

Training For Energy-Efficient Port Operations: Design of Simulator Activities for Sustainable Navigation with Tugboats in the Port of Barcelona

J. Ribet^{1,*}, M. Castells-Sanabra¹, C. Borén¹, M. T. Albayrak², A. Mujal-Colilles¹

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ABSTRACT

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Intra-port services are increasingly relevant within maritime decarbonisation strategies, as they operate continuously in confined waters, close to urban areas and under highly variable load profiles. This article presents the design of a pilot course on sustainable navigation and manoeuvring for tugboats and port services, focused on competence acquisition through progressive simulator exercises. The main contribution is a training framework that transforms sustainability into an observable professional competence: eco-speed, thrust modulation, safe use of inertia, reduction of waiting times, interpretation of energy data and coordination among port stakeholders. To achieve this contribution, the course is structured as an applied training intervention: familiarisation with azimuth propulsion, slalom with maintained heading, orbital displacement around a stationary vessel, replication of real tracks in ECDIS, complex LNG berthing manoeuvres and comparison of executions with different levels of power use.

1. Introduction.

Maritime transport accounts for approximately 2.5% of global greenhouse gas emissions, making its decarbonisation one of the sector's most pressing strategic challenges. The decarbonisation of maritime transport has become one of the sector's main strategic challenges. The 2023 IMO Strategy on the reduction of greenhouse gas emissions from ships sets a pathway for reducing carbon intensity and transitioning towards net-zero

emissions by around 2050 [10]. In parallel, UNCTAD stresses that maritime decarbonisation requires operational changes, innovation, investment and cleaner technologies [15]. Although much international regulation has traditionally focused on ocean-going vessels, port areas also represent critical emission hotspots due to the concentration of manoeuvres, auxiliary services, cargo - handling activities and shore-based equipment. Auxiliary craft, such as pilot boats, bunkering barges, mooring boats, waste-collection units and harbour tugboats, operate continuously and have a direct influence on local emissions and air quality in urban port environments. Harbour tugboats are especially relevant because their operating profile differs from that of conventional merchant ships. Their operations are characterised by short but power-intensive manoeuvres, frequent load transients, waiting periods with engines running, and repeated acceleration and deceleration phases. These conditions can re-

¹Department of Nautical Science and Engineering. Barcelona School of Nautical Studies (FNB). Universitat Politècnica de Catalunya - BarcelonaTech.

²Department of Maritime Management, Piri Reis University, Istanbul, Turkey.

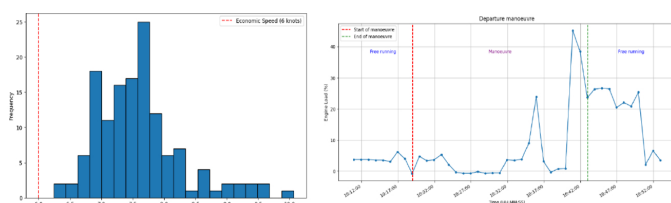
*Corresponding author: J. Ribet. ORCID: 0000-0001-5614-4917. E-Mail: josep.albert.ribet@upc.edu.

duce engine efficiency and increase specific fuel consumption and emissions of CO₂, NO_x, SO_x and particulate matter (PM). However, environmental improvement in port services cannot rely solely on technological renewal; it must also include specific training in low-impact operational decisions [9, 14].

The literature on harbour tugboats confirms their relevance within emission inventories. Ergüven et al. [5] analysed the role of tugs in emissions associated with vessel activity in Izmit Bay, while Ortega-Piris et al. [13] studied the concentration of emissions from the Spanish tugboat fleet. These studies justify treating the tugboat as a strategic agent for port decarbonisation when local evidence is combined with applied training. The tug master's operational behaviour is therefore a key element in any mitigation strategy. Decisions such as transit speed, departure time from base, waiting position, application of thrust, use of inertia and coordination with the pilot can substantially modify the energy consumed during a manoeuvre. The TUG-EMI project addresses this challenge through a methodology to calculate and predict harbour tug emissions and to propose operational reduction strategies [8,11].

This study is framed within two complementary lines of work that together provide both the empirical basis and the educational proposal for the proposed training model. On one hand, the TUG-EMI project contributes operational evidence drawn from the analysis of 101 real harbour tugboat manoeuvres, encompassing power profiles, waiting times and concrete initiatives to reduce fuel consumption under actual working conditions. The relationship between speed, engine load and fuel consumption is a central principle of energy-efficient navigation. In tugboat operations, however, its application is more complex than in deep-sea navigation because manoeuvres are short, safety-critical and conditioned by pilot instructions, traffic, weather, berth configuration and the type of assisted vessel. Nevertheless, periods of free sailing, waiting, approach and repositioning offer room for operational improvement. Analysis of engine-load profiles and recorded speeds makes it possible to identify when power demand is operationally necessary and when it can be reduced without compromising safety. As illustrated in Figure 1, operation speeds in the Port of Barcelona show considerable variability, and individual departure profiles reveal frequent high-load transients that represent clear opportunities for fuel reduction.

Figure 1: Operational evidence used to justify the course. Left: distribution of average speeds between tug-assistance operations in 2024 in the Port of Barcelona. Right: engine-load profile during an individual departure manoeuvre. Source: TUG-EMI project.



Source: Authors.

Maritime education and training has traditionally focused on safety, navigation, regulatory compliance and technical competence. The transition towards sustainable maritime operations requires integrating environmental performance into professional decision-making. Therefore, sustainable navigation should be addressed as an operational competence and not as an environmental concept separated from manoeuvring [2,3,11].

The COM-B model - capability, opportunity and motivation as conditions for behaviour - provides a useful theoretical frameworks for designing training aimed at changing operational habits [12]. Capability is related to knowledge and skills; opportunity relates to access to simulators, operational data and organisational culture; and motivation relates to the perception that sustainability also improves economic efficiency and service quality. Applying this framework to the present context, the course design targets each of the three dimensions: building technical knowledge of emission drivers, providing simulator-based practice, and reinforcing the link between eco-efficient decisions and professional performance.

The review of the GREENPORT alliance project material makes it possible to identify emerging competences for port services: eco-speed, time planning, use of inertia, power modulation, consumption visualisation, data analysis, simulation for eco-navigation, post-operation debriefing and communication with the stakeholders involved. These competences form the basis of the course analysed [8,11]. Together, these two sources connect local operational data with training activities aimed at behavioural change, better use of existing technologies and targeted professional development [8]. Building on this dual empirical and pedagogical basis, and in response to the identified gap in competence-based training for harbour tug operators, this article presents a pilot-course model for sustainable navigation in port services, focused on the design and analysis of simulator-based training activities. Following a structure similar to competence-based maritime education studies, the article is organised into a review and justification of the problem, a training-design methodology, results organised according to that methodology, and a discussion on competence acquisition.

2. Methods.

2.1. Course pilot framework.

The Course Framework proposed in this study translates the simulator-based training sequence into a competence-based educational structure. It is organised into three complementary layers. First, the sustainable-navigation competences derived from the exercises are identified and connected with observable learning outcomes. Second, these competences are aligned with STCW-related competence areas in order to make the course traceable to maritime training standards. Third, an assessment rubric defines how performance is evaluated through simulator observation, ECDIS tracks, power and energy indicators, and post-exercise debriefing.

Table 1: Proposed sustainable-navigation competence framework for the pilot course.

Competence	Learning outcome	Training evidence
Energy competence	Relate speed, engine load, consumption and emissions during transit, waiting and manoeuvring phases.	Analysis of operational data from the TUG-EMI project, simulator records and technical discussion.
Eco-speed	Select transit speeds compatible with safety, the required arrival time and consumption reduction.	Comparison of alternatives in the simulator and analysis of the rush-and-wait pattern.
Thrust modulation	Apply progressive thrust orders adjusted to the real needs of the manoeuvre.	Observation of performance, thrust orders and thrust-power relationship.
Use of inertia	Use the tugboat's momentum to reduce unnecessary engine use.	Slalom, orbital-displacement, approach and debriefing exercises.
Waiting-time management	Identify and reduce avoidable waiting periods with engines running.	Time planning, comparison of tracks and analysis of accumulated energy.
Data interpretation	Use power, energy, force and trajectory indicators to assess the manoeuvre.	Graphs of power, accumulated energy, longitudinal force and geographical track.
Sustainable coordination	Coordinate the manoeuvre with the pilot, port control, terminal and assisted vessel to avoid inefficiencies.	Joint debriefing, analysis of constraints and proposal for operational improvement.
ECDIS/simulator competence	Transfer real tracks to the simulator and use them as manoeuvre references in ECDIS.	Track loading, manoeuvre replication and comparison of constrained/free execution.

Source: Authors.

To make the training proposal traceable to maritime-education requirements, the competence framework derived from the exercises is complemented with a STCW-based mapping and a course assessment rubric. These two instruments translate the simulator activities into observable performance criteria and measurable evidence for briefing, execution and debriefing.

The STCW-based mapping shown in Table 2 does not create a new regulatory standard; rather, it connects the specific simulator activities with recognised maritime competence areas. This makes the sustainability dimension operational and assessable, because eco-speed, thrust modulation, use of inertia, ECDIS-based planning and energy-data interpretation are expressed as observable professional behaviours.

Table 2: STCW-based competence framework for the sustainable tugboat navigation and manoeuvring course.

STCW competence area	Course competence and activity	Observable performance criteria	Assessment evidence
Plan and conduct safe navigation; maintain a safe navigational watch	ECDIS-based replication of real manoeuvre tracks using AI Klor, Azhara and Cala Mesquida references	Follows the planned track safely, anticipates course changes and avoids unnecessary speed or power increases	Track comparison, ECDIS monitoring, route deviation, speed profile and instructor observation
Manoeuvre and handle the ship in restricted waters	Familiarisation with ASD and SDM tugboat models	Relates propulsion order, azimuth angle, thrust, inertia, lateral movement and stopping distance	Smoothness of orders, heading control, lateral-displacement accuracy and instructor checklist
Maintain control and situational awareness during manoeuvring	Slalom along a single line of buoys while maintaining heading	Maintains heading, anticipates lateral displacement and avoids abrupt corrections	Heading stability, position control, continuity of movement and absence of excessive thrust orders
Manoeuvre safely around vessels and structures	Orbital displacement around a stationary vessel	Maintains safe distance, controls relative position and uses minimum necessary power	Orbit stability, safety distance, heading angle, applied thrust and trajectory stability
Use of ECDIS and simulator resources to support safe navigation	Loading and following real tracks in simulator ECDIS	Uses the reference track, monitors deviations and adjusts the manoeuvre progressively	ECDIS track, deviation from reference route, speed evolution and debriefing notes
Respond to operational constraints and maintain safety	LNG berthing scenario and comparison between limited-power and free execution	Coordinates approach, timing, track control, tug assistance and power use without compromising safety	Comparison of executions, safety margins, manoeuvre timing, power profile and instructor assessment
Leadership, decision-making and environmental protection	Eco-speed, waiting-time reduction, thrust modulation and post-exercise debriefing	Justifies when higher power is necessary and identifies power use by habit or lack of anticipation	Average power, maximum power, accumulated energy, load peaks, waiting time and corrective actions

Source: Authors.

The assessment component of the Course Framework is presented in Table 4. It converts the competence mapping into measurable indicators, combining instructor observation with simulator-derived evidence such as track deviation, heading stability, thrust orders, average power, maximum power, accumulated energy and the comparison between limited-power and free executions.

Taken together, Tables 1, 2 and 3 define the Course Framework used in this article: Table 1 identifies the sustainable-navigation competences developed through the exercises, Table 2 aligns those competences with STCW-related areas, and Table 3 specifies the assessment criteria and evidence. This structure supports a coherent progression from simulator activity design to competence acquisition and measurable evaluation.

Table 3: Assessment rubric for the sustainable tugboat navigation and manoeuvring course. Assessment scale: 1 = insufficient, 2 = basic, 3 = competent and 4 = advanced.

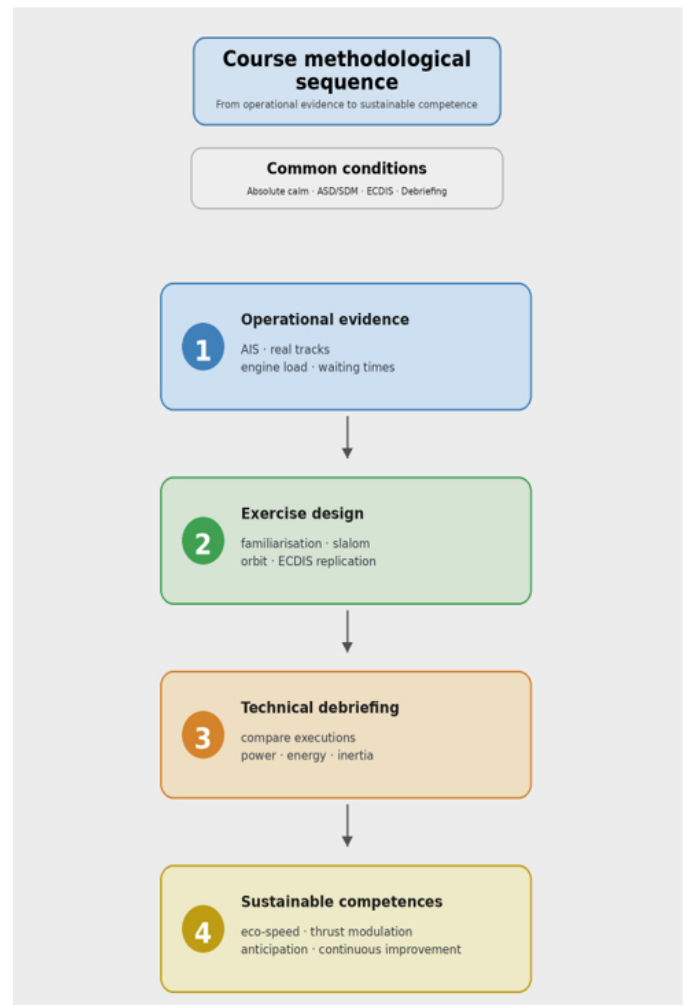
Assessment component	Assessment activity	Performance indicators and evidence collected	Weight
Simulator familiarisation	Initial handling exercises with ASD and SDM models	Understanding of engine order, azimuth angle, thrust, inertia and lateral displacement, smoothness of commands and absence of overcorrections	10%
Lateral control and heading maintenance	Slalom along a single line of buoys while maintaining heading	Heading stability, anticipation, controlled lateral displacement, continuity of movement and minimum necessary thrust	15%
Relative-position control	Orbital displacement around a stationary vessel	Safe distance, orbit stability, approximately perpendicular heading, progressive thrust orders and controlled use of inertia	15%
ECDIS-based manoeuvre planning	Loading and following real manoeuvre tracks in ECDIS	Interpretation of the reference track, planning of approach, route-deviation control, speed profile and briefing notes	15%
Sustainable manoeuvre execution	Execution limited to 50% of propulsive capacity	Safe completion of the manoeuvre with anticipation, inertia management, progressive thrust modulation, reduced power peaks and controlled accumulated energy	15%
Professional judgement under normal conditions	Free execution of the same manoeuvre	Justification of higher power only when operationally necessary; comparison of time saving, maximum power and accumulated energy against the limited-power run	10%
Complex manoeuvre integration	LNG berthing scenario	Coordination of approach, timing, track control, tug assistance and power use in a realistic port manoeuvre while maintaining safety margins	10%
Data interpretation and debriefing	Post-exercise analysis using simulator records	Ability to relate manoeuvring decisions to power demand, accumulated energy, consumption and emissions; proposal of corrective actions	10%

Source: Authors.

2.2. Scenarios Analysis strategy.

The methodological strategy to design simulator scenarios is organised according to an applied educational-research logic (see Figure 2).

Figure 2: Methodological sequence of the course: from operational evidence to sustainable competence through simulator activities and debriefing.



Source: Authors.

First, the available operational evidence from the TUG-EMI project is analysed, including records of real tugboat manoeuvres in the Port of Barcelona, Automatic Identification System (AIS) tracks, simulator data and energy records associated with power use. The tracks used as references correspond to manoeuvres of the vessels Al Khor, Azabra and Cala Mesquida, selected for their didactic usefulness in representing routes of different length, curvature and planning demand. Second, a sequence of simulator activities is designed to transform the identified inefficiencies into trainable competences. Third, simulator execution records are analysed to compare manoeuvring styles and convert them into briefing and debriefing material. The acronyms used in the text are ASD (Azimuth Stern Drive), SDM (Ship Docking Module), ECDIS (Electronic Chart Display and Information System), AIS (Automatic Identification System), LNG (Liquefied Natural Gas), NTI (Navi-Trainer Instructor) and VET (Vocational Education and Training).

This strategy is consistent with a competence-based training approach: the objective is not only to deliver content on sustainability, but to observe whether the participant is able to make navigation and manoeuvring decisions that reduce unnecessary power use while maintaining operational safety. Therefore, assessment focuses on performance during exercises, data analysis and subsequent reflection.

2.3. Design of the sustainable navigation and manoeuvring scenarios.

The workshop was designed as a progression of difficulty in which each exercise addresses a specific sustainable-navigation competence before integrating it into complex manoeuvres. The first phase corresponds to familiarisation with the simulator and with ASD and SDM models. The second phase introduces isolated exercises in lateral control, heading maintenance and use of inertia. The third phase transfers these learning outcomes to realistic manoeuvres through tracks loaded in ECDIS and complex scenarios, where an execution limited to 50% of propulsive capacity is compared with a free execution. In this way, the methodology allows progression from isolated technical skill to sustainable decision-making under conditions close to real operation. All exercises were carried out in absolute calm in the simulator, i.e., without wind, current or waves. This methodological decision made it possible to isolate the manoeuvring and energy components, increase comparability between exercises and attribute the observed differences to the participant's operational judgement rather than to external environmental forcing.

The activities were carried out with both ASD and SDM models. This decision allows different propulsive responses to be compared and prevents the acquired competence from being linked to a single platform. In both cases, the training is oriented towards the same principles: eco-speed, thrust modulation, use of inertia, reduction of waiting times and operational coordination.

For complex manoeuvres, the real manoeuvre tracks are downloaded in order to transfer them to the simulator and display them in ECDIS. Once this representation has been achieved, the manoeuvre can be replicated under controlled conditions.

The training protocol includes a first execution with an explicit constraint: not to use more than 50% of propulsive capacity. A second free execution is then carried out, in which participants manoeuvre according to their professional judgement. Comparing both executions makes it possible to assess the increase in power and, consequently, the potential increase in consumption.

2.3.1. Scenario 1: familiarisation with the simulator and ASD /SDM models.

The first scenario of the course has a preparatory and competence - building function. Its objective is for the participant to understand the tugboat's dynamic response before facing an assistance manoeuvre. The relationship between engine order, effective thrust, azimuth-propulsor rotation, lateral displacement, loss of headway and inertia is addressed. This phase is carried out with both ASD and SDM models so that students can identify differences in propulsive response and do not associate sustainable navigation with a single tugboat configuration.

From a sustainability perspective, this activity introduces the first key competence: distinguishing between necessary power and power applied by habit. Students learn that a higher thrust order does not always imply a safer or faster manoeuvre, and that smooth application of power can reduce load peaks, overcorrections and accumulated consumption.

2.3.2. Scenario 2: slalom along a line of buoys while maintaining heading.

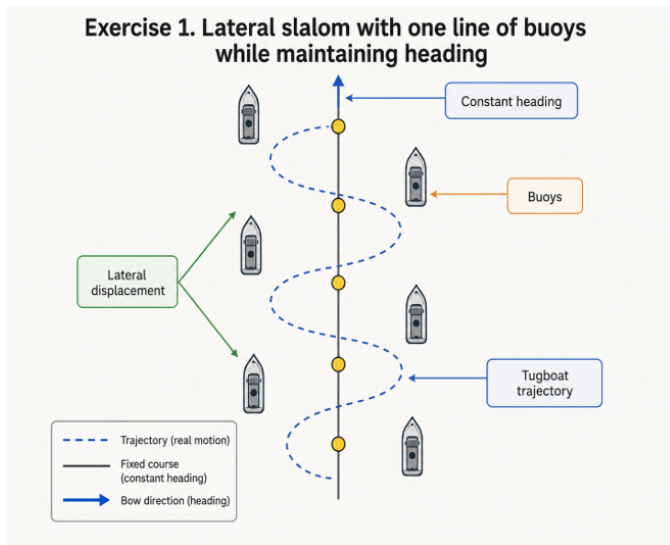
The second exercise consists of a slalom along a single line of buoys. Unlike a conventional slalom, the objective is not to alternate the bow continuously, but to cross the line of buoys while maintaining, as far as possible, a constant heading. The tugboat must move laterally between buoys through coordinated management of the azimuth propulsors. Figure 3 presents the didactic diagram used to explain this exercise visually to students, highlighting the buoy line, heading maintenance and the tugboat's lateral trajectory.

This exercise trains three competences directly related to sustainable navigation: lateral control with minimum power, anticipation of drift and reduction of abrupt corrections. The participant must plan each lateral displacement before the position error becomes excessive, avoiding late reactions that usually result in high thrust orders and greater consumption. The debriefing analyses continuity of movement, heading stability and the actual need for applied power.

2.3.3. Scenario 3: orbital displacement around a stationary vessel.

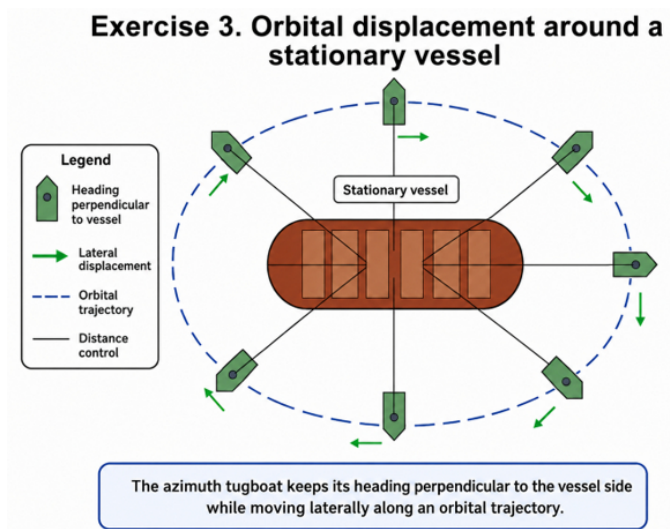
The third exercise consists of performing an orbital displacement around a stationary vessel while maintaining a heading approximately perpendicular to the assisted vessel. The aim is for the student to control relative position, course, safety distance and progressive use of thrust simultaneously. Figure 4 shows the orbital-displacement diagram, representing distance control relative to the stationary vessel, the orbital trajectory and maintenance of an orientation approximately perpendicular to the side.

Figure 3: Explanatory diagram of the scenario 2: lateral slalom exercise with a single line of buoys while maintaining heading.



Source: Authors.

Figure 4: Explanatory diagram of the Scenario 3: orbital displacement exercise around a stationary vessel. Source: authors' own elaboration based on the design of the course exercises.



Source: Authors.

The main sustainable competence in this activity is the strategic use of inertia. Students learn to sustain relative movement without continuously resorting to high engine orders, using the tugboat's momentum as an active part of the manoeuvre. This activity allows a central idea of the course to be discussed: the efficient tugboat is not the one that applies the most power, but the one that applies the necessary power at the right moment.

2.3.4. Scenario 4: transfer of competences between ASD and SDM models.

The previous exercises are carried out with ASD and SDM models. This comparison has important training value because

it forces participants to adapt the same sustainable principles to different manoeuvring responses. In an ASD model, understanding of thrust orientation and its effect on lateral displacement is reinforced; in an SDM model, coordination of propulsive response and movement stability in assistance manoeuvres are addressed.

The competence sought is not to memorise a steering pattern for a single tugboat, but to develop transferable operational judgement: anticipating, modulating, conserving energy, avoiding overuse of thrust and maintaining safety. This approach is essential for continuing professional training, as tug masters may operate different tugboat configurations and must apply sustainability criteria without losing adaptability.

2.3.5. Scenario 5: replication of real manoeuvres in ECDIS LNG berthing and preparation of the NTI scenario.

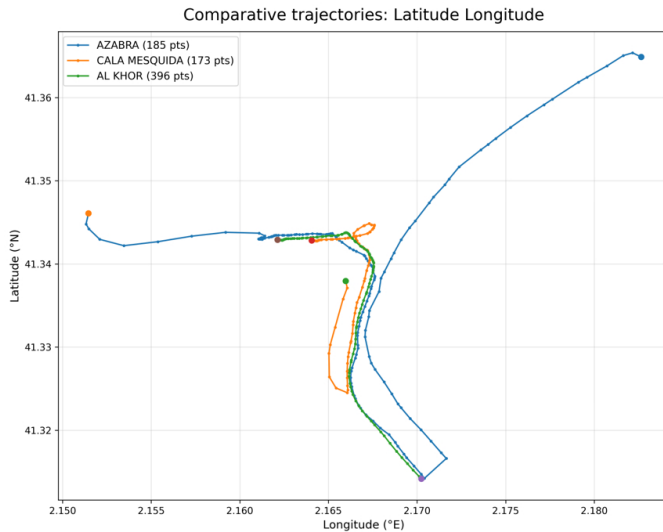
The fifth exercise incorporates real manoeuvres as the basis for advanced scenarios. In this case, tracks associated with the vessels Al Khor, Azabra and Cala Mesquida are used, making it possible to work with real spatial references before transferring them to the simulator. The manoeuvre tracks are downloaded, converted and loaded into the simulator so that they are represented in ECDIS. This visualisation ensures that the participant works not on an abstract situation, but on a recognisable operational track, with spatial references, approach times and conditions similar to those of the real manoeuvre. Figure 5 represents three real trajectories obtained from latitude and longitude coordinates. The use of different colours makes it possible to use these tracks as briefing material before loading them into ECDIS and facilitates comparison of spatial complexity between manoeuvres.

The execution is organised into two comparable runs. In the first, the participant must complete the manoeuvre under the constraint of not exceeding 50% of propulsive capacity. This restriction is not intended as a fixed operational rule, but as a didactic tool that forces anticipation, use of inertia, adjustment of eco-speed and avoidance of abrupt orders. In the second run, the participant executes the manoeuvre according to their usual judgement. The subsequent comparison makes it possible to discuss whether the increase in power really provides less time or greater safety, or whether it only increases accumulated energy, consumption and emissions.

The coordinate analysis is used for a training purpose: to obtain sufficiently clean real tracks to prepare the briefing, select the exercise difficulty level and subsequently compare the student's execution with a spatial reference. The selected trajectories present different lengths and geometries - 4.11 km for Al Khor, 11.19 km for Azabra and 4.30 km for Cala Mesquida (Figure 5)- making it possible to grade the demands of planning, anticipation and eco-speed control. Therefore, the main interest is not to validate the simulator in this article, but to convert real navigation data into useful scenarios for competence acquisition.

From a training perspective, the main value of this scenario lies in the replication methodology. First, the real manoeuvre track is reconstructed and prepared so that it can be displayed in the simulator ECDIS. Once the track is available in the bridge

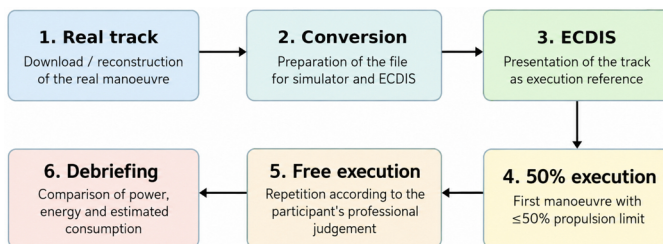
Figure 5: Real manoeuvre trajectories obtained from latitude and longitude coordinates, corresponding to Al Khor, Azabra and Cala Mesquida. Each trajectory is represented with a different colour to facilitate identification, comparison and subsequent loading as a reference track in ECDIS.



Source: Authors.

environment, the manoeuvre is replicated in two successive executions. The first is performed with an explicit constraint: not to exceed 50% of propulsive capacity. This restriction forces the participant to anticipate the manoeuvre, use the vessel's inertia safely, modulate thrust and avoid abrupt corrections. The second execution is carried out without this limitation, according to the participants' professional judgement. The subsequent comparison makes it possible to analyse whether the increase in power actually reduces manoeuvre time or whether it only increases accumulated energy and estimated consumption.

Figure 6: Didactic flow of the complex LNG berthing scenario: from the real track to replication in ECDIS and comparison between execution limited to 50% of propulsive power and free execution.



Source: Authors.

This procedure turns LNG berthing into an advanced sustainable - navigation activity. Unlike the familiarisation, slalom or orbit exercises, in which microcompetences are isolated, LNG berthing requires them to be integrated into a complete manoeuvre: time planning, track control, coordination with the bridge team, thrust modulation, safe use of inertia and subsequent en-

ergy assessment. Consequently, the exercise allows progression from individual technical skill to an integrated and measurable operational competence.

4. Results.

4.1. Pilot case.

The pilot case was used to test the practical applicability of the proposed course framework under controlled simulator conditions. Its purpose was not only to describe the training activity, but also to obtain operational evidence on how different manoeuvring styles influence power demand, energy use and sustainable decision-making during tugboat operations.

The pilot course was delivered to eight maritime professionals linked to port operations, including tugboat masters, Marpol captains and captains of bunkering vessels. It was conducted at the Barcelona School of Nautical Studies (FNB-UPC) during January 2025, using the institution's bridge simulator, and had a total duration of 16 hours. The case study was developed in the operational context of the Port of Barcelona, where the high volume of tug-assisted manoeuvres justifies the need for specific training strategies focused on energy-efficient port operations.

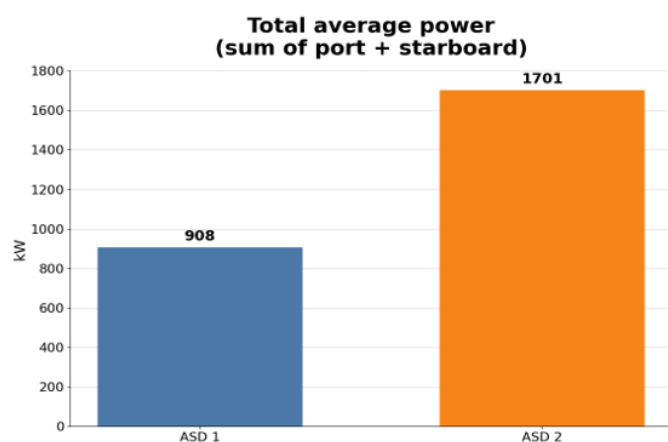
To illustrate the potential of the method, two simulator records corresponding to exercises performed with an ASD tug model were analysed. These records made it possible to compare manoeuvre duration, average power, maximum power, accumulated simulated energy, average thrust, time with high thrust, longitudinal force, the relationship between ordered thrust and power, and geographical track. Although the available quantitative records correspond to the ASD model, the complete course design also included exercises with SDM models, ensuring that the proposed training framework was not limited to a single tugboat configuration but could be applied to different propulsion responses and operational behaviours.

4.2. Analytical result: comparison of two ASD executions.

The comparison between the two ASD executions is presented synthetically so that students can interpret the result during debriefing. Both executions correspond to exercises performed in the simulator within the context of the pilot course and show clear differences in manoeuvring style. For this analysis, total propulsive power was defined as the sum of the instantaneous power recorded in the port and starboard engines. ASD exercise 1 had a longer duration, 71.5 minutes, but showed a lower total average power, 907.8 kW, and accumulated simulated energy of 1081.2 kWh (Figure 7). ASD exercise 2 was shorter, 57.9 minutes, but required a total average power of 1701.2 kW and accumulated 1640.7 kWh (Figure 8). From a didactic perspective, a faster manoeuvre is not always more efficient: any time saving must be assessed against average power and accumulated energy. Both executions were carried out in absolute calm weather, so the comparison more clearly reflects the effects of manoeuvring style on power demand (Figure 9-10)

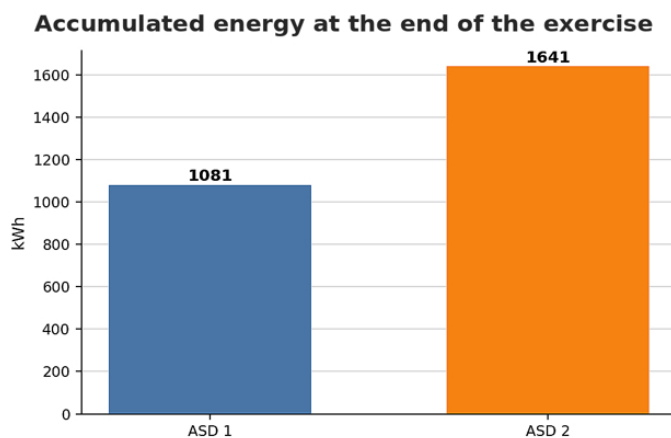
From the debriefing perspective, the comparison was reduced to simple and directly interpretable indicators: total average power, accumulated energy and temporal evolution of power. This simplification prevents a single graph from mixing too many variables and helps students relate their manoeuvring decisions to energy consumption, eco-speed, anticipation and thrust modulation.

Figure 7: Total average power of the two ASD executions, calculated as the sum of the port and starboard engines.



Source: Authors.

Figure 8: Accumulated energy at the end of each ASD exercise.

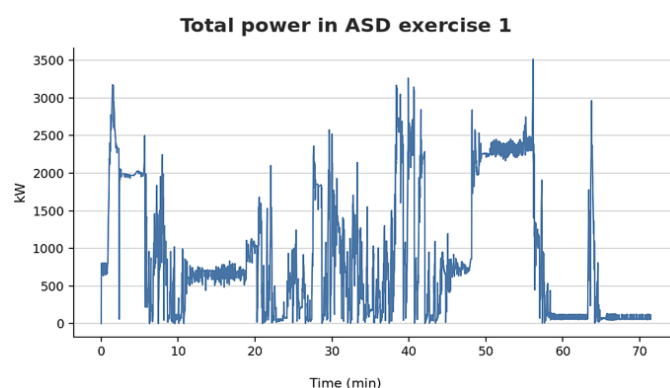


Source: Authors.

5. Discussion.

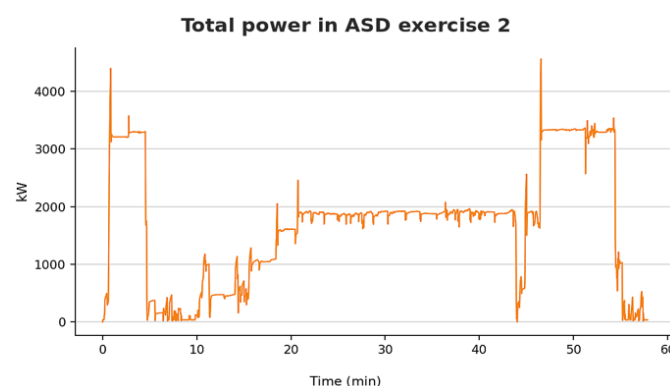
This article is structured around competence acquisition rather than a general course description. Each exercise fulfils a specific training function: familiarisation builds technical capability; the slalom trains modulation and anticipation; orbital displacement develops use of inertia; replication in ECDIS connects training with real operation; and LNG berthing integrates all competences in a complex scenario. This progression turns sustainability into an observable and assessable nautical skill.

Figure 9: Temporal evolution of total propulsive power during ASD exercise 1.



Source: Authors.

Figure 10: Temporal evolution of total propulsive power during ASD exercise 2.



Source: Authors.

The use of operational graphs reinforces the training validity of the course. The speed distribution and engine-load profile show that there are phases in which power and speed management can be improved. The ASD execution graphs demonstrate that efficiency does not depend exclusively on finishing a manoeuvre earlier, but on the combination of duration, average power, thrust used and accumulated energy.

The slalom and orbital displacement activities are useful because they isolate microcompetences that appear mixed in real manoeuvres. The slalom trains lateral control and thrust modulation; orbital displacement trains relative position, orientation and use of inertia. Replication of real manoeuvres in ECDIS then allows these microcompetences to be integrated into more realistic scenarios. Acquiring these new competences is particularly relevant in port operations, where time pressure, safety constraints and energy efficiency demands must be managed simultaneously. Traditional training prepares students to perform the manoeuvre safely; sustainable navigation adds an additional competence layer: performing it with the lowest reasonable use of power, fewer load peaks, fewer unproductive waiting periods and more precise coordination with the pilot, assisted vessel and port control. This competence does not arise solely from the-

ory, but from repeated exercises, comparison of executions and data-based debriefing.

The initial restriction of not exceeding 50% of propulsive capacity has clear didactic value. It is not intended to establish a universal operational limit, but to oblige the participant to explore lower-power solutions, anticipate the manoeuvre and verify whether safety can be maintained with lower energy demand. The subsequent free execution allows usual practice to be contrasted with an optimised alternative. In complex exercises, such as LNG berthing, this restriction acquires additional value because it is applied to a real track displayed in ECDIS. The participant does not work on an abstract scenario, but on a recognisable manoeuvre, which facilitates professional transfer of learning.

Sustainable navigation should not be interpreted as a simplistic reduction in power or speed. In a port environment, safety remains the priority. Professional competence consists of determining when power is necessary and when its use responds to habit, time pressure or lack of coordination. Therefore, training must include briefing, execution, data analysis and debriefing.

The collective component is another critical dimension. Many measures - Just-in-Time arrival, reduction of waiting times and adjusted departure from base - depend on coordination among the tugboat, pilot, assisted vessel, terminal and port control. Therefore, future editions should incorporate multi-actor exercises and scenarios with more tugboats, time constraints, emergencies and weather variability [4,8].

6. Conclusions.

This article presents a pilot-course model for sustainable navigation applied to tugboats and port services in the Port of Barcelona. Unlike approaches focused exclusively on surveys or awareness-raising, this work is organised around the design of training scenarios, the replication of real manoeuvres and the analysis of bridge simulator data.

The main practical contribution is a sequence of separate and progressive exercises that makes it possible to train sustainable - navigation competences: familiarisation with ASD and SDM models, slalom with maintained heading, orbital displacement around a stationary vessel, replication of real tracks in ECDIS, LNG berthing and comparison of executions with different power use. Separating the exercises allows micro-competences to be isolated and then integrated into complex manoeuvres, helping students understand not only what they should do, but why certain decisions reduce consumption and emissions without compromising safety.

The analysis of two ASD executions shows that a shorter manoeuvre may involve higher average power and greater accumulated energy. This result provides a strong training basis for discussing the relationship between safety, time, power and consumption. Although the available quantitative records correspond to ASD, the course was also developed with SDM models, reinforcing the transferability of the principles to different tugboat configurations.

The proposed competence framework can serve as a basis for future editions of professional and continuing training (VET, Vocational Education and Training), as well as for training programmes addressed to tugboat masters, pilots and port operators. In addition, the framework highlights the need to incorporate sustainability-related competences into the academic curriculum aligned with the STCW Convention. Energy-efficient navigation, eco-speed, thrust modulation, reduction of unnecessary power peaks, use of inertia, interpretation of energy data and environmental decision-making should not be treated as complementary topics, but as operational competences integrated into navigation, manoeuvring, bridge resource management and environmental protection training.

From this perspective, the course contributes to the development of new STCW-oriented competences linked to sustainable maritime operations. These competences allow trainees to connect traditional safety-based manoeuvring with the current need to reduce fuel consumption and emissions in port environments. Sustainability thus ceases to be formulated as an objective external to the manoeuvre and becomes integrated into the STCW academic curriculum as an observable professional decision-making criterion in the simulator.

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References.

- [1] Alamoush, A. S., Ballini, F., & Ölçer, A. I. (2020). Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review. *Marine Pollution Bulletin*, 160, 111508.
- [2] Banks, C., Turan, O., Incecik, A., Lazakis, I., & Lu, R. (2014). Seafarers' current awareness, knowledge, motivation and ideas towards low carbon-energy efficient operations. *Journal of Shipping and Ocean Engineering*, 4, 1-9.
- [3] Dewan, M. H., Mustafi, M. A. A., Matos, F., & Godina, R. (2024). Exploring seafarers' knowledge, understanding, and proficiency in SEEMP: A strategic training framework for enhancing seafarers' competence in energy-efficient ship operation.
- [4] Dooms, M., Verbeke, A., & Haezendonck, E. (2019). Community engagement in port planning. *Ocean & Coastal Management*, 177, 1-12. <https://doi.org/10.1016/j.ocecoaman.2019.04.016>.
- [5] Ergüven, O., Bayırhan, I., Deniz, C., & Gazioğlu, C. (2023). Role of port tugs in ship-borne emissions: An analysis in İzmit Bay, Türkiye. *International Journal of Environment*

and Geoinformatics, 10(2), 180-186. <https://doi.org/10.30897/-ijegeo.1300605>.

[6] European Commission. (2019). The European Green Deal. COM(2019) 640 final. Brussels: European Commission.

[7] European Parliament and Council. (2017). Regulation (EU) 2017/352 establishing a framework for the provision of port services and common rules on the financial transparency of ports. Official Journal of the European Union.

[8] GREENPORT Alliance Consortium. (2025). Work Package 4, Deliverable 4.1 (D6): HE Modules and supporting learning material. Erasmus+ Programme, Project No. 101139879.

[9] International Maritime Organization. (2020). Fourth IMO GHG Study 2020. London: IMO.

[10] International Maritime Organization. (2023). 2023 IMO Strategy on Reduction of GHG Emissions from Ships. London: IMO.

[11] Jensen, S., Lützen, M., Mikkelsen, L. L., Rasmussen,

H. B., Pedersen, P. V., & Schamby, P. (2018). Energy-efficient operational training in a ship bridge simulator. *Journal of Cleaner Production*, 171, 175-183.

[12] Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, 6, 42. <https://doi.org/10.1186/1748-5908-6-42>.

[13] Ortega-Piris, A., Díaz-Ruiz-Navamuel, E., Martínez, A. H., Gutiérrez, M. A., & López-Díaz, A.-I. (2022). Analysis of the concentration of emissions from the Spanish fleet of tug-boats. *Atmosphere*, 13(12), 2109. <https://doi.org/10.3390/atmos13122109>.

[14] United Nations. (1982). United Nations Convention on the Law of the Sea. Articles 192-194.

[15] United Nations Conference on Trade and Development. (2024). Review of Maritime Transport 2024. Geneva: United Nations.