

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 analyzing case studies that exemplify best practices for behavioural 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 behavioural 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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1. GENERAL INFORMATION

A. **Case study title**

Optimization of fuel consumption for an offshore supply tug using a backtracking algorithm.

B. **Green practice implemented**

- **Practice 11: Optimization of operation speed**

- Navigational speed directly affects fuel consumption and emissions. The practice of eco-speed involves adjusting vessel speed to be as efficient as possible in relation to sea conditions, cargo load, and travel distance. This approach not only reduces emissions but also improves safety and stability during operations, as slower navigation often leads to fewer risks of accidents.

C. **Specific goals**

- Minimize fuel consumption for offshore supply tugboats.
- Reduce CO₂ emissions by optimizing cruising speed.
- Incorporate operational constraints (time limits, weather conditions, vessel loading) into the optimization process.

D. **Direct impact of the practice**

- Reduced fuel consumption by up to 13.4% in some scenarios.
- Lowered CO₂ emissions, contributing to environmental sustainability.
- Improved operational efficiency for older vessels unable to adopt expensive fuel-efficient technologies.

E. Place of implementation

Offshore supply voyages in the Black Sea region, with routes including stops at platforms like Istria block and ANA platform.

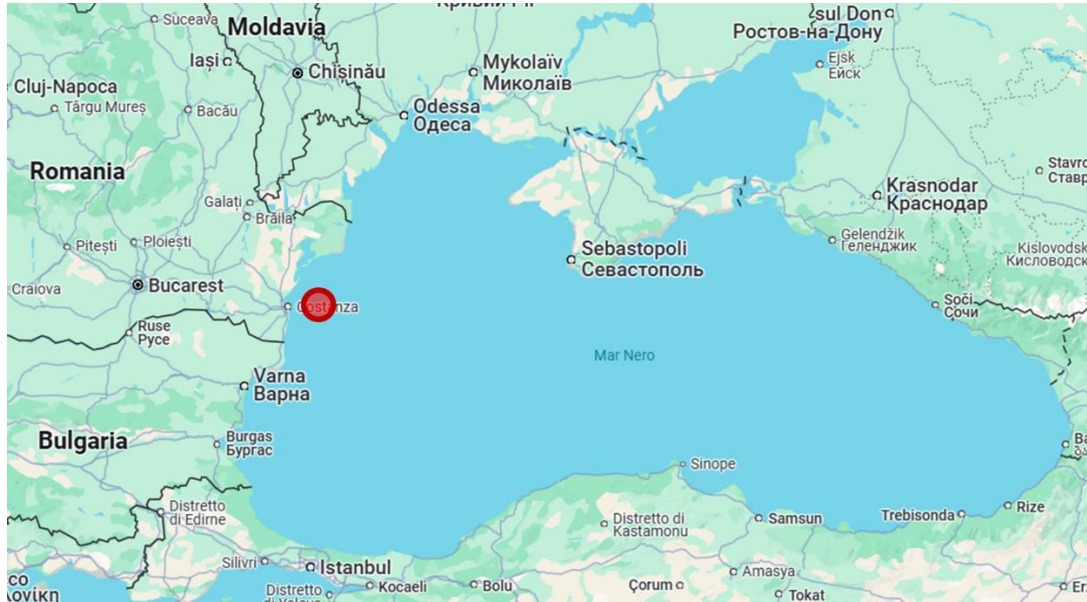


Figure 1 - Area of practice implementation

F. Start and end date or duration of the pilot project

Start in November 2023, end in February 2024.

2. CONTEXT AND DESCRIPTION

A. Description of the practice

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 performs a systematic exploration of all possible speed combinations, considering a set of operational constraints such as time limits, variable weather conditions, and vessel load. Throughout the process, unfeasible solutions are progressively eliminated (pruned), allowing the system to focus exclusively on speed profiles that are compatible with both operational and environmental objectives. This approach enabled the efficient identification of the optimal sequence of speeds along the various legs of the route, with the primary goal of minimizing fuel consumption. The methodology proved particularly effective in dynamic and complex offshore contexts, where environmental and logistical conditions can change rapidly, requiring a flexible, adaptable, and low-cost optimization model.

B. Driving factor behind the adoption of the green practice

One of the main drivers behind the adoption of the proposed practice is the increasingly stringent **international environmental regulations**, which require a significant reduction in greenhouse gas emissions within the maritime sector. According to the International Maritime Organization (IMO), shipping accounts for 2.89% of global CO₂ emissions, with projections indicating a potential increase of between 90% and 130% by 2050 if no corrective measures are implemented. In addition, there are significant **financial constraints**: many tugboats currently in operation—especially older ones—lack the financial resources needed to adopt advanced fuel-saving technologies. In this context, low-cost optimization tools—such as the proposed backtracking algorithm—represent a concrete and accessible alternative for improving energy efficiency without the need for expensive technological retrofits. Lastly, the need to ensure greater **operational efficiency** serves as a further incentive, particularly in the case of offshore support tugboats. These vessels are typically engaged in short routes with multiple stops and frequent speed variations—conditions that make fuel optimization essential for reducing operational costs and improving the environmental sustainability of maritime operations.

C. Stakeholders involved

A list of stakeholders actively involved in the case study:

- **Researchers:** Developed the backtracking algorithm and validated its effectiveness.
- **Ship operators:** Implemented the optimized speed strategies in real voyages.
- **Port Authorities and offshore platforms:** benefited from reduced emissions and improved scheduling.

3. IMPLEMENTATION

A. Description of the adopted practice

The case study addresses the need for more sustainable maritime operations, focusing specifically on offshore support vessels which, due to economic constraints, are often unable to adopt advanced energy-saving technologies. Within this context, an alternative approach was developed based on optimizing cruising speed through a backtracking algorithm, with the aim of reducing fuel consumption during coastal missions subject to operational and environmental constraints.

The project included the following three steps:

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

Phase 1 – Planning and Problem Modelling

The case study began with the identification of a concrete issue: many offshore supply vessels, particularly those of older construction, lacked access to modern energy-saving technologies, often due to economic constraints. In response, the focus was placed on optimizing fuel consumption during the mission of a Platform Supply Vessel (PSV), with the aim of reducing emissions and operational costs through an optimal speed selection strategy. The problem was addressed using a backtracking algorithm, a method typically employed in solving combinatorial problems, which proved particularly suitable for managing scenarios involving strict constraints and numerous discrete variables. The vessel's route was divided into distinct segments, each corresponding to a section between key waypoints, and characterized by specific distances, speed limitations, and operational conditions.

Phase 2 - Integration of environmental factors and model construction

Once the voyage structure had been defined, it became necessary to model fuel consumption as a function of speed and travel time for each individual segment. For this purpose, real data concerning the engine's fuel consumption curve were employed, based on the characteristics of the vessel under examination, an Anchor Handling Tug Supply (AHTS) equipped with two Caterpillar engines delivering a combined power output of 3200 kW. To enhance the realism of the model, environmental factors related to sea and weather conditions were incorporated. The empirical method proposed by Kwon (2008) was adopted to estimate speed losses caused by wind and waves, using the Beaufort scale and the direction of wave motion as reference parameters. This integration made it possible to simulate the vessel's behaviour under realistic operating conditions, even in the absence of real-time meteorological data. Additionally, a global time constraint was introduced, varying across the different scenarios (e.g., 24 or 32 hours), representing the maximum allowable duration of the mission in accordance with the operational time windows of the offshore platforms to be serviced.

Phase 3 - Numerical application and scenario analysis.

The developed model was applied to a real-world scenario involving a closed-loop coastal mission departing from and returning to the port of Constanța, with scheduled stops at two offshore platforms: Istria and ANA. The route, covering approximately 222 nautical miles, was divided into six main segments based on similar navigational characteristics. For computational efficiency, segments with quasi-identical conditions were grouped, and ten operational scenarios were defined by varying sea state (Beaufort scale levels from 1 to 3), vessel displacement, and time constraints (e.g., 24 or 32 hours).

For each scenario, the algorithm calculated the optimal speed for every segment, expressed in terms of engine lever position, to minimize fuel consumption while satisfying all imposed constraints. The reduction in actual speed due to environmental conditions was estimated using Kwon's empirical formula, allowing each segment's adjusted performance to reflect realistic operational conditions. The analysis demonstrated how increased voyage time limits enabled the selection of lower cruising speeds, resulting in significant fuel savings. It also highlighted the importance of dynamically adjusting vessel speed based on sea conditions and loading status. Overall, the application confirmed the effectiveness of the backtracking-based approach in supporting operational decisions, particularly in contexts where access to advanced onboard energy systems is limited.

B. Technologies used (if applicable)

Although the proposed solution does not involve the adoption of new hardware technologies or complex systems, it is based on an **intelligent combination of algorithmic tools, empirical formulas, and existing onboard functionalities**, making it particularly suitable for contexts where efficiency must be improved without substantial financial investment.

At the core of the approach lies the **backtracking algorithm**, a discrete optimization technique that systematically explores all possible speed combinations along the different segments of the tugboat's route. The algorithm evaluates each configuration against operational constraints—such as time limits, weather conditions, and vessel loading—and progressively discards incompatible options (through a mechanism known as *pruning*). This process enables the identification of the speed sequence that minimizes overall fuel consumption while maintaining service reliability. Supporting this optimization process is the **"Kwon formula"**, a well-established empirical method valued for its simplicity and effectiveness. It allows for the estimation of speed loss due to environmental factors—such as headwinds, wave action, and vessel displacement—without requiring detailed data about the hull geometry. Including this factor enables the algorithm to function under realistic operational conditions, thereby enhancing the accuracy of fuel consumption forecasts. Another essential component is the use of **onboard monitoring systems**, which provide real-time data on vessel speed and fuel usage. These systems, commonly available even on older tugboats, make it possible not only to validate the algorithm's recommendations

but also to initiate a virtuous cycle of continuous improvement, driven by comparisons between theoretical forecasts and actual performance.

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.

c. Competencies required

The **technical skills** acquired extend to a deep understanding of optimization algorithms, which are essential for the management and improvement of maritime operations. With this experience, advanced solutions can be applied to resource management, optimizing operations at sea to ensure high efficiency and minimize operational costs. In addition, the ability for **data analysis** has been significantly developed, with particular attention to the accurate interpretation of weather data and fuel consumption parameters. This expertise allows for real-time monitoring of navigation conditions and the adaptation of operational strategies, leading to more informed and targeted decisions for overall efficiency.

Another crucial aspect is the optimization of operational performance, which is achieved not only through data analysis but also through the use of advanced technologies that help predict and improve long-term performance. Finally, **experience in teamwork** has been refined through continuous coordination between researchers, ship operators, and port authorities. Such interaction is essential to ensure that all operational phases are well-integrated and that decisions are made collaboratively, creating an optimized workflow and efficient management of resources and maritime operations

4. COLLECTED DATA

Secondary source analysis did not provide data on the *Key Performance Indicators* (KPIs) that should have monitored the ex-post effects of the devices supporting pilots and tugboats. The absence of such data prevents a quantitative assessment of the effectiveness of the adopted technologies, limiting the analysis to qualitative aspects or preliminary considerations. A systematic collection of KPIs would have been essential to measure the concrete impact of the implemented solutions in terms of operational efficiency, safety, and response times. However, the following section presents some reflections on the critical issues that existed before the introduction of the devices and the tangible benefits resulting from their use.

A. Before implementation

- **Baseline fuel consumption:** Data from unoptimized voyages at fixed speeds (e.g., 13 knots).
- **Operational phases:** 65% of fuel consumed during cruising/slow transit phases.

The **baseline fuel consumption** was determined through the analysis of data collected during non-optimized voyages, carried out at fixed speeds, such as 13 knots. This data serves as a benchmark for assessing operational efficiency before the introduction of optimized solutions. This approach allowed for the identification of areas where energy consumption could be reduced. Specifically, it was found that **65% of fuel** is consumed during the **cruising** and **slow transit** phases, which are the longest and least efficient operational phases in terms of fuel consumption. These phases, including cruising at reduced speeds or transiting through port areas, are particularly energy-intensive and significantly contribute to the overall fuel usage. This scenario suggests that targeted interventions in speed and route management during these phases could lead to a substantial reduction in consumption, thereby enhancing operational sustainability. Additionally, the analysis of these data highlighted the importance of adopting advanced technological solutions to continuously monitor and optimize operations, improving overall efficiency and contributing to long-term sustainability goals.

B. After implementation:

- **Optimized speeds:** Varied speeds (e.g., 9–12.8 knots) based on segments and weather.
- **Fuel savings:** Up to 13.4% reduction in fuel consumption.
- **Emission reductions:** Lower CO₂ emissions due to optimized speeds.

The adoption of **optimized speeds** involved using various speeds, adjusted based on travel segments and weather conditions, with the goal of maximizing operational efficiency at every stage of navigation. Specifically, speeds were adjusted between 9 and 12.8 knots, adapting to the specific characteristics of the route, such as sea conditions, wind direction, and other environmental factors that influence resistance and energy consumption. This strategy led to significant **fuel savings**, with a reduction in consumption of up to 13.4%. Thanks to these

adjustments, fuel usage was optimized during different phases of the journey, thereby reducing operational costs without compromising travel times.

Moreover, the adoption of optimized speeds had a positive environmental impact, resulting in a **reduction in CO₂ emissions**. In fact, the improved fuel efficiency led to a lower production of greenhouse gases, contributing to more sustainable navigation. The combination of intelligent speed management and the use of advanced technologies for real-time monitoring made it possible not only to control operating costs but also to achieve significant improvements in environmental performance. This integrated approach demonstrated how optimizing operations can generate tangible benefits both economically and ecologically, addressing the growing sustainability demands in the maritime sector

5. ECONOMIC AND ENVIRONMENTAL ANALYSIS (*IF THE INFORMATION IS ACCESSIBLE*)

A. Initial investment required

The method is **low-cost**, as it relies on the use of advanced **software algorithms** and the **existing onboard systems** of vessels. This characteristic makes the solution particularly advantageous, as it allows for the implementation of innovative technologies without the need for significant investments in new devices or infrastructure. By utilizing resources already available, such as navigation and control systems, it is possible to enhance operational performance with relatively low costs.

Moreover, the approach leverages the computational power of **software algorithms**, which, combined with real-time data collected from onboard systems, enables the optimization of operations without the need for complex structural interventions. This not only reduces the initial implementation costs but also facilitates the adoption of the technology by companies with limited budgets or those that prefer to avoid invasive modifications. The flexibility of this system allows it to be easily adapted to different types of vessels and operations, ensuring that the solution is scalable and can be applied in various contexts, thus contributing to the continuous improvement of maritime operations at a cost-effective level.

B. Key savings or economic impact

- **Fuel cost savings:** reduced fuel use translates to lower operational costs.
- **Extended engine life:** lower speeds reduce wear and tear on engines.

Fuel cost savings represent one of the main advantages of optimizing operations. By reducing fuel consumption, significant **operational cost reductions** are achieved, directly impacting company finances. This reduction in energy usage not only allows for daily savings but also has a positive effect on **long-term economic efficiency**, as it reduces fixed costs and allows for more sustainable financial planning for long-term operations.

At the same time, the adoption of **reduced speeds** has an equally positive impact on the lifespan and reliability of the engines. Operating at lower speeds reduces mechanical wear and tear, helping to keep engines in good condition for longer. This not only **extends the useful life of the engines** but also decreases the need for **extraordinary maintenance** and **expensive component replacements**, which often involve high costs. Moreover, a more careful management of engine performance and stress contributes to improving their operational reliability, reducing downtime and increasing vessel availability.

Overall, the combination of fuel savings and **extended engine life** provides a dual economic and operational benefit, making the approach not only more cost-effective but also more sustainable in the long term. This improvement in performance, both in terms of cost and efficiency, is essential for addressing the economic challenges of the maritime sector, contributing to more efficient and resource-friendly management

c. Contribution to environmental goals

- **CO₂ reduction:** aligns with IMO's GHG reduction targets.
- **Sustainability:** supports the transition to greener maritime practices without costly retrofits.

CO₂ reduction is one of the primary objectives of this strategy, aligning with the ambitious greenhouse gas reduction targets set by the **IMO (International Maritime Organization)**. By adopting more efficient technologies and operational solutions, significant contributions are made towards **lowering CO₂ emissions**, in line with international commitments to combat climate change and promote more sustainable maritime practices.

Furthermore, this approach supports the **transition to greener maritime practices** without the need for **costly retrofits**. The implementation of advanced technological solutions and the optimization of operations do not require expensive structural modifications but rely on operational adjustments that enhance energy efficiency and reduce environmental impact. In this way, it is possible to adopt more sustainable practices without incurring high costs for vessel upgrades to meet environmental regulations, making the shift to an eco-friendlier maritime sector not only feasible but also economically advantageous.

6. CONCLUSIONS

A. Success of the green practice

The **backtracking algorithm** has proven particularly effective in **optimizing fuel consumption** and **reducing emissions** for **offshore supply vessels**, especially in operational environments with specific constraints. A key aspect of this optimization is the **management of speed**, which has proven crucial in improving efficiency during **tugging operations**. Optimizing speed in tugging operations is essential for significantly reducing fuel consumption and emissions, as speed is one of the most influential factors in energy expenditure.

The algorithm allows for dynamic speed adjustments based on specific operational conditions, thereby optimizing routes and navigation times without compromising safety or operational efficiency. In particular, in tugging situations, where vessels are subjected to unique loads and stresses, precise speed control helps reduce engine wear and improves overall performance. This approach has resulted in significant improvements in fuel efficiency and a reduction in environmental impact, ensuring more sustainable and high-performance management of offshore tugging operations

B. Lessons learned:

- **Flexibility is key:** real-time adjustments are crucial for handling dynamic weather conditions.
- **Data accuracy:** reliable weather and fuel consumption data are essential for optimization.

Flexibility is a key factor in optimized navigation operations, as the ability to make **real-time adjustments** is crucial for managing dynamic and unpredictable weather conditions. Climatic factors such as wind, rough seas, and temperature variations can change rapidly, and the ability to adapt operations to these new circumstances in real time ensures both efficiency and safety.

Similarly, the **accuracy of data** plays an essential role in optimizing operations. Reliable data on weather conditions and fuel consumption is vital for making informed decisions that can minimize energy expenditure and improve operational efficiency. Without accurate data, optimization becomes a challenging task, as strategies based on unreliable information could compromise desired outcomes, both in terms of cost reduction and environmental impact. Therefore, the integration of advanced systems to continuously collect and analyze this data is crucial for ensuring optimal and sustainable operations.

C. Next steps

To further enhance the effectiveness of the algorithm, it is essential to **expand it to include real-time data integration**, making the algorithm even more responsive to rapidly changing operational conditions. This functionality would allow for more precise and timely adjustments, improving overall efficiency and minimizing resource consumption, such as fuel and time.

Additionally, it would be beneficial to **explore hybrid optimization techniques**, combining the backtracking algorithm with machine learning methods. This approach could enhance the algorithm's capabilities, enabling more accurate predictions of operational parameters, improving adaptation to changing conditions, and making operations even more efficient.

Finally, to maximize the benefits, it is important to **promote the adoption of the algorithm across other vessel types** and in **various regions**. Applying this system to a variety of contexts and fleets would help widely disseminate the advantages related to operational optimization, extending the positive impact in terms of operational efficiency and environmental sustainability on a global scale.