of fuel due to storage and transportation.

	Metric	Before Implementation	After Implementation
1	CO2 Emissions (ppm)	450	380
2	NOx Emissions (ppm)	180	140
3	Daily Fuel Consumption (kg/day)	1200	965
4	Daily Operational Costs (US$/day)	5000	4200
5	Engine Running Time (hours)	12	10

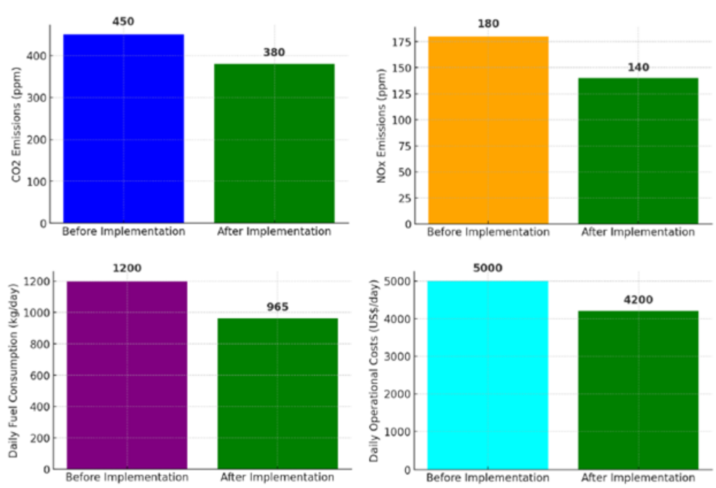

Figure 7 - Port of Varna Emission & Fuel Data

By replacing older, high-emission tugboats and pilot boats with newer, fuel-efficient models, including lighter fibre-reinforced boats, the port has significantly lowered fuel consumption. Improved tugboat deployment planning through better coordination between pilots, tug companies, and port traffic operators has minimized unnecessary vessel movements, fuel saving and cutting emissions. The direct procurement of high-quality fuel from a local refinery ensures cleaner combustion, further reducing environmental impact. These combined efforts demonstrate how strategic fleet upgrades, smarter operational planning, and fuel management can make maritime operations more sustainable while maintaining efficiency and cost-effectiveness.

Implementing such green practice requires a multidisciplinary approach, integrating technical knowledge, operational efficiency, regulatory compliance, financial planning, and stakeholder collaboration. The combination of these competencies ensures that sustainability initiatives are both practical and effective in reducing emissions while maintaining smooth port operations.

Case #7:
Competencies required

- ***Multidisciplinary approach integrating:***
  - ***Technical knowledge***
  - ***Operational efficiency***
  - ***Regulatory compliance***
  - ***Financial planning***
  - ***Stakeholder collaboration***

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It is particularly interesting to observe the data on emissions and fuel consumption before and after the adoption of the described practices, as it provides valuable insight into their actual impact and effectiveness (Figure 7). The initiative at the Port of Varna has resulted in substantial savings and environmental benefits, primarily through a significant reduction in fuel consumption. This not only lowered operational costs for port operators but also contributed to a notable decrease in harmful emissions, aligning the port's activities with broader sustainability targets. Improved operational efficiency—driven by enhanced coordination among tug companies—has led to a 16% reduction in daily operational expenses, with costs dropping from $5,000 to $4,200 per day.

Optimized task-sharing has also minimized idle movements, saving an average of 16 nautical miles per day. This has directly translated into lower fuel consumption and reduced mechanical strain on tugboat engines, ultimately decreasing maintenance and repair needs. In environmental terms, the initiative has proven highly effective, with CO_2 emissions reduced by 15.56% and NO_x emissions by 22.22%.

Beyond these measurable outcomes, the Port of Varna's commitment to sustainability has strengthened its competitive position. As international regulations grow increasingly stringent, ports that proactively implement green strategies are becoming more attractive to shipping companies aiming to reduce their environmental impact. The results at Varna demonstrate how operational improvements can simultaneously drive economic savings and support ambitious environmental goals.

The Port of Varna's green maritime initiative has successfully demonstrated how fleet modernization, and operational optimization can lead to measurable reductions in fuel consumption and emissions. By replacing outdated tugboats and pilot boats with more fuel-efficient models, including lighter fibre-reinforced boats, the port has achieved a 25% reduction in fuel consumption at the pilot station over the past 15 years. Additionally, enhanced coordination between tug companies, pilot stations, and port operators has significantly reduced unnecessary vessel movements, saving miles of idle tugboat passages in just one busy operational day. The adoption of higher-quality fuel sourced directly from a local refinery has further contributed to cleaner port operations. These improvements not only enhance the port's environmental sustainability but also reduce operational costs for maritime stakeholders, proving that eco-friendly practices can be both economically and environmentally beneficial. The case study involving the Port of Varna highlights the importance of cooperation between tugboat companies, pilot stations and port authorities. The next steps towards sustainability proposed by NVNA are of different nature. Following the results obtained in the case study, NVNA highlights the importance of introducing hybrid or electric tugboats; installing cold ironing systems for powering ships while in port; providing training to tugboat crews and port personnel to reduce unnecessary energy consumption. Finally, NVNA highlights the importance of financial and political support for green initiatives to accelerate the transition to low-emission maritime technologies.

3.8 Case #8: Continuous training and updates for pilots in Port of Rotterdam (PRU)

This case study was developed by Piri Reis University (PRU) and focuses on Practice 7 "Continuous training and updates for pilots". The case study consists of the creation of training sessions for maritime pilots. These include simulations, real-time data analysis and environmental awareness programs. The main objective is to promote safe, efficient and environmentally sustainable navigation through targeted training of pilots. Implementing such a training program enables new modes of operation that will reduce emissions, improve energy efficiency and have low operating costs.

The implementation of the practice, which includes regular training sessions for maritime pilots based on simulations, real-time data analysis and environmental awareness programmes, aims to optimise vessel management, reduce fuel consumption and minimise environmental impact. The drivers that led to the creation of training courses capable of introducing and spreading more sustainable operating methods in the technical-nautical services sector are the need for greater navigation efficiency and compliance with environmental regulations. The case study involves the use of cutting-edge technologies in the training courses such as naval simulators, automatic identification systems (AIS), electronic chart display and information systems (ECDIS). The skills required for participation in the training courses consist of a mastery of digital navigation, environmental regulations and naval manoeuvres.

Case #8: Competencies required

Expertise in

- ***Digital navigation***
- ***Environmental regulations***
- ***Vessel manoeuvring***

The proposed KPIs allow measuring the effectiveness of the practice through the reduction of fuel consumption, the optimisation of vessel movements and the general reduction of environmental impact. The implementation of this initiative required an initial investment in training infrastructure, especially in advanced simulation technologies and digital systems for processing and analyzing operational data.

The training initiative has led to increased navigation efficiency, reduced emissions and savings in operating costs. As further developments and future updates of the training courses PRU suggests integrating topics related to AI-based navigation and expanding collaboration with international ports. Further investments in digital learning tools and increased use of real-time environmental data. This approach ensures that port pilots remain up to date with the latest developments including technological ones. Based on the lessons learned, a continuous training and refresher course for port pilots could be designed, pursuing the following objectives:

- improve navigation skills;
- keep pilots updated on the latest maritime regulations and emerging technologies.
- strengthen decision-making skills and speed in emergency management.
- promote continuous professional development and knowledge sharing.

- promote cooperation and knowledge sharing among all actors in the port community.

The program is organized into 9 comprehensive modules covering the key aspects of modern pilotage[1]:

- Introduction to Continuous Training
- Advanced Navigational Techniques and Safety Protocols
- Regulatory Updates (International and Local)
- Technological Innovations (Autonomous ships, AI, digitalization, cybersecurity)
- Emergency Response and Practical Simulations
- Human Factors and Crew Resource Management (CRM)
- Environmental Awareness and Sustainable Practices
- Continuous Professional Development (Mentorship, forums, feedback)
- Practical Assessments and Certification

For a comprehensive Continuous Training and Updates for Port Pilots course, incorporating the latest technologies is essential. Here are some key technologies to include:

- Portable Pilot Units (PPUs): portable devices that provide real-time navigational data for improved situational awareness.
- Simulation Technology: High-fidelity simulators that replicate real-world scenarios for training purposes.
- Artificial Intelligence (AI): AI systems for route optimization, predictive maintenance, and decision support.
- Augmented Reality (AR) and Virtual Reality (VR): AR and VR tools for immersive training experiences.
- Internet of Things (IoT): IoT devices for real-time monitoring of vessel and port operations.
- Big Data and Analytics: Advanced analytics platforms for processing and analyzing large datasets.
- Cybersecurity Tools: Systems and protocols to protect maritime operations from cyber threats.

[1] For further details, please enquire for the full document produced by PRU.

- Energy-Efficient Technologies:Technologies focused on reducing energy consumption and emissions.
- Maritime Robotics: Autonomous and remotely operated vehicles for various maritime tasks.
- Blockchain Technology: Secure and transparent systems for managing maritime transactions and documentation.

AI plays a strategic role in the future of pilotage, offering applications such as:

- Route optimization and autonomous navigation.
- Predictive maintenance to reduce downtime and costs.
- Real-time decision support for enhanced situational awareness.
- Customized training simulations to improve pilot preparedness.
- Operational and energy efficiency improvements.
- Port operations optimization, including traffic management and resource allocation.

Including these technologies in the training course will ensure that port pilots are well-equipped to handle modern maritime challenges and maintain high standards of safety and efficiency.

AI can significantly enhance pilot operations in several ways:

- Navigation and Route Optimization: AI systems analyse vast amounts of data, including weather conditions, traffic patterns, and historical routes, to determine the most efficient and safest paths for vessels.
- Predictive Maintenance: AI-powered predictive maintenance systems monitor the condition of equipment and predict potential failures before they occur.
- Real-Time Decision Support: AI provides real-time data analysis and decision support, helping pilots make informed decisions quickly.
- Autonomous Navigation: AI enables autonomous navigation systems that can operate vessels with minimal human intervention.
- Energy Efficiency: AI optimizes energy usage by analysing consumption patterns and suggesting more efficient operational practices. Enhanced
- Training and Simulation: AI-powered simulators provide realistic training scenarios for pilots, allowing them to practice complex manoeuvres and emergency responses.

- Port Operations Optimization: AI systems optimize port operations by predicting vessel arrival times, managing berth allocations, and coordinating cargo handling.

By integrating AI into pilot operations, the maritime industry can achieve greater efficiency, safety, and sustainability.

3.9 Case #9: Enhancing maritime pilot training at the port of Quebec (PRU)

In this section PRU presents a second case focused on Practice 7: 'Continuous training and updates for pilots.

This case study is based on the establishment of a pilot-owned training facility in Quebec City, as highlighted by Captain Mike Watson, President of the International Maritime Pilots' Association (IMPA) and the American Pilots' Association (APA).

Figure 8 - Training facility in Quebec City

In response to the increasing complexity of maritime navigation and the need for enhanced safety measures, the pilots at the Port of Quebec established their own training facility. This centre is equipped with advanced simulation technologies that replicate various navigational scenarios, allowing pilots to practice and refine their skills in a controlled environment.

Located in Quebec City, Canada, the Maritime Simulation and Resource Centre (MSRC) is a leader in training and development and holds unique expertise in navigational safety. It is open to all members of the maritime community, whether for training, professional development or the validation of economic development projects. It offers a stimulating work environment and an atmosphere conducive to learning and the exchange of knowledge.

MSRC is a division of the Corporation of Lower St. Lawrence Pilots (CLSLP). The Centre's mission is to ensure training and development for pilots belonging to the CLSLP and to share its expertise in simulation with other pilots and professionals in the maritime domain. In operation since 2005, the Maritime Simulation and Resource Centre (MSRC) has been purposely built to function as a total turnkey port procedural development centre. It is one of the few facilities in the world offering a full range of simulation options spanning from standalone desktop simulation to four fully interactive, manned tug and large vessel simulations.

The specific objective is to provide continuous, advanced training for maritime pilots to enhance navigational safety. The direct impacts: of the practice are improved pilot proficiency, a reduction in navigation-related incidents, and enhanced port safety and operational efficiency.

The primary motivation was to ensure that pilots could handle diverse and challenging navigation situations, thereby minimizing the risk of maritime incidents and promoting environmental protection.

The stakeholders involved in the practice are Maritime pilots, Port of Quebec authorities, shipping companies, and local government agencies.

The training facility offers simulation-based programs that cover a wide range of scenarios, including adverse weather conditions, complex port manoeuvres, and emergency response situations. Technologies used are state-of-the-art navigation simulators that can replicate real maritime environments. Skills required are competence in maritime navigation, familiarity with simulation technologies and commitment to continuous professional development

Before and after the implementation of enhanced maritime pilot training at the Port of Quebec, several types of data were collected to assess the impact on environmental goals:

Before Implementation: Limited access to advanced training resources, reliance on on-the-job experience, and a higher incidence of navigation-related incidents.

1. Fuel Consumption and Emissions Data: Baseline data on fuel usage and greenhouse gas emissions from ships navigating the port.
2. Incident Reports: Records of navigational incidents, including near-misses and accidents, to understand the frequency and causes.
3. Environmental Impact Assessments: Studies on the impact of port activities on local ecosystems and biodiversity.
4. Operational Efficiency Metrics: Data on the time taken for docking and undocking procedures, as well as overall port throughput.

After Implementation: Enhanced pilot competencies, a significant reduction in navigation incidents, and improved overall port safety

1. Reduced Emissions Data: Measurements showing changes in fuel consumption and emissions, indicating improvements in efficiency.
2. Incident Reduction Statistics: Updated records showing a decrease in navigational incidents and accidents.
3. Environmental Monitoring Reports: Ongoing assessments to track improvements in local ecosystem health and biodiversity.
4. Operational Efficiency Improvements: Data demonstrating faster and more efficient docking and undocking procedures, contributing to reduced fuel use and emissions.

These data points help in evaluating the effectiveness of the training programs and their contribution to the Port of Quebec’s environmental goals.

The key findings from the data collected before and after the implementation of enhanced maritime pilot training at the Port of Quebec highlight several significant improvements:

1. Emission Reductions:
- Fuel Efficiency: There was a notable decrease in fuel consumption due to more efficient navigation and docking procedures, leading to lower greenhouse gas emissions
- GHG Reduction: The port achieved a reduction in greenhouse gas emissions, contributing to its goal of cutting emissions by 40% by 2035
2. Operational Efficiency:
- Faster Turnaround Times: The time taken for docking and undocking procedures was reduced, improving overall port throughput and reducing idle times for ships
- Incident Reduction: There was a significant decrease in navigational incidents and accidents, enhancing safety and operational reliability
3. Environmental Impact:
- Biodiversity Protection: Improved navigation practices helped protect local marine ecosystems, contributing to the port's biodiversity goals
- Environmental Management: Enhanced training included best practices for environmental management, ensuring pilots were equipped to minimize the environmental impact of port activities
4. Stakeholder Engagement:
- Community Involvement: The port's efforts included active participation in community initiatives and consultations, fostering better relationships with local stakeholders

These findings demonstrate the positive impact of enhanced maritime pilot training on both operational efficiency and environmental sustainability at the Port of Quebec.

The initial investment required includes funding for the construction of the training facility and the procurement of advanced simulation equipment and technology. At the same time, training programs will reduce costs associated with maritime incidents, such as damage to vessels and environmental cleanup, and reduce the risk of environmental contamination by improving navigation safety. The enhancement of maritime pilot training at the Port of

Quebec has led to significant savings and a positive economic impact. Here are some key points:

1. Cost Savings:
- Fuel Efficiency: Improved navigation techniques have resulted in reduced fuel consumption, leading to substantial cost savings for shipping companies.
- Reduced Downtime: More efficient docking and undocking procedures have minimized delays, reducing operational costs associated with idle time.
2. Economic Impact:
- Increased Throughput: Enhanced training has improved the overall efficiency of port operations, allowing for a higher volume of ships to be handled, which boosts port revenues.
- Accident Reduction: Fewer navigational incidents and accidents have decreased costs related to repairs, insurance, and environmental clean up
- Job Creation: The need for ongoing training and the implementation of new technologies have created jobs in the maritime and training sectors.
3. Environmental and Social Benefits:
- Sustainability Goals: By reducing emissions and protecting local ecosystems, the port has enhanced its reputation as a sustainable and environmentally responsible entity, which can attract more business.
- Community Engagement: Improved environmental practices have fostered better relationships with local communities, potentially leading to increased support and collaboration.

These savings and economic impacts demonstrate the value of investing in enhanced maritime pilot training, not only for operational efficiency but also for broader economic and environmental benefits.

Enhancing maritime pilot training at the Port of Quebec has significantly contributed to the port's environmental goals. The training improvements are part of a broader strategy to integrate environmental, social, and governance (ESG) considerations into the port's perations. Here are some key contributions:

- Reduction in Emissions: Enhanced training has led to more efficient navigation and docking procedures, reducing fuel consumption and greenhouse gas emissions from ships.
- Improved Environmental Management: The training includes best practices for environmental management, ensuring that pilots are well-versed in minimizing the environmental impact of port activities.
- Support for Decarbonization: By promoting the use of cleaner technologies and more efficient practices, the training supports the port's goal of reducing its greenhouse gas emissions by 40% compared to 2022 levels by 2035.
- Biodiversity Protection: Pilots are trained to navigate in ways that protect local marine ecosystems, contributing to the port's efforts to preserve and enhance biodiversity.

These efforts are part of the Port of Quebec's comprehensive sustainable development action plan, which aligns with the United Nations' Sustainable Development Goals and aims to make the port a leader in environmental stewardship.

In conclusion, the establishment of the pilot-owned training facility has proven successful in enhancing the skills of maritime pilots, leading to safer and more efficient port operations. There is potential to expand the facility's programs to include training for other port personnel and to collaborate with other ports for shared learning opportunities. Investing in continuous training infrastructure is crucial for ports aiming to enhance safety and operational efficiency.

The "Enhancing Maritime Pilot Training at the Port of Quebec" initiative, primarily conducted through the Maritime Simulation and Resource Centre (MSRC), has provided several valuable lessons:

- Simulation-Based Training:

  Lesson: High-fidelity simulators are crucial for realistic and effective training.

  Impact: Pilots can practice complex manoeuvres and emergency responses in a controlled environment, leading to improved skills and confidence

- Customized Training Programs:

  Lesson: Tailoring training programs to specific port conditions and pilot needs enhances relevance and effectiveness.

  Impact: Customized scenarios help pilots better understand local navigational challenges and improve their decision-making abilities

- Continuous Professional Development:

  Lesson: Ongoing training and skill improvement are essential for maintaining high standards of pilotage.

  Impact: Regular updates and refresher courses ensure pilots stay current with the latest technologies and regulations

- Collaboration and Knowledge Sharing:

  Lesson: Collaboration among pilots, trainers, and industry experts fosters knowledge sharing and innovation.

  Impact: Sharing experiences and best practices leads to continuous improvement and a stronger pilot community

- Use of Advanced Technologies:

  Lesson: Integrating advanced technologies like AI, AR, and VR enhances training effectiveness.

  Impact: These technologies provide immersive and interactive learning experiences, improving retention and application of skills

- Evaluation and Feedback:

  Lesson: Regular evaluation and feedback are critical for assessing training effectiveness and making improvements.

  Impact: Collecting feedback from trainees and stakeholders helps refine training programs and address any gaps

These lessons highlight the importance of realistic simulation, customized training, continuous development, collaboration, advanced technologies, and regular evaluation in enhancing maritime pilot training.

The "Enhancing Maritime Pilot Training at the Port of Quebec" initiative utilized several advanced technologies to improve training effectiveness:

- High-Fidelity Simulators. These simulators replicate real-world maritime scenarios, allowing pilots to practice complex manoeuvres and emergency responses in a controlled environment.
- Example: The Maritime Simulation and Resource Centre (MSRC) uses Full Mission Bridge Simulators and Full Mission Tug Bridge Simulators
- Portable Pilot Units (PPUs). PPUs provide real-time navigational data, including electronic charts, tidal information, and vessel positioning.
- Example: Pilots use PPUs to enhance situational awareness and improve safety during manoeuvres.
- Augmented Reality (AR) and Virtual Reality (VR). AR and VR tools offer immersive training experiences, allowing pilots to visualize navigational data overlaid on the real world or practice in virtual environments.
- Example: AR glasses and VR headsets are used to simulate port environments and complex navigational scenarios
- Artificial Intelligence (AI). AI systems analyse vast amounts of data to provide decision support, route optimization, and predictive maintenance.
- Example: AI-powered tools help pilots make informed decisions quickly and efficiently
- Cybersecurity Tools. Systems and protocols to protect maritime operations from cyber threats.
- Example: Cybersecurity measures ensure the security of navigational and operational data
- Energy Efficiency Technologies. Technologies focused on reducing energy consumption and emissions.
- Example: Green technologies and practices are integrated into training to promote sustainability

These technologies collectively enhance the training experience, ensuring that pilots are well prepared to handle modern maritime challenges.

3.10 Case #10: Technological Solution – Implementation of eco-friendly propulsion systems for tugboats in ports (PRU)

This case study has been developed by Piri Reis University (PRU) and it concerns the Practice 8 "Implementation of eco-friendly propulsion systems". The case concerns the Port of Los Angeles. The Port of Los Angeles introduced eco-friendly propulsion systems in tugboats, integrating battery-electric and hybrid technology to decrease reliance on fossil fuels. The practice Initiated in 2019, ongoing expansion. The specific goals are to reduce emissions, improve fuel efficiency, and enhance sustainability in port operations.

The direct impacts of this implementation include a significant reduction in CO2 emissions, lower fuel consumption, and a decrease in noise pollution.

The primary driver behind the adoption of environmentally friendly propulsion systems in the Port of Los Angeles tugboats was the need to reduce harmful emissions, which was also driven by environmental regulatory constraints. The Port has turned to battery-electric and hybrid power to reduce reliance on fossil fuels and improve air quality.

The implementation of this innovation has involved the participation of several stakeholders, including the Port of Los Angeles, the California Energy Commission (CEC), which supports research and development projects, Crowley Marine Services, which builds and operates the hybrid and battery-electric tugs, ABB Marine & Ports, which provides the technology and equipment needed for the propulsion systems, Ballard Power, which provides the fuel cell technology for the hydrogen tugs, and the California Air Resources Board (CARB), an environmental agency that sets regulations and standards for emissions, ensuring that new technologies meet environmental goals.

Technology is the central element in this case study. The port uses battery electric propulsion systems, diesel-electric hybrid systems and energy recovery systems to reduce environmental impact.

For the correct use of these systems, it is important that pilots and tugboats have experience in electric propulsion maintenance and energy management.

Case #10: Competencies required

- ***Experience in electric propulsion maintenance, energy management and sustainable maritime operations***
- ***Skills needed to operate and maintain these new systems safely, efficiently and in compliance with current regulations***

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To evaluate the impact and effectiveness of the new technologies, different types of data were collected (Table 6). Following the implementation, fuel consumption was reduced by up to 30%.

Table 6 - Measurements of the effectiveness of eco-friendly propulsion systems

Before implementation		**After implementation**	
Emission Levels	*Baseline data on particulate matter (PM) and nitrogen oxide (NOx) emissions from conventional diesel-powered tugboats*	Emissions Reduction	*Emissions from new solutions to be compared with baseline data*
Fuel Consumption	*Amount of diesel fuel consumed by tugboats during their operations*	Fuel saving	*Reduction of diesel consumption*
Operational Efficiency	*Performance of existing tugboats*	Performance Indicators	*Performance of the new tugs, including any improvements or issues*
Air Quality	*General air quality measurements in and around the port area.*	Air Quality Improvement	*Updated air quality measurements*

The Port of Los Angeles has invested significantly in the adoption of these systems. Acquiring and retrofitting ships with battery-electric and hybrid technologies is expensive. However, the investment has been offset by numerous economic and environmental benefits. In fact, the integration of battery-electric and hybrid systems has reduced dependence on diesel fuel, resulting in significant savings in fuel operating costs. Furthermore, compared to diesel engines, electric and hybrid propulsion systems generally require less maintenance. Finally, the choice to implement these types of eco-friendly technologies is supported by incentive programs aimed at promoting environmental sustainability.

At this point, we need to add quality to the creation of the workers and their engineering, production and environmental sciences, increasing the competitiveness of the Los Angeles port that improves its reputation and attracts new activity and investment.

From an environmental point of view, as it were, the port has ridden the emissions of harmful pollutants, contributing to reduce the comprehensive carbon imprint of the port.

It is important to note that thanks to this application of innovation, it is possible to operate in conformity with the regulations and contribute to the transition process versus the use of renewable energy sources, such as hydrogen and renewable energy sources. The Port of Los Angeles' green tugboat propulsion systems are designed to meet specific regulations, such as the California Air Resources Board (CARB) regulations that require significant reductions in emissions from commercial vessels in ports, and the Clean Air Action Plan (CAAP), an action plan that the Port of Los Angeles developed in partnership with the Port of Long Beach to reduce air pollution and health risks.

Additional hybrid and fully electric tugboats are expected to be introduced in other major ports soon. For example: a) the Port of Busan introduced the "Meta 7," a hybrid-electric tugboat equipped with Kongsberg Maritime's propulsion system. This vessel utilizes battery power during transit operations, significantly reducing emissions and improving air quality in the port area. The integration of battery power has also led to lower fuel consumption and reduced maintenance requirements; b) the E3 Tug Project is a collaborative R&D initiative involving Smit International, Damen Shipyards Gorinchem, and Alewijnse Marine Technology, spearheaded by the Port of Rotterdam develops energy-efficient and environmentally friendly tugboats by analysing operational patterns and integrating advanced propulsion systems; c) a pioneering project in the United States saw a 67-year-old diesel-powered tugboat retrofitted to run on ammonia, a carbon-free fuel. Developed by the start-up Amogy, this vessel operates on technology that splits ammonia into hydrogen and nitrogen to power fuel cells, emitting primarily water and nitrogen.

Further investments in renewable energy sources and charging infrastructure are also being explored to support the full electrification of port operations.

The operational, environmental and economic benefits associated with the use of electric tugs allow us to make important observations and draw relevant lessons such as the reduction of environmental impact, operating costs and maintenance interventions. These results are supported by further empirical evidence such as the first electric tug in the United States that will reduce CO2 emissions by 3,100 tonnes in ten years and the electric tug of the Port of Auckland that has operating costs approximately 50% lower than diesel tugs.

Ensuring adequate battery capacity is important for the diffusion of these systems and an efficient charging infrastructure is essential. Furthermore, new training programs for crews and engineers are needed to operate and maintain electric tugs, as the technology and systems differ from those of traditional diesel tugs.

The quest for sustainable maritime solutions doesn't anchor on electric power. The teams continue to evolve design enhancements aiming for elongated battery power and negligible emissions. Innovations like replacing generator sets with batteries illuminate a path where tugs can harness electricity shoreside and reserve diesel for open water. The challenge is a monetary one as well. Diesel maintenance savings do not fully compensate for the capital cost of batteries. Nonetheless, with federal regulations moving in favour of green innovations, grants and funding might soon tip the scales, paving the way for even more eco-friendlier vessels to move into production.

The marine industry hasn't placed its hopes on electric power alone. Other fuels—methanol, hydrogen, and ammonia—are on the radar, but they still require elaborate experimentation. For now, renewable diesel appears most worthy, capable of cutting carbon emissions by 75%. Despite the promising advances in technology, the tides of change flow slowly. The industry's venerable vessels, with lifespans stretching to half a century, won't retire their diesel engines overnight. We're witnessing a balancing act, a pursuit of progress tinged with practicalities of cost and feasibility. In this context, a proposal has been developed for a structured training concept and detailed curricula to qualify and retrain harbour pilots and tugboat operators, with a focus on implementing green propulsion systems.

The aim of the training is to provide port pilots and tug operators with the skills needed to operate and maintain these new systems safely, efficiently and in compliance with current regulations.

The proposed program is divided into a series of modules that cover both theoretical and practical aspects. The first training courses are dedicated to the introduction to innovative ecological propulsion systems, comparing them with traditional technologies. Subsequently, the regulatory framework is addressed, including the guidelines of the International Maritime Organization (IMO), Annex VI of the MARPOL Convention and national and local regulations. The training phase dedicated to the regulations is then followed by that dedicated to the technical aspects of ecological propulsion systems, with indications on maintenance operations and the resolution of the most common faults.

PRU also includes a practical part in the training path represented by simulator exercises, to test the skills acquired in realistic scenarios, followed by a module dedicated to safety and emergency management related to the new systems.

In support of the theoretical contents, the analysis of real case studies is also proposed. Among these, the green ports initiative (such as Rotterdam, Long Beach and Yokohama), the use of electric and hybrid tugboats developed by shipyards such as Sanmar and Damen. The case studies provide concrete ideas on the implementation of ecological technologies in the port context.

The path can only conclude with written tests, practical tests and simulations, at the end of which an official certification is issued[2].

[2] For further details, please enquire for the full document produced by PRU.

3.11 Case #11: Demonstration of the use of biofuel in the pilot boats of the Port of Aveiro to promote the reduction of greenhouse gas emissions in a port (APA)

The two practices most relevant to this case study are: Practice 2 "Active participation of pilots in research and development projects for new green technologies" and Practice 5 "Collaboration with other ports to exchange information and green solutions".

The project focuses on the use of biofuels derived from waste cooking oil in pilot boats operated by APA (The Port of Aveiro Administration). As most maritime vessels currently run on marine diesel, this initiative provides an entry point for energy transition in port operations. By using biofuels without requiring engine modifications, this initiative demonstrates that existing vessels can immediately reduce emissions without significant investment costs. The project further aims to extrapolate its findings to other port vessels, estimating potential GHG emission reductions at the port level. This initiative strengthens the collaboration between the ports of Northern Portugal, facilitating the exchange of knowledge and best practices regarding sustainable fuel adoption and other similar pilots underway. In addition, the Port of Aveiro is involved in several specialised networks, such as, ESPO – European Sea Ports Organisation, and DockstheFuture, among others, increasing the scalability and impact of the project.

The initiative sets out to demonstrate the practical application of biofuels derived from waste cooking oil in conventional pilot boats, offering an immediate and replicable solution for reducing maritime emissions. By using a renewable energy source without requiring any engine modifications, the project ensures that pilot boat operations remain safe, efficient, and cost-effective, making it accessible to a wide range of operators.

This approach is particularly significant for Small and Medium Size Ports (SMPs), which often lack the infrastructure or financial capacity to implement full electrification. Biofuel usage offers an intermediate yet impactful step toward decarbonisation, aligning with the operational realities of smaller ports while still contributing meaningfully to sustainability goals. In addition, the project seeks to strengthen partnerships with other ports in northern Portugal, fostering regional collaboration and knowledge-sharing. By building a network of ports committed to green innovation, the initiative enhances collective capacity to adopt sustainable practices. Finally, the project supports broader GHG emissions reduction strategies and encourages cross-port cooperation on sustainable maritime operations. By engaging with established networks such as ESPO (European Sea Ports Organisation) and DocksTheFuture, the initiative aims to amplify its impact, contribute to policy development, and ensure alignment with European green transition objectives.

Table 7 - Pilot Boats of the Port of Aveiro

Pilot Boats		**Engines**
Triângulo		2 x VOLVO PENTA TAMD31P-A 150HP- 3900 RPM
Mó do Meio		2 x YANMAR 6LYA-STE 350 HP- 3300 RPM
Espinheiro		2 x VOLVO PENTA D9-425 425 HP- 2200 RPM

The pilot project began in May 2022 and is currently ongoing. The initial phase, involving the "TRIÂNGULO" pilot boat, has been successfully completed, concluding the adaptation period for the use of B15 biofuel. With continuous and stable operation now ensured, the project has entered its next phase, which focuses on extending the initiative to the remaining two pilot boats in the Port of Aveiro: “ESPINHEIRO” and “MÓ DO MEIO”.

This expansion aims to further demonstrate to other vessel operators that the transition to biofuels is both safe and reliable, strengthening the case for sustainable fuels as a viable pathway in the maritime energy transition. The European Green Deal, FuelEU, and AFIR Directives, along with the EU Climate Law, require ports to progressively reduce carbon emissions, which will require investment in energy-efficient infrastructure, renewable energy solutions, shore-side power supply for vessels, and new and net fuels, where advanced biofuels are included. Capital investments in this transition are higher than can be afforded by SMP. So, the use of these types of advanced blended fuels will therefore ensure a smooth transition without disrupting maritime operations. In addition, for some boat retrofitting or new boats, the 100% biofuel (B100) could be used as a net fuel. As far as the market is concerned and also knowing that B15 may be slightly more expensive than regular marine gas oil, let’s not forget that fossil fuels are becoming more expensive due to carbon taxation, and also the better efficiency of B15 will allow some savings. In addition, cooperation and benchmarking between ports is becoming a driver for success, and the APA sees inter-port cooperation as a key factor for sustainable growth.

So, in a nutshell, these are the driving factors that motivate the Port of Aveiro to implement this green practice:

- Urgency of Energy Transition – Ports seek alternatives to fossil fuels without high capital investments.
- Environmental Goals & EU Regulations – Compliance with GHG reduction targets.
- Operational Feasibility – Ensuring a smooth transition without disrupting maritime operations.
- Cost-Effectiveness – A low-cost alternative to electrification or the purchase of new vessels.
- Inter-Port Collaboration – Strengthening cooperation to accelerate green technology adoption.

The Administration of the Port of Aveiro (APA) has launched a pilot initiative to test the use of biofuels in port operating vessels, as part of its commitment to the transition to carbon neutrality by 2050. The biofuels, produced locally by PRIO from used cooking oil and other waste-based raw materials, provide a sustainable alternative to conventional marine fuels.

In collaboration with PRIO, which operates in the port, APA asked Tecnoveritas to carry out an analysis of the engine specifications of the *Triângulo* pilot boat to confirm its compatibility with a B15 fuel blend—consisting of 15% biofuel and 85% marine gas oil. As a result, Tecnoveritas issued a certification for the use of biofuels, ensuring compliance with technical and environmental standards. Notably, most existing engines can run on B15 without modification, providing a cost-effective opportunity for vessels to immediately reduce emissions without significant investment. After minor adjustments to the oil filters, the *Triângulo* has been successfully run on B15, maintaining the same operational performance while achieving a direct reduction in fuel consumption.

Table 8 - Average fuel consumption 2020-2024

	2020	2021	2022 (Jan-Apr)	2022 (May-Dec)	2023	2024
Fuel (L)	5,910	5,800	800	2,000	1,400	1,200
"Triângulo" Manoeuvring Time	784	646	96	286	201	152
B0 Fuel Consumption (L/h)	7.54	8.98	8.33	-	-	-
B15 Fuel Consumption (L/h)	-	-	-	6.99	6.97	7.89
Average fuel consumption (B0)	8.20					
Average fuel consumption (B15)				7.20		

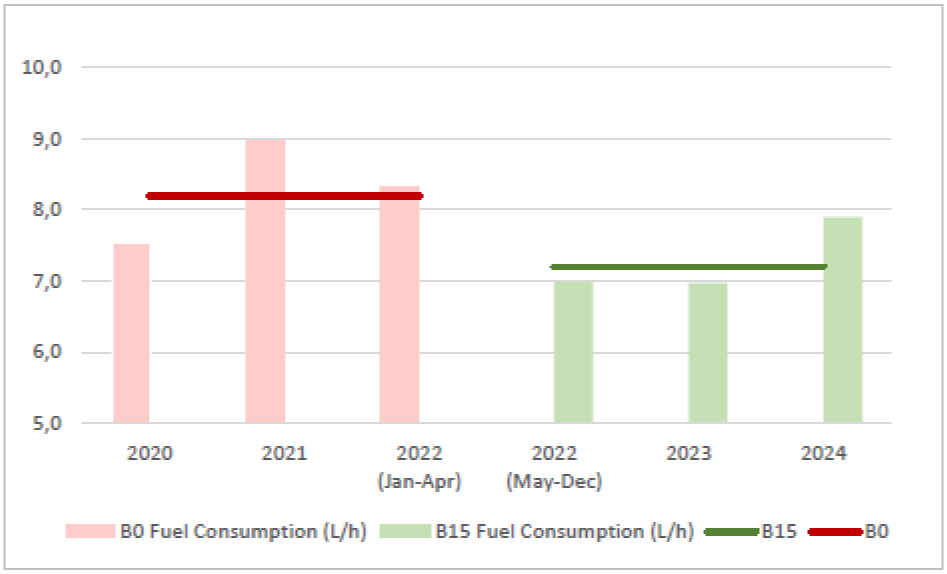

Figure 9 - Graph on fuel consumption 2020-2024

As can be seen in the Figure 9 and Table 8, when comparing the average fuel consumption between 2020-Apr 2022, when the Pilot boat was running on marine gas oil, and May 2022-2024, when it was running on B15, the results for the average fuel consumption were 8.20 L/h to the former and 7.20 L/h for the latter, which represents a 12% reduction in fuel consumption.

According to PRIO, a biofuel supplier, the fuel savings from switching from B0 to B15 are estimated to be at least 5%, but it is important to note that the results achieved may be influenced by other variables, such as the human behaviour when manoeuvring the pilot boat and other operational factors. These elements introduce an inherent variability that cannot be fully isolated, making it challenging to attribute the full extent of fuel savings solely to the use of biofuels.

Building on this success, APA plans to extend the project to two other pilot boats, *Espinheiro* and *Mó do Meio*, as well as to tugboats operating under concession in the Port of Aveiro. To further demonstrate the benefits of B15, the greenhouse gas (GHG) emission reductions for these vessels have been extrapolated based on the technical data and fuel consumption records of the pilot boats and tugboats operating in the port in 2024, with the support of the CO2 Emissions Calculator.

The project is structured in three key phases:

1. Pilot boat biofuel adoption
2. Collaboration and expansion
3. GHG emissions impact assessment.

A detailed overview is provided below.

Pilot boat biofuel adoption

The introduction of biofuels in APA's pilot boats involves a structured testing phase to ensure safe and efficient operation. This process begins with a detailed analysis of each pilot boat's engine specifications to confirm its compatibility with a B15 fuel blend (15% biofuel and 85% marine gas oil). Once compatibility has been established, the vessel undergoes real-world operational testing, during which its performance, fuel efficiency, and emissions are closely monitored. During this phase, the behaviour of the boat is continuously assessed, and any necessary adjustments are made to optimize performance. In the case of the *Triângulo* pilot boat, minor adjustments to the oil filters were required to ensure smooth operation. This cycle of testing and adjustment will be systematically repeated until the vessel demonstrates stable performance with no operational issues. Once the process is successfully completed, the findings serve as a blueprint for wider implementation of biofuels in other pilot boats and port vessels.

GHG emissions impact assessment

Based on the fuel consumption data of the pilot boats and tugboats operating at the Port of Aveiro in 2024, the GHG emissions of each vessels were calculated in tCO_2/l. Specifically, five vessels used marine gas oil (B0), while the pilot boat Triângulo used B15 (a blend of 15% biofuel and 85% marine gas oil). Emission factors from the RED II Directive were used to determine the environmental impact, as shown in Table 9.

Table 9 - Emission factors

Fuel	tCO_2/l	Fuel	tCO_2/l
Marine Gas Oil (B0)	0.00268	Eco diesel/Eco Bunker (B15)	0.00228
Eco Diesel (B7)	0.00246	UCOME (B100)	0.00033

Source: Directive (UE)2018/2001 (RED II)

In addition, the greenhouse gas emission savings were estimated for both B15 and B100 biofuel blends, assuming their use by all vessels operation in the port, including tugboats. The analysis shows that replacing B0 with B15 results in a 15% reduction in GHG emissions, while a full switch to B100 (FAME) results in an 88% reduction. The results of the calculations, including the savings from using B15 or B100 in all vessels, pilot boats and tugboats are shown in Table 10.

Table 10 - Estimated GHG emission (tCO2eq)

Vessel Name	Type of vessel	Type of fuel	Fuel Consumption 2024 (lts)	GHG emission (tCO2eq.), in 2024				
				Real	Using B15 (estimated)	Using B15 savings	Using B100 (estimated)	Using B100 savings
Triângulo	Pilot Boat	B15	1,200	2.74	2.74	0.48	0.00	3.22
Mó do Meio	Pilot Boat	B0	18,400	49.31	41.95	7.36	0.01	49.30
Espinheiro	Pilot Boat	B0	24,982	66.95	56.96	9.99	0.02	66.93
Castelo de Leiria	Tugboat	B0	85,000	227.80	193.80	34.00	0.06	227.74
Castelo de Viana	Tugboat	B0	95,000	254.60	216.60	38.00	0.07	254.53
Salinas de Aveiro	Tugboat	B0	35,000	93.80	79.80	14.00	0.03	93.77
		Total	***259,582***	***695.68***	***591.85***	***103.83***	***0.20***	***695.48***

Collaboration and expansion

To promote the wider use of biofuels in maritime operations, the Port of Aveiro is committed to sharing the results of this pilot initiative with other ports in northern Portugal and beyond. A key part of this strategy includes publishing the findings on its official website and social media channels, ensuring transparency and accessibility to stakeholders interested in sustainable fuel alternatives.

In addition to digital dissemination, the Port of Aveiro will actively promote the implementation of B15 biofuel through its participation in various sustainability-focused initiatives. This includes presenting results and lessons learned at conferences, webinars, and stakeholder meetings, where best practices can be shared with industry professionals and policy makers.

Emphasis is placed on discussions at Port Community Meetings, where key stakeholders are engaged to explore the feasibility of expanding the use of biofuel to a larger fleet of port and commercial vessels.

Furthermore, the Port of Aveiro will leverage its involvement in international collaborations and sustainability projects to amplify the impact of this initiative. By integrating biofuel adoption into broader environmental strategies, the port aims to contribute to the decarbonization of maritime operations, encourage regulatory support for alternative fuels, and foster inter-port cooperation in transitioning towards cleaner energy solutions.

The technologies used in this case study are:

- Diesel-powered boat engines and biofuels use certification
- Biofuels derived from waste cooking oil (B15)
- Carbon calculator to access the GHG emission reductions.

The ECO BUNKERS, by PRIO, is an innovative and advanced marine fuel designed to support the energy transition in the maritime sector. Developed through over a decade of research into biofuels, it incorporates 15% biodiesel produced from recycled raw materials. Aligned with the International Maritime Organization's (IMO) greenhouse gas reduction targets, this fuel helps vessels reduce CO_2 emissions by up to 18% (lifecycle analysis) and lower fuel consumption by up to 10% without requiring engine modifications. PRIO ensures full compliance with ISO 8217 standards, offering a more sustainable, efficient, and cleaner alternative to conventional marine diesel. (Technical sheet source: https://www.prio.pt/downloads/file295_pt.pdf).

The Port of Aveiro, in collaboration with the University of Aveiro, has developed an online Carbon Emissions Calculator designed for the port community, businesses, and the general public. This tool allows users to calculate the CO_2eq. emissions associated with different modes of transport, including ships, heavy and light vehicles, locomotives, and port equipment, as well as different types of fuel. With three levels of complexity, the calculator allows for individual analyses to assessments of entire fleets or logistics chains, raising awareness about reducing carbon emissions and contributing to the goal of carbon neutrality by 2050 (https://portodeaveiro.pt/noticia/pt/488).

Successful implementation of this practice requires technical expertise in fuel conversion and engine performance assessment, along with specialized third-party certification of engines for biofuel use to ensure compliance with safety and performance standards. A thorough understanding of maritime emissions regulations and sustainability policies is essential to align with environmental objectives. In addition, collaboration within the port community is crucial to facilitate the replication of biofuel use in other vessels and equipment, whenever their engines are compatible, promoting a broader adoption of sustainable fuel solutions.

In order to assess the impact of the pilot initiative, key data has been collected before and after the introduction of B15 biofuel in port vessel operations. This data allows for a comprehensive assessment of fuel consumption, engine performance, and emission reductions, providing a basis. for measuring the effectiveness of biofuels as a transitional energy source. Additionally, a specialized maritime engineering and environmental solutions company validated the use of B15, to ensure compliance with technical and operational standards. The findings of this study will contribute to future scalability assessments for extending the use of biofuel to other port vessels.

Table 11 - Data before implementation

Indicator	Value/Description
Annual fuel consumption	[Liters/year]
Annual engine running time	[Hours/year]
CO_2eq. emissions	[Tons/year]
Engine performance	Efficiency, maintenance requirements noted under normal marine diesel (B0) use
Validation	Assessment by a specialist company in maritime engineering and environmental solutions regarding B15 use, based on engine specs (brand, model, power, etc.)

Table 12 - Data after implementation

Indicator	Value/Description
Fuel consumption reduction	(Biofuel B15 vs. marine diesel B0) [Liters/year]
CO_2eq. emissions reduction	[Tons/year]
Potential for scalability	Analysis for extension to other port vessels based on operational and environmental performance

The initial investment required for the introduction of biofuels in port operating vessels depends primarily on the compatibility assessment and potential retrofitting costs. For new vessels, a detailed technical analysis is essential to ensure the engine's suitability for biofuel use. For existing vessels, modifications may be required to adapt the fuel properties, although many modern engines can already run on blends such as B15 without modification. In the pilot case of the *Triângulo* boat, no engine modifications were required, however, increased wear on fuel filters was observed, necessitating more frequent replacement than usual. This highlights the importance of ongoing monitoring and minor adjustments to optimize long-term operational efficiency and cost effectiveness.

The pilot implementation of B15 biofuel at the Port of Aveiro has demonstrated that meaningful environmental progress can be achieved without imposing a significant financial burden. Conducted in partnership with PRIO, a biofuel producer operating within the port, the initiative benefitted from a proof-of-concept agreement through which B15 was supplied at the same price as conventional marine gas oil (B0). This pricing arrangement ensured immediate cost neutrality, allowing the transition to biofuels without additional fuel expenses. While B15 typically carries a higher market price than B0, future tests involving the port's remaining pilot boats will offer a more accurate evaluation of long-term economic impacts, factoring in potential savings from reduced fuel consumption and evolving market dynamics.

A key advantage of this initiative lies in its cost-effective approach to decarbonisation. Unlike full electrification or the purchase of new, energy-efficient vessels—which require substantial capital investment—the adoption of B15 allows existing engines to operate without modification. This enables ports to reduce their carbon footprint while preserving financial flexibility and avoiding the high upfront costs associated with fleet renewal or the installation of charging infrastructure. Additionally, operational continuity has been maintained throughout the pilot, with the only adjustment being a slightly increased frequency of fuel filter replacements—an easily manageable aspect within standard maintenance routines. This seamless integration proves that the use of biofuels can support uninterrupted service delivery while laying the groundwork for more sustainable port operations.

The use of biofuels significantly contributes to environmental goals by directly reducing greenhouse gas (GHG) emissions from port vessel operations. A B15 blend achieves a 15% reduction in GHG emissions, while B100 offers an 88% reduction, making biofuels a valuable tool in the decarbonization of ports.

The direct environmental contribution of this use case is therefore the reduction of GHG emissions, measured in CO2eq.. Regarding the KPIs described above, the fuel consumption of the Triângulo in 2024 was 1200 L/year, which means a saving of 0.5 tCO2eq.. In addition, the average fuel consumption with B0 was 8.20 L/h and, after the implementation it was reduced to 7.20 L/h, resulting in an additional saving and CO2eq emission reduction.

Taking into account the fuel consumption of all pilot boats and tugs in 2024, which was 259,582 litres, the GHG emissions were calculated as 695.68 tCO2eq..

If B15 had been used by all the vessels, a saving of 103.83 tCO_2eq would have been achieved. Using B100 means a saving of 695.484 tCO_2eq.

The pilot test confirmed that B15 is a viable and effective solution that requires only minor operational adjustments, such as more frequent fuel filter maintenance, and does not imply any engine retrofitting. Given the financial and infrastructural constraints of many Small and Medium-Sized Ports (SMPs), scaling up biofuel adoption across European ports could provide a cost-effective and accessible pathway to achieving sustainability goals. Furthermore, the successful implementation of biofuels reinforces the need for stronger policy support at the EU level, encouraging regulatory frameworks and incentives for sustainable fuels.

This use case demonstrates the success of using B15 in the pilot boat without engine modifications, ensuring safe operation while achieving a reduction in greenhouse gas emissions, helping the Port of Aveiro to further its decarbonisation process and sustainability goals.

It has been clearly demonstrated that this blend (B15) can be used without restriction in other harbour craft, including tugs, so there is great potential for its use to be extended.

Collaboration with other ports, following the example of the Port of Aveiro, will make it possible to expand the use of biofuels in ports. Moreover:

- the pilot boat biofuel test demonstrated safe operation without modifications.
- emissions reductions achieved, contributing to sustainability goals.
- expansion potential identified for tugboats and additional port vessels.
- stronger collaboration established between northern portuguese ports.

The implementation of this pilot project has provided some important lessons, highlighting the importance of raising awareness among those involved in the use case, from the board to those using new fuels. The main resistance to change comes from the boat captains.

Another challenge was how to supply the pilot boat outside the normal supply circuit, where the biofuel is not available. Partnering with local suppliers is fundamental to the success of this use case and ensuring its continuity over time.

Therefore, the main challenge highlighted in this case study was ensuring a consistent supply of biofuels while addressing potential cost fluctuations. This was effectively mitigated through the establishment of strategic partnerships with local biofuel producers. As a result, it becomes essential to implement targeted awareness and training programs for port operators, focusing on proper biofuel management and the broader sustainability benefits associated with their use.

Based on the results obtained with the implementation of the use of biofuel instead of marine gas oil in one of the pilot boats of the Port of Aveiro, the *Triângulo*, it is demonstrated that this type of fuel can help ports in their decarbonisation process, as a transitional fuel when other green solutions are not feasible, or even as a definitive fuel in higher blends than B15.

As mentioned above, APA intends to extend its use to the other two pilot vessels in the near future, and also to introduce this green practice to other vessels used in port operations, both in the tugboat operation in the Port of Aveiro and in other Portuguese ports, for wider adoption. Regarding the retrofitting needs for the use of other biofuel blends higher than 15%, and to encourage companies to switch to other advanced fuels, a political commitment with the maritime authorities will be needed to raise awareness and provide funds not only to public administrations but also to private ones.

Looking ahead, several key actions are being considered to build on the success of this initiative and promote broader adoption of biofuels in maritime operations

- expanding the use of biofuels beyond pilot boats to other port vessels;
- strengthening collaboration with additional ports for larger scale adoption;
- policy engagement with maritime authorities to encourage incentives for biofuel transition.

3.12 Case #12: Implementing a training program for sustainable navigation in the port of Aveiro: promoting slow steaming for environmental and economic benefits (APA)

This second case study, provided by Administração do Porto de Aveiro (APA), focuses on Practice 3 "Behavioural change through training and awareness". The primary objective of this case study is to demonstrate how a change in the behaviour of skippers operating pilot boats and tugs in the Port of Aveiro can lead to fuel consumption savings and a consequent reduction in CO_2eq emissions. To achieve this, a structured training and awareness program will be implemented, encouraging port pilots to adopt more sustainable navigation practices, particularly slow steaming. The initiative focuses on educating skippers about the environmental and economic benefits of reducing vessel speed, including fuel savings, lower greenhouse gas (GHG) emissions, and a reduced carbon footprint, through these specific targets:

- develop and implement a structured training and awareness program for skippers of pilot boats and tugs;
- encourage behavioural changes towards more sustainable navigation practices;
- promote the adoption of slow steaming as a key for fuel efficiency strategy;
- quantify the impact of reduced vessel speed on fuel consumption and CO_2eq emissions;
- enhance awareness of the economic and environmental benefits of fuel-efficient navigation.

The implementation of a structured training and awareness program for pilot boat captains, tug operators, and port pilots in the Port of Aveiro has a direct impact on several key areas. By encouraging reduced vessel speeds, the initiative leads to a significant decrease in fuel consumption, which in turn lowers CO_2 and greenhouse gas emissions—contributing meaningfully to maritime decarbonization. This transition not only brings economic benefits to maritime operators through cost savings but also reduces dependence on fossil fuels. Moreover, the training fosters greater awareness of sustainable maritime practices among port personnel, ensuring compliance with environmental regulations and reinforcing the Port of Aveiro's commitment to sustainability. The long-term objective is to cultivate a culture of environmental responsibility within port service operations, while supporting broader international sustainability goals, as reflected in the following key outcomes:

- Reduction in CO_2 and other greenhouse gas emissions through energy-efficient navigation practices.
- Lower fuel consumption, leading to cost savings for shipping operators and increased economic sustainability.
- Enhanced air quality in the port area due to reduced emissions, benefiting both the environment and public health.
- Improved compliance with environmental regulations and international sustainability goals.
- Raise awareness of sustainable maritime practices among pilots, skippers and crew members and encourage a shift towards environmentally responsible behaviour.

This use case will be developed as part of WP5, which will run from September 2025 to October 2026. However, the training program is designed to be an ongoing initiative, with regular refresher courses and awareness campaigns to ensure continued engagement and long-term impact.

Figure 10 - Port of Aveiro, Portugal

The initiative involves the implementation of a structured training and awareness program for skippers of pilot boats and tugs in the Port of Aveiro, also extending to port pilots who play a crucial role in assisting and communicating with vessels arriving in the port, guiding them through safe and efficient navigation practices. The primary focus of the program is to promote slow steaming, demonstrating how controlled speed reductions can significantly decrease fuel consumption and emissions without compromising operational efficiency. The training aims to raise awareness of the environmental and economic benefits of adopting more sustainable navigation practices, and to align port operations with wider sustainability goals.

The program consists of theoretical training sessions on the environmental impact of vessel speed and emission reduction strategies, complemented by practical workshops where pilots and skippers engage in simulations of fuel-efficient navigation techniques. Visual reminders and digital tools will be used to reinforce sustainable behaviour in daily operations. In addition, performance tracking mechanisms will be introduced to assess the long-term impact of the practice, ensuring continuous improvement and adaptation. By integrating education, practical application, and ongoing evaluation, this initiative seeks to enhance operational efficiency while reducing the environmental footprint of port activities.

The adoption of this green practice is driven by environmental compliance, economic efficiency, market demand, and operational benefits. Alignment with EU and IMO sustainability goals is essential to reduce the environmental footprint of port operations, especially as alternative propulsion technologies are not yet widely available. This initiative supports immediate efforts to reduce emissions through behavioural and operational changes, complementing long-term technological advances. From an economic perspective, reducing fuel consumption through optimized navigation practices reduces operating costs for ship operators, offering an efficient and cost-effective solution without requiring major technological investments. In addition, stakeholder pressure from industry organizations and regulatory bodies is driving the adoption of greener maritime operations, reinforcing the need for sustainable practices. Finally, enhancing the long-term sustainability of port operations is crucial.

With many vessels expected to remain in service until 2050, improved training, awareness, and collaboration will enable ports to significantly reduce emissions, optimize resources, and ensure a more resilient and sustainable maritime industry.

The successful implementation of this initiative relies on the active participation and collaboration of key stakeholders across the maritime sector. Each plays a crucial role in ensuring that sustainability goals are met, operational efficiency is maintained, and environmental impact is minimized. From regulatory bodies to operational entities, their collective engagement is essential for achieving long-term improvements in energy efficiency and emission reductions, as reflected in the following stakeholders:

- Administration of the Port of Aveiro (APA) – Oversees and coordinates the initiative, ensuring alignment with sustainability objectives. As the regulatory authority for the tugboat concession, APA facilitates cooperation with the concessionaire company.
- Pilot Boat Skippers – Employed by APA, they are directly responsible for implementing slow steaming and other energy-efficient navigation strategies within the port.
- Harbour Pilots – Also employees of APA, they are licensed navigational experts who guide vessels in and out of the port, ensuring compliance with safe and sustainable navigation practices.
- Tugboat Operators – Operate under the APA's concession and play a key role in aligning operational practices with environmental objectives.
- Shipping Companies – Benefit from reduced fuel consumption, lower emissions, and cost savings, aligning with industry-wide sustainability targets and regulatory demands.
- Regulatory Agencies – Monitor compliance and assess progress toward sustainability goals, ensuring compliance with environmental regulations.
- European Maritime Pilots' Association (EMPA) – Supports training programs and initiatives focused on reducing greenhouse gas emissions in maritime operations.

By fostering cooperation among these stakeholders, the initiative enhances both environmental responsibility and economic sustainability, contributing to a greener and more efficient port ecosystem.

The implementation of this green practice follows a structured approach that combines training, awareness programs, and operational adjustments. The main objective is to promote behavioural change among skippers of pilot boats, tugs, and port pilots through education on fuel-efficient navigation practices, particularly the adoption of slow steaming. The first step involves developing a tailored training curriculum that addresses the specific operational environment of the Port of Aveiro. This curriculum includes theoretical training sessions to raise awareness about the environmental and economic benefits of optimizing vessel speed and fuel consumption. It also provides practical guidance on energy-efficient navigation techniques, considering the need for compliance with EU and IMO sustainability goals. In addition, the initiative includes workshops and digital training sessions, offering hands-on experience in fuel-saving navigation strategies. Performance tracking mechanisms are introduced, enabling pilots to receive real-time feedback on fuel savings and emission reductions. This data-driven approach encourages informed decision-making and reinforces the long-term sustainability of port operations. The program also fosters continuous learning by organizing knowledge-sharing forums and periodic refresher courses. This ensures that skippers, pilots, and tug operators remain engaged with best practices in sustainable navigation and are equipped to adapt to evolving environmental regulations and industry expectations. By integrating education, practical application, and ongoing evaluation, this initiative aims to reduce emissions, improve fuel efficiency, and enhance compliance with sustainability standards, ultimately contributing to a greener and more resilient maritime sector.

The implementation of this green practice relies on a combination of technologies and tools aimed at improving fuel efficiency, monitoring emissions, and promoting sustainable navigation behaviours. A key technological component of the initiative is the use of real-time performance monitoring systems, which provide pilots and skippers with instant feedback on fuel consumption and emission levels. These tools enable data-driven decision-making, allowing operators to adjust their navigation practices in response to fuel efficiency insights.

Additionally, digital training platforms and simulation-based workshops will be used to reinforce best practices in slow steaming and energy-efficient manoeuvring. These training tools will incorporate interactive learning materials and case studies to ensure that pilots, skippers, and tug operators develop practical skills that can be applied in real-world operations. Given the increasing emphasis on alternative fuels, the project will also explore the feasibility of retrofitting existing vessels to accommodate new advanced fuels. However, due to the high costs and slow adoption of alternative fuel infrastructure, the focus remains on optimizing current technologies and navigation practices to achieve immediate emissions reductions. By integrating real-time monitoring, digital training solutions, and sustainable fuel strategies, the initiative aims to create a scalable and cost-effective approach to reducing emissions and improving the environmental performance of port service vessels.

The successful implementation of this green practice requires a combination of technical, operational, and environmental competencies among the stakeholders involved.

Case #12: Competencies required

- ***Understanding the dynamics of vessel speed control and fuel consumption***
- ***Slow steaming and other fuel-efficient navigation techniques***
- ***Sustainable navigation strategies to balance environmental objectives with operational demands***
- ***Knowledge of EU and IMO sustainability goals***
- ***Continuous professional development, refresher courses, and digital learning tools***

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Firstly, technical knowledge is essential, particularly in understanding the dynamics of vessel speed control and fuel consumption. Skippers of pilot boats, tug operators, and port pilots must be proficient in navigating vessels efficiently while ensuring optimum fuel consumption. This includes applying best practice in slow steaming and other fuel-efficient navigation techniques. Operational skills are also critical, as pilots and vessel masters need to execute sustainable navigation strategies without compromising port efficiency and maritime safety. This requires an ability to balance environmental objectives with operational demands, ensuring that emission reductions are achieved without causing delays or disruptions. Environmental awareness plays a crucial role, as all personnel involved must understand the impact of emissions on air quality and climate change. Training programs will reinforce knowledge of EU and IMO sustainability goals, fostering a commitment to reducing the carbon footprint of port operations. Finally, training must be adaptable in order to integrate sustainability practices into daily operations. Continuous professional development, refresher courses, and digital learning tools will be used to ensure that pilots, skippers, and tug operators stay abreast of evolving regulations and industry best practices. By equipping maritime personnel with these skills, the initiative aims to improve fuel efficiency, reduce emissions, and promote long-term sustainability within the Port of Aveiro's maritime operations.

To assess the effectiveness of the training program, a structured data collection process must be conducted before and after the training sessions. This will allow for a comprehensive evaluation of the impact on pilot boat skippers, port pilots, and tugboat operators, measuring changes in navigation behaviour, fuel consumption, and environmental awareness. The collected data will help refine future training strategies and ensure continuous improvement in energy-efficient navigation practices.

Table 13 - Data before implementation

Indicator	Description
Fuel Consumption	Average fuel usage per operation (liters/hour and liters/nautical mile)
Engine Running Time	Average hours per day or per month
Speed Metrics	Average and peak speeds during operations (e.g., approach, departure, escort, idle)
Acceleration/Deceleration	Daily operational acceleration and deceleration patterns
GHG Emissions	Estimated CO_2 and other greenhouse gases based on engine and fuel data
Air Quality	Measurements in port area (if available)
Knowledge Baseline	Pre-training understanding of energy-efficient navigation (questionnaire)
Environmental Awareness	Awareness of the economic and environmental impact of slow steaming
Perceived Barriers	Concerns and challenges about adopting energy-saving practices

Table 14 - Data after implementation

Indicator	Description
Fuel Consumption Comparison	Change in liters/hour and liters/nautical mile under similar conditions
Engine Running Time	Post-training engine hours (daily/monthly average)
Speed Adjustments	Reduction in average and peak speeds (where appropriate)
Acceleration Control	Improvement in controlled acceleration/deceleration behavior
GHG Emissions	Reduction in CO_2 and greenhouse gases due to improved navigation practices
Air Quality	Improvement in air quality indicators (if monitored)
Knowledge Gains	Post-training understanding of sustainable strategies (questionnaire)
Behavioral Change	Self-reported changes in habits and attitudes toward slow steaming
Stakeholder Feedback	Input from skippers, pilots, and tug operators on training impact and future needs

By systematically analysing these key indicators, the training's effectiveness can be quantified, ensuring that its objectives align with sustainability goals while fostering lasting behavioural changes in port operations.

the future implementation will require financial resources for several key components, including the development of the training curriculum, hiring expert trainers, and procuring necessary materials. Additional costs may arise from the establishment of monitoring systems to assess training effectiveness, as well as operational cost for the organisation of workshops and awareness sessions. Expected investment areas include:

- training development costs (curriculum, trainers, materials);
- implementation of monitoring and evaluation systems;
- operational costs for conducting workshops and awareness programs;
- digital infrastructure for potential e-learning components.

As highlighted in Figure 11, which refers to the pilot boat *Espinheiro* from the Port of Aveiro, there is a significant disparity between the increase in RPM and the corresponding rise in fuel consumption. The fuel consumption curve shows a much sharper increase compared to RPM, indicating that higher speeds lead to disproportionately higher fuel usage. This reinforces the importance of avoiding excessive RPM levels, as even small reductions in speed can result in substantial fuel savings. Through slow steaming practices, the expected benefits include:

- fuel cost reduction due to slow steaming practices;
- lower maintenance costs due to reduced engine strain;
- improved operational efficiency for the port of Aveiro;
- potential for increased competitiveness and service reliability.

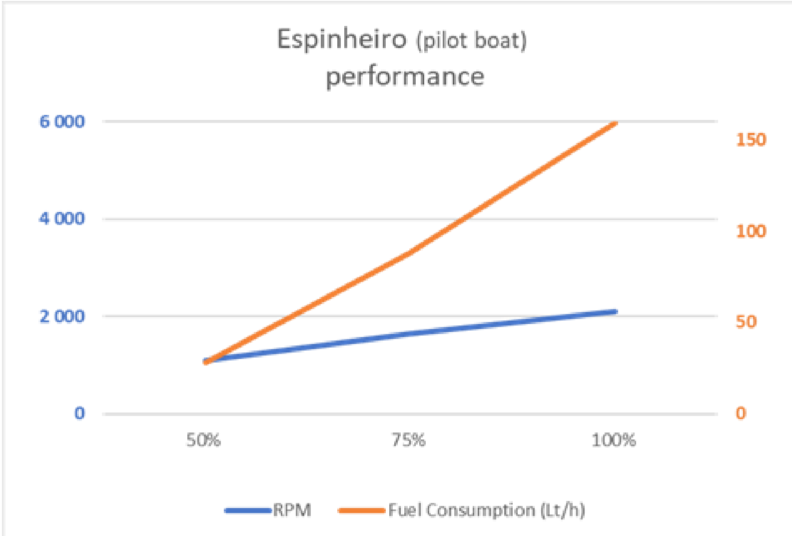

Figure 11 - Espinheiro (pilot boat) performance at different power capacities

The full extent of the environmental impact will be determined post-implementation, but preliminary observations indicate significant potential benefits. As seen in Figure 12, which represents a recent track of the pilot boat *Espinheiro* from the Port of Aveiro, the vessel exhibits varying speed levels along the route, with the darkest green sections indicating higher speeds.

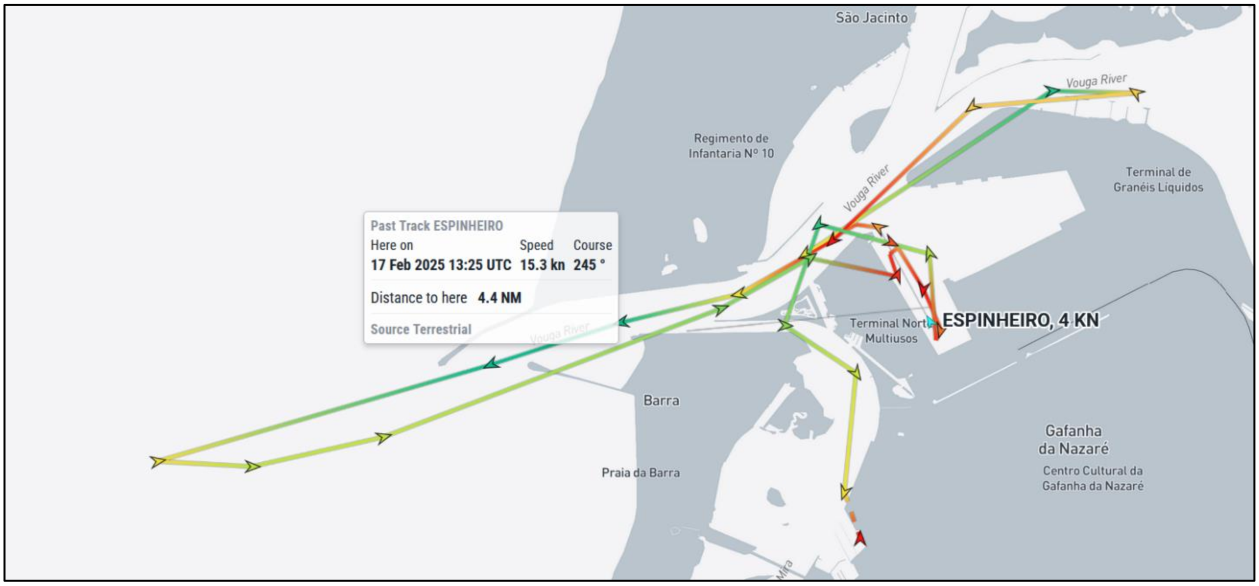

Figure 12 - Route and speed of a recent trip by the pilot boat Espinheiro of the Port of Aveiro

To maximize environmental benefits, the goal is to reduce speed fluctuations and lower the overall average speed of the vessel. This can be achieved through better pre-planning of port operations and increased awareness of slow steaming practices. The expected contributions to environmental sustainability include:

- Direct reduction in GHG emissions through energy-efficient navigation.
- Enhancement of local air quality, benefiting port workers and nearby communities.
- Promotion of sustainable maritime transport practices across the industry.
- Compliance with evolving environmental regulations and international sustainability commitments.

This use case has not yet been implemented, a full assessment of its success will only be possible after its execution and evaluation. However, based on current projections and insights from similar initiatives, the case study is expected to demonstrate a significant reduction in fuel consumption and CO_2 emissions through the adoption of slow steaming practices. The structured training and awareness campaign will likely contribute to improved adherence

to sustainability goals, fostering a long-term cultural shift towards fuel-efficient navigation.
Expected outcomes include:

- Reduced fuel consumption and operational costs.
- Lower CO_2 and greenhouse gas emissions, improving environmental performance.
- Enhanced knowledge and awareness of sustainable navigation among pilots and skippers.
- Greater predictability and efficiency in port operations through better voyage planning.

Although the case is still in the preparatory phase, potential challenges and solutions can already be envisaged:

- Resistance to Behavioural Change - Emphasizing economic benefits and long-term sustainability through targeted awareness campaigns and real-time performance feedback.
- Operational Constraints - Improving port scheduling to reduce pressure on harbour pilots and skippers, allowing for smoother transitions to slow steaming practices.
- Monitoring and Compliance - Implementing fuel and speed tracking systems to assess adherence to training principles.

Training efforts should prioritize the practical application of slow steaming techniques during daily operations, emphasizing real-life relevance. To enhance engagement and understanding, interactive modules should be developed to simulate fuel savings at different engine RPM levels. The curriculum should also stress data-driven decision-making, supported by case studies from real pilot boats such as *Espinheiro* (see Table 7). Looking ahead, it is recommended to integrate real-time tracking tools into training sessions to provide immediate feedback on navigation behavior. Establishing a mentorship program, where experienced pilots guide trainees in fuel-efficient navigation, could further strengthen knowledge transfer. Finally, the development of a digital learning platform would support continuous training and performance monitoring, ensuring long-term impact and adaptability of the training program.

The next steps for this initiative involve expanding the training program to include other vessels operating in the Port of Aveiro, such as tugboats and cargo ships, ensuring a broader adoption of energy-efficient navigation practices. By promoting slow steaming, the initiative is expected to significantly reduce CO_2 and other greenhouse gas emissions, contributing to the decarbonization of maritime operations while improving air quality in the port area. Lower fuel consumption will lead to cost savings for shipping operators, making maritime activities more financially sustainable and reducing dependency on fossil fuels. Additionally, integrating automated fuel monitoring systems would provide real-time data to optimize vessel performance, while an improved scheduling system could help minimize idle time and unnecessary speed fluctuations.

Beyond these environmental and economic benefits, the program aims to foster a culture of environmental responsibility among harbour pilots, skippers, and crew members, increasing awareness of sustainable maritime practices. Compliance with environmental regulations and international sustainability goals will also be reinforced, strengthening the Port of Aveiro's commitment to eco-friendly navigation strategies. Continuous refinement of the training content, based on feedback from the case studies and operational data, will be essential to maintaining its effectiveness. Regular audits and performance evaluations should be conducted to assess long-term impacts, and further research partnerships with academic institutions could enhance data-driven policymaking in maritime sustainability.

3.13 Case #13: Minimization of engine running time - Port of Constanta (CMU)

The case proposed by UNIVER. MARITIMA DIN CONSTANTA (CMU) highlights Practice 10 “Minimization of engine running time”. This case study is a combined research project performed in two steps: first, field research on the site of one towing company at Constanta port, collecting actual and factual data on the spot, and second, extensive desk research for additional data collection, verification and analysis to complete and conclude the study.

This case study showcases the benefits of adopting green practices in port operations by estimating fuel consumption and related CO2 emissions for a fleet of 14 tugboats, comparing figures of consumption/CO2 emissions/costs before (as a scenario) and after implementation of the green practice, i.e. minimisation of engine running time.

Port of Constanta (Romania) is the place of implementation; It is already an implemented practice for the tugboat companies accredited for towage & mooring operations at the port of Constanta.

The tugboats implement the practice while they are idle (moored). Three tugboat companies at the port of Constanta are currently accredited for operations (mooring/unmooring and port towage). Each company operates in sequence, ten days per month; that means 20 days per month tugs are mostly idle; therefore, switching to shore power supply comes with many benefits besides alignment with the green port policies.

Port of Constanța has implemented several green initiatives aimed at enhancing environmental sustainability and reducing its carbon footprint.

- Green Port Master Plan Development: In March 2024, the Port of Constanța organized a workshop to analyse and revise its Green Port Master Plan. This plan is a dynamic roadmap guiding the port towards carbon neutrality and sustainable development.
- Participation in the PIONEERS Project: The Port of Constanța participates in the PIONEERS (PORTable Innovation Open Network for Efficiency and Emissions Reduction Solutions) project to optimize port operations and implement renewable energy and mobility solutions.
- Electrification of port infrastructure: In July 2024, a global logistics company specializing in port operations secured a €50 million loan from the European Bank for Reconstruction and Development to finance the electrification of the Constanța South Container Terminal. This project includes installing new electrical networks, transformer points, electric vehicles, charging stations, and new railway lines to reduce the terminal's carbon footprint and enhance energy efficiency.

On-site research concluded that the tugboat companies implemented the practice primarily because of economic benefits rather than alignment with green port policy.

The stakeholder involved are

- Port Administration
- Towing companies
- Tugboats crew.

The Port Administration is interested in reducing the carbon footprint and is encouraging such practices. Towage companies have primarily financial interests (see sections 4 and 5 below). Tugboats are directly involved, obviously, with the crew connecting/disconnecting the shore power supply.
Connection/disconnection is a simple operation made quickly and safely by a single crew member with adequate training. However, it has been noted that personnel (crew) did show much environmental awareness when questioned about the benefits of switching on the shore power supply. They were satisfied with the comfort gained, no noise and not much equipment running (running hours). This point might be considered regarding environmental awareness and behavioural change education amongst involved personnel within the industry.

As the practice is already implemented, calculations, as shown in the tables below, are made as a scenario by estimating total fuel consumption for a fleet of 14 tugs belonging to one of the towage companies at Constanta Port.
Only one type of fuel is used, marine Diesel Oil; for calculation purposes, an average density of 0.86 kg/m3 and an emission factor of 3.2 kg CO2 per kg of fuel was taken. This approach is widely used in similar studies or research projects.
For calculation purposes:

- The 4 hours/day of manoeuvring time for each tug was calculated based on the average of 20 ship movements (arrival/departure/shifting) per day for the past few months, as a senior pilot at Constanta Pilot Service Office stated. Split over the total fleet of 14 tugs, considering 1.5 tugs used for each manoeuvre, that would give an approximate 2 hours of manoeuvring time, plus another 2 hours proceeding/returning to ship/return to base, going to 4 hrs total for calculation purposes.
- 24 hours of hotelling consumption—this also includes the time for manoeuvring, with hotel load not precisely the same as an idle condition but very close to it.

The table below shows a summary of fuel consumption calculations, for one day, for the whole fleet of 14 tugs:

Table 15 - Data collected before the implementation

Fuel consumption - before practice implementation					
Nr of tugs	Power (kw) range groups	Fuel cons 1 tug 24 hrs hotelling (mt)	ME fuel cons 4 hrs manoeuver (mt)	Aggregate consumption for 1 tug (mt)/day	Total consumption per group of tugs (mt)/day
4	600-1200	0.24	0.15	0.39	1.56
4	1500-2000	0.41	0.27	0.68	2.72
2	2200-2600	0.60	0.41	1.01	2.02
4	3000-3500	0.75	0.51	1.26	5.04
			Fleet total fuel consumption for 1 day		11.34
Note: fuel consumption calculated based on data collected from chief engineers' interview onboard 4 sample tugs					

The table below shows a summary of fuel consumption calculations, for one day, for the whole fleet of 14 tugs:

Table 16 - Data collected after the implementation

Fuel consumption - after practice implementation					
Nr of tugs	Power (kw) range groups	Fuel cons 1 tug 4 hrs hotelling (mt)	ME fuel cons 4 hrs manoeuver (mt)	Aggregate consumption for 1 tug (mt)/day	Total consumption per group of tugs (mt)/day
4	600-1200	0.04	0.15	0.19	0.76
4	1500-2000	0.07	0.27	0.34	1.36
2	2200-2600	0.10	0.41	0.51	1.02
4	3000-3500	0.13	0.51	0.64	2.56
			Fleet total fuel consumption for 1 day		5.70

The Table 17 presents the daily fuel costs for a fleet of tugboats, categorized by power range groups, prior to the implementation of Practice 10: "Minimization of Engine Running Time." It includes:

- The number of tugs in each power category
- The aggregate fuel consumption per tug per day (measured in metric tons)
- The estimated cost of marine diesel oil per ton
- The resulting daily fuel cost per individual tug and per group of tugs

The total fuel cost for operating the entire fleet for one day amounts to €7,938.00.

Table 17 – Key savings and economic impact (Fuel costs before practice implementation)

Fuel costs - before practice implementation					
Nr of tugs	Power (kw) range groups	Aggregate fuel consumption for 1 tug (mt)/day	Estimated cost (euro) per 1 ton fuel (marine diesel oil)	Total cost (euro) for 1 tug / 1 day	Total cost (euro) per group of tugs / day
4	600-1200	0.39	700.00	273.00	1092.00
4	1500-2000	0.68	700.00	476.00	1904.00
2	2200-2600	1.01	700.00	707.00	1414.00
4	3000-3500	1.26	700.00	882.00	3528.00
			Fleet total fuel cost for 1 day		7938.00

Table 18 - Key savings and economic impact (Fuel costs after practice implementation)

Fuel costs - after practice implementation					
Nr of tugs	**Power (kw) range groups**	**Aggregate consumption for 1 tug (mt)/day**	**Estimated cost (euro) per 1 ton fuel (marine diesel oil)**	**Total cost (euro) for 1 tug / 1 day**	**Total cost (euro) per group of tugs / day**
4	600-1200	0.19	700.00	133.00	532.00
4	1500-2000	0.34	700.00	238.00	952.00
2	2200-2600	0.51	700.00	357.00	714.00
4	3000-3500	0.64	700.00	448.00	1792.00
			Fleet total fuel cost (euro) for 1 day		**3990.00**

This table shows the fuel cost savings achieved following the implementation of Practice 10: "Minimization of Engine Running Time." The data is broken down by tugboat power range groups and includes:

- The number of tugs per power category
- The updated aggregate daily fuel consumption per tug (in metric tons)
- The estimated cost of marine diesel oil per ton
- The resulting fuel cost per tug and per group of tugs per day.

Following the implementation of the practice, the total daily fuel cost for the fleet has been reduced to €3,990.00, highlighting significant operational savings. Comparing fuel costs before and after green practice implementation, the whole fleet saved 3948 euros daily; the savings increased to over 100,000 euros monthly.

Certainly, there will be a cost for the shore power supply; however, it should be much less than the total fuel savings, besides the primary goal of emissions reduction. This cost was not chased during this research.

The implementation of Practice 10 – *Minimization of Engine Running Time* – not only leads to significant fuel cost savings but also contributes directly to the achievement of key environmental objectives, particularly the reduction of greenhouse gas emissions. Moreover, by reducing the operating time of tugboat engines, the overall fuel consumption is significantly lowered, which in turn leads to a proportional decrease in CO_2 emissions.

To quantify this environmental benefit, CO_2 emissions were estimated based on actual fuel consumption data, using a standardized calculation method. For the calculation of CO2 emissions, the following formula was used:

CO2 Emissions [kg] = Fuel Consumption [metric tons] × Emission Factor [kg CO2/metric ton fuel]

For the Marine Diesel Oil used on the tugboats, the CO2 emission factor is 3,206 kg CO2 per metric ton of fuel burnt.

Table 19 - Contributions to environmental goals (CO2 emissions – before practice implementation)

CO2 emissions - before practice implementation					
Nr of tugs	**Power (kw) range groups**	**Aggregate fuel consumption for 1 tug (mt)/day**	**Emission factor (kg CO2/m.ton fuel)**	**Emissions for 1 tug / 1 day (kg CO2)**	**Total emissions per group of tugs (kg CO2) / day**
4	600-1200	0.39	3206.00	1250.34	5001.36
4	1500-2000	0.68	3206.00	2180.08	8720.32
2	2200-2600	1.01	3206.00	3238.06	6476.12
4	3000-3500	1.26	3206.00	4039.56	16158.24
			Fleet total emissions for 1 day		**36356.04**

Table 20 - Contributions to environmental goals (CO2 emissions – after practice implementation)

CO2 emissions - after practice implementation					
Nr of tugs	**Power (kw) range groups**	**Aggregate consumption for 1 tug (mt)/day**	**Emission factor (kg CO2/m.ton fuel)**	**Emissions for 1 tug / 1 day (kg CO2)**	**Total emissions per group of tugs (kg CO2) / day**
4	600-1200	0.19	3206.00	609.14	2436.56
4	1500-2000	0.34	3206.00	1090.04	4360.16
2	2200-2600	0.51	3206.00	1635.06	3270.12
4	3000-3500	0.64	3206.00	2051.84	8207.36
			Fleet total emissions for 1 day		**18274.20**

The results, shown in the tables below, provide a clear comparison of the emissions generated before and after the implementation of the practice. Comparing CO2 emissions before and after green practice implementation for the whole fleet, they are estimated to be reduced by about 18000 kg CO2 for one day, going up to more than half a million kg CO2 for a month.

Ultimately, the case study involving the Port of Constanta has shown that the practice of minimizing engine idle time for tugboats generates significant economic and environmental benefits. The shift from continuous fuel consumption during idle time to the use of shore power has resulted in fuel savings of approximately 100,000 euros per month for a fleet of 14 tugboats. Furthermore, CO2 emissions have been reduced by over half a million kilograms per month. These results suggest that with a few simple operational adjustments, significant positive impacts can be achieved while avoiding significant capital investments.

The need to contain operating costs has driven the tugboat company to adopt this practice, which has also reduced the impact of its operations. Economic feasibility is a key factor in the spread of innovative practices and technologies, especially in an economic sector consisting of small and medium-sized enterprises.

Cooperation between the port administration, the towing companies and the tugboat crews has certainly contributed to the success of the practice.

The benefits described could be amplified through educational programs aimed at tug crews and stakeholders to reinforce the environmental importance of shore-based electricity use. Furthermore, in terms of future development, it is important to conduct further research on energy consumption patterns, shore-based electricity efficiency without neglecting potential incentives to maximize economic and environmental benefits.

3.14 Case #14: Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm (MARTE)

The case study described in this section describes the implementation of a software solution for the optimization of the operating speed (Practice 11).

The navigation speed directly affects fuel consumption and emissions. The eco-speed practice involves adjusting the speed of the vessel according to the sea conditions, the load and the distance travelled while preserving the aspects related to the stability and safety of the vessel.

Specific goals are:

- Minimize fuel consumption for offshore supply tugboats.
- Reduce CO_2 emissions by optimizing cruising speed.

- Incorporate operational constraints (time limits, weather conditions, vessel loading) into the optimization process.

Thanks to this practice, the following direct impacts can be achieved:

- reduced fuel consumption by up to 13.4% in some scenarios.
- lowered CO_2 emissions, contributing to environmental sustainability.
- improved operational efficiency for older vessels unable to adopt expensive fuel-efficient technologies.
-

The practice is implemented during offshore supply voyages in the Black Sea region, with routes that include stops at platforms such as the Istria block and the ANA platform.

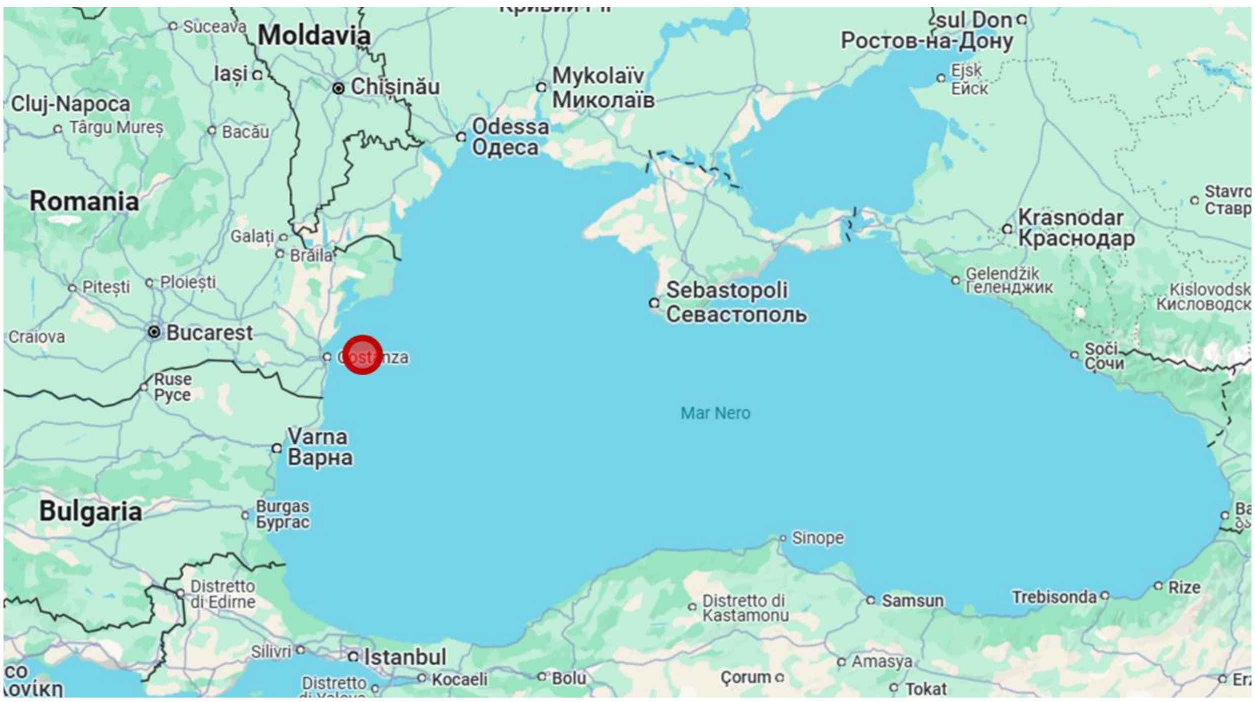

Figure 13 - Area of practice implementation

The pilot project started in November 2023, ended in February 2024.

The case study presents the introduction of a backtracking algorithm designed to optimize the cruising speed of an offshore supply tug used for replenishment operations.

The algorithm, based on a series of operational constraints such as time limits, variable weather conditions and vessel load, identifies the speed profiles compatible with the operational and environmental objectives and then elaborates the optimal sequence of speeds along the various legs of the route. The methodology has proven to be particularly effective in offshore contexts where environmental and logistical conditions can change rapidly.

Environmental legislation is the main driver for the adoption of this practice, combined with the need for low-cost solutions. In fact, many tugboats currently in operation, especially the older ones, do not have the financial resources necessary to adopt advanced fuel-saving technologies. In this sense, solutions such as the proposed backtracking algorithm represent an accessible alternative to improve energy efficiency without the need for expensive technological retrofits. Finally, the need to ensure greater operational efficiency acts as a further incentive. This need is particularly felt in the case of offshore support tugboats, which are typically engaged in short routes and frequent speed variations, conditions that make fuel optimization essential to reduce operating costs.

The development of this solution involved researchers who developed the backtracking algorithm; ship operators who implemented the optimized speed strategies in real voyages and port authorities and offshore platforms.

The case study was divided into three phases:

- Phase 1 - Planning and modelling of the problem.
- Phase 2 - Integration of environmental factors and construction of the model.
- Phase 3 - Numerical application and scenario analysis.

(Phase 1) The case study started with the identification of a concrete problem: many offshore supply vessels, especially those of older construction, did not have access to modern energy saving technologies, often due to economic constraints. The focus was on optimizing the fuel consumption during the mission of a Platform Supply Vessel (PSV) through a backtracking algorithm.

The algorithm is a method typically employed in combinatorial problem solving suitable for handling scenarios characterized by stringent constraints and numerous discrete variables. The vessel route was divided into distinct segments, each corresponding to a section between key waypoints. Each segment was characterized by distances, speed limits and specific operating conditions. (Phase 2) Subsequently, the fuel consumption model as a function of speed and travel time was created for each single segment. For this purpose, real data related to the consumption curve of the engines, based on the characteristics of the vessel under consideration, were used. Finally, a global time constraint, variable depending on the scenarios (e.g. 24 or 32 hours), was introduced, representing the maximum duration allowed for the mission based on the operational time windows of the offshore platforms to be maintained. (Phase 3) In the last phase, the developed model was applied to a real scenario involving a coastal mission departing and returning from the port of Constanta, with scheduled stops at two offshore platforms: Istria and ANA. To ensure computational efficiency, segments with almost identical conditions were grouped and ten operational scenarios were defined, varying the sea state (Beaufort scale levels from 1 to 3), the vessel displacement and the time constraints (e.g. 24 or 32 hours).

The proposed solution is based on a smart combination of algorithmic tools, empirical models and existing on-board functionalities.

The backtracking algorithm is a discrete optimization technique that systematically explores all possible speed combinations along the different segments of the tug route. The algorithm evaluates each configuration based on operational constraints (time, weather conditions and vessel load) and progressively discards incompatible options (through a mechanism known as pruning). This process allows to identify the speed sequence that minimizes the overall fuel consumption, preserving the reliability of the service. The integration with on-board monitoring systems, also available on older tugs, providing real-time data on speed and consumption, further validate the effectiveness of the algorithm. Overall, this methodological approach makes it possible to turn existing data and operational knowledge into a concrete tool for energy savings - without the need for physical intervention on the vessel - by leveraging what is already available through a more strategic and informed use of information.

For an effective use and enjoyment of the processing offered by the algorithm, it is necessary that users are able to understand the optimization algorithms and have data analysis skills with particular attention to the accurate interpretation of meteorological data and fuel consumption parameters. This skill allows real-time monitoring of navigation conditions and the adaptation of operational strategies.

Case #14: Competencies required

- ***Deep understanding of optimization algorithms***
- ***Data analysis with particular attention to the accurate interpretation of weather data and fuel consumption parameters***
- ***Use of advanced technologies that help predict and improve long-term performance***
- ***Experience in teamwork to ensure that all operational phases are well-integrated and that decisions are made collaboratively***

The analysis from secondary sources did not provide data on Key Performance Indicators (KPIs) that should have measured mainly the ex post effects of the practice. However, it is possible to make some reflections in the absence of the use of the algorithm with respect to fuel consumption.

Consumption was determined through the analysis of data collected during non-optimized trips, carried out at fixed speeds, for example 13 knots. After implementation, the speed optimization process involved the use of different speeds, adjusted according to the travel segments and weather conditions, with the aim of maximizing operational efficiency at each stage of navigation. Speeds were adjusted between 9 and 12.8 knots, adapting to the specific characteristics of the route that affect resistance and energy consumption. This strategy led to fuel savings of approximately 13.4%. Furthermore, speed optimization had a positive environmental impact, resulting in a reduction in CO_2 and greenhouse gas emissions. As a result, the combination of intelligent speed management and the use of advanced technologies for real-time monitoring allowed controlling operating costs and achieving significant improvements in environmental performance.

Finally, the flexibility of this system allows it to be easily adapted to different types of vessels and operations, ensuring the scalability and applicability of the solution in different contexts.

Fuel cost savings are one of the main benefits of operations optimization. By reducing fuel consumption, significant reductions in operating costs are achieved, with a direct impact on company finances.

The backtracking algorithm has proven to be particularly effective in optimizing fuel consumption with consequent reduction of emissions especially for offshore supply vessels.

The case described highlighted the importance of flexibility and data accuracy in operations optimization. Operators need reliable data on weather conditions and fuel consumption to make informed decisions that can minimize energy expenditure and improve operational efficiency. The integration of real-time data would further improve the effectiveness of the algorithm, making it even more responsive to rapidly changing operating conditions; this feature would allow for more precise and timely adjustments. Furthermore, it would be useful to explore hybrid optimization techniques, combining the backtracking algorithm with machine learning methods. This would allow operators to consult more accurate forecasts of operating parameters. Finally, to maximize and spread the benefits, it is important to promote the adoption of the algorithm in other contexts and for different types of fleets.

3.15 Case #15: Use of real time sensor data of tugboats to reduce fuel consumption (AMA)

This case study focuses on Practice 4 “Collaboration among stakeholders for real-time data sharing”. The Antwerp Maritime Academy (AMA) is working with tugboat owners to promote the sharing of real-time monitoring data from a selected number of tugboats. The shared data will include fuel consumption, vessel position, speed, and a breakdown of the sequence of operational activities (i.e., the type of task being performed during each operation). While certain operations—such as ship towing—offer limited potential for fuel savings, others, like transit between jobs, present more significant opportunities for fuel optimization.

The collected data will be compared to a fuel consumption baseline—the minimum amount of fuel required to perform similar operations in a past reference period. Different kinds of targets can be defined:

1. a static average per activity type from a reference period,;
2. a dynamic target that adapts itself to activity type, weather, etc.;
3. a total amount of energy for the entire task and it is responsibility of the operator to perform that task with the given amount of energy.

Based on the data provided by tug operators, AMA will study fuel consumption patterns and assess methods for evaluating performance against baseline levels. This collaborative, data-driven approach aims to support more efficient operations and foster a culture of transparency and continuous improvement among maritime stakeholders.

The specific goals are:

- Gather data from monitoring campaigns performed on board tugboats.
- Define parameters for fuel consumption (e.g., total consumption, average consumption rate in L/h, highest peak consumption during the task, number of peaks and valleys per hour, average hourly consumption). Similar parameters will also be used to assess the simulator experiments
- Identify from the information the activities where fuel consumption can be reduced and how much fuel can be reduced.

Data will be collected from tugboat operators along the River Scheldt and in the Port of Antwerp.

The implementation of Practice 4 – *Collaboration among Stakeholders for Real-Time Data Sharing* – is expected to generate several direct and measurable impacts on operational efficiency and environmental performance. Specifically, the following outcomes have been identified:

- reduce fuel consumption by visualizing the real-time fuel consumption with a dashboard

- reduce fuel consumption through awareness raising by publishing monthly reports about consumptions per day, average consumption per activity, and consumption per operator.
- find a way to ensure that the focus on eco-sailing does not wane over time.

By analysing monitoring data, AMA aims to identify mitigation measures to reduce energy consumption. Factors driving the adoption of this practice include cost reduction—since lower fuel consumption leads to decreased operating expenses—and environmental benefits, as reduced fuel use results in lower emissions (CO_2, NO_x, and particulate matter), thereby contributing to improved air quality. In the implementation of this practice AMA will ask companies such as Boluda, Port of Antwerp- Bruges and Antwerp Towing if they are willing to share data for this study.

The adopted practice focuses on improving the energy efficiency of tugboat operations through real-time monitoring and data-driven decision-making. It involves the installation of sensors capable of tracking fuel consumption, speed, and position. These data are then made available to crew members through a dedicated dashboard, enabling them to visualize fuel usage in real time and adjust their behavior accordingly. Additionally, the recorded data are compared with historical benchmarks, and monthly performance reports are shared with the crew to support continuous improvement.

The implementation relies on several key technologies, including:

- sensors for fuel consumption, speed, and GPS position tracking;
- dashboard systems for real-time visualization of operational data;
- data analytics tools and benchmarking methods to assess performance trends.

To effectively adopt and benefit from this practice, specific competencies are required:

- technical skills for installing and maintaining onboard sensors;
- operational knowledge of tugboat activities and energy-efficient navigation;

- environmental awareness and the ability of crew members to adapt behaviors based on data insights and sustainability goals.

To assess the effectiveness of the real-time fuel monitoring practice, a structured comparison of fuel consumption data is carried out before and after its implementation.

<u>Before implementation</u>:

A fuel consumption baseline is established by collecting historical data related to similar tugboat operations under standard operating conditions. This baseline serves as a reference point to measure future improvements. If available, company-specific methodologies for estimating minimum fuel consumption per activity can be used to enhance the accuracy of the benchmark.

<u>After Implementation</u>:

Actual fuel consumption recorded through real-time monitoring is compared with the previously established baseline. This comparison allows for the evaluation of the effectiveness of the practice, particularly in terms of fuel savings. By monitoring these variables, stakeholders can gain valuable insights into behavioural trends, operational performance, and the long-term sustainability impact of the implemented measures.

The initial investment required includes:

- sensor installation: hardware and implementation costs;
- data processing and analysis: skills needed to correctly interpret the data;
- dashboard development: one-time investment, with potential maintenance costs;
- crew training: no hardware costs, just training.

The implementation of real-time fuel monitoring and data sharing generates tangible economic benefits, including:

- reduction in fuel costs thanks to more efficient navigation and increased crew awareness, leading to optimized fuel use during operations.
- lower maintenance costs, as improved operational practices contribute to more stable and efficient engine performance, reducing wear and tear.
- regulatory and certification advantages, as adopting fuel-saving and emission-reducing technologies supports compliance with environmental standards and may facilitate access to green certifications or incentive schemes.

The practice also plays a significant role in advancing environmental sustainability by:

- reducing harmful emissions, including co_2, no_x, and particulate matter, thereby helping to mitigate the environmental footprint of tugboat operations.
- improving onboard air quality, particularly in confined areas such as the wheelhouse, contributing to a healthier and safer working environment for the crew.

By aligning operational efficiency with environmental responsibility, this practice supports both cost-effective performance and the broader goals of decarbonization and sustainable maritime transport.

The implementation of this eco-friendly practice is still ongoing; however, preliminary expectations suggest that the combination of a real-time dashboard and increased crew awareness has the potential to reduce fuel consumption and emissions. Through time series analysis, the initiative aims to generate valuable insights into how behavioral changes can lead to greater energy efficiency.

The success of the practice will be evaluated based on measurable improvements in fuel efficiency, as well as qualitative feedback from the crew involved in its application. These indicators will help assess both the technical effectiveness and the human engagement dimensions of the intervention.

Looking ahead, several future actions can support the further development and scaling of the practice:

- involvement of additional maritime operators or companies to expand the dataset and validate the approach across different operational contexts;
- enhancement and integration of the dashboard with other onboard systems to create a more comprehensive and automated energy management tool;
- further research into the impact of behavioural factors on fuel consumption and the optimization of operational routines.

These steps will not only strengthen the current initiative but also contribute to a broader cultural and technological shift toward sustainable maritime practices.

3.16 #Case 16: Use of a navigation simulator to assess the human factor on fuel consumption (AMA)

Antwerp Maritime Academy (AMA) is preparing a simulator experiment where a group of test participants will perform an identical voyage (see Figure 14), including several manoeuvres with a tugboat using a navigation simulator. All participants will operate the same vessel under identical weather conditions.

The only variable will be the operator executing the exercise.

Figure 14 - Voyage to be realised to enter the port of Bodo, Norway

The simulator will collect and store ship-related parameters in a CSV file, including fuel consumption over time, position, speed, etc.. The following objectives are defined:

- calculate total fuel consumption, maximum fuel consumption peak, and the frequency of fuel consumption peaks and valleys of the entire operation;
- establish a baseline benchmark for energy-efficient vessel operation by comparing individual performances against the group average;
- assess the impact of the human factor by evaluating variations in fuel consumption between operators and determining potential efficiency gains through targeted training;
- identify causes of fuel consumption peaks during specific manoeuvres and correlate these with participant characteristics (e.g., experience level).

The practice addressed in this case study, which is still under development, is Practice 17: 'Use of simulation tools to optimize manoeuvres.

The use of simulation tools to optimize maneuvers offers valuable opportunities not only for operational efficiency but also for targeted crew training. The practice focuses on understanding and improving human performance in relation to fuel consumption, with the following key direct impacts:

- Quantify the impact of experience and behavior on fuel consumption. By using simulators to replicate real-world tugboat operations, it is possible to measure how different levels of experience and specific behavioral patterns influence energy use. This quantification helps to distinguish the fuel-saving potential linked to both technical skills and decision-making under operational pressure.
- Identify key behavioral patterns that influence energy efficiency during operations. Simulation-based training makes it easier to observe how certain actions—such as speed regulation, route planning, or reaction to external conditions—affect overall fuel consumption. Recognizing these behavioral drivers allows for the development of more targeted guidance and performance feedback mechanisms.
- Use these insights to design more effective simulator-based training programs. The results of the analysis can be directly applied to shape the structure and content of training modules. Emphasis can be placed on behaviors and maneuvers that have the greatest potential to reduce fuel use, ensuring that training is not only technical but also behaviorally informed and aligned with environmental goals.

Simulator-based training enables analysis of fuel consumption differences resulting from various maneuver execution styles while maintaining controlled environmental conditions. By monitoring and analyzing collected data, the impact of the human factor on fuel efficiency can be assessed. The findings will contribute to refining training programs to enhance energy-efficient ship handling. Furthermore, simulator experiments will help evaluate participants' competencies in fuel-efficient vessel operation. Through this data-driven and human-centered approach, the practice supports both operational optimization and environmental sustainability, highlighting the crucial role of training in achieving long-term improvements in maritime energy efficiency.

The key drivers for adopting this practice include cost reduction and minimizing the environmental impact of port operations through enhanced crew training.

The experiment will be conducted using the full-mission navigation simulator at AMA. Data will be collected from all participant exercises. The simulator experiment is scheduled to take place in May 2025. •AMA will organize the experiment using its full-mission simulator. Stakeholders such as pilots, tugboat masters, commercial vessel officers, and maritime students will be invited to participate.
The simulation experiment will follow a structured process to ensure reliability:

- design the simulation exercise, defining objectives and parameters,
- develop a briefing outlining the task participants must complete,
- create a questionnaire to gather basic participant characteristics,
- prepare an observation guide for assessors to assess participants' performance during the task,
- establish a data processing method to analyze collected operational data effectively.

A similar simulation experiment can be used as part of the training to assess the competences of the learners. These parts of the course/assessment may include the following steps:

- define and design the simulation exercise.
- conduct pre-training simulations and collect baseline data.
- provide training sessions focused on energy-efficient maneuvering techniques.
- conduct post-training simulations and collect comparative data.
- analyze results and evaluate training effectiveness.

The technology used is full-mission 360° navigation simulator at Antwerp Maritime Academy.

Participants must have basic knowledge of ship maneuvering and navigation. The exercise is designed to minimize the advantage of prior familiarity with the specific vessel and operational area.

Case #16:
Competencies required

- ***Basic knowledge of ship maneuvering and navigation***
- ***The exercise is designed to minimize the advantage of prior familiarity with the specific vessel and operational area***

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To evaluate the effectiveness of the training practice, a structured data collection process was established, both before and after implementation. The simulator plays a central role in this process, allowing for detailed and comparable measurements of vessel performance during predefined manoeuvres. The simulator records all ship parameters over time, generating a time-series dataset. The same exercise is performed post-training, allowing for direct comparison of fuel consumption improvements.

The experiment leverages existing AMA infrastructure, thereby minimizing costs. As a result, investment is primarily limited to the design of training exercises, use of the simulator, data processing, and staff involvement.

The implementation of simulator-based training aimed at optimizing manoeuvres can generate several economic benefits. The most tangible impact is the potential long-term reduction in fuel costs, achieved through improved crew behaviour and greater operational efficiency. By becoming more aware of their fuel consumption patterns and learning how to adjust their manoeuvres accordingly, crew members can contribute to significant cost savings in real-world operations. Lastly, improved manoeuvring skills and more efficient use of onboard systems may also result in lower maintenance needs and longer equipment lifespan, adding further value from an operational cost perspective.

This practice contributes significantly to environmental sustainability by promoting more efficient use of fuel during tugboat operations. Reducing fuel consumption leads directly to a decrease in greenhouse gas emissions, particularly CO_2, as well as a reduction in air pollutants such as NO_x and particulate matter. These improvements support broader efforts to mitigate the environmental impact of port activities.

Moreover, the adoption of simulation-based training fosters improved operational efficiency, aligning with international and local sustainability targets related to maritime transport. By encouraging more responsible and informed behaviour among crew members, the practice helps integrate environmental awareness into daily operations, paving the way for long-term cultural and environmental change within the sector.

The project aims to provide insights into how human factors influence fuel consumption in maritime operations. The success of the initiative will be measured through improvements in efficiency and participant feedback, which will offer a clear picture of the impact of the adopted green practices.

During the experiment, various challenges and targeted solutions may emerge. Specific training requirements for industry professionals may also arise. The recommendations that emerge will be integrated into the maritime education program and professional development to ensure that sustainable practices are adopted globally.

The next steps involve exploring the possibility of expanding the experiment to a broader audience, to gather data from a wider range of conditions and contexts. Additionally, it will be important to investigate other variables influencing fuel efficiency, such as vessel design and weather conditions. Finally, it will be crucial to implement the necessary improvements based on the results obtained, thereby optimizing future training sessions to maximize the impact of green practices in the maritime sector.

3.17 #Case 17: Gisaş Case Study: World's Largest Zero -Emission Tugboat Fleet (PRU)

This case study focuses on the implementation of Practice 8: "Implementation of eco-friendly propulsion systems.". GİSAŞ POWER, also called Zeetug, is a joint R&D project of GİSAŞ and NAVTEK. Gisaş has been operating the world's first zero-emission tugboat for five years. Afterwards, with the addition of three more electric tugboats to its fleet, GİSAŞ operates the world's largest electric tugboat fleet.

The aim of this case study is to demonstrate that zero emissions can be achieved in a bay with ports and shipyards, thanks to the tugboats serving the ships being 100% electric. By including the world's first 100% electric-engine tugboats into its fleet, GISAŞ has introduced a novel paradigm for other global operators in alignment with the United Nations Sustainable Development Goals.

The implementation of eco-friendly propulsion systems has led to significant environmental and operational benefits. These include zero emissions, a 30% reduction in total fuel costs thanks to improved energy efficiency, and an 86% decrease in maintenance and repair expenses. Additionally, the absence of exhaust heat and a 23% reduction in noise compared to traditional diesel engines contribute to lower environmental impact and enhanced comfort.

GİSAŞ primarily engages in "Piloting and Towage" services, which commenced in 1998 at Aydınlı Bay, under the jurisdiction of Tuzla Port Authority in Istanbul. GİSAŞ offers continuous service 24 hours a day, staffed by experienced and dynamic personnel possessing the qualifications outlined in the Seafarers' Regulation. The fleet comprises 5 tugboats, 3 mooring boats, and 1 pilot boat, all outfitted with equipment designed to combat fire and water pollution at Tuzla Port and its adjacent coastal areas.

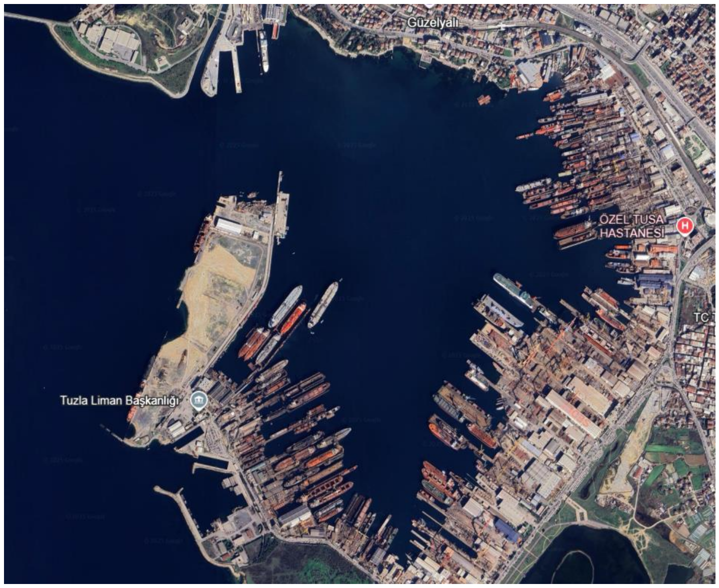


Figure 15 - Aydınlı Bay, Tuzla, Istanbul, Türkiye

GİSAŞ POWER, which was built by Navtek in 2019, started to be operated by Gisaş in March 2020. General features of Gisaş Power are given in the table below.

GISAS POWER Electric Tugboat	
Port of Connection:	İstanbul
Gross Tonnage	104
Building Location:	Tuzla - İstanbul
Date of Construction:	2019
Full Size:	18,70
Net Charge:	31
Host Type:	SIEMENS
Host Power:	2
Pull Power:	2x925 kW
Pull Power:	30 Tons

Gisaş Power, the world's first zero-emission, fully electric tugboat, has completed 1618 days of operation. Gisaş Power's first 5-year onshore survey was carried out in February-March 2025 (Figure 16).

Figure 16 - The first 5-year survey of Gisaş Power

The success of Gisaş Power, the first and important project carried out within the scope of decarbonization that will increase environmental awareness and shape the maritime sector, has also led to the construction of the other 3 electric tugboats. In this context, Gisaş Power 2 started operating in April 2023, Gisaş Power 3 in July 2023, and Gisaş Power 4 in October 2023. These tugboats, also built by Navtek and operated by Gisaş, have made a significant impact on the international platform. Gisaş's electric tugboats epitomize the new generation of environmentally friendly and advanced technology, being rechargeable, fully electric, and producing zero emissions with no noise. This revolutionary design enables the vessels to operate powerfully and efficiently while minimizing environmental impact.

Electric tugboats are being developed with the aim of optimizing various factors such as operational efficiency and ease, minimizing environmental impacts, eliminating air and noise pollution and providing good working conditions for the crew.

Gisaş provides pilotage and tugboat services in the bay under the responsibility of Tuzla Port Authority. This bay also includes the Tuzla Shipyards Region, which is the largest shipyard region in Türkiye. Since Gisaş provides service to all shipyards here, all shipyards in this region can be considered as stakeholders. Two other important stakeholders are, two important cargo ports in this region, AnadoluPort and DFDS. Especially, DFDS, one of the world's major ship and port operators, prefers only electric tugboats for their ships coming to the port it operates in this bay.

Lithium-ion battery packs are used to power electric tugboats. Utilizing robust electrically charged battery packs, electric tugboat effectively accomplishes its daily heavy-duty tasks without causing environmental harm, allowing the port tugboat to work at night with minimal noise. This technology is compatible with any current short-distance watercraft. Moreover, the Smart Tug Energy Management System (STEMS) software, created by NAVTEK, optimizes the electrical energy consumption of electric tugboats, hence enhancing their driving range and operational cycles.

STEMS is a web-based program that offers extensive functionalities for fleet control centers and tugboat operators. Its adaptable construction allows for integration into a fleet. STEMS aggregates all data from the devices and equipment aboard the tugboat and stores it in the Control Center's server. It utilizes pertinent data regarding performance to maximize electric power and provides feedback in the form of recommended actions to the operator.

The information and data included in the case study were obtained from face-to-face interviews with Gisaş and Navtek and by examining Navtek's operation reports.

The total operation time of Gisaş Power, the world's first zero emission tugboat, is 1618 days. The total number of operations (sortie) of Gisaş Power is 4194. While Gisaş Power's total e-motor operating time is 7194 hours, 657 hours were spent on maintenance and repair. Gisaş Power prevented a total of 954.4 tons of CO2 emissions and 2.7 tons of NOx emissions.

The total operation time of Gisaş Power 2 is 500 days. The total number of operations (sortie) of Gisaş Power is 827. While Gisaş Power's total e-motor operating time is 1315 hours, 150 hours were spent on maintenance and repair. Gisaş Power prevented a total of 168.7 tons of CO2 emissions and 0.48 tons of NOx emissions. The total operation time of Gisaş Power 3 is 424 days. The total number of operations (sortie) of Gisaş Power is 835. While Gisaş Power's total e-motor operating time is 1511 hours, 126 hours were spent on maintenance and repair. Gisaş Power prevented a total of 196.3 tons of CO2 emissions and 0.55 tons of NOx emissions.

The total operation time of Gisaş Power 4 is 320 days. The total number of operations (sortie) of Gisaş Power is 626. While Gisaş Power's total e-motor operating time is 720 hours, 129 hours were spent on maintenance and repair. Gisaş Power prevented a total of 142.8 tons of CO2 emissions and 0.40 tons of NOx emissions.

Electric tugboats provide 30% energy cost savings, and 85% maintenance and repair cost savings. As mentioned above, the electric tugboats used by GİSAŞ provide zero emissions. Moreover, electric tugboats have 23% less noise than their diesel-powered counterparts.

This case study aims to demonstrate the success of electric tugboats operating in a region with ports and shipyards in achieving zero emissions. Therefore, the case study is taken as a best practice example of Gisaş, which operates the world's largest electric tugboat fleet. Electric tugboats exemplify the latest generation of environmentally friendly and advanced technology, being rechargeable, fully electric, and producing zero emissions with minimal noise. This revolutionary design enables the boats to operate with enhanced power and efficiency while minimizing environmental impact.

3.18 #Case 18: Best practice - Port of Constanta (Romania) (CMU)

This case study is a combined research project performed in two steps: first, field research on the site of one logistic company and Constanta Port Administration, collecting actual and factual data, and second, extensive desk research for additional data collection, verification and analysis to complete and conclude the study. It implements the practice 9 "Supply chain optimization".

The case study analyses the optimization of a logistic company activities through the adoption of new digitalization tools. It highlights the fact that achieving a high level of effectiveness and efficiency, as well as environmental protection, requires optimized resource utilization and improved coordination among logistics chain actors. Additionally, the study examines the initiatives of the Port of Constanța Administration to implement digitalization measures aimed at enhancing the coordination of port actors' activities, including pilotage and towing services, to increase operational efficiency and reduce environmental impact.

The direct impact of the practice includes a reduction in waiting times for ships and goods, helping to prevent congestion and operational overloads. It also contributes to lowering emissions and operational costs, while aligning with green port practices and policies aimed at reducing the overall carbon footprint of the port.

The digitization and optimization activities of the logistics company analysed in the case study have been implemented. They are currently in the validation phase, during which benefits are being assessed, and solutions for improved utilization are being explored. The Administration of the Port of Constanța, in collaboration with a specialized company, has defined the requirements for the implementation of the Port Community System. In the upcoming period, a tender will be organized to award the development and implementation of this system.

Increasing the level of digitalization and integrating highly automated equipment into logistics chain activities within the port platform are effective solutions that enhance resource efficiency and reduce the impact on climate change. This best practice is encouraged by authorities through the creation of funding lines for such projects, as well as by the Port Administration's efforts to harmonize activities through the implementation of a Port Community System. Best practice involves identifying specialized software applications to optimize terminal activities as well as the associated data flows.

Port of Constanța has implemented several green initiatives aimed at enhacing environmental sustainability and reducing its carbon footprint:

- The establishment of a funding line within the Ministry of Transport's programs, including European funds, to support port companies in implementing measures to reduce the impact of their activities on climate change.
- Green Port Master Plan Development: In March 2024, the Port of Constanța organized a workshop to analyse and revise its Green Port Master Plan. This plan is a dynamic roadmap guiding the port towards carbon neutrality and sustainable development.
- Participation in the PIONEERS Project: The Port of Constanța participates in the PIONEERS (PORTable Innovation Open Network for Efficiency and Emissions Reduction Solutions) project to optimize port operations and implement renewable energy and mobility solutions. One of the outcomes of the project will be the calculation of the port activities carbon footprint, as well as implementation of an online platform to collect data from port actors related to GHG emissions.

Stakeholders involved are Logistic company, Maritime transport connected services providers part of the group and Port Administration. The Port Administration is interested in reducing the carbon footprint and is encouraging such practices. Logistic companies are concerned into aligning with port environmental policies as well as in obtaining an increased efficiency in the use of resources.

This study explores the strategies for improving operational efficiency and promoting sustainable resource use in a port logistic platform and warehouse, namely at LIFE LOGISTICS S.R.L. Located in Constanta South Port Agigea, and having over 15 years of experience, Life Logistics provides complete warehousing and handling services, owning and operating one of the most modern logistic platforms within Constanta Port.

The company operates exclusively on the port platform of Constanta Port and provides 2PL and 3PL logistic services. Currently, the company operates in Constanta South a long-term leased area of approximately 40.000 sqm developed from greenfield where it built covered logistic warehouses of 6.000 sqm. Also, in Constanta North Port, the company runs an area of about 5.000 sqm where it has built a covered warehouse of approximately 2.000 sqm.

Furthermore, Life Logistics built these logistic platforms strategically, near the terminals where all containerized transport carriers operate also, being located in the South sector at 250 sqm from DP World terminal and in the North sector at 150 sqm from SOCEP terminal. Life Logistics relies on extensive experience in handling specialized types of goods such as palletized goods, sensitive and valuable cargo, paper rolls, white goods, oversized and project cargo, pipes, roils and coils, as well as on the adequate equipment to handle them.

All in all, Life Logistics has constantly invested in its logistic platforms and warehouses evolving from a simple company with about 15 employees in an integrated logistic platform with nearly 100 employees.

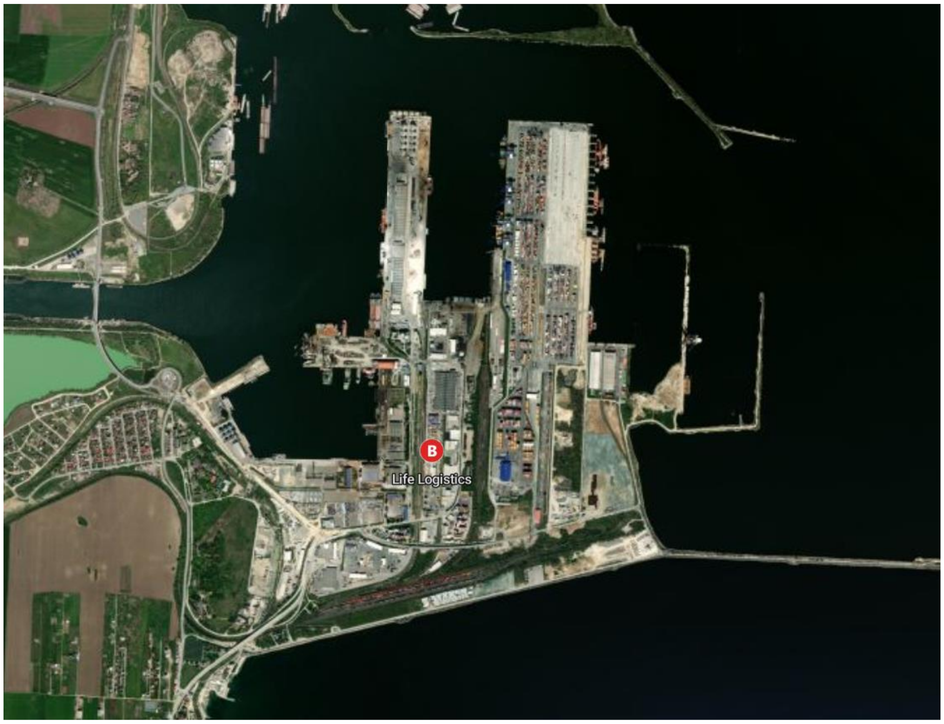


Figure 17 - Aerial photo of the terminal in the Port of Constanta

Life Logistics strongly believes that the future of the company lies in innovation and evolution through sustainability, therefore the adoption of their GO GREEN policy has turned into a success. The company's proactive approach to sustainability and operational efficiency is reflected in initiatives such as the adoption of WMS (warehouse management system), the implementation of ARL LIFE DEPOT terminal system (through which the route of each container is tracked from arrival until departure), the maximizing usage of natural light (up to 80%), solar panels for indoor and outdoor lighting, solar power generator, full electric vehicles for employees, own electric charging stations, migration from diesel to full electric forklifts, and the list goes on.

Life Logistics constantly invests in digitalization, and this is perfectly reflected in the adoption of MANTIS – WAREHOUSE MANAGEMENT SYSTEM, through which it is tracked the route of each cargo from warehouse arrival until departure. As the market becomes more competitive and customers more demanding, requiring accurate and real-time information, Life Logistics needed to have the adequate information-technology tools to support the business and build reliability, control and flexibility into the warehouse operation.

The company decided to implement this intelligent warehouse management system to automate processes and to optimize efficiency within the warehouse. Also, when implementing MANTIS-WMS the company established clear rules to be followed such as: ensuring that all the key people are available during the implementation phase, the appointing of users with training capabilities, developing a training agenda for all employees and also decided to run in parallel their existing system until the new one is fully operational, all the functionalities have been tested and any eventual issues have been solved. This strategic move that enabled Life Logistics to automate its warehouse activities providing real-time tracking of cargo through barcode scanning and mobile terminals, positioned the company as the first in Constanta South Agigea Port to utilize such a system.

Therefore, the introduction of this technology has significantly improved warehouse productivity, reduced costs and increased customer satisfaction. MANTIS WMS manages stocks accurately, processes data quickly and coordinates movements into the warehouse improving competitivity and generating benefits such as:

- real-time stock visibility and traceability
- improved productivity
- reduction in miss-picks
- automatic replenishment
- reductions in returns
- accurate reporting
- improved responsiveness
- remote data visibility
- minimized paperwork
- minimized unproductive labour
- improved customer service
- costs reduction
- accurate stock records
- reduced errors.

Figure 18 -Life Logistics terminal

Consequently, the company opted for MANTIS-WMS due to the fact that it works in real-time, provides instantly inventory updates and it also comes with a user-friendly interface. As a result of implementing MANTIS – WMS, Life Logistics has benefited from significantly improved accuracy, efficiency and productivity being an important step towards the introduction of automation to further improve operational efficiency.

Another clear example of the company's path to automation represents the ARL LIFE DEPOT terminal system that provides accurate tracking for each container from its arrival until departure.

This specialized system can also display whether the container has been moved between terminals, as per below picture. This is an advanced warehouse management and automation system that integrates real-time tracking, AI-driven optimization and automated decision-making to improve warehouse efficiency. Basically, it analyses movement patterns and operational data providing real-time analytics leading to an increased order fulfilment speed by 30% and to an improved warehouse space utilization by 25%.

Also, by adopting EDI streamlined communications and thus replacing the traditional paper-based communication has automated the exchange of documents and inventory reports reducing manual data entry and human errors. Another benefit of EDI streamlined communications is reflected by cost savings because it eliminates costs associated with paper, printing and manual processing, reducing also administrative overhead and operational expenses. The communication system easily integrates with WMS (Warehouse Management System) and TMS (Transportation Management System) improving supply chain responsiveness through the coordination between warehousing, shipping and distribution channels.

Therefore, through real-time visibility and tracking, the system enables effective data sharing between warehouses, suppliers and logistic providers.

Environmental impact represents a constant concern for Life Logistics, the company's GO GREEN policy being reflected in its evolution, promoting and implementing sustainable solutions such as the production of energy through photovoltaic panels, electric forklifts, full electric vehicles for employees and own electric charging stations. With direct access to railway, the company looks forward a multimodal future:

- own rail connected terminal: 18000 sqm
- rail connected warehouse: 1800 sqm
- simultaneous processing capacity: 22 rail carriages

The introduction of a VGM automated scale within the logistic platform and warehouse, has come with significant advantages for the company in terms of compliance with safety regulations as the International Maritime Organization (IMO) mandates VGM verification for all containerized shipments under the SOLAS (Safety of Life at Sea) convention. An automated scale ensures that all shipments comply with weighting regulations, thus avoiding penalties and cargo delays. Furthermore, in order to provide real-time data transfer, the scale has been integrated with WMS (Warehouse Management System) and TMS (Transportation Management Systems). The VGM automated scale comes with instant notifications and alerts if a container exceeds weight limits, enabling quick corrective actions and considerably optimizing stacking and storage within the warehouse. All in all, the VGM automated scale ensures a smooth supply chain flow, working seamlessly with ERP systems (Enterprise Resource Planning), port terminals, shipping lines and customs platforms.

In order to ease the procedures, the company developed its own container maintenance station improving operational efficiency, allowing for faster turnaround times and reducing its dependency on third party services. Before establishing the in-house container maintenance station, the company faced several logistical and operational challenges, such as delays in container repairs, increased operational costs, limited control over repair quality and standards, inefficiencies in tracking and scheduling container maintenance.

Consequently, Life Logistics' container maintenance station strengthened logistic operations and ensured long-term sustainability in container management:

- cost efficiency – significant cost reduction by eliminating third-party repair fees; spare parts inventory for efficient repairs
- faster turnaround times – containers are repaired and returned to service quicker, improving fleet availability
- quality control – direct oversight ensures high maintenance standards and compliance with industry regulations
- increased container lifespan – regular maintenance prevents deterioration, allowing containers to remain in service longer; sustainable practice reducing the need for frequent container replacements
- better compliance and safety – ensure containers meet international shipping standards (ISO, CSC, IICL) and minimizes the risk of cargo damage due to faulty containers.

The introduction of Warehouse Management Systems (WMS) and Verified Gross Mass (VGM) automated scales in logistics and port operations requires workers to develop new competencies. These include:

- System Navigation & Data Entry – Ability to input and retrieve data from WMS interfaces efficiently.
- Inventory Control & Accuracy – Understanding system-based stock management, cycle counting, and minimizing discrepancies.

- Automated Picking & Packing – Operating WMS-integrated picking technologies like RF scanners, voice-picking, or robotics.
- Integration with IoT & AI – Familiarity with smart sensors, predictive analytics, and automated tracking tools.
- Warehouse Layout Optimization – Using system recommendations for efficient product slotting and storage.
- Troubleshooting & System Recovery – Identifying and resolving software and hardware integration issues.

VGM Automated Scale Competencies such as:

- Regulatory Compliance & VGM Protocols – Understanding SOLAS (Safety of Life at Sea) regulations and accurate weight recording requirements.
- Automated Weighing System Operation – Using digital scales integrated with WMS for real-time weight verification.
- Data Interpretation & Transmission – Ensuring accurate weight data is transmitted to customs, shipping lines, and warehouse systems.
- Equipment Calibration & Maintenance – Performing routine checks and troubleshooting scale inaccuracies.
- Safety & Load Balancing – Ensuring cargo weight distribution aligns with vessel and transport regulations.

Cross-Functional Digital & Analytical Skills such as

- Data Analysis & Decision Making – Leveraging reports from WMS and VGM for process improvements.
- Cybersecurity Awareness – Understanding data protection measures to secure warehouse and shipment records.
- Automation & Robotics Coordination – Managing interactions between automated systems and human workflows.
- Operational Efficiency Strategies – Using system insights to optimize port and warehouse throughput.

Case #18: Competencies required

- ***WMS-Specific Competencies (i.e.,System Navigation & Data Entry, Inventory Control & Accuracy, Automated Picking & Packing, Integration with IoT & AI, Warehouse Layout Optimization, Troubleshooting & System Recovery)***
- ***VGM Automated Scale Competencies (i.e., Regulatory Compliance & VGM Protocols, Automated Weighing System Operation, Data Interpretation & Transmission, Equipment Calibration & Maintenance, Safety & Load Balancing)***
- ***Cross-Functional Digital & Analytical Skills (i.e., Data Analysis & Decision Making, Cybersecurity Awareness, Automation & Robotics Coordination, Operational Efficiency Strategies***

GREENPORT Alliances

The company is under process of collecting data in order to perform a carbon footprint audit, as well as to establish sustainability KPIs.

Implementing a Warehouse Management System (WMS) delivers significant economic benefits across multiple operational areas. Automation reduces manual labor in inventory management, picking, packing, and order fulfillment, allowing employees to focus on higher-value tasks and improving overall productivity. Accurate demand forecasting prevents overstocking, reducing capital tied up in unsold inventory, storage, and insurance costs. Real-time tracking minimizes losses from theft, misplacement, and damage, while reducing waste due to expired or obsolete stock.

Automated order picking enhances speed and accuracy, leading to faster shipping, improved cash flow, and higher customer satisfaction. By eliminating human errors in stock counting, order entry, and dispatching, the system also prevents costly delays and incorrect shipments. Integration with VGM (Verified Gross Mass) automated scales accelerates weight verification, helping to reduce port bottlenecks, demurrage, and detention fees. Accurate cargo weights ensure optimal container usage, cutting fuel consumption, while shipment consolidation and route optimization lower transportation and maintenance costs.

Additional savings come from improved shipment accuracy—which reduces returns—and from energy efficiency in warehouse lighting, heating, and cooling systems. Automated forklifts and conveyors further cut fuel and electricity consumption. WMS also encourages sustainable practices, such as the use of recyclable packaging and reduction in waste.

Estimated Savings Potential (Industry Averages):

- Warehouse Labor Cost Reduction: 20–30
- Inventory Holding Cost Reduction: 15–25%
- Freight & Transportation Cost Savings: 10–20%
- Regulatory Fines & Compliance Cost Reduction: 50–80%
- Faster Order Processing & Fulfilment Time: 30–50%.

The implementation of Warehouse Management Systems (WMS) and Verified Gross Mass (VGM) technologies significantly contributes to environmental goals across several key areas. One of the most critical impacts is the reduction of carbon emissions, achieved through optimized transportation efficiency. WMS ensures better load consolidation and reduces the number of trucks, ships, and trips required, which directly cuts down fuel consumption and CO_2 emissions. Accurate cargo weight measurements enabled by VGM scales prevent overweight shipments, thus improving fuel efficiency and minimizing unnecessary fuel burn. Moreover, automated scheduling and weight verification at ports reduce engine idling times, further decreasing emissions linked to congestion and delays.

In terms of energy conservation and sustainable warehousing, WMS helps design smart warehouse layouts that minimize unnecessary movement of goods, thereby lowering energy use from forklifts and conveyor systems. These systems integrate seamlessly with energy-efficient technologies, allowing automation of measures such as smart lighting, HVAC optimization, and even the incorporation of renewable energy sources. By enhancing space utilization, WMS also reduces the demand for building new warehouses, preserving land and natural resources.

Waste reduction and resource optimization are additional areas where WMS proves beneficial. Accurate inventory tracking reduces product damage and spoilage caused by expiry or improper storage. Packing processes are streamlined to minimize excess material use and promote environmentally friendly alternatives. Digital documentation through WMS and VGM further contributes by reducing paper waste, replacing traditional records, invoices, and compliance forms with electronic versions.

WMS and VGM also support compliance with environmental regulations and sustainability objectives. They align operations with international standards such as the IMO decarbonization targets and ISO 14001, and provide real-time data for monitoring and reducing greenhouse gas emissions. This level of digital tracking enhances supply chain transparency and reinforces the adoption of sustainable practices among all stakeholders.

Finally, these systems advance circular economy principles by improving reverse logistics processes, such as product returns, refurbishing, and recycling, extending product lifespans. They also facilitate more efficient waste segregation and recycling tracking, minimizing contributions to landfills. Through accurate demand forecasting, WMS helps reduce overproduction, thereby conserving raw materials and reducing resource depletion. Together, these contributions make WMS and VGM powerful tools for driving environmental sustainability in logistics and warehousing.

By improving efficiency, reducing waste, and optimizing transportation, WMS and VGM automation contributed directly to a more sustainable logistics ecosystem. These technologies enable businesses to reduce their environmental impact while maintaining operational efficiency, making their implementation a clear success for environmental sustainability.

The implementation of Warehouse Management Systems (WMS) and Verified Gross Mass (VGM) automated scales in logistics and port operations has led to several lessons learned in reducing environmental impact and mitigating climate change. They are listed in the table below:

Table 21 - Warehouse Management Systems (WMS) and Verified Gross Mass (VGM) automated scales in logistics and port operations – Lessons learned

CATEGORY	ACTION	ENVIRONMENTAL BENEFIT
Energy Efficiency & Reduced Carbon Footprint	*Optimized Warehouse Layout & Storage*	*Reduces fuel and electricity consumption*
	Automated Picking & Robotics	*Decreases reliance on diesel forklifts and CO_2 emissions*
	Smart Lighting & HVAC Integration	*Optimizes energy usage based on activity levels*
Reduction of Wasted Resources	*Minimized Overproduction & Stockpiling*	*Prevents waste from overordering and overstocking*
	Efficient Space Utilization	*Avoids land use for unnecessary warehouse expansion*
	Sustainable Packaging Insights	*Minimizes excess packaging materials*
Improved Transportation & Emissions Reduction	*Optimized Route Planning*	*Reduces unnecessary trips and fuel consumption*
	Accurate Cargo Weight Management	*Prevents overweight shipments, improves fuel efficiency*
	Data-Driven Load Balancing	*Enhances load distribution and transport efficiency*
Paperless & Digital Transformation	*Electronic Documentation & Reporting*	*Reduces paper usage and associated waste*
	Automated Billing & Customs Clearance	*Lowers environmental impact of documentation processes*
Waste Reduction in Port & Warehouse Operations	*Prevention of Cargo Loss & Damage*	*Reduces spoilage and damage-related waste*
	Sustainable Disposal & Recycling	*Promotes responsible waste disposal and recycling*
Enhanced Regulatory Compliance & Sustainability Metrics	*Carbon Emission Tracking*	*Enables monitoring of warehouse and transport emissions*
	Green Logistics Strategies	*Aligns operations with decarbonization objectives*
	Improved Supply Chain Transparency	*Ensures sustainability practices across the supply chain*

The next steps involve conducting a carbon footprint audit through WMS analytics to establish a clear baseline. From there, specific sustainability KPIs will be defined, targeting reductions in emissions, waste, and energy consumption. Investments in AI and automation will further enhance logistics efficiency, while employee training will focus on green logistics best practices using insights derived from WMS and VGM data.

4 Case study analysis: training actions to support the implementation of best practices in port services

This chapter analyses the case studies in which best practices for the sustainability of technical-nautical services have been successfully implemented in various port contexts. The goal is to identify the key factors that have facilitated the adoption and dissemination of these practices across the sector. The case study analysis highlights the elements and conditions that have enabled the testing and implementation of practices. What emerges is that the effective implementation of best practices in port services requires a thorough understanding of both technical and non-technical factors. Overall, the lessons learned highlight the critical need for continuous training and interdisciplinary collaboration.

What the analysis highlights is that training programs should be designed to improve the technical skills, operational efficiency and regulatory knowledge of port personnel, while promoting a deeper understanding of environmental sustainability. By responding to these needs, the maritime-port sector can better address the challenges of the ecological transition and promote lasting change in its operations.

4.1 Analysis of results

The table below shows the list of the 17 practices considered relevant for promoting sustainability in technical-nautical services to reduce environmental impact. These practices were analysed in the light of 18 case studies, selected to provide initial empirical evidence on the actual application of the solutions considered.

Table 22 - Number of case studies per practice

Practice #1	Active involvement of pilots in the planning of port initiatives	\
Practice #2	Active participation of pilots in research and development projects for new green technologies	1
Practice #3	Behavioral change through training and awareness	1
Practice #4	Collaboration among stakeholders for real-time data sharing	2
Practice #5	Collaboration with other ports to exchange information and green solutions	1
Practice #6	Continuous monitoring of emissions during operations	1
Practice #7	Continuous training and updates for pilots	2
Practice #8	Implementation of eco-friendly propulsion systems	2
Practice #9	Supply chain optimization	1
Practice #10	Minimization of engine running time	1
Practice #11	Optimization of operation speed	1
Practice #12	Periodic publication of reports on environmental performance	1
Practice #13	Accurate route planning	
Practice #14	Real-time navigation route optimization	2
Practice #15	Regular maintenance of tugboat engines	1
Practice #16	Use of biofuels for tugboats	1
Practice #17	Use of simulation tools to optimize maneuvers	1

The final column of the table indicates, for each practice, the number of case studies in which it was described or implemented. Values range from 1 to 2 case studies, with most practices (13 out of 17) found in only one case, while the remaining 4 (Practice #4, #7, #8 and #14) emerge in two cases each.

The fact that almost all the practices are at least reflected in the case studies is a significant result, as it confirms the relevance and concreteness of the 17 proposed practices. They are not merely abstract theorisations but already find application, albeit in embryonic or partial form, in real contexts.

In line with the introductory paragraph, the practices can be divided into two broad categories:

1. Technological practices, which introduce innovative solutions to improve operational efficiency and reduce emissions.
2. Non-technological practices are based on behavioural changes, training, cooperation between actors.

The analysis of the 18 case studies shows that the technical-nautical services sector pursues sustainability objectives by acting on two main approaches:

- technological approach,
- human (non-technological) approach.

Technological practices are based on the use of advanced solutions that aim at direct emission reduction, energy efficiency and operational optimization. These include, for example, continuous monitoring of emissions during operations, the introduction of environmentally friendly propulsion systems, minimizing engine start-up times and the use of alternative fuels and simulation tools to optimize manoeuvres. Non-technological practices, while involving the use of technologies, are mainly based on the active involvement of stakeholders, the dissemination of a sustainable culture, continuous training and knowledge sharing among stakeholders.

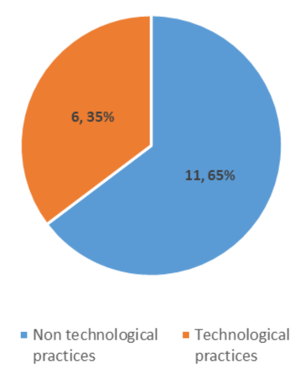


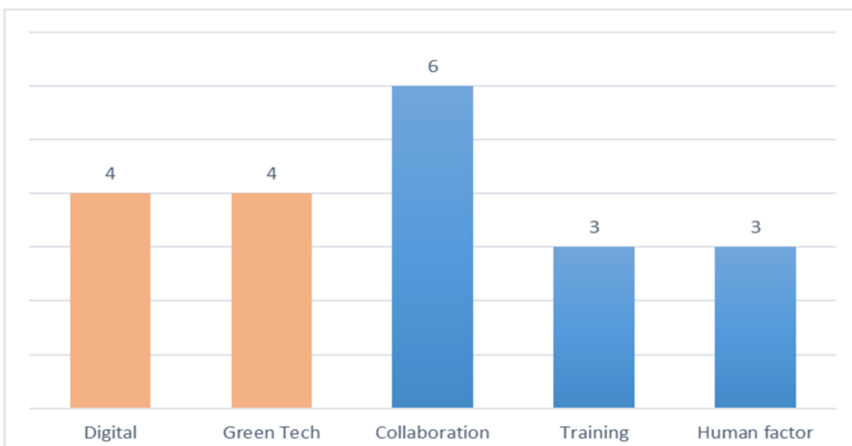
Figure 19 - Technological vs. Non-Technological Practices

Technology-based best practices aim to reduce environmental impact and emissions through innovative technologies. Consequently, innovation drives structural changes in operating and business models, enabling companies to maintain competitiveness while embracing environmental responsibility. Nevertheless, case studies emphasize that factors like training and collaboration with other industry players are equally important for guaranteeing the successful adoption of the practice and the achievement of desired outcomes. In the process of creating and developing an innovation, alongside the end users (in this case, pilots and tugboats), key roles are played by subjects such as technology providers and institutional actors to regulate its implementation and use. At the same time, training becomes fundamental for instructing the end users in the comprehension and correct utilization of the technology.

Non-technological practices are based on human actions and decisions. As a result, key drivers are

- *training*: development of skills and awareness related to sustainability;
- *collaboration among stakeholders*: exchange of knowledge and creation of networks across different actors of industry;
- *behavioural change*: adoption of daily practices aligned with social and environmental responsibility.

The acquisition of sustainability skills and awareness allows individuals to understand the motivations behind the adoption of sustainable practices and to implement them effectively in daily routines and decision-making processes. Knowledge exchange and creation between different stakeholders foster mutual understanding and allow for the identification of innovative solutions capable of addressing sustainability challenges, leveraging the perspectives and resources of each stakeholder. Furthermore, a change in the mindset and values of industry operators and operating companies is needed to activate the ecological transition of the sector in a concrete and lasting way.



TECHNOLOGICAL PRACTICES		***NO TECHNOLOGICAL PRACTICES***		
Digital	***Green Tech***	***Collaboration***	***Training***	***Human factor***
Pr.6; Pr.14; Pr.17	Pr.8; Pr.10; Pr.16	Pr.1; Pr.2; Pr.4; Pr.5; Pr.9	Pr.3; Pr.7	Pr.11; Pr;12; Pr.15
4	4	6	3	3
Case studies		*Case studies*		

Figure 20 - Practice categorization by sustainability drivers

The analysis of the case studies clearly highlights these aspects in the adoption of green practices. Technological innovation provides the tools, but success depends on training, collaboration and cultural change.

The bar chart in Figure 20 shows the distribution of technological and non-technological practices identified in the case studies.

On the left-hand side, "Technology Practices" show that practices involving the adoption of a digital technology solution are 4 (Practices Pr.6, Pr.14, Pr.17)[3], and were observed in four of the case studies analysed (noting that Practice 14 appears in two of the case studies). Green technologies (Practices Pr.8, Pr.10, Pr.16) were the subject of 4 case studies (noting that Practice 8 appears in two case studies) and suggest that green technologies were relevant in as many as 4 of the case studies.

Turning to "No technological Practices" on the right-hand side, Collaboration emerges as the category with the highest number of practices (Pr.1, Pr.2, Pr.4, Pr.5; Pr.9), with a total of 6 case studies. Therefore, once again, the relevance of this aspect in the nature of the practices and the empirical evidence emerges.

Both *Training* (Practices Pr.3, Pr.7) and *Human factor* (Practices Pr.11, Pr.12, Pr.15) have a count of 3 each, indicating their presence in three of the analysed case studies. In the case of practices primarily focused on training, Practice 7 is featured in two case studies.

Finally, it is important to clarify that although Practice #9 "Supply Chain Optimization" is classified in the project as a non-technological practice—since its core element lies in the collaboration among actors within the logistics chain—the case study analysed reveals a strong technological dimension in its practical implementation. In this case, the collaborative dimension remains the conceptual foundation of the practice, but technology acts as a key enabler, enabling dynamic management of information and resources in port and logistics environments. This suggests that the distinction between technological and non-technological practices, while useful from an analytical point of view, does not always reflect the complexity of real cases, where an

[3]

integrated approach combining organisational innovation and digital transformation often proves to be the key to successful and sustainable action.

For a more in-depth understanding, the following provides a detailed analysis of the case studies. A first piece of data to show concerns the geographical areas involved in the case studies.

Country	Number of cases
Italy	2
Spain	1
Portugal	2
United Kingdom	1
Bulgaria	1
Romania	3
Belgium	3
Turkey	1
European countries	1
USA	1
Canada	1

Although the predominance of European case studies can partly be attributed to the composition of the project partnership - which is itself largely European - this distribution shows that the green and digital transition in the field of technical-nautical services is already underway in this geographical context.

The European Union, through directives, decarbonisation strategies and funding programmes dedicated to port sustainability, encourages the adoption of green practices. This has probably accelerated the implementation of emerging technologies and more collaborative and sustainable organisational models in European ports. Therefore, while acknowledging the potential bias introduced by the project context, the empirical evidence reinforces the idea that Europe is currently an advanced laboratory for green transition in the maritime sector.

Most of the case studies examined in this research took place between 2019 and the present day, a temporal concentration that is not surprising given the innovative nature of the phenomenon analysed. Moreover, this period coincides with an increasing focus on environmental sustainability generated mainly by climate change issues. Furthermore, the fact that most of the case studies are recent further suggests that the sector is currently in a phase of active experimentation, learning and diffusion of best practices. The case studies allow to draw timely lessons that can guide future innovation strategies also through training within and beyond Europe.

Continuing the analysis according to the main sections of the case study identification sheet, a certain recurrence of certain driving factors that led to the adoption of the practices emerges. In some of the empirical evidence described these factors are not isolated, but often interconnected, reflecting both external pressures and internal motivations of the organizations involved. One of the most important driving factors is environmental regulatory constraints. We can identify in at least nine cases (e.g. case no. 2, no. 3, no. 4, no. 7, no. 8, no. 10, no. 11, no. 12). In many sectors, and thus also in port services, the presence of clear environmental directives and sustainability targets - particularly in the EU context - has incentivised actors in the maritime sector to invest in green technologies and adopt more responsible operating models. The implementation of best practices reveals a proactive rather than reactive approach as regulatory compliance is not only perceived as a legal obligation, but also as a strategic lever for innovation and change. The presence of clear environmental directives and sustainability targets, especially in the EU context, has incentivised maritime stakeholders to invest in green technologies and adopt more responsible operating models. Regulatory constraints, in this sense, become a catalyst for modernisation especially when addressed proactively rather than reactively.

Cost savings and operational efficiency are another strong motivation for the adoption of green practices. This is evident in cases 1, 14, 15, 16 and 17. Ports and technical service providers increasingly recognise that digitisation allows them to optimise processes and reduce, albeit indirectly, waste and environmental impact, enabling companies to remain competitive.

Cases no. 2 and no. 5 instead highlight the growing importance of market demand and stakeholder pressure. Customers, investors and local communities are paying more attention to environmental performance and transparency. Consequently, it becomes important to meet the expectations of a market that is increasingly attentive to sustainability to defend their competitive advantage. This change pushes organizations to adopt more visible, measurable and accountable green practices.

In three cases, No. 6, No. 7 and No. 8, cultural change towards environmental responsibility is identified as one of the factors driving the implementation of the practice, thus emphasising the importance of a proactive approach towards environmental protection. Indeed, such empirical evidence pursues the goal of reducing emissions by adopting a proactive attitude towards environmental management, which becomes a fundamental component of organisational identity and, as in case no. 8, a new perspective with which to view and redefine technical-nautical services shortly.

The implementation of sustainable practices in technical-nautical services has produced a range of tangible, measurable impacts. These effects validate the effectiveness of the interventions and highlight their multidimensional benefits, spanning environmental, operational, and relational domains.

The most widespread impact among the case studies is the reduction of emissions, reported in at least ten cases, identifying it as a key outcome of the green transition in port operations. These reductions often concern greenhouse gases (GHG) and air pollutants such as nitrogen oxides (NO_x) and sulphur oxides (SO_2).

Improvements in energy efficiency are also observed as direct impacts in the case studies (e.g. Cases #4, #6, #8, #10). This dual impact reflects the synergy between advanced technologies and sustainable practices. For example, route optimization, the use of electric or hybrid propulsion and intelligent monitoring systems also reduce energy and fuel consumption, generating both ecological and economic value.

In Cases #13, #14 and #15 some of the impacts generated by the practices are represented by the reduction of operating costs and fuel consumption. These results are particularly significant from a long-term sustainability perspective, as they directly impact economic profitability. For example, by reducing fuel expenses and maintenance needs through optimized operations, ports and service providers can reinvest in further innovation, creating a virtuous circle of efficiency.

Cases such as #1 and #15 noted that technological tools, including advanced simulators, augmented reality and data sharing platforms have led to significant improvements in communication, coordination and operational precision. These advances also translate into higher safety standards and a more resilient workforce, supported by targeted training and knowledge transfer.

In initiatives such as Case #2, a notable direct impact is the enhancement of environmental strategy. Sustainability reports facilitate the traceability of decisions and actions, fostering transparency and accountability.

Moreover, these tools enable a more inclusive dialogue with stakeholders improving public perception and reinforcing trust in port institutions.

Analysing the KPIs and the measures identified for each case study, we can observe recurring patterns that primarily refer to fuel consumption, emission levels, indicators related to vessel operations, and the vessels themselves. In general, the KPIs provided in most of the case studies indicate that the effectiveness of the implemented practice can be measured. In some cases (i.e. Case #1 and Case #9), parameters referring to safety and security aspects are also considered.

In each of the case studies analysed, various stakeholders participate in the implementation and success of sustainable practices within the maritime sector. These stakeholders include institutional bodies, technical service providers, operational personnel, and environmental agencies.

Port authorities are key institutional actors that oversee the governance of port operations (e.g. Port of Varna, Port of Aveiro, Port of Quebec, Port of Los Angeles). They are responsible for setting regulations, ensuring compliance with environmental standards, and facilitating the coordination of various stakeholders. One of the main tasks is to actively work on the port's ecological transition by supporting the adoption of sustainable practices throughout the port ecosystem. In many of the case studies, port authorities play a key role in implementing green practices by providing the necessary infrastructure for innovation.

Pilots and tugboat operators are undoubtedly the main end-users and those most directly affected by the implementation of green practices. As they are responsible for the navigation of ships in and out of the port, their role is critical for operational efficiency, safety and environmental responsibility. Their feedback and active involvement are crucial to refine and scale up the sustainability measures tested in the case studies. In the process of innovation in the sector geared towards the ecological transition, it is necessary to take into account the needs of these operators in order to develop solutions that are effective and efficient and that also combine safety and economic aspects. Technical support providers provide the tools, technologies and expertise that enable the transition to more sustainable operations. They can ensure the availability and operation of the equipment needed to reduce emissions and improve efficiency. Shipping companies manage ships entering and leaving ports and are among the main players interacting with technical-nautical service operators. Environmental agencies address national and international environmental regulatory aspects by providing guidance on mitigation strategies and issuing regulations and guidelines to support economic sectors. Finally, research institutes and industry associations act as intermediaries between the private sector and government bodies, helping to bridge the gap between innovation and practical implementation. Furthermore, they promote collaboration and ensure that new technologies are effective and adaptable to real-world conditions.

The collaboration among stakeholders in the case studies highlights the complexity of adopting green practices in technical-nautical services. However, pilots and tug operators remain the key actors in this process as they are the ones who can most directly influence the operational success of these initiatives. Therefore, it is important that they are adequately trained to foster the diffusion of best practices in the sector.

4.2 Recommendations for curriculum development and training needs

The analysis of the 18 case studies clearly shows that for green practices to produce tangible effects, they must be accompanied by a change in the operational behaviour of the actors involved. The actors operating in the technical-nautical services sector, at various levels, are the main end-users of the new solutions described in the case studies, whose effectiveness will depend on their ability to consciously embrace change and on their skills and knowledge that the use of these innovative practices will require. In this sense, training becomes an indispensable and concrete tool capable of accelerating and consolidating the transition process that is affecting the sector.

The training needs identified as fundamental are grouped into technical, operational and regulatory training needs. This classification highlights the need to integrate advanced technical knowledge, operational skills and a solid understanding of the regulatory framework to ensure systemic and lasting change. They reflect the multidimensional skills required to support the transition to more sustainable practices in the technical-nautical services.

Technical needs refer to the need to train personnel on the use of new technologies and digital systems. In many cases, the effectiveness of the sustainable practices implemented depends on the ability of operators to use advanced tools such as route optimization software, low-emission engines and real-time monitoring systems. It follows that technical training is essential to ensure operational efficiency and the ability to know how to use innovations effectively.

Operational needs arise from the need to improve the daily management of manoeuvring activities and logistics processes in the port. In particular, it is essential that suppliers of technical-nautical services have the knowledge and skills needed to be able to evaluate, based on the scenario in which they find themselves, how to act and how to manage a new technology or procedure to always guarantee its effectiveness. Furthermore, operational training aims to promote sustainable behaviours, strengthen communication between the various parties involved and spread best practices in conducting operations.

Training needs relating to regulations are linked to the understanding and application of environmental and safety regulations. In all sectors, the transition to green practices requires operators to remain up to date on legal obligations and European and international standards on emissions, sustainability and reporting. Therefore, training in regulatory matters is aimed at ensuring compliance with regulations and strengthening the culture of environmental responsibility.

Therefore, the need for training programs that combine technological updates, operational efficiency and regulatory awareness emerges, contributing to the development of a new model of professionalism for the maritime-port sector. Moreover, professional updating emerges in relation to the three identified categories, reflecting the growing complexity of the skills required to address the transition of ecological change in technical-nautical services.

In several case studies, the need to acquire skills related to the use and management of new technologies is observed. These include: the implementation of continuous emission monitoring systems, which requires training on sensors and environmental data collection (Case No. 3); the use of electric or hybrid propulsion and digital systems for route and consumption optimization (e.g., Cases No. 6, No. 13); and initiatives related to automation and digitalization systems, such as the use of dashboards and data visualization for operational efficiency (e.g., Cases No.8, No. 9, No. 14, No. 16). These imply the need to train operators by providing them with knowledge and skills in using tools such as intelligent systems, digital twins, fuel monitoring, navigation simulators and predictive analytics. This result is not surprising, given the importance of the digital transition, also considering that digitalization, albeit indirectly, represents a powerful tool to reduce environmental impact by enabling the optimal use of resources. The same applies to "green technologies". In the case studies, green tech is represented by hybrid boats, eco-friendly propulsion systems (e.g., Case No. 10) and the use of biofuels (e.g., Case No. 11). The introduction of these technologies must be accompanied by targeted training courses, capable of transferring the technical skills necessary for use and management in any operational scenario.

The need for training in understanding data generated by advanced digital tools and in the ability to manage different scenarios is central in several case studies (e.g., #1, #3, #4, #8, #14) and shows, as already mentioned, the importance of operational training needs. There is a clear need to strengthen operational skills (e.g., optimizing manoeuvre times and efficiently planning operations) to reduce consumption and environmental impact while ensuring the safety levels that characterize technical-nautical services. Operational safety is also a priority, especially in contexts where new towing methods, hybrid engines or automated solutions are introduced. In some case studies, the use of simulators enables pilots to prepare to handle complex scenarios in adverse weather conditions by giving them the opportunity to interact with new on-board or ground-based technologies. These tools promote correct behaviour and improve decision-making skills. In this way, operators are able to ensure safety with minimal margins of error. Furthermore, there is a clear need to strengthen operational skills in order to optimise manoeuvring times and improve coordination between tugboat crews and other operators involved, as demonstrated by cases #12 and #15. Reducing downtime, dynamically adapting parameters such as speed (case #14) and efficiently planning operations are key elements in reducing consumption and environmental impact.

Human-machine interaction, new on-board procedures and real-time communication methods require updated skills, which only an adequate training program can provide. Operational training represents strategic pillar for the success of the implemented innovations because it helps to reduce the risks associated with the adoption of new technologies and improves the readiness and responsiveness of operators.

Finally, as shown in cases no. 2 and no. 10, training in environmental regulations involves not only understanding the rules, but also their correct application in daily operations, fully understanding their objectives and operational implications. Training in this area also includes skills related to environmental reporting and sustainability reporting, tools increasingly required by regulators, shipowners and institutional stakeholders. In this context, training programs should help participants develop a transparent approach to measuring environmental performance. Equally important is the growing focus on integrating ESG (Environmental, Social, Governance) criteria into port management practices. This specific training area should support this cultural shift by providing both conceptual and practical tools to promote organizational behaviors aligned with ESG principles. Preparing operators to correctly interpret this change means providing them with a broader perspective on their role within the port ecosystem, turning them into active and proactive actors of the ecological transition. There is a clear need for port operators, especially pilots and tug operators, to acquire specific knowledge of current environmental regulations, both at national and international level. This involves not only understanding the rules, but also their correct application in daily operations, fully understanding their objectives and operational implications. Although not clearly stated in all case studies, it is important not only to provide training on international, European and national regulations that generally affect the sector in environmental matters but also to know the technical-operational ones that can regulate the implementation and adoption of specific practices.

The growing complexity of port operations and the transition to more sustainable practices require training that goes beyond technical or operational aspects, promoting an interdisciplinary approach. Indeed, the interaction among various stakeholders.

This interdisciplinary approach not only allows for a better understanding of the various factors influencing the sustainability of port operations but also enables the adaptation of strategies to meet the different needs of the involved parties. Training, therefore, should not be limited to teaching isolated technical skills, but should promote a global and integrated vision of the challenges and solutions, enhancing collaboration among all stakeholders.

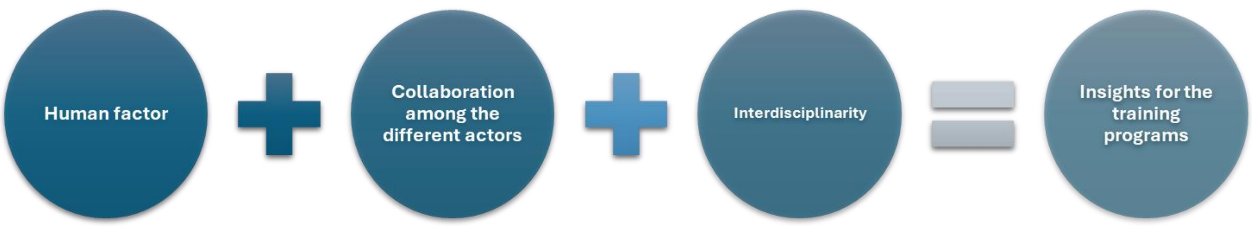
4.3 Discussion and implications

The added value of the analysis lies in its exploratory and demonstrative approach by connecting the theoretical dimension (the practices considered relevant) with the empirical one (the real case studies). Furthermore, the evidence collected highlights the importance of strengthening the enabling conditions, such as continuous training, collaboration between actors and institutional support, so that these practices can be replicated, scaled up and consolidated in a systemic perspective. The identified practices emerge as promising levers for a sustainable transition of technical-nautical services and the analysis of the case studies provides a solid basis to guide policies, investments and sectoral development paths.

The predominance of non-technological practices underlines how sustainability in technical-nautical services cannot ignore the human factor: training, participation and collaboration are essential levers to ensure the effective implementation of innovations. At the same time, technological practices show a high potential for direct environmental impact, representing key and effective tools in the ecological transition. Finally, it is evident that in some practices there is an integration between the two dimensions: for example, real-time data sharing and supply chain optimization (Pr.4, Pr.9) require digital technologies and the willingness of actors to collaborate. Therefore, the case studies demonstrate that the reduction of environmental impact in technical-nautical services cannot be based exclusively on the adoption of advanced technologies, but requires a profound change in the relational, organizational and training dynamics of the sector. The complementarity between technological and non-technological levers therefore represents the key to a sustainable and integrated transformation.

Overall, the analysis confirms the following important aspects:

- the human factor
- collaboration between different actors
- the interdisciplinarity.



The human factor is a key factor for the success of sustainability initiatives in port operations. The data highlights that the success of best practices is directly linked to the ability of staff to understand and optimise their use. This highlights the importance of technical training and promoting awareness of environmental impact and sustainability goals. For example, for operators to be able to use systems that optimise route planning and minimise emissions, they need to have a deep understanding of both the technology used and the wider operational context. Training must therefore evolve to include not only the technical aspects of using these systems, but also the wider operational strategies that lead to efficient, safe and sustainable port operations. Case studies demonstrate that changes in behaviour, attitudes and decision-making at all levels are necessary for a successful green transition. This requires staff to understand the long-term benefits of adopting sustainability practices and how they contribute to both operational efficiency and environmental responsibility. Continuous training of personnel is essential to ensure not only the effective adoption of new operational procedures aimed at reducing emissions, but also a conscious and efficient use of available technologies. Training programmes must therefore be designed to keep personnel updated on the latest technologies and operational methods. It also emerges that the effectiveness of these technologies is directly linked to the ability of personnel to understand and optimise their use. This underlines the importance of promoting awareness of environmental impacts and sustainability objectives by acting, through training, also on the attitudes of industry stakeholders and their decision-making processes at all levels.

Another key aspect highlighted by the case studies is the importance of collaboration between the different actors involved in the port operational chain. The interaction between port authorities, pilots, tug operators, shipping companies, regulatory agencies and industry associations serves as a strategic lever to overcome operational and regulatory barriers. Collaborative efforts have proven essential to align operational practices with regulatory standards, enabling ports to address sustainability challenges more effectively and consistently. Cooperation between port authorities and pilots can facilitate efficient vessel traffic management, optimizing route planning and reducing environmental impact. Similarly, collaboration between regulatory agencies and port operators ensures that sustainable initiatives comply with legal standards while achieving environmental goals. Case studies have shown that encouraging open dialogue and mutual support between stakeholders enables fruitful collaborations that allow for the easier identification of innovative solutions to the challenges posed by the ecological transition, supporting each actor in achieving sustainability objectives while respecting their own economic and operational interests and needs.

Another significant finding from the case studies is the value of interdisciplinarity for a successful transition towards sustainable port services. The integration of technical, managerial, environmental and regulatory knowledge is essential to design and implement effective solutions for the ecological transition of ports. This holistic approach enables ports to design solutions that are not only technically feasible, but also environmentally responsible, economically sustainable and in line with regulatory requirements. Furthermore, the interdisciplinary approach fosters innovation by bringing together different perspectives and is enabled by the participation of different stakeholders with different backgrounds and roles (e.g., engineers, environmental scientists, regulators and business managers). This approach also helps to ensure that sustainability practices are not only reactive, but proactive, anticipating challenges and addressing them in a comprehensive and integrated way.

The findings of this analysis therefore underline the need for continuous professional development, which is particularly important in a rapidly technologically evolving sector. Policy makers should prioritize the design and implementation of training programs that equip operators with the skills needed to use new technologies effectively while maintaining high standards of safety and environmental performance. It is desirable that policy makers, industry leaders and educational institutions work together to develop policies, strategies and training programs that address the full range of factors that influence sustainability in port operations.

Conclusions

The research aims to generate evidence-based recommendations for the development of curricula and professional training pathways. These recommendations aim to enable a concrete, effective and lasting transformation of operational behaviours in ports. The study, conducted in the context of Tasks 3.1 and 3.2, therefore contributes to the design of training strategies capable of equipping pilots, tug operators and other professionals in the sector with the necessary skills to adopt innovative and environmentally responsible practices.

The results of the analysis offer a comprehensive overview of the current state of sustainability in the port services sector, drawing on 18 detailed case studies provided by project partners across different European contexts. Some focus on high-tech solutions—such as the use of biofuels, augmented reality devices for navigation, or real-time emission monitoring systems—while others emphasise human and organisational dimensions, including sustainability reporting, regular engine maintenance, and structured training programmes for maritime pilots. Each case was analysed using a standardised tool, the Case Study Identification Sheet, which allowed for the collection of qualitative and quantitative data on objectives, implementation processes, environmental impacts, stakeholder engagement, and training implications. This methodological approach made it possible to detect common patterns and to highlight the enabling factors that influence the success or replicability of sustainable practices. Notably, the findings show that technological solutions, while promising, cannot reach their full potential without the parallel development of human capital and institutional collaboration. For example, the adoption of AR navigation tools in Livorno or continuous emission monitoring on tugboats is only effective when paired with dedicated training programmes, clear governance frameworks, and the willingness of operators to embrace new ways of working.

Looking ahead, the project will translate these findings into the development of training modules and pilot courses designed to address both current and emerging needs in the sector. These educational tools will target different audiences—from university students to experienced professionals—and will incorporate real-life case studies as core learning materials.

In terms of curriculum development, the study suggests that future training programmes should adopt an integrated approach, combining technical content (on green technologies, emission control, and digital tools) with soft skills related to environmental awareness, decision-making, and inter-organisational cooperation. Learning strategies should favour practical, experiential formats and promote peer-to-peer knowledge exchange. Ultimately, these recommendations aim to foster a professional culture in which sustainability is no longer an add-on, but rather the starting point for all operational, technological, and strategic decisions in the maritime-port ecosystem.

Finally, any future development and deepening of the presented analysis could be oriented to fill the gap represented by the absence of case studies concerning Practice No. 13 (Accurate route planning) caused by the lack of documented experiences among the partners. Practice No. 13 (Accurate Route Planning) proposes a strategic solution that introduces new ways of working; therefore, it should not be neglected. This suggests the opportunity to deepen this area in future phases by promoting the involvement of further actors outside the project partnership to guarantee a comprehensive coverage of the whole range of practices identified within the project.

References

Acciaro M., Ghiara H., Cusano M.I. (2014), "Energy Management in Seaports: A New Role for Port Authorities", Energy Policy. vol.71, pp 4–12

Acciaro, M., Vanelslander, T., Sys, C., Ferrari, C., Roumboutsos, A., Giuliano, G., Lam, J.S.L., And S. Kapros. (2014a), "Environmental sustainability in seaports: a framework for successful innovation." Maritime Policy & Management. vol.4 n.5, pp.480-500.

Arduino, G., R. Aronietis., Y. Crozet., K. Frouws., C. Ferrari., L. Guihéry., S. Kapros, Et Al. (2013), "How to Turn an Innovative Concept into a Success? An Application to Seaport-Related Innovation." Research in Transportation Economics. vol.42, n.1, pp. 97–107.

SRM (2023). Italian Maritime Economy. Porti, shipping e logistica al centro dei nuovi scenari del Mediterraneo. 10 anni di analisi, dati e riflessioni sulla competitività del settore e sul ruolo dell'Italia

www.consilium.europa.eu

www.imo.org

Sheth, M. (2022). AR Pilot Navigation (Deliverable No. D4.3, Version 1.0, PortForward project). TeamViewer, ADSP-MTS. (Case #1).

Fratelli Neri's Sustainability Report 2023 (Caso #2)

Svitzer first biofuel pilot project press release (Caso #5)

Svitzer achieves UK green scheme accolade (Caso #5)

Svitzer, Caterpillar collaborate on biofuel pilots (Caso #5)

Svitzer press release on its new strategy to become fully carbon neutral by 2040 (Caso #5)

Svitzer and Caterpillar team up to test 100% biofuel operation press release

UECC teams up with Svitzer on biofuels in tug operations

ETA EMPA Recommendations for Energy Efficient Harbour Towage https://www.youtube.com/watch?v=y1yba1AOL1E (Case #6)

https://aqicn.org/station/@96565/ (Caso #7) https://portfleet99.com/en (Caso #7)

https://www.vtc-bg.com/services.html (Caso #7)

https://varnapilots.com/aboutus_en.html (Caso #7)

Pilotage Technology - A look inside a Pilot's technology toolkit (Case #8)

Pilot Training - Port Technology International (Case #8)

10 Smart Ship Technologies For The Maritime Industry - Marine Insight (Case #8)

Top 10 Trends in Maritime Industry (2025) | StartUs Insights (Case #8)

8 Technology Trends Transforming the Maritime Industry (Case #8)

Smart Shipping and Maritime Technology News - Seatrade Maritime (Case #8)

Latest Maritime Industry Updates (Case #8)

Top Emerging Trends Transforming the Maritime Transportation (Case #8)

How AI Is Changing the Maritime Industry - Maritime Institute of ... 10. 10 ways AI is being used in Marine Industry [2025] (Case #8)

The Role of AI in Port Management - Thetius (Case #8)

AI-Powered Ports: Unlocking Efficiency, Sustainability, and Innovation (Case #8)

www.ardentlearning.com/blog/what-is-the-kirkpatrick-model (Case #8)

www.ardentlearning.com/blog/how-to-boost-the-roi-of-training-and-learning programs (Case #8)

Pilot Training - Port Technology International (Case #9)

Maritime Simulation and Resource Centre (MSRC) - Training programs (Case #9)

MSRC - Port Technology International (Case #9)

Environment, Social, Governance, and Sustainable Development Action ... (Case #9)

The Port of Québec's Sustainable Development Approach (Case #9)

Maritime Simulation and Resource Centre (MSRC) - Training programs (Case #9)

Pilot Training - Port Technology International (Case #9)

Port of Quebec Sustainable Development Plan (Case #9)

Port of Quebec Press Release on Decarbonization (Case #9)

The Port of Québec's Sustadnable Development Approach (Case #9)

Sustadnable Development Plan: the Port of Québec Focuses on ... (Case #9)

Marine Pilotage in Canada: A Cost Benefit Analysis (Case #9)

The Economic Impact of Pilotage on Port Operations (Case #9)

Maritime Simulation and Resource Centre (Case #9)

Maritime Simulation And Resource Centre (Case #9)

Maritime Simulation and Resource Centre (MSRC) - Training programs (Case #9)

Hayton, M. (2023). Marine Electrification is the Future: A Tugboat Case Study. In: Li, Y., Hu, Y., Rigo, P., Lefler, F.E., Zhao, G. (eds) Proceedings of PIANC Smart Rivers 2022. PIANC 2022 (Case #10)

Lecture Notes in Civil Engineering, vol 264. Springer, Singapore. https://doi.org/10.1007/978-981-19-6138-0_77 (Case #10)

Tugboats Powered by Ammonia, https://apnews.com/article/ammonia-fuel-diesel-amogyshipping-60beccfb8894c79ddc624026fbf0a8e5 (Case #10)

Electric Propulsion Solutions for Tugboats, https://medha.com/electric-propulsion-solution-fortugboats/ (Case #10)

A Green Solution to BUSAN Port, https://www.kongsberg.com/maritime/feature_articles/2025/2/a-green-solution-for-busan-port/ (Case #10)

Techno-economic investigation of alternative propulsion systems for tugboats, Istanbul Technical University, *Student thesis: Master's thesis, https://research.itu.edu.tr/en/studentTheses/techno-economic-investigation-of-alternativepropulsion-systems-f/* (Case #10)

Optimization of Tugboat Propulsion System Configurations: A Holistic 2 Life Cycle Assessment Case Study Haibin Wang, Peilin Zhou, Yibo Liang, Byongug Jeong, Ana Mesbahi, https://strathprints.strath.ac.uk/71632/1/Wang_etal_JCP_2020_Optimization_of_tugboat_propulsion_system_configurations (Case #10)

First Environmentally Friendly Next-Generation Electric Propulsion Ship System in Japan System integration enabling to reduce CO2 emissions by 30%,

https://www.ihi.co.jp/en/technology/techinfo/contents_no/1201051_13586.html (Case #10)

Challenges and Triumphs: Electrifying the Future of Tugboat Design, https://pepmobile.org/electrifying-the-future-of-tugboat-design/ (Case #10)

The benefits of electric tugboats - TT Club, https://www.ttclub.com/news-and-resources/casestudies/ (Case #10)

case-studies-new/case-study-the-benefits-of-electric-tug-boats/ (Case #10)

The Hydrogen Zero-Emission Tugboat Project Final Project Report (Case #10)

New zero-emissions tug could be tested in the ports of LA, Long Beach (Case #10)

The Hydrogen Zero-Emission Tugboat Project Final Project Report (Case #10)

Tug Industry Embraces Electric Propulsion for Sustainable Future (Case #10)

LA Waterfront (Case #10)

15 Port Rebates and Incentives Every Shipowner Should Know About (Case #10)

Sustainable Technologies and Green Ports – Maritime Education (Case #10)

MINIMAL project reaches experimental stage on the road to reduce … (Case #10)

Filimon, D., Rosca, E., & Rusca, F. V. (2023). Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm. Sustainability, 15(22), 15787. https://doi.org/10.3390/su152215787 (Case #14)

Technical sheet source: https://www.prio.pt/downloads/file295_pt.pdf (Case #11)

https://portodeaveiro.pt/noticia/pt/488 (Case #11)

In order to analyze various cases and ensure accurate representation of best practices, minimal AI support was employed for the identification and analysis of the cases.

Annexes

Table 23 - Driving factors vs Direct impacts & KPI

ID	TITLE	PRACTICE	DIRECT IMPACT	DRIVING FACTOR	KPI AND MEASURES
Case #1	*AR Pilot Navigation Aid: enhancing efficiency and safety at the port of Livorno*	4, 14	Improved communication between pilots and ground crews Improved safety and decision-making for port pilots Enhanced operational efficiency and reduced resource wastage	Operation efficiency Safety of the operations	Reduction of response times in critical situations Reduction of incidents due to human error
Case #2	*Sustainability reporting as a driver for operational efficiency and environmental responsibility*	12	Enhanced transparency and accountability Identification of gaps and potential risks in environmental, social, and governance areas	Market demand Stakeholder expectations Compliance with environmental regulations	Environmental performance Social performance Governance performance
Case #3	*Continuous monitoring of emissions during operations*	6	Emission reduction	Compliance with environmental regulations	Reduction of emissions
Case #4	*Regular maintenance of tugboat engines*	15	Energy efficiency Reduction of operational costs Emission reduction	Compliance with environmental regulations Cost optimization	Engine performance (e.g., exhaust gas temperature, cylinder pressure, and the air-fuel ratio)
Case #5	*Use of biofuels in tugboats by Svitzer and development of a new business model, EcoTow*	16	Emission reduction	Financial incentives Market demand	Reduction of emissions
Case #6	*Energy Efficient Harbour Towage and Pilotage*	1	Energy efficiency Behavioral change	Proactive approach to change Environmental and social responsibilities	Not specified
Case #7	*Sailing toward sustainability: green port of Varna*	14	Fuel consumption reduction Operation Efficiency Reduction of operational costs Compliance with environmental regulations Strengthening collaboration among key actors	Environmental Responsibility Emission Reduction Compliance with environmental regulation Cost Savings Industry Competitiveness Stakeholder Collaboration Operational Optimization	CO2 emissions NOx emissions Daily Fuel consumptions Daily Operational Costs Engine Running Times
Case #8	*Continuous training and updates for pilots in port of Rotterdam*	7	Emission reduction Energy efficiency Reduction of operational costs	Need for improved navigation efficiency Compliance with environmental regulations	Fuel consumption Optimized vessel movements Lower environmental impact
Case #9	*Enhancing Maritime Pilot Training at the Port of Quebec*	7	Improved pilot proficiency Reduced navigation incidents Enhanced port safety	Safety of the operations Environmental responsability	Fuel Consumption Emissions Data Incident Reports Environmental Impact Assessments Operational Efficiency Metrics
Case #10	*Technological solution – Implementation of eco-friendly propulsion systems for tugboats in ports*	8	Emission reduction Lower fuel consumption Reduced noise pollution	Emission reduction Compliance with environmental regulations	Emission Levels Fuel Consumption Operational Efficiency Air Quality
Case #11	*Demonstration of the use of biofuel in the pilot boats of the Port of Aveiro to promote the reduction of greenhouse gas emissions in a port.*	2,5	Reduction of GHG emissions Validation of biofuel feasibility Lower carbon footprint in port operations Collaboration with other ports	Compliance with environmental regulations Operational Feasibility Cost-Effectiveness Inter-Port Collaboration	Annual fuel consumption Annual engine running time CO_2eq. emissions Engine performance (Efficiency, maintenance requirements) Validation by a specialist company in maritime engineering and environmental solutions for B15 use, based on engine technical features (brands, models, power, and other specifications). Reduction of fuel consumption (Biofuel B15 vs. marine diesel B0) [Liters/year] Potential scalability analysis for other port vessels
Case #12	*Implementing a training program for sustainable navigation in the port of Aveiro: promoting slow steaming for environmental and economic benefits*	3	Enhance energy-efficient navigation Emission reduction Lower fuel consumption Behaviuoral change Improved compliance with environmental regulations Awareness of sustainable maritime practices	Compliance with environmental regulations Economic efficiency Market demand Operational benefits	Fuel consumption per operation Average engine running time [h/day or h/month]. Average and maximum speeds of the pilot boats and tugs in different operational scenarios (e.g., approaching/departing of ships, escorting, idling). Daily operating acceleration and deceleration rates. Estimated CO_2 and other greenhouse gas emissions (based on fuel consumption and engine efficiency). Air quality measurements in the port area, where applicable. Initial understanding of energy-efficient navigation concepts (measured through a pre-training questionnaire) Increased understanding of sustainable navigation strategies. Self-reported changes in behaviour and attitudes toward slow steaming. Feedback from skippers, pilots, and tug operators on the training's applicability and areas for further improvement.
Case #13	*Minimization of engine running time - Port of Constanta*	10	Emissions reduction Reduction of operational costs Compliance with environmental regulations	Enhancing environmental sustainability Economic benefits	Fuel consumptions Fuel costs Reduction of CO2 emissions
Case #14	*Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm*	11	Reduced fuel consumption Operational efficiency Lowered CO_2 emissions	Compliance with environmental regulations Financial constraints Operational efficiency	Fuel consumption Emission reductions Optimized speeds
Case #15	*Use of real time sensor data of tugboats to reduce fuel consumption*	4	Reduce fuel consumptions	Cost reduction Environmental benefits	Fuel consumption measures
Case #16	*Use of a navigation simulator to assess the human factor on fuel consumption*	17	Quantify the effect of experience and training on fuel consumption to optimize simulator-based training programs Identify behavioral factors influencing fuel consumption Training to reduce energy consumption	Cost reduction Enhancing awareness of fuel consumption patterns	Ship parameters over time
Case #17	*Gisaş Case Study: World's Largest Zero-Emission Tugboat Fleet*	8	Zero-emission 30% total fuel cost savings (energy savings). 86% total maintenance and repair cost savings. No waste heat of exhaust. 23% less noise than their diesel-powered counterparts.	Operational efficiency Environmental benefits Reduced noise pollution Good working condition for crew	Total operating time (days) Total number of operations (missions) Total electric engine running hours Hours spent on maintenance and repair CO_2 emissions avoided (tons) NO_x emissions avoided (tons)
Case #18	*Best practice - Port of Constanta (Romania)*	9	Reducing waiting times for ships or goods Preventing congestion and operational overloads Emissions reduction Reduction of operational costs Alignment with green port practices and policies for reducing the port's carbon footprint	Institutional and financial support Strategic sustainability planning Participation in innovation projects Emission monitoring and digitalization	Carbon footprint audit

Table 24 - Training needs

ID	TITLE	PRACTICE	TRAINING NEEDS		
			Technical	*Operationanal*	*Regulatory*
Case #1	AR Pilot Navigation Aid: enhancing efficiency and safety at the port of Livorno	4, 14	Managing AR devices and interpreting GPS and sensor data. .	Using "smart glasses" and interacting with data.	Understanding the sustainability benefits of operations
Case #2	Sustainability reporting as a driver for operational efficiency and environmental responsibility	12	Collection, analysis, and management of data related to sustainability performance indicators (KPIs). Use of digital tools for monitoring and reporting.	Coordination of information flows between different company departments. Management of timelines and deadlines for report publication.	Up-to-date knowledge of applicable environmental regulations in the maritime sector (e.g., pollution prevention, energy efficiency). Continuous training on legislative updates in the ESG (Environmental, Social, Governance) field.
Case #3	Continuous monitoring of emissions during operations	6	Familiarity with the operational features of the monitoring system for emissions and environmental parameters. Ability to configure system settings for accurate data collection.	Understanding the System Functionality Data Interpretation Ability to generate comprehensive and accurate reports for regulatory bodies, stakeholders, and internal use. Ability to regularly analyze collected data and compare it against national and international regulatory limits	In-depth understanding of environmental regulations governing the maritime sector, particularly MARPOL. Awareness of the latest developments in maritime environmental law and its practical implications for reporting and operations.
Case #4	Regular maintenance of tugboat engines	15	Engine maintenance and calibration Ability to use digital systems for automatic data logging and performance analysis through predictive algorithms	Maintenance planning Comparative analysis between actual data and parameters from the Engine Technical File (ETF)	Management of compliance documentation Knowledge of maintenance and inspection requirements for these systems
Case #5	Use of biofuels in tugboats by Svitzer and development of a new business model, EcoTow	16	Adjustment of onboard operational practices with biofuels	Implementation of maintenance guidelines provided by manufacturers (e.g., CAT).	Environmental regulations
Case #6	Energy Efficient Harbour Towage and Pilotage	1	Training courses designed to address the gaps in our current knowledge and sustainability practices		
Case #7	Sailing toward sustainability: green port of Varna	14	Multidisciplinary approach, integrating technical knowledge, operational efficiency, regulatory compliance, financial planning, and stakeholder collaboration		
Case #8	Continuous training and updates for pilots in port of Rotterdam	7	Digital navigation Navigational skills and safety awareness Technological Advancements Portable Pilot Units Simulation Technology Artificial Intelligence, Internet of Things, Big Data analytics, Cybersecurity, Energy-Efficient Technologies Maritime Robotics Blockchain technology Predictive maintenance	Vessel manoeuvring Decision-making and emergency response capabilities Emergency Response and Crisis Management Human Factors and Crew Resource Management	Environmental regulations
Case #9	Enhancing Maritime Pilot Training at the Port of Quebec	7	Familiarity with simulation technology	Expertise in maritime navigation	Environmental regulations
Case #10	Technological solution – Implementation of eco-friendly propulsion systems for tugboats in ports	8	Expertise in eco-friendly propulsion systems Expertise in electric propulsion maintenance Energy management	Sustainable maritime operations Safety and emergency procedures Advanced navigation and manoeuvring techniques	IMO guidelines, MARPOL Annex VI, and other relevant regulations
Case #11	Demonstration of the use of biofuel in the pilot boats of the Port of Aveiro to promote the reduction of greenhouse gas emissions in a port.	2,5	Expertise in fuel conversion and engine performance assessment Specialized third-party certification of engines for biofuel use to ensure compliance with safety and performance standards	Collaboration within the port community	Understanding of maritime emissions regulations and sustainability policies
Case #12	Implementing a training program for sustainable navigation in the port of Aveiro: promoting slow steaming for environmental and economic benefits	3	Understanding the dynamics of vessel speed control and fuel consumption. Focus on real-world application of slow steaming in daily operations	Sustainable navigation strategies Interactive training modules to simulate fuel savings at different RPM levels. Data-driven decision-making using case studies	EU and IMO sustainability goals
Case #13	Minimization of engine running time - Port of Constanta	10	//	Reinforce the environmental importance of shore power usage.	Environmental regulations
Case #14	Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm	11	Understanding of optimization algorithms Data analysis	Interpretation of weather data and fuel consumption parameters Experience in teamwork	Environmental regulations
Case #15	Use of real time sensor data of tugboats to reduce fuel consumption	4	Technical skills for sensor installation and maintenance.	Operational knowledge of tugboat activities and energy efficiency. Environmental awareness and behavioral adaptation by the crew.	Environmental regulations
Case #16	Use of a navigation simulator to assess the human factor on fuel consumption	17	Basic knowledge of ship maneuvering and navigation.		Environmental regulations
Case #17	Gisaş Case Study: World's Largest Zero-Emission Tugboat Fleet	8	Lithium-ion battery technologies Smart Tug Energy Management System (STEMS) Maintenance of electric propulsion systems Charging infrastructure	Onboard safety Electric tugboat piloting Mission planning	Environmental standards and certifications Funding and incentives ocal port regulations
Case #18	Best practice - Port of Constanta (Romania)	9	System Navigation & Data Entry Inventory Control & Accuracy Automated Picking & Packing Integration with IoT & AI Warehouse Layout Optimization Troubleshooting & System Recovery Cybersecurity Awareness Automation & Robotics Coordination	Automated Weighing System Operation Data Interpretation & Transmission Equipment Calibration & Maintenance Safety & Load Balancing Data Analysis & Decision Making Operational Efficiency Strategies	Regulatory Compliance & VGM Protocols

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Table 25 - Synthesis matrix

PARTNER	ID	TITLE	PRACTICE	COUNTRY	DIRECT IMPACT	DRIVING FACTOR	KPI AND MEASURES	STAKEHOLDER INVOLVED	TIMELINE	TRAINING NEEDS		
										Technical	*Operationanal*	*Regulatory*
MARTE	Case #1	**AR Pilot Navigation Aid: enhancing efficiency and safety at the port of Livorno**	4, 14	Italy	Improved communication between pilots and ground crews Improved safety and decision-making for port pilots Enhanced operational efficiency and reduced resource wastage	Operation efficiency Safety of the operations	Reduction of response times in critical situations Reduction of incidents due to human error	Port Authority Pilots Technical support provider). Port operators	October 2021 - 2022	Managing AR devices and interpreting GPS and sensor data.	Using "smart glasses" and interacting with data.	Understanding the sustainability benefits of operations
MARTE	Case #2	**Sustainability reporting as a driver for operational efficiency and environmental responsibility**	12	Italy	Enhanced transparency and accountability Identification of gaps and potential risks in environmental, social, and governance areas	Market demand Stakeholder expectations Compliance with environmental regulations	Environmental performance Social performance Governance performance	Stakeholders (i.e., institutional bodies, customers, employees, suppliers, and local communities) Board of Directors Operational personnel, including tugboat crews	2021 - 2022	Collection, analysis, and management of data related to sustainability performance indicators (KPIs). Use of digital tools for monitoring and reporting.	Coordination of information flows between different company departments. Management of timelines and deadlines for report publication.	Up-to-date knowledge of applicable environmental regulations in the maritime sector (e.g., pollution prevention, energy efficiency). Continuous training on legislative updates in the ESG (Environmental, Social, Governance) field.
UNIRI	Case #3	**Continuous monitoring of emissions during operations**	6	Spain	Emission reduction	Compliance with environmental regulations	Reduction of emissions	Pilots and tugboat operators	Not specified	Familiarity with the operational features of the monitoring system for emissions and environmental parameters. Ability to configure system settings for accurate data collection.	Understanding the System Functionality Data Interpretation Ability to generate comprehensive and accurate reports for regulatory bodies, stakeholders, and internal use. Ability to regularly analyze collected data and compare it against national and international regulatory limits	In-depth understanding of environmental regulations governing the maritime sector, particularly MARPOL. Awareness of the latest developments in maritime environmental law and its practical implications for reporting and operations.
UNIRI	Case #4	**Regular maintenance of tugboat engines**	15	Not specified	Energy efficiency Reduction of operational costs Emission reduction	Compliance with environmental regulations Cost optimization	Engine performance (e.g., exhaust gas temperature, cylinder pressure, and the air-fuel ratio)	Pilots and tugboat operators	//	Engine maintenance and calibration Ability to use digital systems for automatic data logging and performance analysis through predictive	Maintenance planning Comparative analysis between actual data and parameters from the Engine Technical File (ETF)	Management of compliance documentation Knowledge of maintenance and inspection requirements for these systems
ETA	Case #5	**Use of biofuels in tugboats by Svitzer and development of a new business model, EcoTow**	16	United Kingdom	Emission reduction	Financial incentives Market demand	Reduction of emissions	Crews and tug masters Technics providers Port and governmental authorities	2021	Adjustment of onboard operational practices with biofuels	Implementation of maintenance guidelines provided by manufacturers (e.g., CAT).	Understanding of maritime emissions regulations and sustainability policies
EMPA	Case #6	**Energy Efficient Harbour Towage and Pilotage**	1	European countries	Energy efficiency Behavioral change	Proactive approach to change Environmental and social responsibilities	Not specified	Pilots Port authorities Tugboat operators Crew members Other key players within the port community	2023 - ongoing	Training courses designed to address the gaps in our current knowledge and sustainability practices		
NVNA	Case #7	**Sailing toward sustainability: green port of Varna**	14	Bulgaria	Fuel consumption reduction Operational efficiency Reduction of operational costs Compliance with environmental regulations Strengthening collaboration among key actors	Environmental Responsibility Emission Reduction Compliance with environmental regulation Cost Savings Industry Competitiveness Stakeholder Collaboration Operational Optimization	CO2 emissions NOx emissions Daily Fuel consumptions Daily Operational Costs Engine Running Times	Towage Company Tugboat operators Pilots	2025	Multidisciplinary approach, integrating technical knowledge, operational efficiency, regulatory compliance, financial planning, and stakeholder collaboration		
PRU	Case #8	**Continuous training and updates for pilots in port of Rotterdam**	7	Belgium	Emission reduction Energy efficiency Reduction of operational costs	Need for improved navigation efficiency Compliance with environmental regulations	Before implementation Higher fuel consumption, inefficient navigation, increased emissions B. After implementation: Reduced fuel usage, optimized vessel movements, lower environmental impact	Port authorities Shipping companies Environmental agencies	ongoing	Digital navigation Navigational skills and safety awareness Technological Advancements Portable Pilot Units Simulation Technology Artificial Intelligence, Internet of Things, Big Data analytics, Cybersecurity, Energy-Efficient Technologies Maritime Robotics Blockchain technology Predictive maintenance	Vessel manoeuvring Decision-making and emergency response capabilities Emergency Response and Crisis Management Human Factors and Crew Resource Management	Environmental regulations
PRU	Case #9	**Enhancing Maritime Pilot Training at the Port of Quebec**	7	Canada	Improved pilot proficiency Reduced navigation incidents Enhanced port safety	Safety of the operations Environmental responsability	Fuel Consumption Emissions Data Incident Reports Environmental Impact Assessments Operational Efficiency Metrics	Pilots Port authorities Shipping companies Local government agencies	2010 - ongoing	Familiarity with simulation technology	Expertise in maritime navigation	Environmental regulations
PRU	Case #10	**Technological solution – Implementation of eco-friendly propulsion systems for tugboats in ports**	8	USA	Emission reduction Lower fuel consumption Reduced noise pollution	Emission reduction Compliance with environmental regulations	Emission Levels Fuel Consumption Operational Efficiency Air Quality	Port authorities Tugboat operators Environmental agencies Technology providers	2019 - ongoing	Expertise in eco-friendly propulsion systems Expertise in electric propulsion maintenance Energy management	Sustainable maritime operations Safety and Emergency Procedures Advanced Navigation and Manoeuvring Techniques	IMO guidelines, MARPOL Annex VI, and other relevant regulations
APA	Case #11	**Demonstration of the use of biofuel in the pilot boats of the Port of Aveiro to promote the reduction of greenhouse gas emissions in a port.**	2,5	Portugal	Reduction of GHG emissions Validation of biofuel feasibility Lower carbon footprint in port operations Collaboration with other ports	Compliance with environmental regulations Operational Feasibility Cost-Effectiveness Inter-Port Collaboration	Annual fuel consumption Annual engine running time CO_2eq. emissions Engine performance (Efficiency, maintenance requirements) Validation by a specialist company in maritime engineering and environmental solutions for B15 use, based on engine technical features (brands, models, power, and other specifications). Reduction of fuel consumption (Biofuel B15 vs. marine diesel B0) [Liters/year] Potential scalability analysis for other port vessels	Port authority Pilots and tugboat operators Fuel suppliers and technology providers Port networks (Ports, ESPO, etc.)	2022 - ongoing	Expertise in fuel conversion and engine performance assessment Specialized third-party certification of engines for biofuel use to ensure compliance with safety and performance standards	Collaboration within the port community	Understanding of maritime emissions regulations and sustainability policies
APA	Case #12	**Implementing a training program for sustainable navigation in the port of Aveiro: promoting slow steaming for environmental and economic benefits**	3	Portugal	Enhance energy-efficient navigation Emission reduction Lower fuel consumption Behavioural change Improved compliance with environmental regulations Awareness of sustainable maritime practices	Compliance with environmental regulations Economic efficiency Market demand Operational benefits	Fuel consumption per operation Average engine running time (h/day or h/month). Average and maximum speeds of the pilot boats and tugs in different operational scenarios (e.g., approaching/departing of ships, escorting, idling). Daily operating acceleration and deceleration rates. Estimated CO_2 and other greenhouse gas emissions (based on fuel consumption and engine efficiency). Air quality measurements in the port area, where applicable. Initial understanding of energy-efficient navigation concepts (measured through a pre-training questionnaire). Increased understanding of sustainable navigation strategies. Self-reported changes in behaviour and attitudes toward slow steaming. Feedback from skippers, pilots, and tug operators on the training's applicability and areas for further improvement.	Port authority Pilots and tugboat operators Shipping companies Regulatory Agencies Industry associations	2025 - 2026	Understanding the dynamics of vessel speed control and fuel consumption. Focus on real-world application of slow steaming in daily operations. Interactive training modules to simulate fuel savings at different RPM levels. Emphasizing data-driven decision-making using case studies from vessels like the Espinheiro (See table 1).	Sustainable navigation strategies	Knowledge of EU and IMO sustainability goals
CMU	Case #13	**Minimization of engine running time - Port of Constanta**	10	Romania	Emissions reduction Reduction of operational costs Compliance with environmental regulations	Enhancing environmental sustainability Economic benefits	Fuel consumptions Fuel costs Reduction of CO2 emissions	Port Administration Towing companies Tugboats crew	Not specified	//	Reinforce the environmental importance of shore power usage.	Understanding of maritime emissions regulations and sustainability policies
MARTE	Case #14	**Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm**	11	Romania	Reduced fuel consumption Operational efficiency Lowered CO_2 emissions	Compliance with environmental regulations Financial constraints Operational efficiency	Fuel consumption Emission reductions Optimized speeds	Researchers Ship operators Port Authorities and offshore platforms	2023-2024	Understanding of optimization algorithms Data analysis	Interpretation of weather data and fuel consumption parameters Experience in teamwork	Environmental regulations
AMA	Case #15	**Use of real time sensor data of tugboats to reduce fuel consumption**	4	Belgium	Reduce fuel consumptions	Cost reduction Environmental benefits	Fuel consumption measures	Port Administration Towing companies Tugboats crew	Not specified	Technical skills for sensor installation and maintenance.	Operational knowledge of tugboat activities and energy efficiency. Environmental awareness and behavioral adaptation by the crew.	Understanding of maritime emissions regulations and sustainability policies
AMA	Case #16	**Use of a navigation simulator to assess the human factor on fuel consumption**	17	Belgium	Quantify the effect of experience and training on fuel consumption to optimize simulator-based training programs. Identify behavioral factors influencing fuel consumption. Define essential elements for training to reduce energy consumption effectively.	Cost reduction Enhancing awareness of fuel consumption patterns	Ship parameters over time	Pilots and tugboat masters Commercial vessel officers Maritime students will be invited to participate.	2025	Basic knowledge of ship maneuvering and navigation.		Environmental regulations
PRU	Case#17	**Gisaş Case Study: World's Largest Zero-Emission Tugboat Fleet**	8	Turkey	Zero-emission 30% total fuel cost savings (energy savings). 86% total maintenance and repair cost savings. No waste heat of exhaust. 23% less noise than their diesel-powered counterparts.	Operational efficiency Environmental benefits Reduced noise pollution Good working condition for crew	Total operating time (days) Total number of operations (missions) Total electric engine running hours Hours spent on maintenance and repair CO_2 emissions avoided (tons) NO_x emissions avoided (tons)	Port authority Pilots and tugboat operators Shipyard Port operators	2019 - 2020	Lithium-ion battery technologies Smart Tug Energy Management System (STEMS) Maintenance of electric propulsion systems Charging infrastructure	Onboard safety Electric tugboat piloting Mission planning	Environmental standards and certifications Funding and incentives ocal port regulations
CMU	Case#18	**Best practice - Port of Constanta (Romania)**	9	Romania	Reducing waiting times for ships or goods Preventing congestion and operational overloads Emissions reduction Reduction of operational costs Alignment with green port practices and policies for reducing the port's carbon footprint	Institutional and financial support Strategic sustainability planning Participation in innovation projects Emission monitoring and digitalization	Carbon footprint audit	Logistic company Maritime transport connected services providers part of the group Port Administration	Not specified	System Navigation & Data Entry Inventory Control & Accuracy Automated Picking & Packing Integration with IoT & AI Warehouse Layout Optimization Troubleshooting & System Recovery Cybersecurity Awareness Automation & Robotics Coordination	Automated Weighing System Operation Data Interpretation & Transmission Equipment Calibration & Maintenance Safety & Load Balancing Data Analysis & Decision Making Operational Efficiency Strategies	Regulatory Compliance & VGM Protocols

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