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GREENPORT Alliances

Work Package 4, Deliverable 4.1 (D6)
HE Modules and
supporting learning material

August 2025

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Sustainable Maritime Operations and Green Ports

HE Modules & Supporting Learning Material

August 2025

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INTRODUCTION

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Executive Summary

The maritime industry, responsible for over 80% of global transport, plays a pivotal role in international trade and environmental sustainability. Generating approximately 3% of global greenhouse gas emissions, maritime industry needs sustainable practices, necessitating more sustainability education. Maritime education is essential for equipping future professionals with the skills and knowledge required to address these challenges.

GREENPORT targets an overlooked sub-sector within the Green Deal's strategy to decarbonise the maritime industry: that of in-port services. Vessels such as tugboats and pilot boats, and personnel such as pilots and harbour masters, carry out an important role of ensuring the safety of port assets and vessels whilst in port. However, because of these service vessels' small size, and because larger vessels pollute much more, in-port operations have not been included in the EU's emission reduction targets.

The lack of enforced targets does not mean the sector is not polluting. Moreover, greener technology, whilst in development, is not yet ready for large scale commercial use. Nonetheless, the actors within the sector themselves show a willingness to reduce emissions.

GREENPORT posits that a **change in human behaviour** can reduce the environmental impact of in-port services in the short- to medium-term. Modifications can be made to day-to-day operations, with better use of existing digital technologies, that would contribute to a significant drop in emissions. To meet re/training and education for current/future personnel requirements, GREENPORT consortium thus brings together 10 organisations from 8 countries in education, research, and industry:

- Pooled knowledge and resources by conducting an industry and academy wide needs identification, data collection and analysis and case study research

- Used this information to develop curricula along 3 modular learning lines that target HEI students (future personnel) through integration of developed material into existing HEI programmes; VET short course for working professionals via Train the Trainer e-learning course for the educators and trainers of both streams

During these studies, it became evident that maritime educators' commitment to sustainability principles, their awareness of sustainability issues in port services and the integration of behavioural change approaches in their teaching practices plays an important role in any form of sustainability education and training.

A quantitative study was undertaken, guided by the **Capability, Opportunity, Motivation - Behaviour (COM-B)** model, to collect and analyse data through an online survey completed by 86 maritime educators from various countries. The findings revealed that, although educators have the motivation to integrate behavioural change approaches into teaching methods, they need to improve their capability with more training and resources as there is a lack of necessary opportunities such as real case studies and interactive learning methods. The study also revealed the differences by demographic characteristics and offers various theoretical and practical implications emphasizing educators' role in enhancing awareness and adoption of sustainable behaviours among maritime professionals, contributing to both environmental and economic sustainability.

The global maritime industry plays an important role in international trade, transporting more than 80% of the world's merchandise by volume, accounting for approximately 3% of global greenhouse gas (GHG) emissions. Due to its dual significance in facilitating international trade and impacting the environment, the maritime industry holds a critical position in advancing global sustainability efforts.

Amid increasing pressure to adopt sustainable practices, the International Maritime Organization (IMO) has committed to reducing total annual GHG emissions from international shipping by at least 20%, with an ambition for 30% by 2030, and further aiming to cut emissions by at least 70%, striving for 80% by 2040, both compared to 2008 levels. The ultimate target is to achieve net-zero GHG emissions by or around 2050.

This challenge offers an opportunity for the industry to take a leadership role in sustainability through innovation and advanced technologies, while maritime education is tasked with **equipping future professionals with the knowledge, skills, and behaviours** required to address these challenges. In this context, maritime educators bear a vital responsibility for **fostering sustainability principles** among students, shaping their ability to implement environmentally and socially responsible practices in the workplace.

Additionally, the European Green Deal underscores the essential role of education in achieving Europe's ambitious goal of becoming carbon-neutral by 2050. It promotes the integration of environmental topics into all levels of education and emphasizes the development of **key competencies such as critical and systems thinking** (European Commission, 2019). Although there is consensus that **incorporating sustainability topics into curricula** enhances understanding of the **interconnections between**

social, economic, and environmental systems, integrating these topics into higher education are still limited in scope and impact.

This integration of sustainability principles demands a **transformative approach** to curriculum design, teaching methodologies, and institutional strategies. However, designing transformative educational experiences is challenging within entrenched **educational paradigms** and structures that often remain untransformed and lack critical reflexivity.

Within this context, **restructuring training programs to include sustainability principles** to achieve behavioural change emerges as an important requirement. Despite its potential, the application of behavioural change approaches to foster sustainability within maritime education has been largely overlooked. Grounded in social and behavioural sciences, such approaches offer valuable insights into how educators and students can adopt sustainable practices and overcome barriers to implementation. However, the lack of empirical studies in this area highlights a pressing need for research on embedding sustainability principles into maritime education.

Basic Principles of Behavioural Change

Aiming to fill the research gap, the consortium addressed the limited understanding of maritime educators' commitment to sustainability principles which has not been adequately explored in the existing literature. The research, developed under Greenport Alliances Project funded by European Union Commission, explored the role of maritime educators in fostering sustainability within the maritime industry by examining their commitment to **environmental, economic**, and **social** sustainability principles. In parallel with the needs analysis and the scientific analysis of the project to develop curricula for training programs targeting behavioural change in port services sustainability, 86 educators from various countries working in the field of maritime education and training were included in the sample. The analysis of the data was structured in alignment with the **COM-B model** (Capability, Opportunity, Motivation = Behaviour), offering a behavioural lens through which to explore the enablers and barriers to **integrating sustainability principles into maritime education.** By applying this model to an under-researched area, the study contributes empirical insights into how educators can be better supported in developing the behavioural competencies required for fostering a sustainable maritime industry. Specifically, it examines educators' commitment to environmental, economic, and social sustainability, **their awareness of key sustainability challenges in port services (such as towage, pilotage, and mooring)** and the extent to which they incorporate behavioural change strategies into their pedagogical practices.

Port services contribute to greenhouse gas emissions, energy consumption, and environmental pressures in port areas, underscoring the necessity for targeted solutions and a commitment to sustainability principles at environmental, economic, and social levels.

Tugboats, essential for towage operations, are notable contributors to port-related air pollution, primarily due to their reliance on diesel engines, which emit greenhouse gases and other pollutants. The adoption of **cleaner fuels**, such as LNG, and the implementation of **energy-efficient technologies** are critical steps being taken to mitigate these emissions. Accidents during towage or mooring operations can lead to severe environmental consequences, such as oil spills, which harm marine life and ecosystems. **Effective practices** and **robust safety protocols** are essential to minimize such risks.

Port services such as towage, pilotage, and mooring play an important role in maritime operations, but they also involve significant economic considerations. The **operational costs** associated with these services including fuel expenses, vessel maintenance, and skilled labour can impact overall shipping costs. The regulatory framework governing these services varies, particularly regarding competition. While towage and mooring services are subject to market competition under the EU Port Services Regulation (EU 2017/352), pilotage remains exempt due to its critical role in maritime safety, environmental protection, and port efficiency. The primary reason is that pilotage provides an essential and unique service to the shipping industry and opening it to competition could jeopardise maritime safety and security, environmental protection, and port efficiency. However, **a balanced approach to economic sustainability in port services remains crucial to maintaining cost efficiency while ensuring safety**, environmental responsibility, and the long-term viability of the maritime industry.

As port operations evolve technologically, continuous training and upskilling of workers in towage, pilotage, and mooring are crucial. The adoption of sustainable practices and new technologies necessitates a well-trained workforce. Port operations affect nearby communities through noise, air pollution, and increased traffic. Balancing port efficiency with **community well-being** remains a persistent challenge, requiring inclusive planning and **stakeholder engagement**.

Existing literature in the maritime sustainability domain predominantly centres on decarbonisation and CO2 emissions), with reduced attention given to the role of education in fostering a sustainability-trained workforce. Researchers widely accepted that maritime professionals are in key positions for implementing sustainable practices and reducing the environmental impact of shipping operations. Their daily decisions and actions influence fuel consumption, emissions, and overall environmental performance. Research indicates that changes in crew behaviour alone can lead to substantial fuel savings. For instance, Svitzer's 'Aim for 8' initiative, which encourages crews to maintain an 8-knot speed during mobilisation, highlights how simple behavioural changes can yield significant environmental benefits. Moreover, effective communication and coordination within bridge teams, including pilots, are crucial for ensuring safe navigation and protecting the environment. Enhancing these behavioural aspects can help prevent accidents and mitigate the risk of environmental disasters. Moreover, as port operations evolve technologically, continuous training and upskilling of professionals are crucial. Consequently, the adoption of sustainable practices and new technologies necessitates a well-trained workforce

Discussing the role of education, it is emphasized that employers in the maritime sector are increasingly looking for environmentally and socially responsible professionals, and therefore it is necessary to integrate sustainability principles into maritime education curricula using **best practices**. Therefore, Maritime Education and Training (MET) institutions should develop a strategy aimed at integrating the sustainability trend into their curricula more comprehensively. Similarly, the research suggests that professionals in the maritime sector should have skills **beyond traditional maritime**, including competencies such as **technology management, sustainability and innovation**, and by examining the experiences of industry professionals and education experts, a new curriculum is to prepare maritime students for real-life challenges after graduation. The developed curriculum intended to **raise awareness of environmental issues** covering the subjects of training a new generation of maritime professionals compatible with global sustainability obligations. Insights into how academic institutions can develop **environmentally conscious and globally competent** maritime professionals, emphasize that academic institutions should shape professionals who are not only skilled in their technical roles but also **responsible for sustainable practices**.

Despite growing recognition of the importance of embedding sustainability into maritime operations, there is limited research that critically examines how educators internalise and promote sustainability principles in their teaching practices. A notable gap in the literature lies in the **disconnect between knowledge dissemination and actual behavioural change.** Although sustainability themes may be introduced into curricula, educators often lack the necessary training, resources, or institutional support to translate these principles into effective pedagogical strategies. This gap highlights the need for a deeper understanding of the behavioural dimensions influencing maritime educators' engagement with sustainability.

This study turns to behavioural science as a conceptual foundation. Among the various behavioural theories available, the COM-B model (Capability, Opportunity, Motivation = Behaviour) developed by Michie et al. (2011) was selected for its simplicity, versatility, and proven effectiveness in analysing behaviour across diverse settings, including health, **education, and organisational change**.

The COM-B model posits a certain behaviour can only occur if three key prerequisites are met: **capability, opportunity**, and **motivation**.

Capability refers to everything that enables an individual to perform a certain behaviour, including psychological factors such as **knowledge, understanding**, and **skills**, as well as physical aspects such as access to resources and practical training. Many educators' express awareness of the importance of sustainability but at the same time admit that they do not possess all the necessary competencies or access to additional training and workshops that would allow for better integration of sustainable practices into teaching content. This clearly indicates the need for continuous professional development and the creation of practical tools for applying sustainability in education.

Opportunity, the second component of the model, refers to external factors that enable or encourage a certain behaviour. This includes physical resources such as **teaching materials, technological equipment, access to case studies**, as well as social conditions like institutional culture, peer support, and **cooperation with industry.** Even if educators are highly motivated and capable, without adequate opportunities it is difficult to achieve sustainable change in their work. Many educators face these types of barriers, from a lack of didactic materials and practical examples to weak institutional support and limited opportunities for collaboration with external partners. Therefore, it is extremely important to develop systems that will ensure better access to resources, encourage knowledge exchange among educators, and strengthen the connection between educational institutions and industry, as well as other relevant stakeholders.

Motivation, the third component of the model, encompasses the internal **psychological** processes that direct and maintain behaviour—including both **conscious evaluations** and planning, as well as **automatic impulses, habits**, and **emotional reactions**. In maritime education, most educators show a high level of motivation to incorporate sustainability into their work. They recognize the importance of raising awareness of sustainable development among students and wish to contribute to the creation of more responsible generations of professionals. However, motivation alone is not enough. Change can occur only when capability, opportunity, and motivation are simultaneously present and balanced.

This comprehensive framework enables a systematic analysis of the factors that influence educators' ability and willingness to integrate sustainability into their teaching. It enables educators and institutions to precisely identify where the obstacles lie—whether it is a lack of knowledge, insufficient support, or low motivation—and to develop targeted measures to encourage behaviour change. In the context of maritime education, it offers a practical lens to assess whether educators not only can teach sustainability but want to and are supported in doing so.

Methodology

Development of the course material has started with an industry-wide needs analysis to obtain the necessary data, statistics, and information from both fields of industry and academia/research, forming an improved European level understanding of port services, its sustainability and current education/training offerings. The following steps were followed to carry out the survey in accordance with project objectives:

- A survey for industry representatives was created and disseminated via the industry representatives' vast networks to compile European-level information on the port service industry. This information include but is not limited to; employee number and profiles, employee awareness of sustainability, their current emissions, and company initiatives to reduce emissions.

- Extensive desk-based research was conducted to analyse existing literature and data on port services emissions, to benchmark what is currently known of the sector's impact on the environment and identify knowledge gaps that to be addressed.

- Research into national, regional and European incentives for early adopters to compile a list of currently existing commercial incentives for port service providers and ports who adopt sustainability measures, which serves as a marker for the direction in which the market is moving as a well as a best-practice repository for policy making.

- Collection and review of port services information on the current degree of integration of sustainability within port service training in education. Academic partners issued a survey amongst their academic peers using their network to identify current educators' commitment and understanding towards sustainability principles, academia's awareness of the specific issues relating to port service sustainability, and current capacity to integrate behavioural change approaches to their educational offerings. This was complemented by a desk-based review of current sustainability education offerings available in Europe, to identify more accurately the need gaps to be addressed by GREENPORT's framework.

The next steps aimed to analyse the gathered data and information, and pool best practices, to scientifically support curriculum creation. In this context the following steps were accomplished

- Cross-sectoral identification of best practices by pooling knowledge, experience, and information to determine methodological best practices for port services industry across the board. These were defined as best practices and compromised solutions between the needs of operators and the achievement of sustainability goals.

- Scientific analysis based on the gathered data and **analysis of various real-life cases** to demonstrate how different working methods can affect the emission of harmful gases, highlighting the need for behavioural training, and , and assess the current emissions and the various factors that affect emissions (such as weather, tide, specificities of the port area, availability of OPS, waiting time etc.).

- An internal working document was compiled detailing the full results of previous steps, which became the **scientific basis for curriculum development**.

The final step for the development of the GREENPORT modules and associated learning material has started with definition of learning content and syllabi for all three learning streams (HE; VET; train the-trainer). The consortium collaborated to agree upon a definition for the learning content, including target group/s and their preference for teaching styles, format, syllabus, learning outcomes, number of units/modules, distribution of modular learning content, delivery, need for supplemental learning resources, assessment, and accreditation methodology.

All three learning streams were piloted across 3 Universities, 2 VET providers, 1 pilot port and as an eLearning Course to create and implement a comprehensive evaluation and impact assessment framework, analysing the effectiveness of the curricula across various real-world situations. Piloting of short vocational course was carried out in selected pilot port, the port of Aveiro (APA), which also provided the vocational course to its port service staff in-house by a trainer from APA who has attended the train-the-trainer course beforehand. Due to the complexity of the task of monitoring impact on a real-world scale (within the pilot port of Aveiro), a select number of the academic and research partners attended an LTTA in Aveiro to observe the training taking place and resulting operation in the port and drew conclusions on the impact of the material and what needs to be amended for improved action. The impact of CO2 emission was be determined by looking at fuel consumption, observing the behaviour of tugboat operators, CO2 emission monitoring, and interviews with port staff.

Together with all feedback received from all piloting evaluation were compiled into 1 evaluation report, including aggregate evaluation results and suggestions for curriculum amendments. Then, a meeting was held to discuss the evaluation report and agreed on a way forward for editing the final version of the curricula. Amendment to learning streams content and curriculum was carried out by the respective education providers and finalized as described in the following chapters.

Conclusion

As the maritime industry faces increasing scrutiny over its environmental impact, the role of maritime educators is emerging as a pivotal element in fostering sustainability among future professionals. Integrating sustainable practices into maritime education is of vital importance, as it equips students with the necessary knowledge and skills to navigate their future careers. Maritime educators should develop and implement curricula that not only focus on technical competencies but also include sustainability principles, thereby encouraging future professionals who would be aware of the ecological consequences of their actions.

Maritime educators' awareness of sustainability principles, especially in terms of port services sustainability, their capacity to incorporate behavioural change approaches into their courses, the challenges they face, and methods that would motivate learners to adopt sustainability into their behaviours has vital importance on the successfully implementation of the training programs developed. When evaluated within the framework of the

COM-B model, the results provide inferences regarding the capability, opportunity and motivation levels of educators, offering important implications from both theoretical and practical perspectives. In this aspect, maritime educators need to understand and believe that integration of sustainability principles in maritime education has critical importance. Educators' belief in the necessity of integrating sustainability principles into their courses, combined with their high awareness of the importance of these principles create a strong ground for the "motivation". Finally, educators have to be open to incorporating behavioural change methods into their teaching materials, showing a positive indicator in terms of "motivation".

In that respect, these findings provide important clues for improving maritime education programs and increasing the competencies of instructors. Although educators have the motivation and are open to integrating behavioural change approaches into teaching methods, they need to improve their capability with more training and resources to incorporate sustainability principles more effectively into educational materials. With this consideration, a comprehensive sets of reference documents were provided for each curriculum and these documents were included in the repository on the project web site for a quick reference.

Additionally, various real time case studies were included in the repository together with educational materials as an open science document to the benefit of all interested parties besides project partners. Curricula also aimed at integrating practical training by simulations to the theoretical aspects, using a structured approach to develop participants' skills effectively. The curriculum design accounted for sequencing of activities and knowledge transfer, ensuring that related concepts are taught in a coherent manner. It has been understood that methods such as real case studies and interactive learning activities are effective in encouraging sustainable behavioural change in students. On the other hand, it has become clear that cooperation between academia and industry should be increased in order to produce solutions to sustainability issues in port services. With the pressing need to address sustainability challenges, the collaboration between maritime educators and industry stakeholders is crucial for equipping future professionals with the requisite tools to enact environmentally responsible practices.

Sustainability is becoming increasingly important in the maritime sector and education can be considered one of the cornerstones of this transformation. In the maritime world, education and training are vital and their importance extends far beyond shipping itself, as the safety and security of life at sea, the protection of the marine environment and the efficient movement of global trade depend on the professionalism and competence of seafarers. In that respect, the role of educators is very crucial to increase sustainability practices in maritime transportation. Supporting the capability, opportunity and motivation levels of educators in a balanced way is critical for the future of a sustainable maritime sector, in terms of both environmental and economic sustainability. Sustainability education, especially in operational areas such as port services, can enable personnel to make more conscious decisions on issues such as energy efficiency, fuel savings, resource use, and equipment life. **This means reducing operating costs, increasing operational efficiency, and thus contributing to economic sustainability**. In addition, the quality of human resources developed through education is also the key to achieving **competitive advantage** in the sector. The sustainability awareness of the workforce would help port service providers adapt to international standards more quickly and achieve success in green port certification processes, allowing for not only short-term cost advantages but also long-term **reputation** and **strategic gains**. Thus, investing in **behavioural change** with sustainability education should be considered not only as part of environmental responsibility but also as part of economic performance.

HEI Learning Content (Course Catalog)

Course Name: Sustainable Maritime Operations and Green Ports				**Degree: HEI Undergraduate/Graduate**		
Code	**Year/Semester**	**Local Credits**	**ECTS Credits**	**Course Implementation, Hours**		
				Course	**Tutorial**	**Simulator Laboratory**
GRNPRT01	**1/2**	**2**	**4**	**28**	**20**	**8**

Department	Maritime Business Management/Maritime Transport/Maritime Logistics			
Instructors	…………………..			
Contact Information	…………………….			
Office Hours	………………………….			
Web page	https://greenportalliance.eu			
Course Type	Blended Learning (Online and Classroom)	**Course Language**	English	
Course Prerequisites	N/A			
Course Category by Content (%)	**Basic Sciences**	**Engineering Science**	**Engineering Design**	**Humanities Social Sciences**
	20	20	-	60
Course Description	Environmental protection and climate change issues are important especially in the context of a shared sea basin and adjacent coasts. Air pollution is also a transboundary issue in marine areas due to maritime transport. Dealing with the adverse effects of climate change on ecosystems, as well as facing sea level rise due to the changing climate are additional considerable challenges. **GREENPORT** targets an overlooked sub-sector within the Green Deal's strategy to decarbonise the maritime industry: that of port services. Vessels such as tugboats and pilot boats, and personnel who crew these craft, although often operating outside the scope of international conventions and European regulation, play a crucial role in supporting the broader decarbonization goals of the shipping industry while playing an important role in ensuring the safety of port assets and vessels whilst in port. **GREENPORT** posits that a change in **human behaviour** can reduce the environmental impact of in-port services in the short- to medium-term. Modifications can be made to day-to-day operations, with better use of existing digital technologies, that would contribute to a drop in emissions while maintaining the highest standards of navigational safety. This course is developed for education and training of future personnel at the Maritime Higher Education institutions (HEI) and focus on managers, future pilots and harbour masters who make policy decisions regarding how ports and port services are provided., as one of the main outcomes of the GREENPORT Project. Course is designed to be delivered in **14 weeks in 28 hours (2 hrs tutorial, supported by case studies and simulator practices)** as a standalone unit. However, HEIs those already delivering sustainability courses may adopt and incorporate some of these modules **(novel approaches to small vessels and in-port operations)** to their existing courses to meet **in-port operations requirements.** If needed tutorial and lab/simulator hours can be divided into separate weeks according to course flow, number of attendees and simulator availability.			
Course Objectives	**General Objective:** To increase **awareness** and **behavioural change** through accumulation of knowledge and training of skills necessary to prevent and combat marine pollution by ensuring compliance with legislative requirements, application of operational procedures and use of pollution control systems as the best practices. The GREENPORT Learning			

	methodology for higher education institutions focuses on seamlessly integrating sustainable practices, emissions reduction strategies, and green technologies into HEI maritime studies programmes that fosters a shared understanding of sustainable operations and empowers participants to lead change within their ports and professional communities. Students engage in practical applications through hands-on experiences and real-world cases to develop competencies for addressing sustainability challenges in port services. Collaboration with industry partners ensures that curricula reflect the latest trends and provides valuable networking opportunities. Continuous evaluation and feedback mechanisms enhance the methodology's effectiveness. By promoting innovation, multidisciplinary approaches, professional development, and networking opportunities, the methodology prepares students to drive positive change in the maritime industry and contribute to a more sustainable future. **Specific Objectives:** 1. To enhance knowledge on the general ideas associated with the protection of the marine environment (terminology, legislation, impact) and of the main sources of pollution related to the activities carried out in maritime transport and port operations 2. To help improve the impact of maritime operations on the environment and air quality in line with UN SDG14. 3.To develop fuel-efficient navigation techniques and slow steaming strategies. 4.To increase the use of digital tools for emissions monitoring and energy efficiency tracking. 5. To optimize tugboat and pilot vessel operations for sustainability. 6. To implement best practices for eco-friendly port logistics and fuel management.
Course Learning Outcomes	1. Apply digital tools and advanced technologies to collect, analyse and report data on sustainability, emissions and energy efficiency. 2. Manage and maintain environmentally friendly ship systems and propulsion technologies, including engine optimization, use of alternative fuels and implementation of innovative technical solutions to make people understand how their interaction with an engine affects its emissions will have a direct impact on the environment. 3. Interpret and use data from digital sources, sensors and simulation models to make operational decisions and optimize port operations. 4. Apply safety, crisis management and maintenance procedures in accordance with the latest technological and operational standards for port efficiency. 5. Understand and apply international and national environmental regulations and manage documentation and reporting in accordance with regulatory requirements. 6. Effectively collaborate and coordinate with various stakeholders (e.g. port authorities, pilots, shipowners, technical departments) to achieve sustainability and operational excellence goals.
Instructional Methods and Techniques	Lecture – explication - case study – simulation
Tutorial Place (classroom, simulator)	Classroom (physical or virtual)
Learning Resources (Textbook, PPT, video)	Textbook (handouts), PPT presentations, case studies (available in the web repository to support relevant unit), animated videos, seminar & simulator exercises
Other References	1. 2023 IMO Strategy on Reduction of GHG Emissions from Ships, https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx 2. BALAMAN, Dilek and ÖZDEMİR, Ünal and Yazir, Devran – Investigating the Factors Affecting Ship Fuel Consumption Using Quantitative Methods. Available at SSRN: https://ssrn.com/abstract=4876934 or http://dx.doi.org/10.2139/ssrn.4876934 3. Barata, Ricardo, Cruz, Maria, Macedo, Joaquim, & Coelho, Margarida (2025). Improving Transport Performance and Decarbonization Potential in Small-Medium Ports. https://doi.org/10.1007/978-3-031-89444-2_30 4. Barbosa, S., Cruz, M.M., Coelho, M.C. (2025). Green Mobility for Small-Medium Size Ports: A GHG Emissions Web Calculator. In: McNally, C. et

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Homework & Projects	-
Laboratory Work	BRIDGE, PISCES-II/GNOME/ADIOS SIMULATIONS AND CASE STUDIES
Other Activities (Group Discussions, Guest speakers..)	Seminar, Group Discussions and Guest Speaker

Assessment Criteria	Activities	Quantity	Effects on Grading, %
	Attendance	14	20
	Midterm	1	20
	Quiz	-	
	Homework	-	
	Term Project	-	-
	Laboratory Work	-	-
	Practices	-	-
	Tutorial	-	-
	Seminar	-	-
	Presentation	-	-
	Field Study	-	-
	Final Exam	1	60
	TOTAL		
	Effects of Midterm and Activities on Grading, %		40
	Effects of Final on Grading, %		60
	TOTAL		100

Week	TOPICS	Learning Outcomes
1	**An introduction to maritime sustainability and environmental regulations** - Importance of behavioural change for sustainable operations - Basic concepts of sustainability in the maritime operation, understanding energy saving and emission reduction principles - Overview of EU and IMO regulations and their indirect impact on port services (Green Deal, Fit for 55, FuelEU, EU ETS/IMO NZF) and port services not specifically falling within these regulations for the time being - Navigation Safety versus Emission Reduction - The role of sustainability in the operational excellence and competitiveness of ports. - Importance of aligning with client expectations and future-proofing operations	2, 5
2	**Industry Ecosystem and Technological Landscape** - Port requirements (e.g. Onshore Power Supply- OPS) - Trends in shipping: Alternative fuel vessels (e.g. LNG, methanol, ammonia) - Use of ShaPoli systems on client vessels and implications for port services - Emission monitoring tools and their usability for crews - Best practices: Different types of tug and pilot boats using cleaner fuels, including HVO. - Challenges for their uptake: Limited availability and high cost of alternative fuels - Available funding and the cost of going green.	1, 3
3	**Operational Strategies for Energy Saving and Emission Reduction** - Techniques using existing resources. - Eco Speed Steaming: Benefits and Implementation - Scheduling with tidal windows to optimize fuel use. - Real-time fuel consumption visualization for port service craft - Tug energy saving, before and after a job	1, 3
4	**Collection and analysis of emissions and sustainability data** - Green port and emission reduction strategies in ports and maritime operations - Key sustainability/progress indicators and their monitoring - Data collection and processing techniques - Analytics and reporting for environmental responsibility	2
5	**Interpretation and use of data in operational decision-making** - Data analysis and visualization for decision support - Application of data in daily operations - Data-driven risk management	2
6	**Use of simulation for Eco Navigation 1** - Using simulation tools to estimate savings - Utilizing simulation to train on energy efficient manoeuvring techniques - Encouraging behavioural change through data-driven feedback	2, 3
7	**Use of simulation for Eco Navigation 2** - Port-specific digital modelling	1, 3

	- Using vessel momentum strategically - Prioritizing safety in manoeuvring - Using elements to advantage - Monitoring for overuse of tugs and ship's engine by pilot - Elements which a tug master can do better to save energy. - Post-operation pilot and tug master/s debrief	
8	**Security procedures and crisis management in a digitalized environment** - Security procedures for digitalized systems - GNSS spoofing, jamming, and cyber threats in navigation - Crisis management and emergency response - Human factors and crew management	1, 3
9	**REVIEW & MIDTERM EXAM**	
10	**Application of biofuels and alternative propulsion technologies** - Fuel conversion technologies and biofuel systems - Adaptation of operating procedures for alternative fuels - Collaboration with engine manufacturers and suppliers	4
11	**Management and maintenance of environmentally friendly systems** - Maintenance and calibration of ship engines and systems - Performance monitoring and use of predictive algorithms - Maintenance documentation management - Predictive and preventive maintenance techniques - Use of digital tools for maintenance management - Life cycle management of ship equipment	2, 4
12	**Reporting and document management according to ESG and regulatory requirements** - ESG (Environmental, Social, and Governance) standards and reporting requirements - Management and archiving of compliance documentation - Preparation of reports for regulatory bodies	1, 5
13	**Communication and Stakeholder Engagement** - Roles of various stakeholders in sustainable port operations - Behavioural change: The role of training, leadership, and peer influence - Good planning of effective communication with all players involved. - Eliciting the required information for smooth operations - Clarifying the role of digital aids (e.g. PPU, VR)	6
14	**Development and implementation of sustainable port and shipping strategies** - Planning and implementation of sustainability strategies - Operational efficiency in ports and optimizing port logistics. - Measuring impact and continuous improvement - The role of innovation and new technologies in port development	2, 5, 6

ECTS / WORKLOAD TABLE

Activity	Count	Hours	Total Workload
Course	14	2	28
Preparation for the lecture	12	1	12
Homework	0	0	0
Quiz	0	0	0
Presentations/ Seminars Preparation	1	10	10
Midterm(s) (Exam +Preparation)	1	20	20
Group Project	0	0	0
Lab.	0	0	0
Field Work	0	0	0
Final Exam (Exam +Preparation)	1	30	30
Total Workload			**100**
Course ECTS Credits	**(Total Workload/ 25)**		**4**

Prepared by	***Date***	***Signature***
Prof. Mustafa Taner Albayrak	31.07.2025	

CHAPTER 1

COURSE Module 1 (Week 1)

GREENPORT *Alliances*

Module 1 | Introduction to Maritime Sustainability and Environmental Regulations

Co-funded by the European Union

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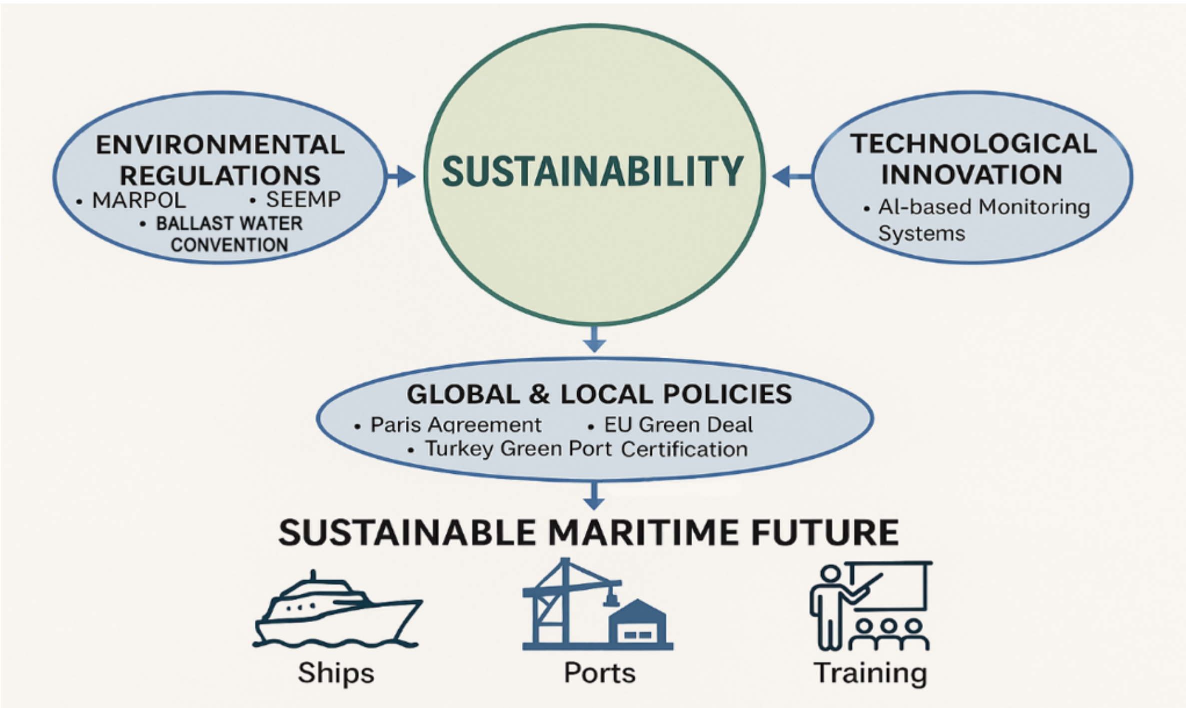
1. Importance of Behavioural Change for Sustainable Operations

Sustainability and **environmental policies**, although have some **common issues,** they are not the same and mistakenly used in the same meaning.
Sustainability is a broader concept that goes beyond protecting the environment alone. It refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission, 1987). Sustainability issues focus on; Social and Economic Dimensions, Corporate Sustainability and ESG criteria and Sustainable Development Goals (SDGs). On the other hand, Environmental Policies cover Legal and Regulatory Frameworks, Permitting and Compliance and Site-Specific Regulations.
Topics such as Climate Change Mitigation, Resource Conservation, Pollution Control, Environmental Impact Assessments (EIAs) and Public Awareness and Education are covered in both policy approaches.



Relationship Between Sustainability Goals and Environmental Policies in the Maritime Sector (Produced by Artificial Intelligence)

The maritime industry, responsible for over 80% of global transport, plays a pivotal role in international trade and environmental sustainability. Generating approximately 3% of global greenhouse gas emissions, maritime industry needs sustainable practices, necessitating more sustainability education. Thus, the ultimate target is to achieve net-zero GHG emissions by or around 2050 (IMO, 2023).

The UN Climate Change Conference COP26, held in Glasgow, United Kingdom, in 2021, was particularly notable for emphasizing the importance of **behavioural change** in addressing climate change and reducing carbon footprints through

Individual and societal behaviour change, public engagement and lifestyle changes. While subsequent COPs (COP27 in Sharm El-Sheikh and COP28 in Dubai) continued to build on these themes, COP26 was a turning point in framing **behavioural change as a central pillar of climate strategy** alongside policy and technological innovation.

Vessels such as tugboats and pilot boats, and personnel such as harbour masters, carry out an essential role of ensuring the safety of port assets and vessels whilst in port. However, because of these service vessels' small size, in-port operations have not been included in the EU's emission reduction targets. The lack of enforced targets does not mean the sector is not polluting. Moreover, greener technology, whilst in development, is not yet ready for large scale commercial use.
GREENPORT posits that a **change in human behaviour** can reduce the environmental impact of in-port services in the short- to medium-term. Modifications can be made to day-to-day operations, with better use of existing digital technologies, that would contribute to a significant drop in emissions.
The behaviour change requires a change of education concepts in order to shape future professionals by Integrating knowledge, behaviour, and responsibility as well as maritime educators' commitment to sustainability.

The **COM-B** model posits a certain behaviour can only occur if three key prerequisites are met: **capability, opportunity, and motivation**.
Capability refers to everything that enables an individual to perform a certain behaviour, including psychological factors such as knowledge, understanding, and skills, as well as physical aspects such as access to resources and practical training.
Opportunity refers to external factors that enable or encourage a certain behaviour. This includes physical resources such as teaching materials, technological equipment, access to case studies, as well as social conditions like institutional culture, peer support, and cooperation with industry.
Motivation encompasses the internal psychological processes that direct and maintain behaviour—including both conscious evaluations and planning, as well as automatic impulses, habits, and emotional reactions.

Sustainability education, especially in operational areas such as port services, can enable personnel to make more conscious decisions on issues such as energy efficiency, fuel savings, resource use, and equipment life. This means reducing operating costs, increasing operational efficiency, and thus contributing to economic sustainability. In addition, the quality of human resources developed through education is also the key to achieving competitive advantage in the sector. The sustainability awareness of the workforce would help port service providers adapt to international standards more quickly and achieve success in green port certification processes, allowing for not only short-term cost advantages but also long-term reputation and strategic gains. Thus, investing in sustainability education should be considered not only as part of environmental responsibility but also as part of economic performance.

2. Basic concepts of sustainability in the maritime operations, understanding energy saving and emission reduction principles

One of the most essential conditions for sustainability is **raising awareness for behavioural change**. As society becomes more informed on various issues, the standards for sustainability will rise accordingly. If this awareness is embraced as a guiding principle, it can lead to long-term prosperity. In contrast, environmental policies primarily aim to correct negative externalities. **Policy coherence** involves the systematic promotion of mutually reinforcing policy actions across governments and agencies, thereby enabling broader progress toward the Sustainable Development Goals.

While all sustainability policies are crucial, sustainability in the seas is an area that should not be underestimated. This is because nearly 85-90% of global trade has been and continues to be carried out via the seas. Additionally, a significant portion of tourism activities also take place on the seas. If the seas become polluted and face various negative impacts, it will inevitably lead to an economic decline.

From the **Climate Change Mitigation** perspective, Sustainability and Environmental Policies both aim to reduce greenhouse gas emissions and promote renewable energy sources in the maritime sector. Policies like carbon pricing, emissions trading systems, and subsidies for clean energy are shared tools.

Corporate Sustainability and ESG Focus on how businesses operate sustainably, including governance, ethics, and stakeholder engagement, and **goes beyond compliance with environmental laws.**
Environmental Policies are Site-Specific Regulations that may target specific ecosystems or regions, while **sustainability** tends to be more holistic.

Tugboats are indispensable in port logistics, especially during piloting operations where they assist larger vessels in docking, undocking, and navigating confined waters. These tasks require high manoeuvrability and responsiveness, often resulting in inefficient fuel usage. With increasing environmental regulations and fuel costs, improving energy efficiency in tug operations has gained utmost importance.

Piloting operations involve short bursts of high power, frequent idling, and rapid directional changes. These conditions lead to low average engine loads, which are inefficient for conventional diesel engines. The variability in load and speed makes energy optimization complex but essential.

Reducing fuel consumption and improving energy efficiency on vessels is not a one-size-fits-all proposition. To maximise benefits and produce acceptable financial returns from any energy savings technology, it is first necessary to understand in sufficient detail how the vessel operates and consumes energy. Solutions that work well for a harbour tug with very low average engine loads will not produce the same value for ocean towing tugs that operate predominantly where diesel engines are most efficient.

Recent studies have applied genetic algorithms (GA) to optimize tugboat routes and speeds during piloting operations. By minimizing unnecessary movements and selecting fuel-efficient paths, significant savings can be achieved.

Main energy-saving measures for behavioural change in pilotage and tugboat operations require holistic view on available technological innovations such as Hybrid Propulsion Systems (Electric-diesel hybrids are particularly effective in piloting operations, where low-speed manoeuvring dominates), Real-Time Monitoring (Energy management systems track fuel consumption and engine performance, enabling adaptive control strategies).

Skilled piloting crews can reduce fuel consumption through efficient throttle control and manoeuvring techniques while task scheduling coordinating tug assignments to minimize idle time and unnecessary repositioning improves overall energy use. These skills can be developed through a dedicated behavioural change training for respective crew.

Behavioural change from the port and tug managers/operators' perspective may consider, Hull and Propeller Optimization**,** designs tailored for low-speed, high-manoeuvrability operations that improve thrust efficiency, and use of Energy-Efficient nozzles to enhance bollard pull while reducing fuel consumption. Collaboration with shipping companies and other ports to share best practices and importance of incentives for using cleaner technologies are also key issues for behavioural change**.**

Piloting operations present unique challenges for energy efficiency due to their dynamic and demanding nature. However, through a combination of advanced propulsion technologies, data-driven optimization, and crew training for upskilling and behavioural change, significant improvements can be achieved. As ports strive for greener operations, enhancing the energy performance of piloting tugs will be a key component of sustainable maritime logistics.

3. Overview of EU and IMO regulations and their indirect impact on port services and port services not falling within these regulations

In 1973, the International Maritime Organization (IMO) adopted the **International Convention** for the Prevention of Pollution from Ships, now known universally as MARPOL, which has been amended by Protocols and kept updated through other relevant amendments. The MARPOL Convention Annex VI addresses Prevention of Air Pollution from Ships.

The European Union and the IMO have also introduced a series of climate-focused regulations aimed at decarbonizing the maritime sector such as EU Green Deal, Fit for 55, FuelEU, EU ETS/IMO NZF.

European Green Deal: A broad strategy to make the EU climate-neutral by 2050, influencing all transport sectors including maritime

Fit for 55 Package: A legislative framework to reduce EU greenhouse gas emissions by 55% by 2030. It includes measures affecting shipping and port operations

FuelEU Maritime: Promotes the use of sustainable maritime fuels by setting GHG intensity limits for energy used onboard ships
EU Emissions Trading System (EU ETS): Since January 2024, large ships (≥5,000 GT) entering EU ports are subject to carbon pricing, covering CO_2 emissions from voyages and port stays

IMO Net Zero Framework (NZF): IMO's 2023 strategy sets targets for reducing GHG emissions from international shipping, though criticized for lacking strong enforcement and incentives

While these regulations primarily target ships ≥5,000 GT, they indirectly affect **port services** in several ways:

Infrastructure Demands: Ports must adapt to support alternative fuels (e.g., green hydrogen, e-methanol), requiring investment in bunkering and storage facilities.

Operational Adjustments: Increased monitoring and reporting obligations (e.g., MRV regulations) affect port logistics and coordination.

Competitive Pressure: Ports not aligned with green standards may lose traffic to more sustainable alternatives.

Energy Supply and Efficiency: Shore-side electricity and energy-efficient terminal operations are becoming essential to support low-emission vessels.

Certain port activities—such as **pilotage, mooring, and towage services**—are not yet directly covered by EU or IMO climate regulations. However, these services are increasingly expected to align with broader sustainability goals through:

- Voluntary adoption of low-emission technologies (e.g., electric or hybrid tugboats).
- Participation in green port initiatives and certification schemes.
- Integration into port-wide energy management systems**.**

K**ey challenges** in implementing EU and IMO maritime decarbonization regulations, along with the ship tonnage limitations include:

Infrastructure Gaps at Ports: Many ports lack the necessary infrastructure for onshore power supply (OPS)**,** alternative fuel bunkering**,** and energy monitoring systems. Retrofitting ports is capital-intensive and requires long-term planning.

Technological Readiness: Ships and port service vessels (e.g., tugs, pilot boats) may not yet be equipped to use low-emission fuels or connect to OPS. Hybrid and electric propulsion systems are still emerging technologies for many vessel types.

Compliance Complexity: Operators must navigate overlapping regulations from the **EU MRV**, **IMO DCS**, and **FuelEU Maritime**, each with different reporting standards. Monitoring, reporting, and verification (MRV) systems must be externally audited and standardized.

Cost Burden: Compliance with EU ETS and FuelEU Maritime introduces carbon pricing and penalties, increasing operational costs. Smaller operators and ports may struggle to absorb these costs without subsidies or incentives.

Global Coordination: IMO's Net Zero Framework (NZF) lacks binding enforcement, leading to asymmetric compliance across regions.

Limited Scope of Regulations: Port services like **pilotage, towage, and mooring** are not directly regulated but are indirectly affected by ship compliance requirements. These services may need to upgrade equipment and practices to align with broader sustainability goals.

Even though port service operations are not regulated or monitored at the EU level, because of this sub-sector's relatively smaller size than other shipping, emissions are still being made by the sector. Technology that would mitigate these vessels' environmental impact is being developed, e.g., hydrogen, methanol, ammonia or synthetic drop-in fuels from renewable energy, as well as electric engines. Sustainable supply of new fuels is still a problem. Unfortunately, these technological advancements are either not yet ready for commercial use at a large scale or are not convincing to be long term solutions, being still at a conceptual level or being piloted in test contexts. Although there are several attempts for electric engines, the desired power level is not at the satisfactory level especially for larger ships (and their towage) and for use during severe weather conditions. Moreover, the boats in question have a long lifecycle of 30 years or more. Consequently, the 2050 goals are hard to achieve because many ships operating today will still be sailing by then, even if more efficient ships come onto the market at a later point. The viable technological solution to reach the goals would then be to retrofit ships with transition technologies. However, the extra cost of cleaner technology over one that emits more greenhouse gases (the 'green premium') is a barrier that slows down the introduction of transition technologies. Additionally, it is a fact that **investing in new technology without changing people's attitudes** will not solve the climate crises. What this all means is that in the immediate and medium-term, emissions within the port services industry will continue rising, because shipping itself is continuously increasing (Eurostat).

A change in human attitude and behaviour is therefore needed. For that reason, the way how technology is used in practice needs to be considered as well. A collateral advantage of changing attitudes is that we can already initiate this today by changing maritime education and training approaches without the need of high investment costs, and without waiting for the greener technology that is still under development. By optimising the **interaction between humans and existing technology** in the short term and more efficient use of technology results in less fuel consumption (i.e., an economic incentive to change behaviour) and at the same time to less emission (i.e., an ecological incentive to change behaviour).

4. Navigation Safety versus Emission Reduction

Balancing navigation safety and emission reduction in port pilotage and towing operations is a critical challenge in the maritime sector.

Port pilotage and towing operations are essential for preventing collisions and groundings in congested or narrow waterways, ensuring safe docking and undocking of large vessels, especially in adverse weather or tidal conditions, and protecting port infrastructure, cargo, and human lives.

Safety is non-negotiable in these operations. Pilots and tug operators must prioritize vessel control, responsiveness, and reliability—often requiring high engine power and manoeuvrability, which can conflict with emission reduction goals.

With increasing pressure from **EU and IMO regulations**, ports and operators are expected to:

- **Reduce greenhouse gas (GHG) emissions** from all maritime activities.
- **Adopt cleaner technologies** like hybrid or electric propulsion systems.
- **Improve fuel efficiency** through operational optimization.

Emission reduction is vital for meeting climate targets and improving air quality especially in port cities.

The Trade-Off and Integration Challenge

Aspect	Navigation Safety	Emission Reduction Priority
Engine Power	High, responsiveness	Lower, fuel efficiency
Manoeuvring Speed	Fast, precise movements	Slower, optimized movements

Aspect	Navigation Safety	Emission Reduction Priority
Equipment Redundancy	Essential for safety	May increase energy use
Real-Time Decisions	Based on safety needs	May conflict with fuel-saving plans

Strategies for Harmonizing Both Goals

- **Hybrid Tugboats**: Use electric propulsion during low-speed operations and diesel when high power is needed.
- **Smart Navigation Systems**: Optimize routes and manoeuvres to reduce fuel use without compromising safety.
- **Training and Simulation**: Equip pilots and tug operators with tools to balance safety and sustainability.
- **Port Coordination**: Synchronize vessel movements to minimize idle time and unnecessary manoeuvres.

While emission reduction is a growing priority, navigation safety must remain paramount in pilotage and towing operations. The key lies in integrating clean technologies and behavioural change for smart operational practices that support both goals. Ports and regulators must ensure that sustainability efforts do not compromise the safety of maritime operations.

5. The role of sustainability in the operational excellence and competitiveness of ports

As global maritime regulations and environmental expectations evolve, sustainability has become a cornerstone of operational excellence and competitiveness in port services. Port operational excellence centers on optimizing processes while minimizing waste. Sustainability drives this through; resource efficiency, energy management, adoption of on shore power systems (OPS), water conservation through closed-loop water systems in container washing (Lam, J. S. L., & Notteboom, T. , 2020) , process innovation, digitalization: IoT-enabled smart ports (optimizing truck routing, reducing idle times and lowering CO_2 emissions (Yang, Y., et al. ,2023), circular economy models, repurposing dredged sediment for coastal restoration turns waste into revenue streams (Van der Lugt, L. M., et al. ,2021).

Ports leveraging sustainability gain competitive advantages through; regulatory foresight such as compliance with IMO 2020 sulphur caps and EU Green Deal requirements that pre-empts fines and secures market access. Ports with ESG-aligned operations attract "green premiums" from eco-conscious shipping lines (e.g., Maersk's carbon-neutral vessel contracts).

Community engagement (e.g., noise reduction initiatives) mitigates social license risks and enhances stakeholder management (Dooms, M., et al., 2019). Transparent sustainability reporting (GRI/ESG frameworks) enhances investor confidence (Global Reporting Initiative (GRI), 2023).

Supply Chain Integration that creates Ports serving as "green hubs" becomes preferred partners in low-carbon logistics corridors (Woo, S. H., et al.,2022).
Port services such as pilotage, towing, and mooring are critical to the safe and efficient movement of vessels. Historically, these services have prioritized navigational safety and operational reliability. However, with the rise of climate-

focused regulations like the EU Green Deal, FuelEU Maritime, and IMO's Net Zero Framework, sustainability is now a key performance metric. Ports that embrace sustainable practices in these auxiliary services are better positioned to meet regulatory demands, attract eco-conscious clients, and maintain competitive advantage.
Sustainable operations often lead to improved fuel efficiency, reduced emissions, and optimized resource use. For example:

- **Hybrid and electric tugboats** reduce fuel consumption during low-speed maneuvers.
- **Smart scheduling and routing** of pilotage services minimize idle time and unnecessary movements.
- **Energy-efficient mooring systems** reduce wear and energy use during vessel berthing.

These improvements not only lower environmental impact but also enhance service reliability and cost-effectiveness.
Sustainable practices help ports comply with evolving regulations, reducing the risk of penalties and reputational damage. Services aligned with EU ETS and FuelEU Maritime frameworks demonstrate proactive environmental stewardship, which is increasingly valued by shipping lines and regulators.
Ports offering low-emission pilotage and towing services can differentiate themselves in a competitive market. Shipping companies seeking to reduce their carbon footprint may prefer ports with green credentials, including:

- Availability of **shore-side electricity** for service vessels.
- Use of **alternative fuels** like bio-LNG or hydrogen.
- Participation in **green port certification schemes**.

Sustainable port services foster stronger relationships with stakeholders, including local communities, environmental agencies, and international partners. Transparent reporting and visible green initiatives build trust and support long-term growth.
While the transition to sustainable operations presents challenges—such as high capital investment, technology integration, and workforce training—it also opens opportunities for innovation and leadership. Ports that invest early in sustainable pilotage, towing, and mooring systems can shape industry standards and influence policy development.

Sustainability is no longer a peripheral concern in port operations—it is central to achieving operational excellence and maintaining competitiveness. By embedding sustainability into pilotage, towing, and mooring services, ports can enhance safety, efficiency, and environmental performance simultaneously. The future of maritime logistics depends on the ability of ports to evolve into smart, green hubs that support both economic and ecological goals.

6. Importance of aligning with client expectations and future-proofing operations

In today's rapidly evolving maritime landscape, ports are under increasing pressure to deliver high-performance services while adapting to environmental, technological, and regulatory changes. Operational excellence and competitiveness are no longer defined solely by speed and cost-efficiency—they must now align with client expectations for sustainability, transparency, and innovation. This alignment is especially critical in auxiliary services such as

pilotage, towing, and mooring, which directly influence vessel turnaround times, safety, and environmental impact.

Operational excellence in port services traditionally focuses on:

- **Safety and reliability** in vessel handling.
- **Minimizing delays** and optimizing resource use.
- **Compliance** with maritime regulations.
-

However, excellence today also includes:

- **Sustainability performance** (e.g., low-emission operations).
- **Digital integration** (e.g., real-time tracking, predictive analytics).
- **Service flexibility** to meet diverse vessel and cargo needs.

Ports compete not only on throughput and location but increasingly on:

- **Environmental credentials** (e.g., green port status).
- **Service innovation** (e.g., autonomous mooring systems).
- **Client-centric operations**, including tailored pilotage and towing schedules.

Shipping companies and logistics providers now expect ports to support their own decarbonization goals, offer transparent emissions data, and provide efficient, low-impact services.

To remain competitive and resilient, ports must:

- **Invest in clean technologies**: Hybrid tugboats, electric pilot vessels, and smart mooring systems reduce emissions and future-proof operations against tightening regulations.
- **Adopt digital platforms**: Integrated port community systems (PCS) and AI-driven scheduling tools enhance coordination and responsiveness.
- **Engage stakeholders**: Collaborating with clients, regulators, and technology providers ensures that port services evolve in line with market expectations.

Operational excellence and competitiveness in port operations must evolve to reflect client expectations and future challenges. By integrating sustainability, innovation, and stakeholder engagement into pilotage, towing, and mooring services, ports can position themselves as forward-looking, resilient hubs in the global maritime network.
As ports transition toward greener and more efficient operations, the human element becomes increasingly critical. While technology and infrastructure upgrades are essential, **education and training for behavioural change** are equally vital in aligning operational practices with sustainability goals. This is especially true for **pilotage, towing, and mooring services**, where real-time decision-making and operational habits directly impact fuel use, safety, and service quality.

Behavioural change refers to the shift in attitudes, habits, and decision-making processes that support sustainable and efficient operations. In port services, this includes:

- **Throttle control and manoeuvring techniques** that reduce fuel consumption.
- **Efficient communication and coordination** between pilots, tug operators, and mooring crews.

- **Proactive maintenance and energy-conscious operations** of service vessels.

Without behavioural alignment, even the most advanced technologies may be underutilized or misapplied. Training programs should focus on **Sustainability Awareness** and personnel must understand:

- The **environmental impact** of their operations.
- How their actions contribute to **port-wide emission goals**.
- The importance of **energy efficiency** in daily tasks.

Training should emphasize that safety and sustainability are not mutually exclusive. For example:

- Efficient tug manoeuvres can reduce fuel use **without compromising safety**.
- Smart mooring practices can improve turnaround time and reduce emissions.

Creating a culture of sustainability requires:

- **Leadership buy-in** and role modelling.
- **Recognition and incentives** for sustainable practices.
- **Continuous feedback and improvement loops**.

Education and training for behavioural change are foundational to achieving sustainability, operational excellence, and competitiveness in port operations. By empowering pilots, tug operators, and mooring crews with the knowledge and mindset to operate efficiently and responsibly, ports can unlock the full potential of their technological investments and meet the expectations of regulators and clients alike.

7. Conclusion

In conclusion, the relationship between environmental policies and sustainability is a dynamic and interdependent one. While environmental policies address specific ecological challenges, sustainability provides a broader framework that ensures long-term resilience by integrating economic and social dimensions. A holistic approach, combining both policy areas, is essential to ensure that development is both environmentally sound and socially inclusive, paving the way for a sustainable future.

Sustainability transcends ethical obligation to become a core enabler of port resilience and market leadership. Ports embedding sustainability into operational DNA achieve efficiency gains, regulatory agility, and stakeholder trust—key pillars of long-term competitiveness.

Sustainability is no longer a peripheral concern in port operations—it is central to achieving operational excellence and maintaining competitiveness. By embedding sustainability into pilotage, towing, and mooring services, ports can enhance safety, efficiency, and environmental performance simultaneously. The future of maritime logistics depends on the ability of ports to evolve into smart, green hubs that support both economic and ecological goals.

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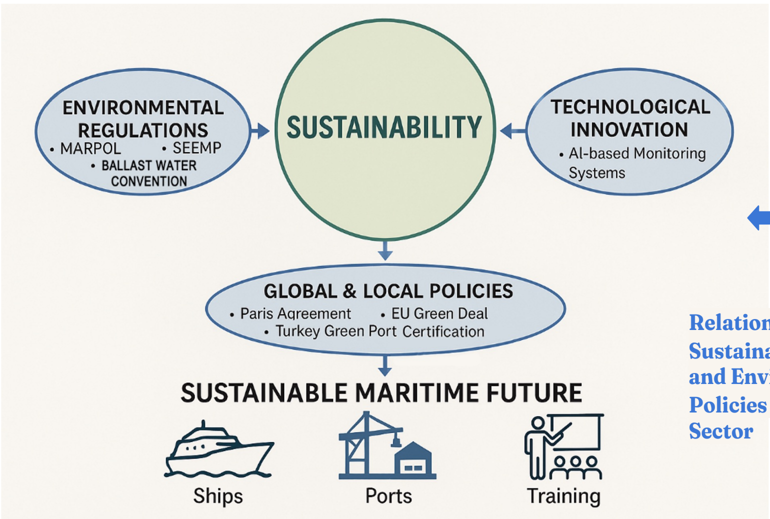
Chapter 1 Supporting Material

Introduction

- **Sustainability** and **environmental policies**, are not the same
- Sustainability is a **broader concept** that goes beyond protecting the environment alone.
- It refers to the ability to **meet the needs of the present without compromising the ability of future generations** to meet their own needs
- **Environmental Policies** cover Legal and Regulatory Frameworks, Permitting and Compliance and Site-Specific Regulations.

Topics such as Climate Change Mitigation, Resource Conservation, Pollution Control, Environmental Impact Assessments (EIAs) and Public Awareness and Education are covered in both policy approaches.



Relationship Between Sustainability Goals and Environmental Policies in the Maritime Sector

Basic concepts of sustainability in the maritime sector:

- Raising awareness
- Policy coherence
- Climate Change Mitigation
- Resource Conservation
- Pollution Control
- Environmental Impact Assessments

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Overview of EU and IMO regulations, impact on port services

- European Green Deal
- Fit for 55 Package
- FuelEU Maritime
- EU Emissions Trading System (EU ETS)
- IMO Net Zero Framework (NZF)

these regulations primarily target ships ≥5,000 GT, they indirectly affect port services in several ways

With increasing pressure from **EU and IMO regulations**, ports and operators are expected to:

- **Reduce greenhouse gas (GHG) emissions** from all maritime activities.
- **Adopt cleaner technologies** like hybrid or electric propulsion systems.
- **Improve fuel efficiency** through operational optimization.

Emission reduction is vital for meeting climate targets and improving air quality especially in port cities.

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The role of sustainability in the operational excellence and competitiveness of ports:

- Port operational excellence centres
- Optimizing processes
- Minimizing waste
- Resource efficiency
- Energy management
- Cold ironing
- Water conservation through closed-loop water systems in container washing
- Process innovation
- Digitalization
- IoT-enabled smart ports
- Optimizing truck routing, reducing idle times and lowering CO_2 emissions
- Circular economy models
- Repurposing dredged sediment for coastal restoration

The role of sustainability in the operational excellence and competitiveness of ports:

Repurposing dredged sediment for coastal restoration turns waste into revenue streams.

Ports leveraging sustainability gain competitive advantages through:

- Regulatory foresight such as compliance with IMO 2020 sulphur caps and EU Green
- Preempts fines and secures market access.
- Ports with ESG-aligned operations attract "green premiums" from eco-conscious shipping lines
- Community engagement (e.g., noise reduction initiatives) mitigates social license risks
- Enhanced stakeholder management
- Transparent sustainability reporting – investor
- Supply Chain Integration

Ports serving as "green hubs" becomes preferred partners in low-carbon logistics corridors

Conclusion:

- The relationship between environmental policies and sustainability is a dynamic and interdependent.
- While environmental policies address specific ecological challenges, sustainability provides a broader framework that ensures long-term resilience by integrating economic and social dimensions.
- A holistic approach, combining both policy areas, is essential to ensure that development is both environmentally sound and socially inclusive, paving the way for a sustainable future.
- Sustainability transcends ethical obligation to become a core enabler of port resilience and market leadership. Ports embedding sustainability achieve efficiency gains, regulatory agility, and stakeholder trust for long-term competitiveness.

Chapter 1 Assessment Questions

An introduction to maritime sustainability and environmental regulations

EXAM QUESTIONS

1. **What is the fundamental difference between sustainability and environmental policies?**
    a. Sustainability only targets economic growth, while environmental policies prioritize social justice.
    b. **Sustainability covers social/economic dimensions and ESG criteria, while environmental policies focus on legal compliance and permitting processes**.
    c. Environmental policies regulate global trade, while sustainability only addresses local ecological issues.
    d. Both use the same tools; the sole difference is the scale of implementation.
    e. Both are the same, there is no difference

2. **Which of the following is a resource conservation goal ''common to both'' sustainability and environmental policies?**
    a. Reducing income inequality
    b. Protecting biodiversity in oceans
    c. Mandating hybrid tugboats
    d. Strengthening labour unions
    e. Reducing CO2 footprint

3. **Which of the following IMO/EU regulation targets tugboats and port service crafts?**
    a. European Green Deal
    b. None of them
    c. Fit for 55 Package
    d. EU Emission Trading System (EU ETS)
    e. IMO NZF

4. **Which example illustrates the contribution of sustainability to operational excellence in ports?**
    a. Banning private construction along coastlines
    b. Reducing ship emissions via shore-side electricity (cold ironing)
    c. Mandatory ESG training for maritime personnel
    d. Increasing penalties for ballast water discharge
    e. All of them

5. **Which of the following topics falls directly under the scope of both sustainability and environmental policies?**
    a. Corporate board diversity
    b. Climate change mitigation strategies

c. Shareholder dividend distribution policies
d. Regulation of wage inequality
e. None of them

6. **Mark the wrong statement**
   a. Port services like **pilotage, towage, and mooring** are not directly regulated but are indirectly affected by ship compliance requirements
   b. Investing in new technology without changing people's attitudes will solve the climate crisis
   c. Pilots and tug operators must prioritize vessel control, responsiveness, and reliability
   d. Skilled piloting crews can reduce fuel consumption through efficient throttle control and manoeuvring techniques
   e. Task scheduling coordinating tug assignments to minimize idle time and unnecessary repositioning improves overall energy use.

7. **Which regulation specifically addresses a broad strategy to make the EU climate-neutral by 2050.**
   a. MARPOL Annex VI
   b. European Green Deal
   c. IMO Net Zero Framework
   d. Fit for 55 Package
   e. EU Emission Trading System

8. **How do sustainability-focused ports gain a "green premium" advantage?**
   a. By obtaining tax exemptions from local governments
   b. Through preference from eco-friendly shipping lines
   c. By constructing special tourism zones along coastlines
   d. Through funding international credit rating agencies ,
   e. All of them are correct

9. **Which of the following measure can be prioritized for sustainability?**
   a. Implementing nuclear energy on all ships
   b. Transitioning to hybrid/electric tugboat technology
   c. Providing free maritime training to port workers
   d. Increasing international cargo taxes
   e. Joint operations with neighbouring ports

10. **OPS stands for.**
    a. Optimized Port Services
    b. Onshore Power Supply
    c. OPerational Standards
    d. Optimized Piloting System
    e. Offshore Piloting Services

CHAPTER 2

COURSE Module 2 (Week 2)

1. Port requirements

Ports are critical nodes in global trade, and their efficiency hinges on robust piloting, towing, and mooring services. These operations require a symbiotic relationship between industry stakeholders and cutting-edge technology.

Industry ecosystem requirements mainly focus on good stakeholder collaboration and workforce expertise. Piloting, towing, and mooring demand seamless coordination among diverse stakeholders. For instance, pilotage services rely on licensed mariners with localized knowledge of waterways, as mandated by their national legislation. Towing operations require agreements with tugboat operators for 24/7 availability. The International Tugowners Association (ITA) emphasizes standardized Service Level Agreements to prevent delays, as seen in Singapore's port, where tug dispatch times are capped at 15 minutes during peak hours. Mooring crews, meanwhile, must adhere to the International Mooring Equipment Guidelines, which prescribe tensile strength standards for mooring lines.

Regulatory and environmental compliance requires ports alignment with global and regional regulations. The IMO's 2020 Global Sulphur Cap pushed ports to adopt low-emission tugboats, such as the hybrid-electric tugs deployed in some ports. Similarly, the EU's Port Reception Facilities Directive mandates waste management protocols for tugboats and pilot vessels.

Infrastructure resilience envisages dedicated boarding zones with wave-dampening structures, as implemented in the Port of Hamburg. Maintenance hubs for tugboats, such as Dubai's Drydocks World, offer azimuth thruster retrofitting services. Corrosion-resistant bollards and smart fenders, like the Trelleborg SeaStar systems used in Shanghai, which reduce vessel impact forces by 40%. Also plays an important role in infrastructure resilience.

From the technological landscape perspective, the main requirement is an Advanced Navigation System. Modern piloting liaise with Vessel Traffic Services (VTS) integrated with AI-driven risk assessment tools. The Port of Antwerp's SEAONICS system, for instance, uses machine learning to predict collision risks in congested channels. Tugboats may employ Dynamic Positioning Systems (DPS), achieving millimeter-level precision during berthing. For mooring, IoT-enabled tension sensors provide real-time load data, reducing line failures by 30% according to research.

Digital integration and cybersecurity measures are another important issue to consider. Centralized platforms like Port Community Systems (PCS) streamline operations. Some blockchain platforms automates billing for towage services, cutting administrative costs by 18%. However, digitization introduces risks: a 2023 IBM Security Report noted a 220% rise in ransomware attacks on port systems, underscoring the need for zero-trust architectures.

As part of the sustainability approach, hybrid tugboats eliminate a significant amount of CO_2 annually. Shore power systems, allow moored vessels to draw renewable energy, aligning with the IMO's 2050 Net-Zero Roadmap. Ports using hybrid/electric tugboats can pair them with OPS to create a fully decarbonized mooring-towing ecosystem. OPS can be integrated with Port Community Systems (PCS) for real-time energy monitoring, and Predictive analytics (discussed for tug deployment) can optimize power demand forecasting. Onshore power systems are not standalone solutions but part of a holistic port modernization strategy. They intersect with every layer of discussions above —from stakeholder collaboration and regulatory compliance to digital innovation and workforce training—reinforcing the need for ports to adopt integrated, future-ready frameworks.

The evolution of port services hinges on harmonizing industry collaboration, regulatory agility, and technological adoption. By leveraging these frameworks and investing in scalable solutions, ports can navigate these challenges while enhancing safety, efficiency, and sustainability.

The GREENPORT training program will transform theoretical knowledge into actionable behaviours by embedding real-world tools (predictive analytics, IoT), regulatory frameworks, and sustainability imperatives into immersive, incentive-driven learning. By aligning individual performance with port-wide goals—efficiency, safety, decarbonization—it ensures pilots and tugboat operators evolve from task executors to strategic partners in modern maritime ecosystems.

2. Trends in shipping: Alternative fuel vessels

As ports worldwide accelerate decarbonization efforts, tugboats and port service vessels—critical to harbor operations—are transitioning from traditional diesel to alternative fuels. Driven by stricter emission regulations, port sustainability mandates, and advancements in fuel technology, this shift is reshaping port ecosystems.

LNG has become the most widely adopted alternative fuel for tugboats due to its immediate emission reductions and operational feasibility. LNG-hydrogen dual-fuel tugs are reducing CO_2 emissions by 65% and eliminating particulate matter and cutting NO_x emissions by 90% compared to diesel counterparts. Methane slip remains a concern, though newer engines mitigate this. Limited bunkering infrastructure (only 25% of major ports have LNG bunkering capabilities as of 2025) is another concern.

Methanol's ease of storage and compatibility with existing engines make it ideal for retrofitting older tugs. Methanol Hybrid Tugs combine methanol combustion with battery storage, achieving 40% lower emissions. Green methanol supply chains are nascent and crew training for methanol's toxicity risks are being developed.

Ammonia's zero-carbon potential is compelling but requires rigorous safety protocols, especially in congested ports. Innovations such as Ammonia-Ready Tug Design that features double-walled fuel tanks and AI-powered leak detection systems, and ammonia-fueled vessels with 100% emission-free operation during standby are promising but safety concerns still exist. Global Ammonia Safety Council mandates ammonia-specific firefighting gear and ventilation systems for port crews. Ammonia refuelling is prohibited within 500 meters of residential zones in EU ports.

Tugboats and port service vessels are at the forefront of maritime decarbonization, serving as testbeds for alternative fuels. While LNG dominates today, methanol and ammonia are poised to redefine port operations by 2030. Success hinges on port-level infrastructure upgrades, safety innovation, and global standardization of training protocols. As urban ports face increasing pressure to improve air quality, the transition to cleaner fuels will solidify their role as sustainable logistics hubs.

3. Use of ShaPoli systems on client vessels and implications for port services

Shaft Power Limitation (ShaPoLi) systems are increasingly adopted by vessels to comply with the International Maritime Organization's (IMO) Energy Efficiency Existing Ship Index (EEXI) regulations. These systems restrict the shaft power delivered to the propeller, thereby reducing greenhouse gas emissions without requiring extensive engine modifications.

The system monitors shaft torque and RPM in real time, automatically enforces power limits during normal operations, permits emergency overrides and integrates with fuel efficiency dashboards and CII tracking tools. Port State Control (PSC) Inspection protocols may include verification of ShaPoLi settings and override logs which brings increased emphasis on documentation and transparency.

Vessels with limited shaft power may require additional tug assistance especially in adverse weather conditions. Port scheduling and resource allocation may need adjustment for revised berth allocation to prioritize ShaPoLi-equipped ships.

Port personnel, pilots, and tug operators must be trained on ShaPoLi-related limitations and override protocols. Enhanced coordination between ship and port services is essential. These systems, on one hand, offer a solution for reducing emissions, but on the other hand, they make vessels equipped with these systems more challenging to manoeuvre due to limited engine power. Certain ports have requested the disabling of these systems, prioritising safety over emission reduction. Ports may require real-time propulsion data for traffic and emissions management which brings cybersecurity risks in propulsion data sharing. Integration with digital port platforms (e.g., Just-In-Time arrival systems and automated berth scheduling tools) may be expanded for more efficiency.

4. Emission monitoring tools and their usability for crews

The IMO Ship and Port Emissions Toolkits are comprehensive resources developed under the GEF-UNDP-IMO GloMEEP Project to help countries and maritime stakeholders assess and reduce emissions from ships and port operations. These toolkits aim to support the development of national strategies for reducing maritime emissions, provide practical guidance for assessing emissions from ships and ports, and help implement IMO MARPOL Annex VI regulations on air pollution and energy efficiency.

Ship Emissions Toolkit is designed for maritime administrations and ship operators, this toolkit includes guidance on emissions assessment from ships (CO_2, NO_x, SO_x, PM), methodologies for calculating emissions based on fuel consumption and vessel activity, templates and tools for data collection and analysis, and policy development support for national emission reduction strategies.

Port Emissions Toolkit targeted at port authorities and planners, this toolkit covers; assessment of port-related emissions, including seagoing and domestic vessels, cargo handling equipment, trucks and locomotives and electrical grid usage, inventory development for port emissions, scenario modeling to evaluate emission reduction strategies and stakeholder engagement and policy integration guidance.

Free to download from the [IMO GloMEEP website] which includes training materials, case studies, and technical references.

Emission monitoring tools used in maritime operations are;

- **Continuous Emission Monitoring Systems (CEMS):** Tracks SO_x/NO_x/CO_2/PM emissions in real-time from ship exhausts. This may help pilots to adjust docking speed using emission heatmaps and identify low pollution holding positions. Tugboats may utilize it to avoid exhaust plumes during close manoeuvres and flag high-emission vessels to port authorities

Fuel Flow Monitoring Systems (FFMS): Calculates fuel use and emissions per nautical mile. Compares actual vs planned consumption during approach and optimize ballast based on fuel patterns while predict required assist power using vessel efficiency data

Smart Buoy Networks: Monitors air quality across port zones. Help pilots to navigate via pre-approved green corridors and validate compliance pre-inspection. Tugboats may prioritize service for vessels in clean zones and generate ESG reports from operation data

Data overload from multiple systems requires unified dashboard with color-coded alerts. Cybersecurity risks in data sharing can be solved by blockchain-verified emission logs and crew training gaps can be closed by AR-based simulation modules.

Future development includes smart helmets with air quality sensors, port-wide emission "digital twin" systems and autonomous inspection drones.

5. Best practices: Different types of tug and pilot boats using cleaner fuels, including HVO

The maritime industry is undergoing a significant transformation in response to global environmental regulations and sustainability goals. Tug and pilot boats, which play a critical role in port operations and coastal navigation, are increasingly adopting cleaner fuels to reduce emissions and improve energy efficiency.

Tug and pilot boats are essential for maneuvering larger vessels in confined waters and ensuring safe navigation in ports and harbors. Traditionally powered by diesel engines, these vessels contribute to local air pollution and greenhouse gas emissions. With the International Maritime Organization (IMO) and national governments tightening emissions regulations, there is growing interest in cleaner fuel alternatives.

Conventional Tugboats are typically powered by high-horsepower diesel engines and are used for towing, pushing, and escorting ships. They include harbor tugs, ocean-going tugs, and escort tugs.

Azimuth Stern Drive (ASD) Tugs offer enhanced maneuverability and are commonly used in modern port operations. Their propulsion systems are well-suited for hybrid and alternative fuel integration.

Tractor Tugs use forward-mounted propulsion units and Voith Schneider propulsion are ideal for precision maneuvering. Their design supports retrofitting with cleaner propulsion technologies.

Pilot Boats are smaller and faster than tugs, pilot boats transport maritime pilots to and from ships. Their operational profile favors lightweight, efficient engines that can benefit from cleaner fuels.

Cleaner fuels like HVO, LNG, and biofuels offer a significant reduction in greenhouse gas emissions. HVO, in particular, can cut CO_2 emissions by up to 90% compared to traditional diesel. And the best part? It's a drop-in fuel—meaning it can be used in existing diesel engines with little to no modification.

Hydrotreated Vegetable Oil (HVO)
HVO is a renewable diesel alternative produced from waste fats and vegetable oils. It is chemically similar to fossil diesel, allowing for drop-in use in existing engines. HVO offers up to 90% reduction in CO_2 emissions and improved combustion characteristics.

Liquefied Natural Gas (LNG)
LNG is a low-emission fossil fuel alternative that reduces NO_x, SO_x, and particulate matter. However, it requires specialized storage and engine systems.

Methanol and Ammonia
Emerging fuels like methanol and ammonia are gaining attention for their potential in zero-carbon shipping. Their use in small vessels is still in early stages due to safety and infrastructure challenges.

Biofuels and Hydrogen
Advanced biofuels and hydrogen offer promising pathways but face scalability and storage limitations in small vessel applications.

Cleaner fuels often come at a premium and may have limited availability in certain regions. Strategic partnerships with suppliers are essential. Transitioning to new fuels requires updated training on fuel handling, safety protocols, and maintenance procedures. Operators must adhere to IMO MARPOL Annex VI and local regulations. Accurate emissions reporting and fuel documentation are critical for compliance.

The adoption of cleaner fuels in tug and pilot boats is a vital step toward sustainable maritime operations. While challenges remain in terms of cost, infrastructure, and technology, the benefits—both environmental and operational—are substantial. HVO stands out as a practical and impactful solution for immediate implementation, while other fuels and hybrid systems offer long-term potential. Collaborative efforts across the industry will be key to accelerating this transition.

Switching fuels isn't just about environmental impact, it's also about performance. Cleaner fuels often burn more efficiently, reducing engine wear and improving reliability. Pairing them with hybrid propulsion systems can further enhance fuel savings and reduce noise and emissions.

6. Challenges for their uptake: Limited availability and high cost of alternative fuels

The maritime sector is under increasing pressure to decarbonize, with tug and pilot boats playing a critical role in port operations and coastal navigation. Despite the environmental benefits of alternative fuels such as Hydrotreated Vegetable Oil (HVO), Liquefied Natural Gas (LNG), and methanol, their adoption remains limited.

Global maritime operations are transitioning toward sustainability in response to regulatory pressures and environmental concerns. Tug and pilot boats, though small in scale compared to ocean-going vessels, contribute significantly to port emissions due to their frequent operations in densely populated areas. Cleaner fuels offer a promising solution, but their uptake is hindered by systemic challenges. Maritime managers must navigate these complexities to ensure compliance, cost-effectiveness, and operational continuity.

Tugboats assist in maneuvering large vessels in confined waters, while pilot boats transport maritime pilots to and from ships. These vessels operate intensively in port environments, making them ideal candidates for early adoption of cleaner fuels. However, their operational profiles—short voyages, high maneuverability, and frequent idling—require fuel solutions that are both efficient and readily available.

Promise and Limitations of alternative fuels can be summarized as below:

Hydrotreated Vegetable Oil (HVO)
HVO is a renewable diesel substitute that can be used in existing engines without modification. It offers significant emissions reductions but is often priced higher than conventional diesel and is not widely available in all regions.

Liquefied Natural Gas (LNG)
LNG reduces NO_x, SO_x, and particulate emissions but requires specialized infrastructure and storage systems, making it less feasible for small vessels and ports with limited investment capacity.

Methanol and Ammonia
These fuels are emerging as zero-carbon options but face challenges in terms of safety, handling, and regulatory approval. Their infrastructure is still under development, especially for small-scale applications.

Fuel supply chains for HVO, LNG, and methanol are underdeveloped in many regions. Maritime managers face logistical hurdles in sourcing these fuels consistently, especially in secondary ports. This limits the ability to plan fleet-wide transitions and undermines operational reliability.

Alternative fuels often come at a premium. For example, HVO can cost 2–3 times more than conventional diesel. Fleet managers must balance environmental goals with financial sustainability, especially in competitive markets where cost efficiency is critical.
The lack of bunkering infrastructure for alternative fuels adds to operational complexity. Retrofitting vessels or building new ones with compatible systems requires significant capital investment, which may not be feasible for smaller operators.
Rapid technological changes and evolving regulations create uncertainty in long-term planning. Maritime managers must make decisions with incomplete information about future fuel standards, availability, and pricing trends.

Ports and operators should collaborate to develop regional fuel supply networks, ensuring consistent availability and reducing procurement risks. Starting with pilot projects using HVO or hybrid systems in selected vessels and monitoring performance and scale gradually based on cost-benefit analysis could be a viable option under above mentioned limitations and challenges. Engaging with regulators to promote subsidies, tax incentives, and infrastructure investment for alternative fuels should be considered as well. Public-private partnerships can accelerate adoption.

The transition to alternative fuels in tug and pilot boats is essential for sustainable maritime operations. However, limited availability and high costs present significant challenges for maritime managers. Strategic planning, regional collaboration, and policy support are critical to overcoming these barriers and enabling a resilient, low-emission future for port operations.

7. Available funding and the cost of going green

Port piloting operations and service vessels are essential components of maritime infrastructure. However, their reliance on fossil fuels contributes to greenhouse gas emissions and local air pollution. As global climate goals intensify, stakeholders are seeking ways to transition these operations to low- or zero-emission alternatives. The challenge lies in balancing environmental benefits with financial feasibility.

Governments and financial institutions have responded to the green transition with a range of funding programs:

Federal and Regional Grants: In the United States, agencies such as the Environmental Protection Agency (EPA) and the Department of Energy offer grants and cooperative agreements to ports and near-port communities. These programs support infrastructure upgrades, electrification, and deployment of low-emission technologies.
Green Ship Financing: Private and institutional investors are increasingly linking loan terms to sustainability targets. For example, Windward Offshore secured financing for service operation vessels (CSOVs) supporting offshore wind farms, while Hapag-Lloyd obtained funding for LNG-powered container ships.
Public-Private Partnerships: Collaborative models involving governments, port authorities, and private operators are emerging to share the financial burden of green investments.

Transitioning to sustainable operations involves several cost components:

Capital Expenditure (CAPEX): Retrofitting existing vessels or acquiring new low-emission ships requires substantial upfront investment. LNG, hybrid-electric, and hydrogen-powered vessels are significantly more expensive than conventional diesel-powered ones.
Operational Expenditure (OPEX): While green vessels may offer lower fuel costs and maintenance savings over time, they often require specialized crew training and infrastructure (e.g., charging stations, LNG bunkering).
Regulatory Compliance Costs: Meeting IMO and regional emission standards may necessitate additional monitoring, reporting, and certification expenses.
Financing Costs: Rising interest rates in 2025 have made loans more expensive, although green financing options may offer favourable terms for sustainable projects.

Conclusion

Despite the costs, going green offers long-term advantages for emission reduction, operational efficiency and market competitiveness. While cleaner vessels contribute to improved air quality and reduced carbon footprint in port areas, modern green technologies often enhance vessel performance and reliability and ports and operators that adopt sustainable practices may gain preferential access to funding, partnerships, and contracts.

The long-term savings from going green in tugboats, service vessels, and piloting operations are increasingly compelling in 2025, despite the high upfront costs such as Electric and Hybrid Vessels can reduce fuel consumption by up to 85%**,** especially when using hydrofoil or energy-optimized propulsion systems, Battery-powered tugs offer rapid charging and can operate multiple shifts without refuelling, cutting fuel costs significantly. From the maintenance and lifecycle costs aspects Electric motors have fewer moving parts than diesel engines, leading to lower maintenance costs and fewer breakdowns and longer service intervals. Hydrofoil pilot boats reduce hull drag, which minimizes wear and tear and extends vessel lifespan. By reducing emissions, operators can avoid paying up to €90 per ton of CO_2 under the EU Emissions Trading System and operators may earn tradable carbon credits, creating a new revenue stream or offsetting operational costs. While CAPEX for electric or hybrid tugs is higher, studies show that ROI can be achieved within 5–8 years due to Fuel savings, Reduced maintenance, and Lower regulatory costs.

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Industry Ecosystem and
Technological Landscape
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1. Port requirements

Ports are critical nodes in global trade, and their efficiency hinges on robust piloting, towing, and mooring services. These operations require a symbiotic relationship between industry stakeholders and cutting-edge technology.

Industry ecosystem requirements mainly focus on good stakeholder collaboration and workforce expertise. Piloting, towing, and mooring demand seamless coordination among diverse stakeholders.

Pilotage services rely on licensed mariners with localized knowledge of waterways, as mandated by the International Maritime Organization (IMO) under SOLAS Chapter V. Ports need to establish Pilot Transfer Stations equipped with motion-compensated gangways to ensure safe boarding in rough seas.

Port requirements

Towing operations require agreements with tugboat operators for 24/7 availability.

The International Tugowners Association (ITA) emphasizes standardized Service Level Agreements to prevent delays, as seen in Singapore's port, where tug dispatch times are capped at 15 minutes during peak hours.

Mooring crews, meanwhile, must adhere to the International Mooring Equipment Guidelines, which prescribe tensile strength standards for mooring lines.

Regulatory and environmental compliance requires ports alignment with regulations. The IMO's 2020 Global Sulphur Cap pushed ports to adopt low-emission tugboats, such as the hybrid-electric tugs deployed in some ports.

2. Trends in shipping: Alternative fuel vessels

As ports worldwide accelerate decarbonization efforts, tugboats and port service vessels—critical to harbour operations—are transitioning from traditional diesel to alternative fuels.

LNG has become the most widely adopted alternative fuel for tugboats due to its immediate emission reductions and operational feasibility. LNG-hydrogen dual-fuel tugs, Methane slip and Limited bunkering infrastructure are the main issues to consider

Methanol's ease of storage and compatibility with existing engines make it ideal for retrofitting older tugs. Green methanol supply chains are nascent and crew training for methanol's toxicity risks are being developed.

Ammonia's zero-carbon potential is compelling but requires rigorous safety protocols, especially in congested ports.

3. Use of ShaPoli systems on client vessels and implications for port services

Shaft Power Limitation (ShaPoLi) systems are increasingly adopted by vessels to comply with the International Maritime Organization's (IMO) Energy Efficiency Existing Ship Index (EEXI) regulations. These systems restrict the shaft power delivered to the propeller, thereby reducing greenhouse gas emissions without requiring extensive engine modifications.

Vessels with limited shaft power may require additional tug assistance especially in adverse weather conditions. Port scheduling and resource allocation may need adjustment for revised berth allocation to prioritize ShaPoLi-equipped ships.

Port personnel, pilots, and tug operators must be trained on ShaPoLi-related limitations and override protocols. Enhanced coordination between ship and port services is essential.

4. Emission monitoring tools and their usability for crews

- The IMO Ship and Port Emissions Toolkits

- Continuous Emission Monitoring Systems (CEMS

- Fuel Flow Monitoring Systems (FFMS)

- Smart Buoy Networks

5. Best practices: Different types of tug and pilot boats using cleaner fuels

- **Conventional Tugboats** are typically powered by high-horsepower diesel engines and are used for towing, pushing, and escorting ships. They include harbor tugs, ocean-going tugs, and escort tugs.

- **Azimuth Stern Drive (ASD) Tugs** offer enhanced maneuverability and are commonly used in modern port operations. Their propulsion systems are well-suited for hybrid and alternative fuel integration.

- **Tractor Tugs** use forward-mounted propulsion units and are ideal for precision maneuvering. Their design supports retrofitting with cleaner propulsion technologies.

- **Pilot Boats** are smaller and faster than tugs, pilot boats transport maritime pilots to and from ships. Their operational profile favors lightweight, efficient engines that can benefit from cleaner fuels.

5. Best practices: Different types of tug and pilot boats using cleaner fuels

- Hydrotreated Vegetable Oil (HVO)
HVO is a renewable diesel alternative produced from waste fats and vegetable oils.

- Liquefied Natural Gas (LNG)
LNG is a low-emission fossil fuel alternative that reduces NO_x, SO_x, and particulate matter. However, it requires specialized storage and engine systems.

- Methanol and Ammonia
Emerging fuels like methanol and ammonia are gaining attention for their potential in zero-carbon shipping. Their use in small vessels is still in early stages due to safety and infrastructure challenges.

- Biofuels and Hydrogen
Advanced biofuels and hydrogen offer promising pathways but face scalability and storage limitations in small vessel applications.

6. Challenges: Limited availability and high cost of alternative fuels

- Hydrotreated Vegetable Oil (HVO)

HVO is a renewable diesel substitute that can be used in existing engines without modification. It offers significant emissions reductions but is often priced higher than conventional diesel and is not widely available in all regions.

- Liquefied Natural Gas (LNG)
LNG reduces NO_x, SO_x, and particulate emissions but requires specialized infrastructure and storage systems, making it less feasible for small vessels and ports with limited investment capacity.

- Methanol and Ammonia
These fuels are emerging as zero-carbon options but face challenges in terms of safety, handling, and regulatory approval. Their infrastructure is still under development, especially for small-scale applications.

7. Available funding and the cost of going green

- Federal and Regional Grants
- Green Ship Financing
- Public-Private Partnerships
- Capital Expenditure (CAPEX)
- Operational Expenditure (OPEX)
- Regulatory Compliance Costs
- Financing Costs

Conclusion:

Despite the costs, going green offers long-term advantages for emission reduction, operational efficiency and market competitiveness.

While cleaner vessels contribute to improved air quality and reduced carbon footprint in port areas, modern green technologies often enhance vessel performance and reliability and ports and operators that adopt sustainable practices may gain preferential access to funding, partnerships, and contracts.

The long-term savings from going green in tugboats, service vessels, and piloting operations are increasingly compelling.

Despite the high upfront costs such as Electric and Hybrid Vessels can reduce fuel consumption by up to 85%, especially when using hydrofoil or energy-optimized propulsion system

Battery-powered tugs offer rapid charging and can operate multiple shifts without refuelling, cutting fuel costs significantly

Electric motors have fewer moving parts than diesel engines, leading to lower maintenance costs and fewer breakdowns and longer service intervals.

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Chapter 2 Assessment Questions

Industry Ecosystem and Technological Landscape

EXAM QUESTIONS

1. Which of the following best describes the role of Pilot Transfer Stations in port operations?

a. They serve as customs checkpoints for incoming vessels.
b. They facilitate cargo loading and unloading.
c. They ensure safe boarding of pilots in rough seas using motion-compensated gangways.
d. They provide fuel bunkering for pilot vessels.
e. They monitor vessel emissions during docking.

2. What is the primary reason ports adopt hybrid-electric tugboats?

a. To reduce crew training costs.
b To align with the IMO's 2020 Global Sulphur Cap and reduce emissions.
c. To increase towing speed during peak hours.
d. To eliminate the need for mooring lines.
e. To replace traditional pilotage systems.

3. According to the International Tugowners Association (ITA), what is a key strategy to prevent delays in towing operations?

a. Using blockchain for billing automation.
b. Implementing AI-powered leak detection systems.
c. Establishing standardized Service Level Agreements.
d. Retrofitting tugboats with azimuth thrusters.
e. Deploying ammonia-ready tug designs.

4. What technological advancement allows tugboats to achieve high level precision during berthing?

a. IoT-enabled tension sensors
b. SEAONICS collision prediction system
c. **Dynamic Positioning Systems (DPS)**
d. Port Community Systems (PCS)
e. Predictive analytics for power demand

5. What is a major concern associated with LNG as an alternative fuel for tugboats?

a. Toxicity risks for crew
b. Methane slip and limited bunkering infrastructure
c. Incompatibility with existing engines

d. High cost of ammonia firefighting gear
e. Emission of sulfur oxides

6. How do Onshore Power Systems (OPS) contribute to port sustainability?

a. By replacing pilotage services with automated systems
b. By enabling moored vessels to draw renewable energy
c. By reducing the need for Service Level Agreements
d. By eliminating the use of mooring lines
e. By increasing vessel dispatch speed

7. Which alternative fuel is noted for its ease of storage and compatibility with existing engines?

a. LNG
b. Ammonia
c. Methanol
d. Hydrogen
e. Biofuel

8. What is the primary function of ShaPoLi systems on vessels?

a. To enhance vessel speed during docking
b. To reduce greenhouse gas emissions by limiting shaft power
c. To monitor crew performance in real time
d. To automate berth scheduling
e. To replace traditional propulsion systems

9. What operational impact might ShaPoLi-equipped vessels have on port services?

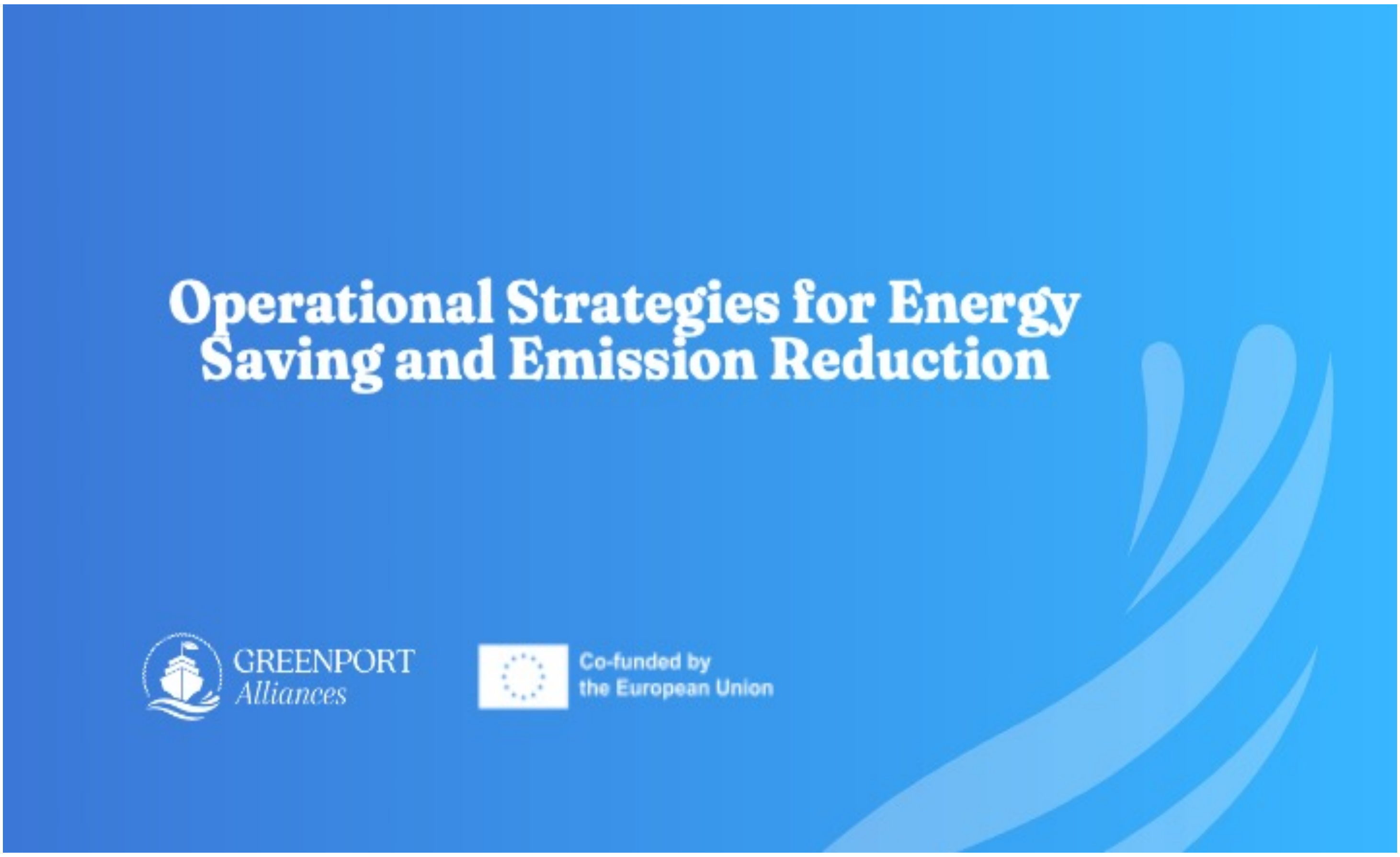
a. Reduced need for pilotage services
b. Increased fuel consumption during docking
c. Requirement for additional tug assistance in adverse weather
d. Elimination of berth scheduling protocols
e. Decreased cybersecurity risks

10. What is a key financial challenge in transitioning to low-emission port service vessels?

a. Lack of crew availability
b. High capital expenditure for retrofitting or acquiring new vessels
c. Incompatibility with existing port infrastructure
d. Reduced vessel lifespan
e. Increased fuel consumption

CHAPTER 3

COURSE Module 3 (Week 3)



COURSE Module 3 (Week 3)

Operational Strategies for Energy Saving and Emission Reduction

1. Techniques using existing resources.

A port operational strategy focused on using existing resources to reduce energy consumption and emissions in port operations emphasizes **efficiency, collaboration**, and **technology**—without requiring major infrastructure overhauls.

Smarter, Cleaner and Leaner port operations require optimized equipment deployment at the first place. In a holistic approach to all respective operations, scheduling cranes, trucks, and yard equipment to minimize idle time will be important for an efficient collaboration**.** Using automated systems to track and manage energy consumption should be considered as well.

Implementing an onshore power supply system will encourage vessels to plug into shore-side electricity while docked, reducing emissions from onboard generators. Energy monitoring by installing smart meters and dashboards to monitor energy use in real time and identify areas for improvement and renewable energy integration through utilizing existing rooftops and open spaces for solar panels to power administrative buildings and lighting must be part of this holistic strategy.

Behavioural change for piloting operations for efficient navigation and fleet management must include route optimization using digital navigation tools to plan the shortest, safest routes for pilot transfers, which will help reduce fuel use. Fleet scheduling coordinates pilot boat movements to avoid unnecessary trips and waiting times. Hybrid boat transition to gradually replace older pilot boats with hybrid or electric models, starting with high-usage routes will enhance operational efficiency.

Tug employment for collaborative and intelligent operations may include measures such as tug pooling for sharing tug resources across terminals to reduce redundancy and maximize utilization, dynamic dispatching by using AI-based systems to assign the most suitable tug based on vessel size, weather, and traffic conditions, and maintenance optimization by applying predictive maintenance to keep tugs running efficiently and avoid fuel-wasting breakdowns.

By leveraging what we already have—smart scheduling, digital tools, and collaborative practices—we can significantly reduce energy use and emissions. This strategy is not just environmentally responsible; it's economically smart and operationally sound.

2. Eco Speed Steaming: Benefits and Implementation

Eco-speed steaming, also known as slow steaming, is a strategy where ships reduce their cruising speed to save fuel and cut emissions. While it may sound simple, its impact on port operations and environmental sustainability is profound.

Benefits of Eco-Speed Steaming are significant emission reduction as slower speeds mean lower fuel consumption, improved air quality in port cities with fewer emissions released near ports, reduced port congestion as ships arriving more gradually help smooth out docking schedules, reducing bottlenecks and idle time, lower Operational Costs as fuel savings directly reduce shipping costs, which can benefit port operators through more predictable and efficient vessel handling and enhanced predictability as slower, steady arrivals allow better planning for berth allocation, cargo handling, and labour scheduling.

Implementation of this strategies in port operations require **collaborative scheduling,** working with shipping lines to align vessel arrival times with port capacity, avoiding the “sail fast, then wait” model, digital arrival management systems using real-time data and predictive analytics to adjust vessel speeds en route, ensuring just-in-time arrivals, incentive programs offering reduced port fees or priority berthing for vessels that adopt eco-speed steaming practices, stakeholder engagement to coordinate with terminal operators, pilots, and tug services to adapt to slower vessel arrivals without compromising turnaround times, and efficient monitoring and reporting tracking vessel speeds and emissions to measure impact and continuously improve scheduling and environmental performance.

Eco-speed steaming is more than just slowing down—it’s about smarter, cleaner, and more coordinated port operations. By embracing this strategy, ports can play a leading role in reducing maritime emissions while improving efficiency and service quality.

To drive behavioural change that improves coordination and reduces emissions in port operations—especially in support of eco-speed steaming—several strategic approaches rooted in behavioural science can be applied. These strategies aim to shift habits, perceptions, and decision-making patterns across teams and stakeholders.

Key Behavioural Strategies to be considered are;

Social Norming: Sharing success stories and data from other ports or teams that have successfully implemented eco-speed practices by using leader boards or dashboards to show which teams are performing best in terms of emission reductions or scheduling efficiency.
Commitment and Public Pledges: To increase accountability and follow-through by encouraging departments or individuals to make visible pledges to support eco-speed steaming and sustainable coordination and displaying these commitments in common areas or internal platforms.
Feedback Loops: Providing real-time data on vessel arrival efficiency, fuel savings, and emission reductions by using dashboards or alerts to show the impact of operational decisions.
Simplification and Default Options: Making eco-speed settings the default in scheduling systems. Simplifying the process for selecting sustainable options in dispatch and coordination tools.
Incentives and Recognition: Offering incentives such as reduced port fees for compliant vessels or recognition awards for teams that meet sustainability targets helps motivation for behavioural change.
Role modelling: Having senior leaders and experienced operators visibly support and practice eco-speed coordination sets the tone for others.

Framing and Messaging: Framing eco-speed steaming as a strategic advantage rather than a constraint by using positive language like “smart arrival” or “green coordination.”

3. Scheduling with tidal windows to optimize fuel use.

To schedule pilotage operations with tidal windows for optimized fuel use, ports can adopt a strategy that aligns vessel movements with favourable tidal conditions. This reduces resistance, improves manoeuvrability, and minimizes fuel consumption during pilotage operations.

Tidal windows refer to specific time periods when tidal conditions (high or low tide) are optimal for vessel movement, especially in shallow or constrained waterways. Moving with the tide (e.g., during flood tide for inbound vessels) reduces engine strain and fuel use.

Scheduling Strategies in this aspect require integration of tidal data into Planning Systems. Using real-time and forecasted tidal data in vessel traffic management systems will help scheduling pilotage during periods of favourable tide to reduce fuel consumption. Dynamic Pilot Dispatching may alleviate assignment of pilots based on tidal timing rather than fixed schedules. Prioritizing vessels that benefit most from tidal assistance (e.g., large or heavily loaded ships) may be also considered. Collaborative Arrival Planning can be achieved by coordinating with shipping lines to adjust Estimated Time of Arrival (ETA) to match tidal windows. This will also help use eco-speed steaming to slow vessels en route, aligning arrival with optimal tide.

Reducing tug power requirements by scheduling movements during slack or favourable tide, will help tug optimization or shorter assist times when tidal conditions aid manoeuvring.

Tools and Technologies that can be utilized for this purpose are; AIS and VTS Integration that monitor vessel positions and adjust pilotage schedules dynamically, Tidal Forecasting Software for Prediction of optimal windows for different vessel types, and Decision Support Systems to recommend pilotage slots based on fuel efficiency and tidal conditions.

4. Real-time fuel consumption visualization for port service craft

To enable real-time fuel consumption visualization for port service craft (e.g., pilot boats, tugs, workboats), several advanced tools and systems are available. These tools help tug masters/pilot boat coxswain monitor, analyse, and optimize fuel usage, contributing to lower emissions and operational costs.

These tools and systems available in the market provide; real-time fuel efficiency and consumption visualization by integration with flow meters, torque sensors, GPS, and other NMEA (U.S. National Marine Electronics Association) and IEC (EU/International Electrotechnical Commission) signals. This also supports SEEMP compliance and continuous improvement.
These will help crew understand how operational conditions affect fuel use which enables data-driven decisions for route and speed optimization.

Port Optimiser platforms feature real-time fuel and GHG emission monitoring for all vessels by Geospatial visualization of fuel consumption within the port by forecasting and historical trend analysis, which enhances planning and scheduling to reduce fuel use and supports environmental performance management and reporting.

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.

Training crew to effectively use fuel monitoring tools on port service craft involves a combination of technical instruction, behavioural reinforcement, and hands-on practice. This will help respective crews understand how fuel monitoring systems work, interpret real-time fuel data and performance metrics, apply fuel-saving techniques based on data insights, and develop habits that support efficient and sustainable operations.

Behavioural reinforcement techniques may include Gamification to create challenges or competitions around fuel efficiency, Recognition that reward crew members who consistently apply best practices, Peer Learning to encourage sharing of tips and experiences among crew and continuous Feedback to provide regular updates on performance and progress.

5. Tug energy saving, before, during, and after a job

For a behavioural change training program aimed at tug operators and crew, focusing on energy saving before and after a job, the goal is to instil habits and awareness that reduce fuel consumption and emissions throughout the entire operation cycle.

Before the Job: Preparation and Planning
Pre-Departure Checklist

- **Engine Warm-Up Optimization:** Avoid excessive idling; warm up only as needed.
- **Route Planning:** Use the shortest, safest route with minimal resistance (consider tide and wind).
- **Tide Awareness:** Schedule jobs to align with favourable tidal windows to reduce engine load.
- **Load Assessment:** Match tug power to vessel size—avoid overpowered assignments.
- **System Checks:** Ensure fuel monitoring systems are active and sensors are calibrated.

Behavioural Strategies

- Encourage checklist discipline: Make it routine to follow energy-saving prep steps.
- Use visual dashboards to show expected fuel use vs. optimized targets.
- Reinforce team briefings to align on energy goals before each job.

During the Job: Operational Efficiency

- Maintain steady throttle and avoid unnecessary manoeuvres.
- Optimal towing line length is to be agreed with the pilot to ensure safety is balanced with optimal engine output.
- Use tide and current to assist movement.

- Communicate clearly with pilot and vessel master to ensure a shared mental model of the intended manoeuvre is fully understood so as to avoid accidents.

After the Job: Shutdown and Review

Engine Shutdown Protocol

- Timely Shutdown: Avoid post-job idling—shut down engines promptly when safe.
- Auxiliary Systems: Turn off non-essential systems immediately after use**.**

Fuel Use Review

- Log Actual Consumption: Compare with expected values.
- Identify Deviations: Discuss any overuse or inefficiencies.
- Feedback Loop: Share insights with crew for continuous improvement.

Maintenance Awareness

- Report any issues that may affect fuel efficiency (e.g., fouled hull, engine irregularities).

Behavioural Strategies

- Use post-job debriefs to reinforce learning and accountability.
- Celebrate fuel-saving achievements with recognition or incentives.
- Encourage peer feedback to build a culture of shared responsibility**.**

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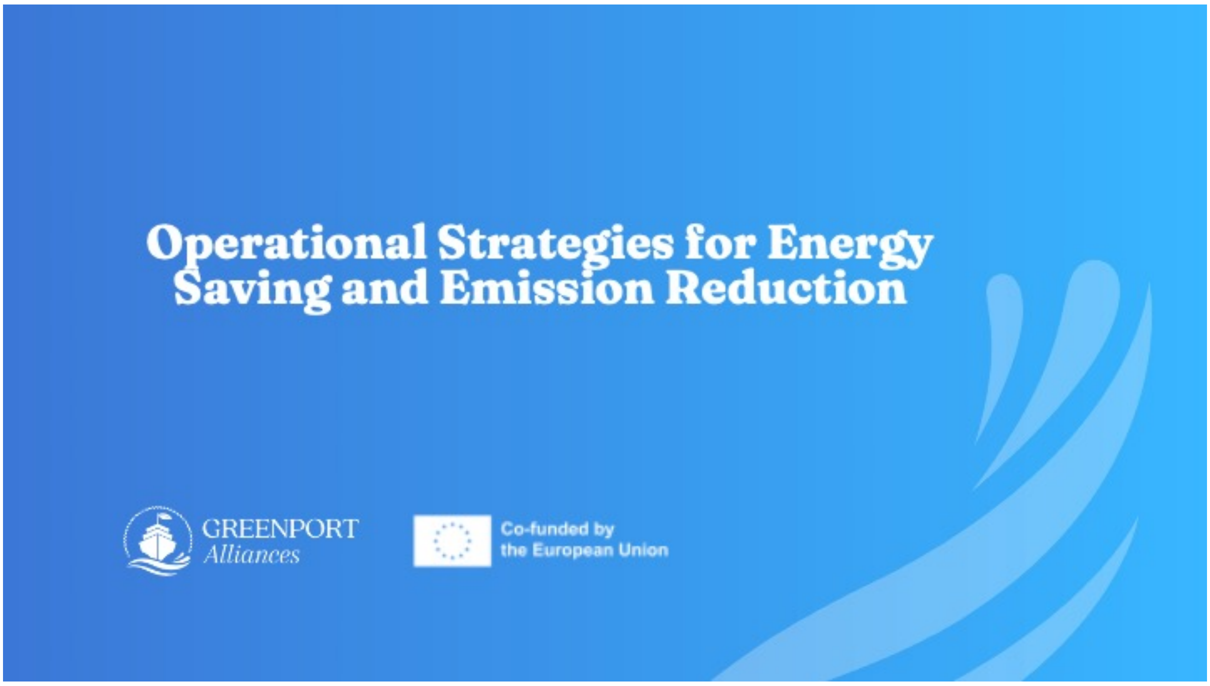
Operational Strategies for Energy
Saving and Emission Reduction
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1. Techniques using existing resources.

A port operational strategy focused on using existing resources to reduce energy consumption and emissions emphasizes **efficiency, collaboration**, and **technology**

Smarter, Cleaner and Leaner port operations require **optimized equipment deployment**

Holistic approach to all respective operations, scheduling cranes, trucks, and yard equipment to **minimize idle time**

Using **automated systems** to track and manage energy consumption

Implementing onshore power system

Energy monitoring

Renewable energy integration

Techniques using existing resources.

Behavioural change for piloting operations for efficient navigation and fleet management must including **route optimization** using digital navigation tools to plan the shortest, safest routes for pilot transfers, will help reducing fuel use.

Fleet scheduling coordinate pilot boat movements to avoid unnecessary trips and waiting times.

Hybrid boat transition to gradually replace older pilot boats with hybrid or electric models, starting with high-usage routes will enhance operational efficiency.

Tug employment for collaborative and intelligent operations such as tug pooling for sharing tug resources across terminals to reduce redundancy and maximize utilization, dynamic dispatching by using AI-based systems to assign the most suitable tug based on vessel size, weather, and traffic conditions, and maintenance optimization by applying predictive maintenance to keep tugs running efficiently and avoid fuel-wasting breakdowns.

2. Eco Speed Steaming: Benefits and Implementation

Eco-speed steaming, also known as slow steaming, is a strategy where ships reduce their cruising speed to save fuel and cut emissions.

Collaborative scheduling, working with shipping lines to align vessel arrival times with port capacity, avoiding the "sail fast, then wait" model

Digital arrival management systems using real-time data and predictive analytics to adjust vessel speeds

incentive programs offering reduced port fees or priority berthing

Eco-speed steaming is more than just slowing down—it's about smarter, cleaner, and more coordinated port operations..

Eco Speed Steaming: Benefits and Implementation

To drive behavioural change that improves coordination and reduces emissions in port operations—especially in support of eco-speed steaming—several strategic approaches rooted in behavioural science can be applied.

These strategies aim to shift habits, perceptions, and decision-making patterns across teams and stakeholders.
Key Behavioural Strategies to be considered are;

- **Social Norming**
- **Commitment and Public Pledges**
- **Feedback Loops:**
- **Simplification and Default Options**
- **Incentives and Recognition**
- **Role modelling Framing and Messaging**

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3. Scheduling with tidal windows to optimize fuel use.

To schedule pilotage operations with tidal windows for optimized fuel use, ports can adopt a strategy that aligns vessel movements with favourable tidal conditions. This reduces resistance, improves manoeuvrability, and minimizes fuel consumption during pilotage and tug operations.

Tidal windows refer to specific time periods when tidal conditions (high or low tide) are optimal for vessel movement, especially in shallow or constrained waterways.

Moving with the tide (e.g., during flood tide for inbound vessels) reduces engine strain and fuel use

Reducing tug power requirements by scheduling movements during slack or favourable tide, will help tug optimization to use fewer tugs or shorter assist times when tidal conditions aid manoeuvring .

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4. Real-time fuel consumption visualization for port service craft

To enable real-time fuel consumption visualization for port service craft (e.g., pilot boats, tugs, workboats), several advanced tools and systems are available. These tools help operators monitor, analyse, and optimize fuel usage, contributing to lower emissions and operational costs.

Training crew to effectively use fuel monitoring tools on port service craft involves a combination of technical instruction, behavioural reinforcement, and hands-on practice. This will help respective crew understand how fuel monitoring systems work, interpret real-time fuel data and performance metrics, apply fuel-saving techniques based on data insights, and develop habits that support efficient and sustainable operations.

5. Tug energy saving, before and after a job

For a behavioural change training program, the goal is to instil habits and awareness that reduce fuel consumption and emissions throughout the entire operation cycle.

Before the Job: Preparation and Planning

Pre-Departure Checklist

- **Engine Warm-Up Optimization**
- **Route Planning**
- **Tide Awareness**
- **Load Assessment**
- **System Checks**

During the Job: Operational Efficiency

- Maintain steady throttle and avoid unnecessary manoeuvres.
- Use tide and current to assist movement.
- Communicate clearly with pilot and vessel master to avoid delays.

Tug energy saving after a job

Shutdown and Review
Engine Shutdown Protocol
Fuel Use Review
Maintenance Awareness

Behavioural Strategies

- Encourage checklist discipline: Make it routine to follow energy-saving prep steps.
- Use visual dashboards to show expected fuel use vs. optimized targets.
- Reinforce team briefings to align on energy goals before each job
- Use post-job debriefs to reinforce learning and accountability.
- Celebrate fuel-saving achievements with recognition or incentives.
- Encourage peer feedback to build a culture of shared responsibility.

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Chapter 3 Assessment Questions

Operational Strategies for Energy Saving and Emission Reduction

EXAM QUESTIONS

1. Which of the following is NOT part of the strategy to reduce energy consumption using existing port resources?

a. Scheduling cranes and trucks to minimize idle time
b. Installing smart meters for real-time energy monitoring
c. Building new terminals with green-certified materials
d. Using rooftops for solar panel installations
e. Implementing onshore power systems for docked vessels

2. What is the primary environmental benefit of eco-speed steaming?

a. Increased cargo capacity
b. Reduced fuel consumption and emissions
c. Faster turnaround times at ports
d. Enhanced vessel manoeuvrability
e. Lower insurance premiums for shipping lines

3. Which behavioural strategy involves making sustainable choices the default in operational systems?

a. Role modelling
b. Feedback loops
c. Simplification and default options
d. Commitment and public pledges
e. Incentives and recognition

4. What is the purpose of tug pooling in port operations?

a. To increase the number of tugboats available
b. To reduce redundancy and maximize utilization
c. To train tug operators in hybrid technology
d. To centralize tugboat ownership under one authority
e. To eliminate the need for predictive maintenance

5. Which of the following is a key implementation strategy for eco-speed steaming?

a. Installing solar panels on vessels
b. Using AI to optimize crane movements
c. Offering reduced port fees for compliant vessels
d. Replacing pilot boats with autonomous drones
e. Increasing vessel speed during peak hours

6. What is the main advantage of scheduling pilotage operations during tidal windows?

a. Reduces crew workload
b. Improves vessel aesthetics
c. Minimizes fuel consumption and engine strain

d. Increases port fees
e. Enhances cargo security

7. Which of the following tools supports dynamic pilot dispatching based on tidal conditions?

a. Port Optimiser
b. AIS and VTS Integration
c. Solar Panel Monitoring System
d. Emission Estimation Models
e. Hybrid Tug Control Panel

8. What is a key feature of Port Optimiser platforms?

a. Crew scheduling for pilot boats
b. Real-time fuel and GHG emission monitoring
c. Vessel design optimization
d. Predictive maintenance for cranes
e. Automated customs clearance

9. Which behavioural reinforcement technique involves creating challenges around fuel efficiency?

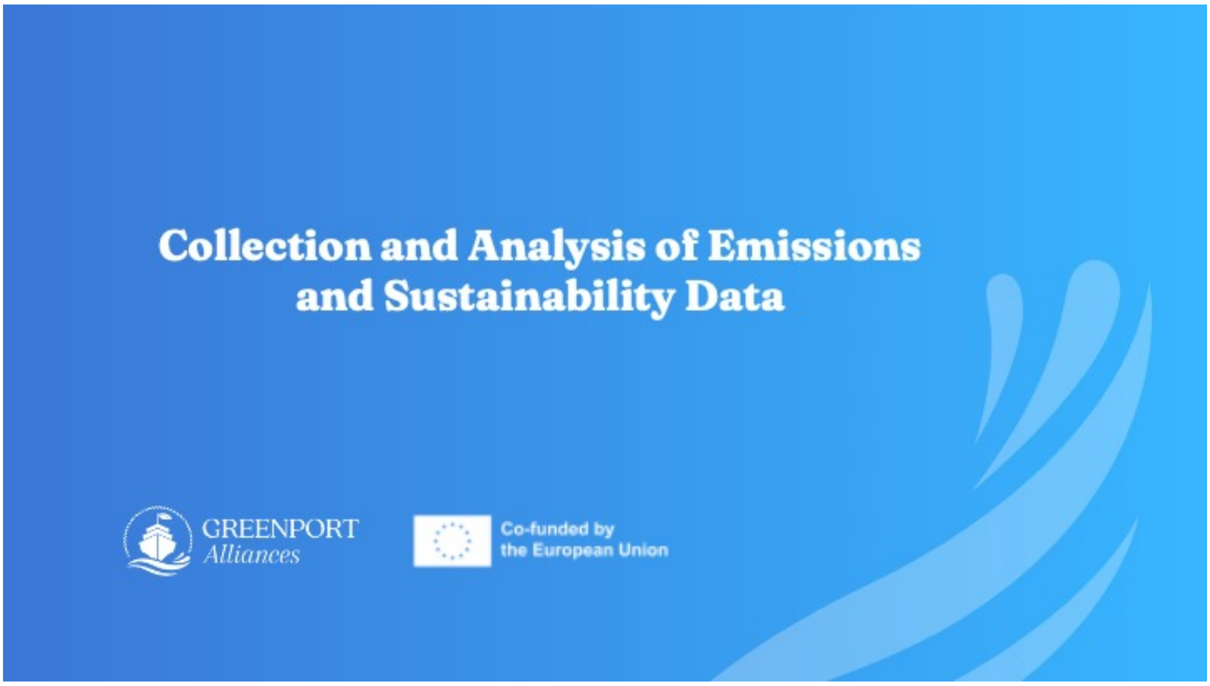
a. Peer Learning
b. Recognition
c. Gamification
d. Feedback Loops
e. Role Modelling

10. Which of the following is part of the pre-departure checklist for tug energy saving?

a. Increase throttle during warm-up
b. Ignore tidal conditions
c. Match tug power to vessel size
d. Delay system checks until mid-operation
e. Use maximum engine load regardless of vessel type

CHAPTER 4

COURSE Module 4 (Week 4)



COURSE Module 4 (Week 4)

Collection and analysis of emissions and sustainability data

1. Introduction

The maritime sector accounts for nearly **3% of global CO_2 emissions**, positioning it as a key player in the global decarbonization effort. With tightening environmental regulations and growing public scrutiny, ports and shipping companies must embrace data-driven strategies to minimize their ecological footprint.
This chapter outlines a structured approach to:

- Understanding the **connection between emissions data and sustainability objectives**
- Navigating **regulatory frameworks** such as the IMO 2023 sulphur cap and the EU Emissions Trading System (ETS) (applies to ships not port service craft)
- Evolving from **reactive to predictive** environmental management through digital innovation

> ***"You can't manage what you don't measure – but measurement alone won't decarbonize our oceans. (Dr. Elena Rodriguez, IMO Climate Special Envoy)"***

2. GREENPORT and emission reduction strategies in ports and maritime operations

Core Principles

- **Energy Transition**: Shift to alternative fuels such as LNG, hydrogen, and shore power to reduce dependence on heavy fuel oil.
- **Operational Efficiency**: Improve voyage planning, minimize idle time, and optimize cargo handling.
- **Ecosystem Integration**: Collaborate with local communities and supply chains to promote sustainable development.

Implementable Solutions

Strategy	Technology	Emission Reduction Potential
Shore Power	OPS	Up to 50% CO_2 reduction during port stays
Smart Grids	AI-driven microgrids	20–30% reduction in energy waste
Slow Steaming	RPM optimization tools	15–25% fuel savings
Hybrid Tugboats	Battery-diesel propulsion	30–40% emissions reduction
Port Electrification	Electrified cranes and vehicles	Significant NO_x and PM reduction

According to the **IMO Port Emissions Toolkit**, effective strategies for reducing emissions from piloting operations include:

Operational Measures

- **Optimized vessel scheduling** to reduce idle time and unnecessary movements.
- **Speed reduction programs** to lower fuel consumption and emissions.
- **Use of low-emission pilot boats**, including hybrid or electric vessels.

Equipment and Technology Upgrades

- **Retrofitting pilot boats** with cleaner engines or emission control technologies like Diesel Particulate Filters (DPFs) and Selective Catalytic Reduction (SCR).
- **Onshore Power Supply (OPS)** for pilot boats when docked, reducing emissions from auxiliary engines.

Policy and Planning

- **Emissions inventory and monitoring** to identify high-emission activities and prioritize interventions.
- **Stakeholder engagement** to align port authorities, pilotage services, and environmental agencies on emission goals.
- **Cost-effectiveness analysis** to evaluate the impact and feasibility of different strategies.

Tugboat Emission Reduction Strategies include:

Emission Abatement Systems (EAS)

- **Selective Catalytic Reduction (SCR)**: Reduces NOx emissions by up to 90% using urea-based reagents.
- **Exhaust Gas Recirculation (EGR)**: Lowers combustion temperatures to reduce NOx formation.
- **Scrubbers**: Remove SOx and particulate matter from exhaust gases, especially effective for high-sulphur fuel use.

Fuel and Energy Optimization

- **Use of low-carbon or zero-carbon fuels** such as LNG, biofuels, or hydrogen.
- **Electrification and hybrid systems** for tugboats to reduce reliance on diesel engines.
- **Wind and current-assisted routing** to minimize fuel consumption during transit.

AI-Based Operational Optimization

- **Machine learning models** to predict and optimize fuel consumption based on environmental and operational data.
- **Reinforcement learning algorithms** for route and speed optimization during tug operations.
- **Sensor anomaly detection** to ensure accurate fuel and emissions data for decision-making.

3. Key sustainability/progress indicators and their monitoring

Specific sustainability and progress indicators are used in the industry to assess sustainability performance and monitor progress. Metrics such as emission intensity, fuel consumption rate, and port carbon footprint are monitored and reported to measure the environmental performance of maritime operations. Continuous monitoring of these indicators is a fundamental building block for achieving sustainability goals.

a. Mandatory Metrics

- Carbon Intensity Indicator (CII):
  - Measures grams of CO_2 per tonne-mile
  - Vessels rated A–E; lower ratings may incur penalties or restrictions
- Air Quality Indices:

- Real-time monitoring of SO_x, NO_x, and $PM_{2.5}$ concentrations
- Circular Economy Metrics:
  - Waste recycling rate (%)
  - Water reuse efficiency (%)

b. Monitoring Tools

- IoT Sensor Networks: Deployed on cranes, vessels, and terminals to collect real-time emissions and energy data.
- Satellite Surveillance: Identifies illegal fuel use and emissions manipulation.
- Blockchain: Ensures transparency and traceability in fuel sourcing and consumption records.

c. Specific Indicators for Pilotage and Tugboat Operations

- **Sustainability performance** is typically assessed through a combination of environmental, operational, and economic indicators.
- **Emissions Metrics:** [CO2] emissions per nautical mile (kg/NM), [NOx], [SOx], and particulate matter (PM) emissions during docking/undocking, Fuel consumption rate (litres/hour) for main and auxiliary engines and Percentage of biofuels/low-sulphur fuels in total fuel mix
- **Fuel Efficiency:** Fuel consumption per towed vessel (litres/ton-mile), Idle time reduction (hours/month) through optimized scheduling
- **Equipment Performance:** Hybrid/electric propulsion system utilization rate (%), Energy recovery efficiency from waste heat systems (%)
- **Maintenance:** Interval between engine overhauls (hours), use of biodegradable lubricants (litres/month)
- **Economic & Compliance Indicators:** Cost Metrics, Fuel cost savings from eco-speed navigation (€/month), ROI on emission-reduction technologies (e.g., scrubbers, DPF filters)
- **Regulatory Compliance:** Port-specific environmental regulation adherence (e.g., EU MRV)
- **Innovation & Progress Tracking:** Technology Adoption, Number of AI-assisted route optimizations deployed, Shore power connectivity usage rate (%)
- **Progress Benchmarks:** Annual reduction in carbon intensity (gCO_2/ton-mile), Crew training hours on sustainability protocols (hours/employee/year)
- **Social & Stakeholder Metrics:** Community Impact, Local air quality improvement near ports, Stakeholder satisfaction scores from port communities
- **Safety:** Incident rate during low-emission manoeuvres (e.g., hybrid mode)

4. Data collection and processing techniques

Data collection and processing techniques are also critical in this process. Operational data is collected through sensor technologies, IoT devices for real time emissions monitoring and navigational data recorder systems (VDR, ECDIS), AIS (Automatic Identification System) for route efficiency analysis and Predictive maintenance algorithms for engine performance.

a. Primary Collection Methods

- Automated Emission Sampling via maritime sensors
- Telemetry: GPS/AIS for route efficiency, engine load sensors.
- Human Input: Crew logs, port audits, spill incident reports.

b. Data Processing Workflow

- Validation: Identify and flag anomalies (e.g., sudden SO_x spikes)

- Normalization: Convert data into IMO-compliant units
- Harmonization: Integrate data from AIS, EEDI, and port logistics systems
- Storage: Utilize cloud-based data lakes with GDPR and IMO compliance

5. Analytics and reporting for environmental responsibility

Advanced Analytical Models

- **Predictive Maintenance**: Leverages sensor data to anticipate equipment failures and minimize downtime.
- **Emission Forecasting**: Machine learning models to simulate future emissions under various operational scenarios.

Stakeholder Reporting

- **Automated Dashboards**: Real-time KPI tracking for regulators, investors, and port authorities.
- **Materiality Assessments**: ESG risk matrices to prioritize environmental and social concerns.
- **Third-Party Verification**: Certification by recognized classification societies to enhance credibility.

6. Conclusion

Sustainable maritime operations demand a **transformation in both mindset** and **infrastructure** and require three foundational shifts:

- **Data Democratization**: Enable real-time access to emissions data across all operational levels.
- **Predictive Governance**: Leverage analytics to anticipate and prevent environmental violations.
- **Holistic KPIs**: Align emissions reduction with social equity, biodiversity, and economic resilience.

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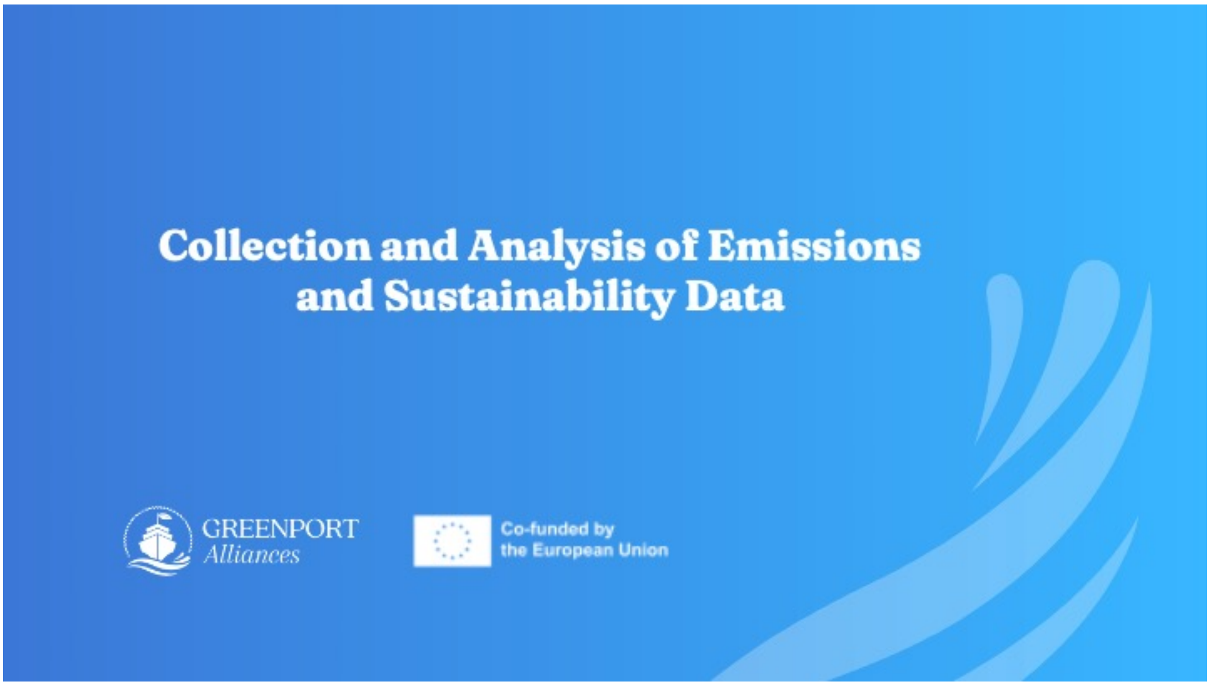
Chapter 4 Supporting Material



1. Introduction

The maritime sector...

- accounts for nearly 3% of global CO_2 emissions,
- a key player in the global decarbonization effort
- under tightening environmental regulations and growing public scrutiny

Ports must embrace data-driven strategies to minimize their ecological footprint

- Understanding the connection between emissions data and sustainability objectives
- Navigating regulatory frameworks: IMO 2023 sulphur cap - EU Emissions Trading System (ETS)
- Evolving from reactive to predictive environmental management through digital innovation

2. Green Port and Emission Reduction Strategies:

Core Principles

- **Energy Transition**: Shift to alternative fuels such as LNG, hydrogen, and shore power to reduce dependence on heavy fuel oil.
- **Operational Efficiency**: Improve voyage planning, minimize idle time, and optimize cargo handling.
- **Ecosystem Integration**: Collaborate with local communities and supply chains to promote sustainable development.

Implementable Solutions:

Strategy	Technology	Emission Reduction Potential
Shore Power	OPS	Up to 50% CO_2 reduction
Smart Grids	AI-driven microgrids	20–30% reduction in energy waste
Slow Steaming	RPM optimization tools	15–25% fuel savings
Hybrid Tugboats	Battery-diesel propulsion	30–40% emissions
Port Electrification	Electrified cranes and vehicles	NO_x and PM reduction

3. Key Sustainability Indicators and Monitoring:

Mandatory Metrics

- **Carbon Intensity Indicator (CII):** Measures grams of CO_2 per tonne-mile. Vessels rated A–E; lower ratings may incur penalties or restrictions.
- **Air Quality Indices:** Real-time monitoring of SO_x, NO_x, and $PM_{2.5}$ concentrations.
- **Circular Economy Metrics:** Waste recycling rate (%), Water reuse efficiency (%).

Monitoring Tools:

- **IoT Sensor Networks:** Deployed on cranes, vessels, and terminals to collect real-time emissions and energy data.
- **Satellite Surveillance:** Identifies illegal fuel use and emissions manipulation.
- **Blockchain Audits:** Ensures transparency and traceability in fuel sourcing and consumption records.

4. Data Collection and Processing Techniques:

Primary Collection Methods

- Automated Emission Sampling via maritime sensors:
- Parameters: CO_2, NO_x, SO_x, fuel flow rate.
- Frequency: Every 5 minutes.
- Geo-fencing for location-specific data.

Data Processing Workflow:

- **Validation**: Identify and flag anomalies (e.g., sudden SO_x spikes).
- **Normalization**: Convert data into IMO-compliant units.
- **Harmonization**: Integrate data from AIS,EEDI, and port log systems
- **Storage**: Utilize cloud-based data lakes with GDPR and IMO comp.

5. Analytics and Reporting for Environmental Responsibility:

Advanced Analytical Models

- **Predictive Maintenance:** Leverages sensor data to anticipate equipment failures and minimize downtime.
- **Emission Forecasting:** Machine learning models to simulate future emissions under various operational scenarios.

Stakeholder Reporting:

- Automated Dashboards: Real-time KPI tracking for regulators, investors, and port authorities.
- Materiality Assessments: ESG risk matrices to prioritize environmental and social concerns.
- Third-Party Verification: Certification by DNV-GL, Bureau Veritas, or Lloyd's Register enhances credibility.

6. Conclusion:

Sustainable maritime operations demand a transformation in both **mindset** and **infrastructure**

- **Data Democratization**: Enable real-time access to emissions data across all operational levels.
- **Predictive Governance**: Leverage analytics to anticipate and prevent environmental violations.
- **Holistic KPIs**: Align emissions reduction with social equity, biodiversity, and economic resilience.

"You can't manage what you don't measure – but measurement alone won't decarbonize our oceans."

Dr. Elena Rodriguez, IMO Climate Special Envoy

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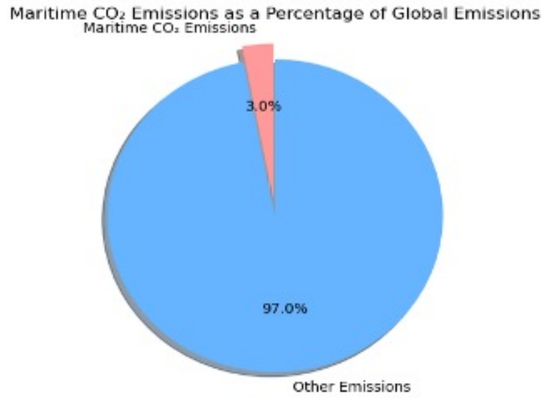
Maritime CO_2 Emissions as a Percentage of Global Emissions



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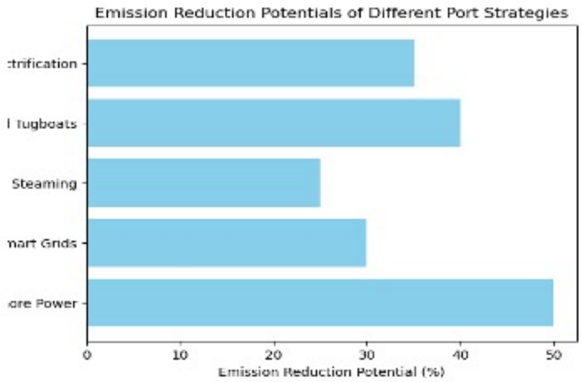
Emission Reduction Potentials of Different Port Strategies



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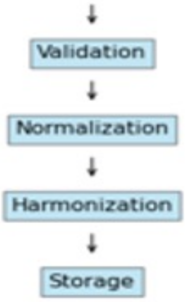
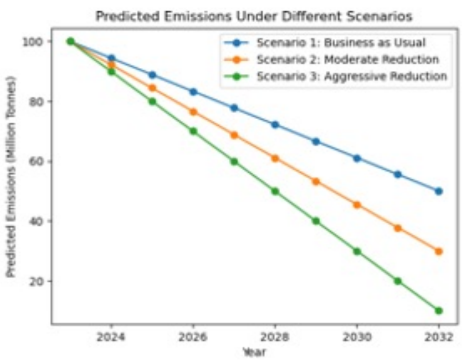
Data Processing Workflow



Predicted Emissions Under Different Scenarios



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Module 4 | Collection and Analysis of Emissions and Sustainability Data

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Chapter 4 Assessment Questions

Emissions and sustainability data in maritime operations

EXAM QUESTIONS

1. **What percentage of global CO_2 emissions is attributed to the maritime industry?**
    a. 1.5%
    b. 2.1%
    c. 3%
    d. 4.7%
    e. 30%

2. **Which strategy can reduce CO_2 emissions by up to 50% during vessel port stays?**
    a. Vessel slow steaming
    b. Smart grid optimization
    c. Shore power ()
    d. Solar Park integration
    e. None of the above

3. **The Carbon Intensity Indicator (CII) measures:**
    a. Waste recycling rates
    b. Annual efficiency ratio (g CO_2/tonne-mile)
    c. Real-time SO_x concentrations
    d. Water reuse efficiency
    e. All of the above

4. **Which technology creates immutable records for fuel sourcing audits?**
    a. IoT sensor networks
    b. Satellite surveillance
    c. Blockchain
    d. ARIMA models
    e. Digital Twins

5. **In data processing, what causes reporting errors in 68% of ports?**
    a. Lack of cloud storage
    b. Inadequate normalization
    c. Underutilized timestamp synchronization
    d. Poor outlier validation
    e. Human errors

6. **Which regulatory framework now includes maritime shipping under its emissions trading system?**
    a. Paris Agreement
    b. Kyoto Protocol
    c. EU ETS (European Union Emissions Trading System)
    d. IMO DCS (Data Collection System)
    e. MARPOL

7. **The SEEMP (Ship Energy Efficiency Management Plan) is a key component of:**
    a. ISO 14083 certification
    b. IMO's mandatory CII (Carbon Intensity Indicator) framework
    c. EU smart grid standards
    d. Port waste recycling protocols
    e. None of the above

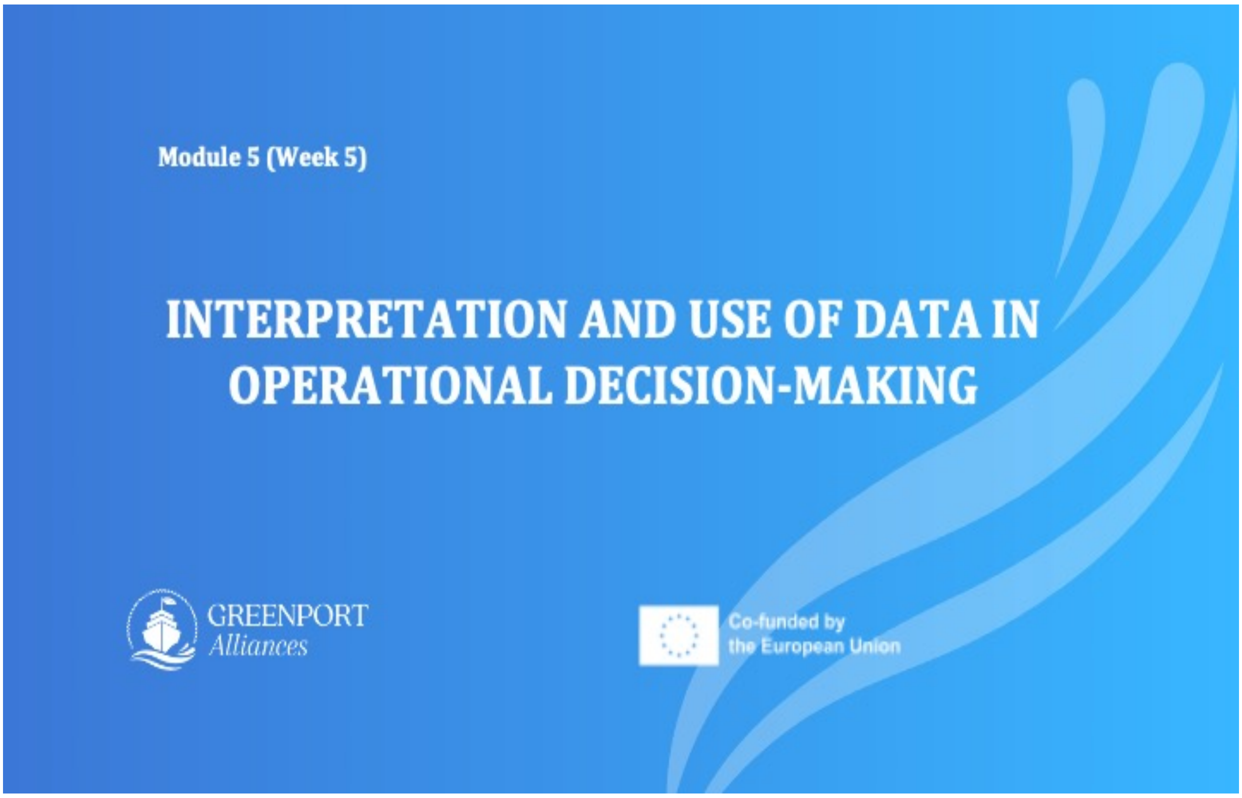
8. **Circular economy metrics in ports prioritize tracking:**
    a. Vessel speed compliance
    b. Waste recycling rates and water reuse efficiency
    c. Fuel consumption per nautical mile
    d. Crane operational hours
    e. Operators' circularity

9. **ARIMA models in maritime analytics are primarily used for:**
    a. Real-time SO_x monitoring
    b. Blockchain-based audit trails
    c. Forecasting CO_2 trajectories under operational scenarios
    d. Calculating failure probability of equipment
    e. All of the above

10. **ISO 14083:2025 standardizes:**
    a. Air quality indices
    b. ESG risk matrices
    c. Logistics chain carbon footprints
    d. Blockchain audit protocols
    e. IoT network security standards

CHAPTER 5

COURSE Module 5 (Week 5)



COURSE Module 5 (Week 5)

Interpretation and use of data in operational decision-making

1. Introduction

The maritime industry, as a backbone of global trade and logistics, pressing the need to improve energy efficiency and meet stringent environmental regulations, creates a critical demand for advanced data analysis and decision support systems. While often perceived as more environmentally friendly than other transport sectors, maritime shipping contributed 2.9% of global GHG emissions in 2018, representing a concerning 9.6% rise from 2012 [1]. In this context, data-driven decision-making has emerged as a critical enabler for optimizing vessel operations and port management. The modern maritime industry is undergoing a digital transformation, where vast amounts of data from digital sources, onboard sensors, and simulation models are reshaping operational decision-making. As shipping companies and port operators strive for greater efficiency, safety, and sustainability, the ability to interpret and utilize this data has become essential. From real-time engine performance analytics to predictive maintenance algorithms and route optimization models, data-driven insights are enabling smarter, more proactive management of maritime operations.

As part of the course *Sustainable Maritime Operations and Green Ports*, this module examines how data interpretation and use can affect operational decision-making in supporting greener and more efficient port and vessel operations.

2. Data analysis and visualization for decision support

In today's data-driven world, organizations across industries rely on advanced analytics and visualization techniques to transform raw data into actionable intelligence. Data analysis enables the extraction of meaningful patterns and trends, while visualization provides intuitive representations of complex information, facilitating faster and more informed decision-making processes. These methodologies are particularly valuable in dynamic environments where real-time insights can significantly impact operational efficiency, cost management, and strategic planning.
The maritime industry, with its complex operations and vast data streams, presents unique opportunities for data-driven decision support. Ships generate enormous amounts of operational data from sensors, navigation systems, and engine monitors, while ports collect information on cargo flows, berth availability, and environmental conditions. Effective analysis and visualization of this data can [2]:

- enhance situational awareness,
- optimize route planning and
- support environmental compliance.

When it comes to environmental considerations, modern maritime operations face increasing pressure to meet stringent environmental regulations while maintaining operational efficiency. Digital tools and advanced analytics have become indispensable for collecting, processing, and interpreting vast amounts of sustainability-related data such as monitoring and reducing emissions in compliance with IMO regulations [3].

There is extensive research on data-driven decision support systems addressing environmental challenges in the maritime sector. The study of Guerra and Jenssen demonstrates how structured data analysis frameworks can enhance decision-making by systematically incorporating environmental criteria alongside traditional operational and economic factors [4]. By quantifying and weighting sustainability metrics such as emissions data and energy efficiency indicators, this research provides a methodological foundation for developing advanced decision support systems that integrate complex, multi-dimensional datasets. The findings particularly highlight the role of interactive data visualization in presenting trade-off analyses between competing objectives, enabling maritime operators to make more informed choices that balance environmental compliance with business performance. This approach aligns with modern decision support systems that leverage data analytics to transform regulatory requirements and operational parameters into actionable strategic insights for sustainable shipping operations.

Furthermore, the study of Karatuğ et. al. demonstrates how advanced data analysis and optimization models can transform operational data into actionable insights for sustainable shipping [5]. By integrating real-time sensor readings, weather data and voyage parameters into a structured analytical framework, this research provides a practical example of how visualization tools can present complex efficiency trade-offs in an accessible format for maritime decision-makers. The developed system's ability to process multi-source data and generate optimized speed and routing recommendations illustrates the critical role of interactive decision support platforms in balancing environmental compliance with operational requirements, directly aligning with modern needs for data-driven energy management in shipping. This approach showcases how properly analyzed and visualized operational data can bridge the gap between technical performance metrics and practical decision-making on board and ashore.

To conclude, the integration of advanced data analysis and visualization tools provides a transformative approach to maritime decision-making, enabling operators to balance economic efficiency with stringent environmental requirements. By converting complex operational data into actionable insights through interactive dashboards and predictive models, these digital solutions empower the industry to achieve regulatory compliance, optimize fuel consumption, and drive sustainable shipping practices in line with IMO decarbonization goals [6].

3. Application of Data in Daily Operations

The maritime industry’s transition toward data-driven operations is transforming daily decision-making processes, enabling more efficient and sustainable practices. By leveraging real-time data from IoT sensors, AIS, engine monitoring systems, and weather forecasts, shipping companies can optimize routes, adjust speeds, and schedule maintenance proactively—all while minimizing fuel consumption and emissions. For instance, predictive analytics can forecast engine performance degradation, allowing pre-emptive repairs that avoid costly breakdowns and reduce idle time. Similarly, dynamic route optimization tools integrate weather, current, and port congestion data to recommend the most fuel-efficient paths, supporting compliance with IMO’s Carbon Intensity Indicator (CII) requirements [7].

Beyond navigation and machinery management, data analytics enhances cargo handling, bunkering strategies, and crew scheduling. Ports utilize predictive models to streamline berth allocation and reduce turnaround times, while emission-tracking dashboards help monitor compliance with sulphur cap regulations in ECAs. These applications demonstrate how systematically collected and analyzed data can translate into tangible operational improvements – lowering costs, improving safety, and supporting the industry's decarbonization goals. The challenge lies in integrating these digital tools into existing workflows, ensuring seamless adoption by crews and shore-based teams to maximize their potential in day-to-day operations.

4. Data-driven Risk Management

The maritime industry faces numerous operational risks—from mechanical failures and adverse weather to security threats and regulatory non-compliance. Data-driven risk management leverages advanced analytics, machine learning, and real-time monitoring to predict, assess, and mitigate these risks proactively. By integrating sensor data, historical incident reports, weather forecasts, and AIS tracking, shipping companies can develop predictive models that identify potential hazards before they escalate. For example, AI-powered anomaly detection in engine performance data can signal impending failures, while dynamic risk assessment tools evaluate weather patterns and traffic density to recommend safer routes or speed adjustments.

A critical application is in environmental risk management, where emissions monitoring systems ensure compliance with evolving regulations, avoiding fines and reputational damage. Similarly, port risk analytics help optimize operations by predicting congestion delays or cargo handling disruptions. Cybersecurity risks are also addressed through data-driven threat detection, analysing network traffic patterns to prevent breaches. The challenge remains in unifying these disparate data streams into a centralized risk dashboard, providing decision-makers with clear, actionable insights to enhance safety, efficiency, and regulatory adherence across daily operations.

5. Conclusion

The maritime industry stands at a crucial moment where digital transformation is no longer optional but essential for achieving operational excellence, regulatory compliance, and environmental sustainability. Advanced data analytics and visualization tools are revolutionizing decision-making processes—from optimizing route efficiency and fuel consumption to enhancing risk management and port operations. By harnessing real-time data from IoT sensors, AIS, and predictive models, shipping companies can not only reduce costs and improve safety but also meet stringent IMO decarbonization targets.

However, the full potential of data-driven maritime operations can only be realized through seamless **integration of these technologies into daily workflows** and **organizational cultures**. Challenges such as data silos, risks, and crew adoption must be addressed to unlock the transformative power of digital solutions. Moving forward, the industry must prioritize investments in interoperable systems, user-friendly dashboards, and **continuous training** to ensure that data insights translate into actionable strategies. As the sector navigates toward a greener and more efficient future, the **synergy between data analytics, human expertise, and regulatory frameworks** will be critical in shaping sustainable and resilient maritime operations.

Data isn't just numbers on a screen, but a **catalyst for human change**.
In piloting and tugboat operations, sustainability isn't just about technology—it's about people. Imagine a tugboat captain seeing live emissions data during docking—a gauge turning red when fuel use spikes. This instant feedback creates accountability. In Rotterdam, crews reduced sulphur oxide emissions by 12% in three months simply by knowing their performance was visible. Data becomes a mirror, reflecting both triumphs and areas to improve.

We have to move beyond traditional bonuses to achieve behavioural change. In Singapore, crews now earn carbon credits for beating efficiency targets—credits they trade for extra shore leave. When we tie rewards to metrics like [CO_2/kg/NM], sustainability becomes personal. One crew saved 2,000 kg of CO_2 last quarter—equivalent to planting 100 trees.

By 2030, we'll likely see AI co-pilots whispering advice like, "Reduce RPM by 5% to save 8 liters an hour." Blockchain will let crews own their carbon savings as tradable tokens. And neurofeedback? Imagine helmets guiding captains to calmer, fuel-efficient focus during tight manoeuvres.

As we sail toward IMO's 2050 net-zero goal, remember: the toughest currents to navigate are **human habits**. But with transparency, smart incentives, and technology **GREENPORT is not just tracking metrics but charting a new course for maritime tradition.**

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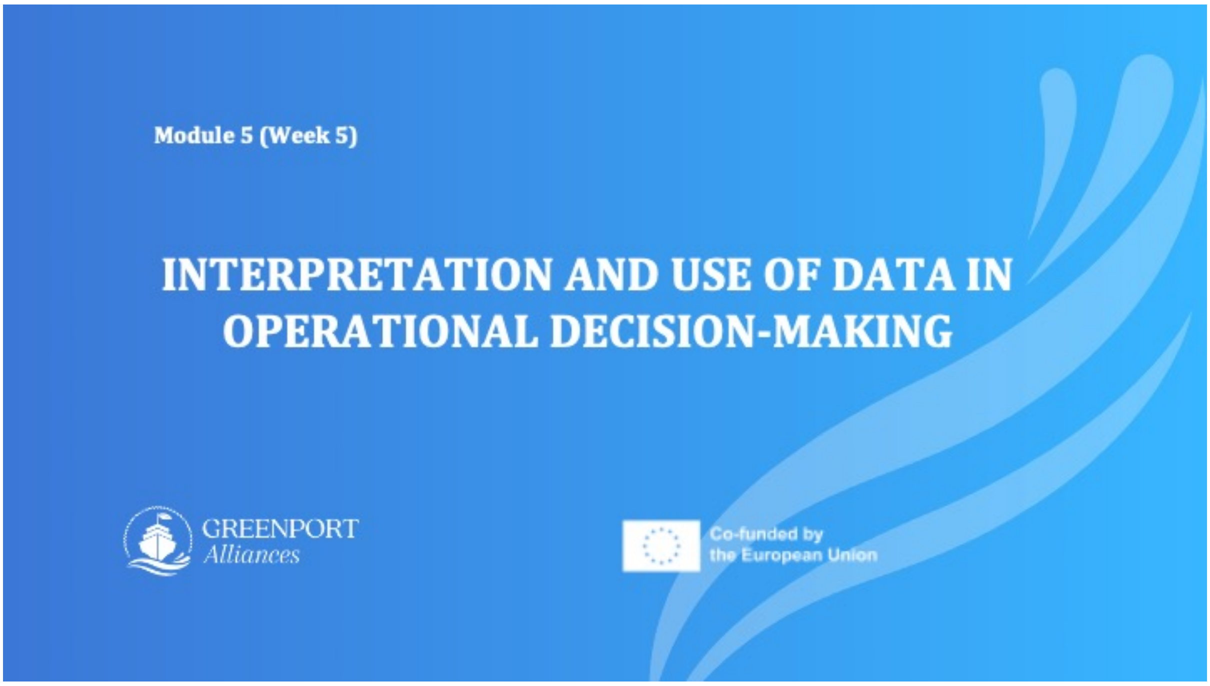
Chapter 5 Supporting Material



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1. Introduction

- Maritime industry as global trade backbone
- Environmental impact of shipping
- Digital transformation in shipping
- Data-driven decision making

From real-time engine performance analytics to predictive maintenance algorithms and route optimization models, data-driven insights are enabling smarter, more proactive management of maritime operations

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2. Data Analysis and Visualization for Decision Support

- **Maritime industry** → unique opportunities for data-driven decision support
- **Data-driven Maritime Operations:**
  - advanced analytics + visualization → actionable insights for efficency & compliance
- **Effective analysis and visualization of data:**
  - enhance situational awareness,
  - optimize route planning and
  - support environmental compliance

Data Analysis and Visualization for Decision Support

- **Stringent Environmental Regulations:**
  - IMO regulations,
  - Emission monitoring,
  - Digital reporting

- **Integration of advanced data analysis and visualization tools provides:**
  - transformative approach to maritime decision-making,
  - operators to balance economic efficiency with stringent environmental requirements,
  - regulatory compliance,
  - drive sustainable shipping practices

Data Analysis and Visualization for Decision Support

- The integration of advanced data analysis and visualization tools provides a transformative approach to maritime decision-making, enabling operators to **balance economic efficiency with stringent environmental requirements.**

- By converting complex operational data into actionable insights through interactive dashboards and predictive models, these digital solutions empower the industry to achieve regulatory compliance, optimize fuel consumption, and drive sustainable shipping practices in line with decarbonization goals

3. Application of Data in Daily Operations

- **Data-Driven Shipping: Smarter Routes, Lower Emissions:**
  - IoT Sensors,
  - Automatic Identification System (AIS),
  - engine monitoring systems,
  - weather forecasts etc.

- Dynamic route optimization tools integrate weather, current, and port congestion data to recommend the most fuel-efficient paths,

- predictive analytics can forecast engine performance degradation, allowing pre-emptive repairs that avoid costly breakdowns and reduce idle time

4. Dana-driven Risk Management

- **Predictive Maintenance:**
  - AI detects engine anomalies to prevent failures
- **Dynamic Route Risk:**
  - weather + traffic analytics for safer navigation
- **Regulatory Compliance:**
  - real-time emission monitoring avoids penalties
- **Port & Cyber Risks**
  - congestion forecasting + threat detection

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Conclusion

- **Digital Transformation is Imperative:** The maritime industry must embrace data-driven operations to remain competitive, compliant, and sustainable—leveraging IoT, AI, and real-time analytics to optimize routes, fuel use, and risk mitigation.
- **Operational & Environmental Gains:** Advanced analytics enable tangible benefits, from cost reduction and safety improvements to meeting IMO decarbonization goals (CII, EEXI, ECA compliance).
- **Future Success =** Human + Machine Collaboration: Sustainable maritime operations will rely on balancing cutting-edge technology with crew expertise and evolving regulatory frameworks.

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Conclusion

- Toward a greener and more efficient future, the **synergy between data analytics, human expertise, and regulatory frameworks** will be critical in shaping sustainable and resilient maritime operations.

- Data isn't just numbers on a screen, but a **catalyst for human change**.

- In piloting and tugboat operations, sustainability isn't just about technology—it's about **people.**

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Module 5 (Week 5)
COURSE NAME: Sustainable Maritime Operations and Green Ports

INTERPRETATION AND USE OF DATA IN OPERATIONAL DECISION-MAKING

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Chapter 5 Assessment Questions

Interpretation and use of data in operational decision-making

EXAM QUESTIONS

1. What percentage of global GHG emissions did maritime shipping contribute in 2018?

a) 1.5%
b) 2.9%
c) 4.7%
d) 5.8%
e) 7.2%

2. Which of the following is NOT a benefit of data-driven decision-making in maritime operations?

a) enhanced situational awareness
b) optimized route planning
c) increased manual paperwork
d) support for environmental compliance
e) predictive maintenance

3. What is a key challenge in implementing data-driven decision-making in maritime operations?

a) lack of available data
b) seamless integration into existing workflows
c) over-reliance on traditional methods only
d) excessive fuel consumption
e) none of the above

4. Which technology is used for real-time vessel tracking and route optimization?

a) blockchain
b) AIS (Automatic Identification System)
c) RFID tags
d) satellite imaging
e) sonar

5. What does CII stand for in the context of IMO regulations?

a) carbon Intensity Indicator
b) cargo Inspection Index
c) crew Integration Interface
d) compliance and Innovation Initiative
e) coastal Impact Index

6. How can predictive analytics improve maritime operations?

a) by increasing fuel consumption
b) by forecasting engine failures and enabling proactive maintenance
c) by eliminating the need for crew training
d) by reducing the number of sensors on ships
e) by replacing all human decision-making

7. Which of the following is a critical application of data-driven risk management?

a) reducing internet speed on ships
b) predicting weather patterns and traffic hazards
c) eliminating all regulatory requirements
d) increasing manual record-keeping
e) ignoring cybersecurity threats

8. What is a major environmental benefit of data-driven maritime operations?

a) higher emissions due to increased speed
b) lower CO_2 and NO_x emissions through optimized operations
c) more frequent engine breakdowns
d) increased use of heavy fuel oil
e) none of the above

9. What is essential for maximizing the potential of data-driven decision-making in shipping?

a) avoiding digital transformation
b) keeping data in isolated silos
c) user-friendly dashboards and crew training
d) reducing the number of sensors
e) ignoring regulatory compliance

10. What is the primary goal of integrating data analytics in maritime operations?

a) to make operations slower and less efficient
b) to increase fuel consumption
c) to balance economic efficiency with environmental sustainability
d) to eliminate the need for real-time monitoring
e) to reduce the number of ships in operation

CHAPTER 6

COURSE Module 6 (Week 6)

COURSE Module 6 (Week 6)

Use of simulation for Eco Navigation 1

1. Using simulation tools to estimate savings

Tugs are indispensable tools for ships arriving and departing from the port to manoeuvre safely in the confined sea areas of the port. However, due to their powerful engines and stop-start operations, they sometimes consume more fuel than necessary and, as a result, produce excessive carbon emissions. The use of bridge simulators provides training for tugboat operators, reduces emissions, and also estimates potential fuel savings (Jensen et al., 2017).

Bridge simulators can replicate highly realistic port conditions, including traffic density, weather variability, and ship sizes. By modelling different tug deployment scenarios, such as the number of tugs used, towing configurations, engagement timing, and manoeuvring strategies, simulation exercises can identify the most energy-efficient practices **without compromising navigational safety**. For example, simulations can compare traditional fixed tug deployments to dynamic, demand-based approaches, where the optimum number and location of tugs are adjusted in real time according to ship size, wind, and current conditions.

In addition, engine load optimization and speed management of tugs during assisted manoeuvres can be analysed using simulator data. Tug captains may run engines above the power levels required for safety margins; however, simulation-based training and planning can reduce unnecessary fuel consumption by encouraging more efficient throttle control. Studies have shown that simulator-informed operations can save 10-20% of fuel per auxiliary cycle, depending on tug size and port complexity.

Bridge simulators also support crew training in energy-conscious operations, such as minimizing idle times, preventing excessive repositioning, and coordinating more effectively with the piloted vessel. These improvements reduce total tug engagement time and optimize engine-operating hours, contributing to both energy savings and engine life.

Additionally, combining bridge simulation results with port traffic and weather forecast models enables more advanced planning of tug operations, minimizing last-minute changes and energy-intensive waiting times. As ports move toward digitalization, integrating these simulator outputs with port energy management systems improves strategic planning for fuel-efficient tug deployments.

2. Utilizing simulation to train on energy efficient manoeuvring techniques

The **European Tugowners Association (ETA)** and the **European Maritime Pilots Association (EMPA)** have jointly developed a set of recommendations aimed at improving safe and energy efficient towage operations. These are based on three core principles:

- **Planning**: Careful scheduling and route optimization to minimize idle time and unnecessary movements.
- **Cooperation**: Close coordination between pilots, tugboat captains, and harbour masters to ensure efficient use of resources.
- **Communication**: Real-time sharing of operational data to adjust power usage and manoeuvring tactics dynamically

Modern pilotage and towage operations are increasingly leveraging digital tools such as:

- **IoT sensors and satellite communication** to monitor vessel movements.
- **Analytics platforms** to assess fuel consumption patterns and identify inefficiencies. These technologies help reduce greenhouse gas emissions without compromising safety

Simulators play a crucial role in enhancing energy-efficient manoeuvring techniques in port operations, especially for pilotage and tugboat operations.

Training for Optimal Manoeuvring
Simulators allow pilots and tug operators to practice:
- Low-speed control
- Efficient turning and docking
- Minimizing engine revs and fuel use

This helps crews internalize energy-saving habits without risking real-world operations.

Scenario-Based Decision Making
Simulators can replicate:
- Different weather and sea conditions
- Traffic congestion
- Emergency situations

Operators learn to make quick, efficient decisions that reduce unnecessary movements and fuel consumption.

Performance Analytics
Advanced simulators track:
- Fuel usage
- Thrust application
- Route efficiency

Environmental Impact Awareness
Simulations can visualize the carbon footprint of different manoeuvring strategies, helping crews understand the environmental consequences of their choices.

Developing energy-efficient simulator practical training for pilotage operations involves a blend of precision navigation, real-time decision-making, and collaborative coordination. Scenario planning may include one or more of the following options :

- Minimizing distance and time spent for manoeuvring.
- Avoiding unnecessary course corrections.
- Choosing optimal paths that reduce fuel consumption and emissions.

- Maintaining steady, low speeds during approach and docking.
- Avoiding abrupt acceleration or deceleration.
- Using minimum effective thrust to control the vessel, especially in tight spaces.
- Real-Time Communication and Coordination with pilots, tugboats, port control and terminal operators

Use of simulators for training helps pilots practice energy-efficient techniques in various port layouts and weather conditions, analyse fuel usage and manoeuvring efficiency, and learn to handle vessels with different propulsion systems (e.g., azimuth thrusters, LNG-powered ships).

Scenarios may also include integration with Port Digital Systems, Port Management Information Systems (PMIS) and Just-In-Time (JIT) arrival systems. This may provide training of pilots for a behavioural change in aligning vessel arrival with berth availability, reducing waiting times at anchor, supporting dynamic scheduling to avoid congestion.

Simulation-based training can be a powerful catalyst for **behavioural change** in pilotage operations, especially when aiming to improve **energy efficiency**. This can be achieved through:

Experiential Learning for Habit Formation
Simulators allow pilots and tug masters to repeatedly practice energy-efficient techniques in realistic scenarios. This repetition helps:

- Reinforce low-speed manoeuvring habits.
- Build muscle memory for optimal thrust control.
- Encourage smoother coordination with tugboats and port control.

Immediate Feedback and Performance Metrics
Simulators provide real-time feedback on:

- Fuel consumption
- Emissions
- Time efficiency
- Tug usage

Pilots and tug masters can **see the impact of their decisions**, which fosters awareness and motivates change. For example, seeing how a small adjustment in speed reduces fuel use can lead to more mindful navigation.

Scenario-Based Sustainability Training can include port congestion, adverse weather and tight berthing conditions to teach pilots how to maintain energy efficiency even under pressure, reinforcing sustainable decision-making.

Joint simulations with tug operators and port controllers improve communication, timing and role clarity This leads to smoother operations and reduced energy waste due to misalignment or delays.

Simulation platforms can log pilot performance across sessions, allowing personalized coaching, recognition of improvement and identification of persistent inefficiencies to develop a culture of continuous learning and accountability.

3. Encouraging behavioural change through data-driven feedback

As the maritime industry advances toward decarbonization targets, simulator-based training has emerged as a critical tool for instilling sustainable operational behaviours. Structured feedback mechanisms within virtual training environments are reshaping decision-making paradigms in pilotage and tugboat operations, with measurable impacts on emissions reduction and operational efficiency.

Modern maritime simulators provide a controlled yet realistic platform for skill development, combining hydrodynamic modelling, port-specific scenarios, and real-time environmental variables. Key advantages include:

Risk Mitigation: Safe experimentation with low-emission techniques (e.g., tidal current utilization, optimized throttle curves).
Benchmarked Performance: Comparative analytics against IMO-aligned efficiency standards.
Global Standardization: Access to training modules reflecting diverse regulatory environments, from Singapore's port limits to EU Emission Control Areas.

A 2024 meta-analysis of 23 port authorities revealed that simulator-trained crews demonstrated 12–15% greater adherence to emission protocols during actual operations compared to traditionally trained counterparts.

The transition to sustainable maritime operations necessitates a dual focus: technological innovation and human behavioral adaptation. Simulator training, when coupled with structured feedback systems, provides a replicable framework for transforming abstract emission targets into concrete operational habits. As evidenced by the 17% reduction in harbor-side particulate matter achieved by early adopters, this approach converts regulatory compliance into competitive advantage.

For organizations committed to IMO 2050 objectives, the strategic imperative is clear: invest not only in cleaner engines but in data-fluent crews capable of translating simulation insights into real-world environmental stewardship.

Our intention is not to instruct pilots or tug captains on how to manoeuvre; rather, it is to enhance their existing skills with the aim of potentially adopting behaviours that could lead to reduced emissions, all while maintaining the same level of safety that is currently provided.

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Chapter 6 Supporting Material

1. Using simulation tools to estimate savings

GREENPORT Alliances | Co-funded by the European Union

Use of bridge simulators provides training for tugboat operators, reduces emissions, and also estimates potential fuel savings

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By modelling different tug deployment scenarios, such as the number of tugs used, towing configurations, engagement timing, and manoeuvring strategies, simulation exercises can identify the most energy-efficient practices without compromising navigational safety.

For example, simulations can compare traditional fixed tug deployments to dynamic, demand-based approaches, where the optimum number and location of tugs are adjusted in real time according to ship size, wind, and current conditions.

Module No. 6 Use of simulation for Eco Navigation 1 003

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Using simulation tools to estimate savings

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Simulation-based training and planning can reduce unnecessary fuel consumption by encouraging more efficient throttle control.

Bridge simulators also support crew training in energy-conscious operations, such as minimizing idle times, preventing excessive repositioning, and coordinating more effectively with the piloted vessel. These improvements reduce total tug engagement time and optimize engine-operating hours, contributing to both energy savings and engine life.

Combining bridge simulation results with port traffic and weather forecast models enables more advanced planning of tug operations, minimizing last-minute changes and energy-intensive waiting times.

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- **Analytics platforms** to assess fuel consumption patterns and identify inefficiencies.

Training for Optimal Manoeuvring
- Low-speed control
- Efficient turning and docking
- Minimizing engine revs and fuel use

Utilizing simulation to train on energy efficient manoeuvring techniques

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Simulators can replicate
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- Emergency situations

Performance Analytics
Advanced simulators track
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Simulations can visualize the carbon footprint of different manoeuvring strategies, helping crews understand the environmental consequences of their choices.

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Simulators allow pilots and tug masters to repeatedly practice energy-efficient techniques in realistic scenarios. This repetition helps:

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- Build muscle memory for optimal thrust control.
- Encourage smoother coordination with tugboats and port control.

Immediate Feedback and Performance Metrics
Real Time feedback on; Fuel consumption, Emissions, Time efficiency, Tug usage
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Simulator training, when coupled with structured feedback systems, provides a replicable framework for transforming abstract emission targets into concrete operational habits.

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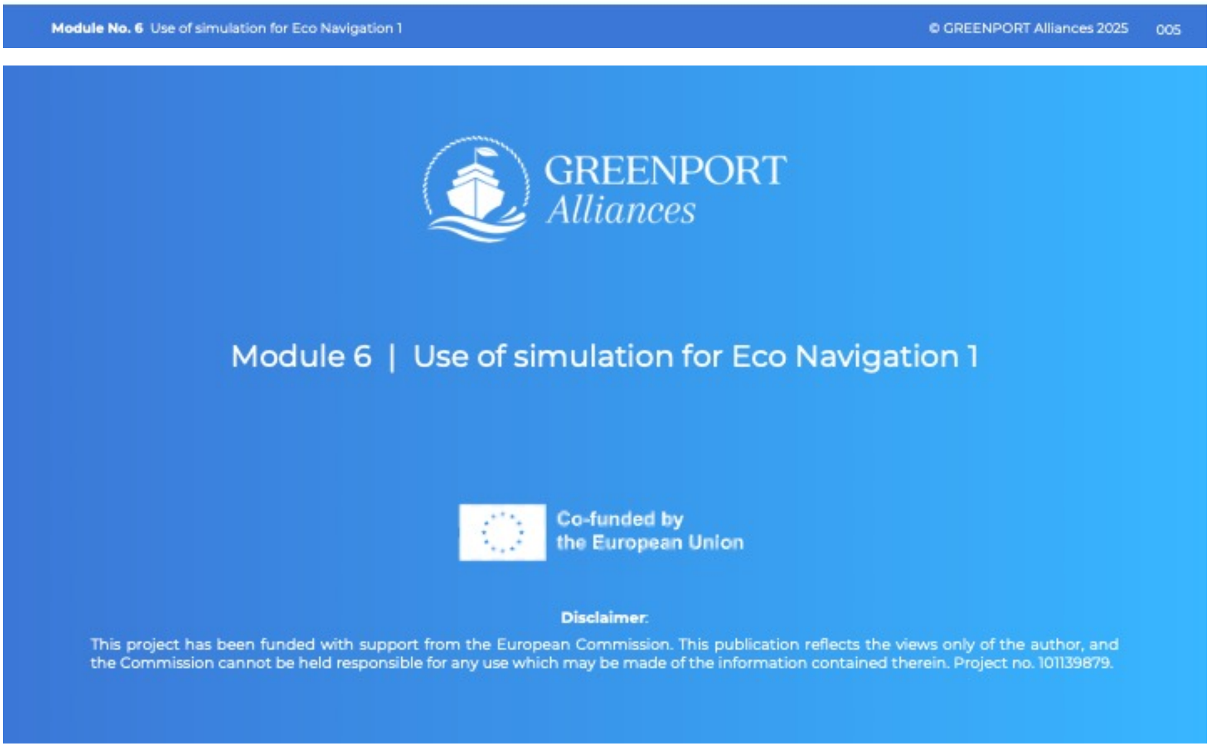


Chapter 6 Assessment Questions

Use of simulation for Eco Navigation 1

EXAM QUESTIONS

1. What is the primary benefit of using bridge simulators in tug operations?

a. Increasing tug speed
b. Enhancing crew comfort
c. Estimating fuel savings and reducing emissions
d. Automating tugboat navigation
e. Replacing tugboats with drones

2. Which of the following is a feature of simulation-based tug deployment planning?

a. Fixed tug assignments regardless of conditions
b. Real-time adjustment based on ship size and weather
c. Manual scheduling without digital tools
d. Ignoring engine load during operations
e. Always using maximum engine power

3. How can simulators help reduce fuel consumption during tug-assisted manoeuvres?

a. By increasing throttle usage
b. By encouraging fixed-speed operations
c. By optimizing engine load and throttle control
d. By disabling engine monitoring systems
e. By reducing the number of crew members

4. Which principle is NOT part of the ETA and EMPA recommendations for energy-efficient port operations?

a. Planning
b. Cooperation
c. Communication
d. Automation
e. Scheduling

5. Which of the following is a benefit of scenario-based simulator training?

a. Increased fuel consumption
b. Reduced safety margins
c. Improved decision-making under pressure
d. Elimination of pilot roles
e. Fixed route enforcement

6. What do advanced simulators track to support energy-efficient training?

a. Crew attendance
b. Vessel colour schemes
c. Fuel usage and thrust application
d. Port fee structures
e. Weather forecasts only

7. Which of the following is a recommended energy-efficient manoeuvring technique?

a. Abrupt acceleration during docking
b. Maximum thrust in tight spaces
c. Maintaining steady, low speeds
d. Frequent course corrections
e. Ignoring weather conditions

8. How do simulators support behavioural change in pilotage operations?

a. By replacing pilots with AI
b. Through experiential learning and feedback
c. By enforcing rigid navigation rules
d. By removing communication with tugboats
e. By increasing engine revs during training

9. What is the role of joint simulations with tug operators and port controllers?

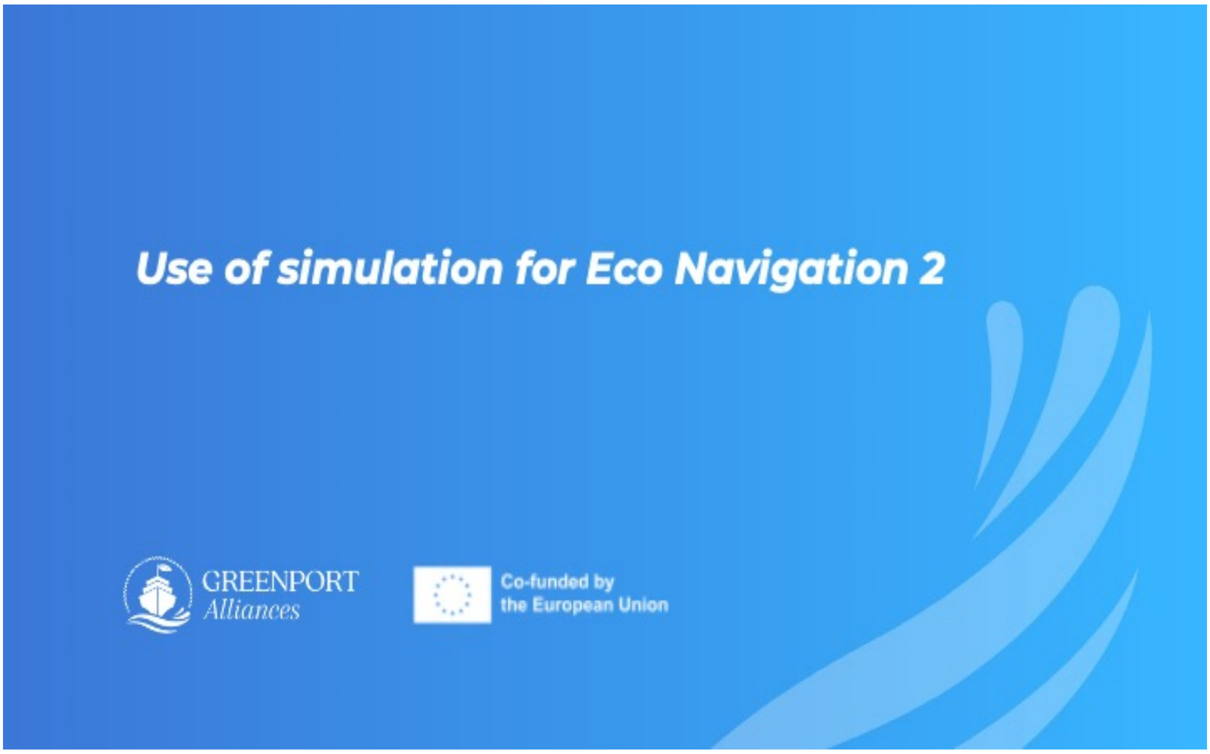
a. To reduce training time
b. To eliminate manual coordination
c. To improve communication and reduce energy waste
d. To increase tug usage
e. To simulate vessel construction

10. Which system integration supports energy-efficient pilotage training?

a. Port gate security systems
b. Port Management Information Systems (PMIS)
c. Crew payroll systems
d. Customs declaration platforms
e. Entertainment systems

CHAPTER 7

COURSE Module 7 (Week 7)



COURSE Module 7 (Week 7)

Use of simulation for Eco Navigation 2

1. Introduction

Advanced technology-based simulation tools play a critical role in the planning, management, and decision-making processes in ports. These tools, developed specifically to increase operational efficiency and optimize resource use, provide strategic advantages in port management. Tools used various simulations in the world within the scope of port operations optimization. Terminal simulation software models operations in container terminals, ensuring that work is done in the optimum way and that the system is continuously improved. To increase the safety and efficiency of approaching, docking, and leaving manoeuvres of ships arriving at ports, Ship Traffic and Manoeuvring Simulations are used. Another type of simulation tool is port logistics and supply chain simulations. With this simulation tool, cargo flow within the port, warehouse usage, integration and optimization of port connection roads are simulated. In addition, digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data have also become widespread in recent years. Thanks to the digital twin, data at ports can be monitored instantly, corrective actions can be taken, when necessary, experiments that cannot be done in real life can be conducted and the results can be evaluated, and as a result, the digital twin prepares an infrastructure for automation.

2. Port-specific digital modelling

Terminal Simulation Software Tools enables the analysis of complex processes in ports in order to identify problematic areas in port terminals, propose solutions and increase operational efficiency. Software helps to evaluate issues such as ship handling times in terminals, modelling port traffic (Carboni et al., 2024) and logistics flows, testing operational decisions, port infrastructure planning and design, and capacity analysis. Simulation software simulates loading/unloading operations, container-handling processes (Weerasinghe, 2024), railway/road operations, warehouse optimization, personnel and shift planning.
Ship Traffic and Manoeuvring Simulations are used to increase the safety and efficiency of approaching, docking and leaving manoeuvres of ships arriving at ports. These simulations ensure optimum planning of loading and unloading times for ships arriving at ports.
Port logistics and supply chain simulations are digital modelling and simulation processes developed to analyse, plan and optimize the logistics operations of ports and their impact on the overall supply chain. With this simulation tool, cargo flow within the port, warehouse usage, integration and optimization of port connection roads are simulated.
Digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data have also become widespread in recent years (Cao et al., 2025). The concept of Digital Twins can be explained as the transfer of all information of an object to its twin in a virtual environment and the continuous updating of the created twin with current data. The biggest difference between simulation technology and digital twin technology is that there is no real-time information flow to the simulated

object. A digital twin consists of a real object, its virtual twin and the transmitted real data. A virtual object is a living copy of the real object in a virtual environment. Digital twin technology has been used effectively in the maritime industry and especially in ports in recent years.

Artificial Intelligence (AI) enables computers to mimic human-like decision-making, learning, and problem-solving abilities. It has subfields such as machine learning (ML), deep learning (DL), and computer vision (CV). Predictive Analytics, on the other hand, predicts future possibilities from past data (Rao, Wang and Gupta, 2025).. This is usually done with AI-supported algorithms (Kováts et al., 2024). In ports, artificial intelligence (AI) and predictive analytics analyse large data sets collected from ports, strengthen operational decision support systems, predict congestion in ports, and optimize resource usage. Applications play a critical role in making operations more efficient, safe, and economical. Thanks to these applications, studies such as the estimated port entry time analysis of ships, optimization of container placement strategies, periodic estimation of ship and cargo demands to the port and effective equipment and personnel planning, predictive maintenance, and repair of port equipment with sensor data, development of port security applications, and optimization of energy consumption can be carried out. As a result, operational efficiency increases, cost reductions, delay prevention, better decision support systems, environmental sustainability and customer satisfaction can be achieved in ports.

3. Using vessel momentum strategically

Using vessel momentum strategically in eco-navigation simulations for port piloting and tugboat operations can greatly enhance efficiency and reduce environmental impact.

Momentum is the product of a vessel's mass and its velocity. It plays a crucial role in manoeuvring, especially in confined waters. Larger vessels have significant inertia, meaning they require more time and distance to change speed or direction.

Strategic Use of Momentum provides Efficient Speed Management by determining Optimal Speed. Maintaining an optimal speed balances fuel efficiency with the need for manoeuvrability. Reducing speed can lower fuel consumption and emissions. Using natural currents and wind to maintain momentum, reduce the need for engine power.

Using simulations to predict how momentum affects vessel behaviour in various scenarios, allow for better planning of manoeuvres, waypoints and routes that take advantage of momentum, such as utilizing the vessel's speed to coast into turns or docking.

Using vessel momentum helps employ tugboats strategically to assist in maintaining or redirecting momentum, especially in tight spaces or during docking and using tugboats to create controlled drag, allowing larger vessels to slow down gradually while maintaining control.

Continuous Training and Simulation must be considered for training crews on the principles of momentum and eco-navigation to ensure they can make informed decisions during operations.

Strategically using vessel momentum in eco-navigation simulations can lead to more efficient port piloting and tugboat operations. By optimizing speed, leveraging natural forces, and coordinating effectively with tugs, vessels can navigate more sustainably while reducing their environmental impact. Regular training and simulation can further enhance these strategies, ensuring that crews are well-prepared for real-world applications.

4. Prioritizing safety in manoeuvring

Prioritizing safety during manoeuvring in piloting and tugboat operations is crucial to ensure the well-being of crew members, the integrity of the vessel, and the protection of the marine environment. Here are several key considerations and strategies to enhance safety:

Comprehensive Risk Assessment: Pre-Operation assessments to evaluate environmental conditions, vessel characteristics, and potential hazards. A good scenario planning to develop and review various scenarios that could arise during operations, including equipment failure, adverse weather, and unexpected obstacles will enhance safety and decision making in real time operations.

Implement ongoing training programs for crew members that cover emergency procedures, navigation techniques, and vessel handling, using simulation drills to practice manoeuvres in different conditions, will allow crew members to gain experience without real-world risks.

Clear Communication Protocols: Establish clear communication protocols among crew members and between the piloting team and tugboats. Use standardized terminology to avoid misunderstandings.

Real-Time Updates: Maintain real-time communication regarding environmental conditions, vessel status, and any changes in the operational plan.

Navigation and Situational Awareness play an important role for safety in manoeuvring. Utilizing modern navigation systems (e.g., GPS, AIS) to track vessel positions and monitor nearby traffic to enhance situational awareness will also foster a culture of situational awareness among the crew, encouraging them to remain vigilant about their surroundings and potential hazards.

Continuously monitoring weather conditions and being prepared to adjust operations based on forecasts and real-time data and implementing measures to protect marine environments, such as avoiding sensitive areas and adhering to regulations regarding emissions and waste disposal should be also part of navigation and situational awareness.

For emergency preparedness, emergency response plans are to be developed and regularly updated for various scenarios, including collisions, grounding, and man-overboard situations. This should also ensure that all safety equipment (life jackets, fire extinguishers, first aid kits) is readily available, well-maintained, and easily accessible.

5. Using elements to advantage

Antwerp Maritime Academy (AMA) has prepared a navigation simulator experiment to evaluate the impact of human factors on fuel consumption. In this experiment, participants with different experience levels will perform various manoeuvres using a tugboat in the same weather conditions and on the same route. The simulator will collect tug-related data such as fuel consumption, speed, and position in a time series. Thus, data such as total fuel consumption, peak consumption moments and their frequency will be analysed. The aim is to determine human behaviours that will increase fuel efficiency by evaluating differences between operators.

This information will be used to develop more effective and targeted training programs. Thanks to the simulations, the impact of experience and behaviour patterns on energy consumption will be concretely demonstrated. The effectiveness of the training can be measured by pre- and post-training comparisons. The application will not only reduce operational costs but will also contribute to the reduction of harmful emissions such as CO_2 and NO_x. The project aims to promote a data-based and human-cantered approach that supports environmental sustainability in the long term.

EMPA's "Active Participation of Pilots in Planning Port Initiatives" is based on a video guide on energy efficiency prepared together with the European Tug Owners' Association (ETA). The video, published in October 2023 and widely available on social media, aims to improve port towage and pilotage operations in three main areas: planning, communication, and collaboration.

The aim of the project is to ensure collaboration that is more effective and communication between pilots, tugboat operators, port authorities and other stakeholders, ensuring that port entry and exit manoeuvres are carried out in an energy-efficient and low-emission manner. During the planning phase, a detailed towage plan is prepared according to the ship's characteristics, while real-time information flow is provided in communication, aiming for safe and efficient operations. In collaboration, joint meetings are held to determine best practices.

Instead of waiting for technology to reduce environmental impacts, EMPA and ETA aim to create a culture of sustainability through behavioural change and conscious practices. This initiative is an important step in encouraging the adoption of environmentally friendly operational habits in the industry.

6. Monitoring for overuse of tugs and ship's engine by pilot

Monitoring the overuse of tugs and a ship's engine during piloting operations is essential for optimizing resource efficiency, reducing operational costs, and minimizing environmental impact.

Establishing clear guidelines and standards through operational protocols plays an important role for developing guidelines for when and how tugs should be used, including specific scenarios that warrant tug assistance. This should also include engine usage policies outlining optimal engine usage patterns, including speed limits and RPM ranges during manoeuvres.

Implementing real-time data monitoring systems provide real-time data on tug usage and engine performance which may include tug tracking systems using GPS and AIS to monitor the position and operational status of tugs, engine monitoring systems that track engine parameters such as RPM, fuel consumption, and power output and data analytics tools utilizing software to analyse historical data on tug and engine usage, identifying trends and patterns that indicate overuse.

Key Performance Indicators (KPIs) to be established to measure the efficiency of tug and engine use, such as, tug utilization rate (ratio of actual tug hours to planned hours), fuel consumption per manoeuvre (measurement of fuel consumption relative to the type and complexity of manoeuvres), and engine load factor (monitoring the percentage of engine capacity being used during operations).

For benchmarking purposes, performance metrics can be compared against industry standards or historical data to identify areas of overuse.

Conducting regular debriefings after operations to discuss tug and engine usage, highlights instances of overuse and strategies for improvement. This will allow creating channels for crew members to provide feedback on operational practices and suggest improvements.

Action plans based on monitoring results to address issues of overuse, including adjustments to operational protocols or additional training can be updated by iterative assessments that regularly reassess monitoring strategies and protocols to ensure they remain effective and relevant to changing operational needs.

Monitoring for the overuse of tugs and a ship's engine is vital for enhancing operational efficiency and sustainability in piloting operations. By establishing clear guidelines, utilizing technology, training crew members, and implementing continuous improvement processes, organizations can effectively manage resources and minimize unnecessary usage, ultimately benefiting both the environment and operational costs.

7. Elements which a tug master can do better to save energy.

Tug masters play a crucial role in optimizing energy efficiency during operations. Key elements and strategies that tug masters can implement to save energy:

Efficient tug manoeuvring through optimal speed management: Maintaining a steady speed that balances efficiency with operational requirements, avoiding rapid accelerations and decelerations, using slow and controlled movements, especially during docking and undocking, to minimize fuel consumption.

Use of Momentum: Taking advantage of the vessel’s momentum when manoeuvring, allowing for coasting rather than relying solely on engine power.

Appropriate Tug Selection: Choosing the right type and size of tug for the specific operation. Using a tug that is too powerful for the task can lead to unnecessary fuel consumption.

Tug Pairing: When multiple tugs are required, pair them effectively to optimize their combined power and reduce overall energy use.

Efficient Routing: Planing the most efficient routes to minimize travel distance and time, considering factors like currents, wind, and traffic, using software tools for route optimization, taking into account real-time environmental conditions.

Optimal tow line length: The optimal tow line length shall be established in agreement with the pilot. If the line is excessively short, the propulsion from all tugs will exert force against the side of the ship, generating an opposing force to the tow. Conversely, if the line is excessively long, control of the vessel may be compromised.

Engine RPM Optimization: Operating engines at optimal RPMs to ensure they are running efficiently. Avoid running at excessively high RPMs unless necessary.

Regular Maintenance: Ensuring that engines and propulsion systems are regularly maintained for peak performance. This includes checking fuel filters, cleaning injectors, and ensuring proper lubrication.

Implementing Energy Recovery Technologies: Exploring the use of energy recovery systems that can capture and reuse energy generated during operations, such as regenerative braking systems.

Real-Time Monitoring: Utilizing monitoring systems to track fuel consumption, engine performance, and operational efficiency in real-time.

Data Analysis: Regularly analysing operational data to identify trends and areas for improvement, adjusting practices based on findings to enhance energy efficiency.

Training Programs: Providing training for crew members on energy-efficient practices and the importance of fuel conservation.

Promoting Awareness: Fostering a culture of energy efficiency among the crew by encouraging them to suggest and implement energy-saving measures.

Effective Communication: Maintaining clear communication with the pilot and other vessels to coordinate manoeuvres and optimize tug usage, establishing a feedback mechanism to discuss energy-saving practices and share successful strategies.

By focusing on efficient manoeuvring, reducing the frequency of unnecessary movements or standby times when not actively engaged in operations, proper tug selection, effective route planning, monitoring and adapting to changing environmental conditions such as tides and winds, which can impact fuel efficiency, and ongoing monitoring, tug masters can significantly reduce energy consumption during operations. Implementing these strategies not only contributes to cost savings but also supports environmental sustainability in maritime operations.

8. post-operation pilot and tug master/s debrief

Conducting a post-operation debrief for pilots and tug masters is essential for continuous improvement, safety enhancement, and operational efficiency. A structured debriefing process helps identify lessons learned, address issues encountered, and reinforce best practices.

Steps for Conducting a Post-Operation Debrief:

A debriefing session must be held as soon as possible after the operation while details are fresh in participants' minds. Participants should include all relevant crew members, including pilots, tug masters, and any other personnel involved in the operation. Debrief sessions must be conducted in a comfortable environment to foster an open and non-judgmental environment where all participants feel comfortable sharing their thoughts and experiences. A facilitator must be designated to guide the discussion and ensure all topics are covered.

The debrief shall start with a brief overview of the operation, including objectives, planned manoeuvres, and any changes made during execution and continue with a timeline of key events, highlighting critical moments during the operation.

Discussion on key topics include operational performance to evaluate how well the operation met its objectives, effectiveness of communication and coordination among crew members, identify any safety concerns or near misses that occurred during the operation, and how these issues were addressed and what could be improved.

Environmental conditions need to be reviewed to discuss how weather, currents, and visibility impacted the operation, and whether the crew adapted effectively to changing conditions.

Equipment performance assessment is to include the performance analysis of all equipment used, including tugboats, navigation systems, and safety gear, and any malfunctions or issues that arose and how they were handled.

Crew Performance evaluation should focus on individual and team performance, including decision-making and situational awareness to determine any training needs or areas for improvement.

All participants should be encouraged to share insights and lessons learned from the operation, discuss best practices that emerged and how they can be applied in future operations.

A well-structured post-operation debrief for pilots and tug masters is vital for enhancing safety, improving operational efficiency, and fostering a culture of continuous improvement. By covering key topics such as operational performance, safety issues, environmental conditions, equipment performance, and crew performance, organizations can learn from each operation and apply those lessons to future missions.

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Chapter 7 Supporting Material

1. Introduction

- Advanced technology-based simulation tools play a critical role in the planning, management and decision-making processes in ports.
- These tools, developed specifically to increase operational efficiency and optimize resource use, provide strategic advantages in port management
- To increase the safety and efficiency of approaching, docking, and leaving manoeuvres of ships arriving at ports, Ship Traffic and Manoeuvrings Simulations are used.
- Digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data have also become widespread in recent years.

2. Port-specific digital modelling

Terminal Simulation Software Tools enables the analysis of complex processes in ports in order to identify problematic areas in port terminals, propose solutions and increase operational efficiency.

Ship Traffic and Manoeuvring Simulations are used to increase the safety and efficiency of approaching, docking and leaving manoeuvres of ships arriving at ports. These simulations ensure optimum planning of loading and unloading times for ships arriving at ports.

Port logistics and supply chain simulations

Port-specific digital modelling

Digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data

Artificial Intelligence (AI) enables computers to mimic human-like decision-making, learning, and problem-solving abilities. It has subfields such as machine learning (ML), deep learning (DL), and computer vision (CV). Predictive Analytics, on the other hand, predicts future possibilities from past data

3. Using vessel momentum strategically

Using vessel momentum strategically in eco-navigation simulations for port piloting and tugboat operations can greatly enhance efficiency and reduce environmental impact.

Momentum is the product of a vessel's mass and its velocity. It plays a crucial role in manoeuvring, especially in confined waters.

Strategic Use of Momentum provides Efficient Speed Management by determining Optimal Speed.

Using simulations to predict how momentum affects vessel behaviour in various scenarios, allow for better planning of manoeuvres,

Using vessel momentum helps employing tugboats strategically to assist in maintaining or redirecting momentum, especially in tight spaces or during docking and using tugboats to create controlled drag.

4. Prioritizing safety in manoeuvring

- Crucial to ensure the well-being of crew members, the integrity of the vessel, and the protection of the marine environment

- Comprehensive Risk Assessment: Pre-Operation assessments to evaluate environmental conditions, vessel characteristics, and potential hazards.

- Training programs for crew members that cover emergency procedures, navigation techniques, and vessel handling, using simulation drills to practice manoeuvres in different conditions

- Clear Communication Protocols among crew members and between the piloting team and tugboats. Use standardized terminology to avoid misunderstandings

- Maintain real-time communication regarding environmental conditions, vessel status, and any changes in the operational plan

- Navigation and Situational Awareness play an important role for safety in manoeuvring.

5. Using elements to advantage

- Navigation simulator can be utilized to evaluate the impact of human factors on fuel consumption - human behaviours that will increase fuel efficiency by evaluating differences between operators.

- This information can be used to develop more effective and targeted training programs.

- EMPA's "Active Participation of Pilots in Planning Port Initiatives" is based on a video guide on energy efficiency prepared together with the European Tug Owners' Association (ETA)

- Instead of waiting for technology to reduce environmental impacts, EMPA and ETA aim to create a culture of sustainability through behavioural change and conscious practices. This initiative is an important step in encouraging the adoption of environmentally friendly operational habits in the industry.

- The aim of the project is to ensure collaboration that is more effective and communication between pilots, tugboat operators, port authorities and other stakeholders, ensuring that port entry and exit manoeuvres are carried out in an energy-efficient and low-emission manner.

- During the planning phase, a detailed towage plan is prepared according to the ship's characteristics, while real-time information flow is provided in communication, aiming for safe and efficient operations. In collaboration, joint meetings are held to determine best practices.

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6. Monitoring for overuse of tugs and ship's engine by pilot

- Monitoring the overuse of tugs and a ship's engine during piloting operations is essential for optimizing resource efficiency, reducing operational costs, and minimizing environmental impact.

- Establishing clear guidelines and standards through operational protocols plays an important role for developing flawless guidelines for when and how tugs should be used, including specific scenarios that warrant Tug assistance

- Implementing real-time data monitoring systems provide real-time data on tug usage and engine performance which may include tug tracking systems using GPS and AIS to monitor the position and operational status of tugs

- Key Performance Indicators (KPIs) to be established to measure the efficiency of tug and engine use, such as, tug utilization rate (ratio of actual tug hours to planned hours), fuel consumption per manoeuvre, and engine load factor

- Conducting regular debriefings after operations to discuss tug and engine usage, highlights instances of overuse and strategies for improvement

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7. Elements which a tug master can do better to save energy

- Efficient tug manoeuvring
- Use of Momentum
- Appropriate Tug Selection
- Tug Pairing
- Efficient Routing
- Engine RPM Optimization
- Regular Maintenance
- Implementing Energy Recovery Technologies
- Real-Time Monitoring and Data Analysis

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8. Post - Operation pilot and tug master/s debrief

A well-structured post-operation debrief for pilots and tug masters is vital for enhancing safety, improving operational efficiency, and fostering a culture of continuous improvement.

By covering key topics such as operational performance, safety issues, environmental conditions, equipment performance, and crew performance, organizations can learn from each operation and apply those lessons to future missions

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Conclusion:

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Advanced technology-based simulation tools play a critical role in the planning, management and decision-making processes in ports.

These tools, developed specifically to increase operational efficiency and optimize resource use, provide strategic advantages in port management.

As a result, operational efficiency increases, cost reductions, delay prevention, better decision support systems, environmental sustainability and customer satisfaction can be achieved in ports.

To fully leverage these benefits, maritime professionals must embrace continuous learning and adapt to evolving technologies.

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Module 7 | ***Use of simulation for Eco Navigation 2***

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Chapter 7 Assessment Questions

Use of simulation for Eco Navigation 2

EXAM QUESTIONS

1. What is the primary purpose of terminal simulation software in ports?

a. To monitor weather conditions
b. To simulate ship construction
c. **To model container terminal operations and improve efficiency**
d. To manage port security systems
e. To track crew performance

2. Which simulation tool is used to enhance the safety and efficiency of ship manoeuvres in ports?

a. Terminal simulation software
b. Port logistics simulation
c. **Ship Traffic and Manoeuvring Simulations**
d. Digital twin applications
e. Predictive analytics

3. What is a key feature of digital twin technology in port operations?

a. It uses historical data only
b. It does not require real-time data
c. It replaces physical infrastructure
d. **It continuously updates a virtual copy of the port with real-time data**
e. It simulates weather patterns

4. Which of the following is NOT typically simulated by terminal simulation software?

a. Container-handling processes
b. Railway and road operations
c. Personnel and shift planning
d. **Ship construction techniques**
e. Warehouse optimization

5. What distinguishes digital twin technology from traditional simulation tools?

a. It uses outdated data
b. It does not require a virtual model
c. **It integrates real-time data with a virtual model of the physical object**
d. It is only used for ship navigation
e. It cannot be used in maritime applications

6. What is the purpose of regenerative systems in eco-navigation?

a. To increase vessel weight
b. To simulate weather conditions
c. **To recover energy from vessel momentum during manoeuvres**
d. To replace traditional engines
e. To reduce crew workload

7. What is the strategic benefit of using vessel momentum in eco-navigation simulations?

a. Increases fuel consumption
b. Reduces the need for tugboat assistance
c. **Enhances efficiency and reduces environmental impact**
d. Eliminates the need for navigation systems
e. Increases vessel speed in all conditions

8. How can tugboats assist in managing vessel momentum during docking?

a. By increasing vessel speed
b. By replacing navigation systems
c. **By creating controlled drag to slow down vessels**
d. By towing vessels at full speed
e. By disabling vessel engines

9. Why is continuous training and simulation important in eco-navigation?

a. To reduce the number of crew members
b. To eliminate the need for tugboats
c. **To help crews make informed decisions using momentum principles**
d. To automate all port operations
e. To increase vessel speed

10. What is a key component of comprehensive risk assessment in piloting operations?

a. Ignoring weather conditions

b. Avoiding scenario planning

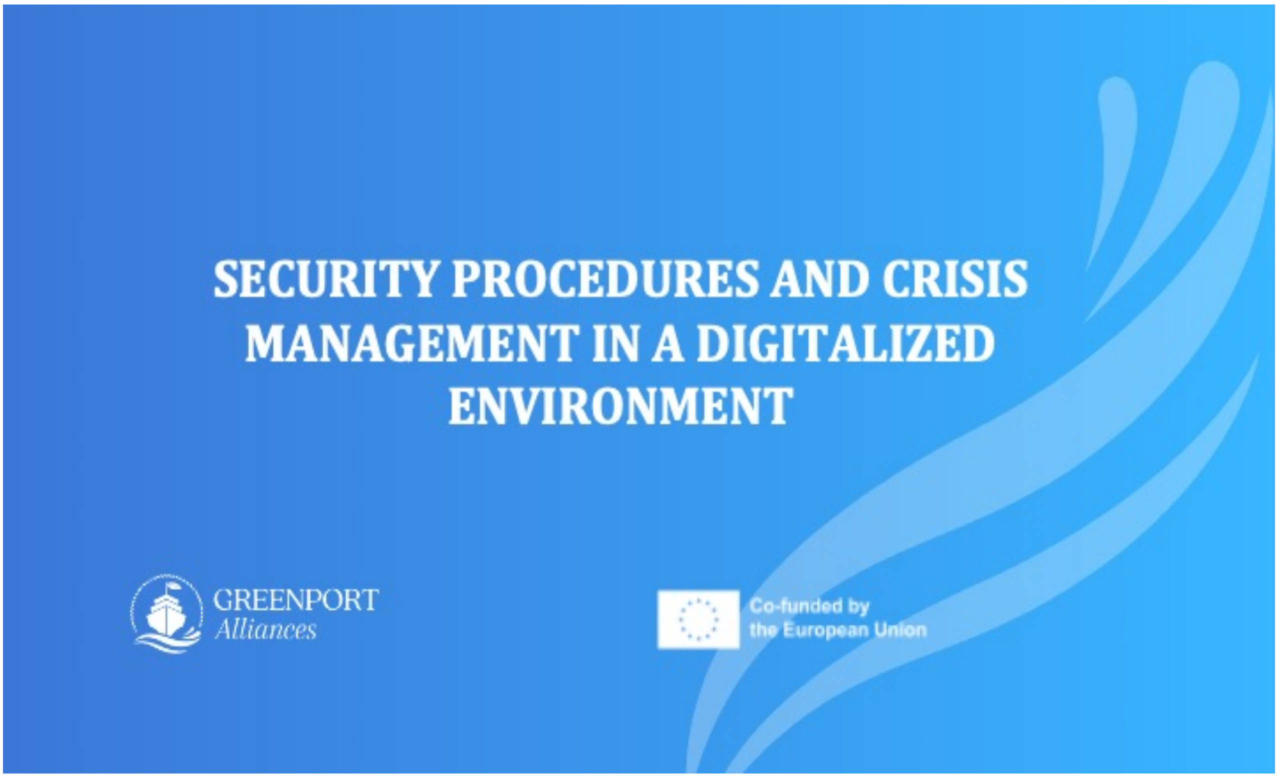
c. **Evaluating environmental conditions and potential hazards**

d. Relying solely on manual navigation

e. Disabling communication

CHAPTER 8

COURSE Module 8 (Week 8)



COURSE Module 8 (Week 8)

Security procedures and crisis management in a digitalized environment

1. Introduction

The maritime industry, the foundation of global trade, is undergoing significant transformation driven by digitization and the imperative of sustainability. This change aims to improve efficiency, safety and environmental performance, especially within the concept of **"green ports"** that seek to minimize environmental impact. Digitalization enables real-time tracking, optimized routes, reduced fuel consumption and lower emissions, which is aligned with sustainability goals. Increased ship-to-land connectivity through cloud platforms and satellite communications enables real-time data exchange, rapid decision-making and better supply chain transparency. Digitalization in the maritime sector encompasses the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning and automation in all maritime operations, logistics and management. This includes everything from remote monitoring of critical assets to autonomous vessel operations. **Although digitization offers enormous benefits, it also widens the industry's exposure to cyber risks, creating a wider surface for attacks.** The increasing reliance on interconnected digital systems, including information technology (IT) and operational technology (OT), introduces vulnerabilities that can disrupt global trade, threaten the safety of vessels, crews and lead to environmental disasters.

Cyber threats are especially devastating in **port operations** and **port approaches** due to a combination of **operational complexity**, **critical infrastructure**, and **high interconnectivity**. Ports are busy environments with **tight schedules**, **dense traffic**, and **restricted manoeuvring space**. A cyberattack disrupting pilotage or tug coordination can lead to **collisions**, **groundings**, or **blockages**.
Ports are gateways for **global trade**, handling fuel, food, medical supplies, and military assets. Disruption can have **national security** and **economic consequences**.

Port operations rely on **integrated digital systems** such as cargo tracking, vessel traffic services (VTS), customs, logistics etc. A breach in one system can cascade across others, amplifying the impact. For example, delays in pilotage or tug operations can cause **missed berthing windows**, **demurrage costs**, and **supply chain disruptions**. Unlike open sea operations, ports have **limited fallback options**. If a tugboat or pilot system fails, alternatives are scarce.

Cyber-induced accidents in port approaches can result in **loss of life**, **oil spills**, or **hazardous material exposure**. Besides, the risks such as loss of control over ships or sensitive data, as well as hijacking of ships and/or cargo [1], require implementation of effective security procedures and robust crisis management measures that are no longer just IT concerns, but fundamental aspects of maritime safety, environmental protection, and business continuity.

2. Security procedures for digitalized systems

Digitalization in maritime operations brings significant benefits, including improved efficiency through remote monitoring of engine performance, fuel consumption and cargo temperature monitoring, resulting in reductions in unplanned downtime, fuel costs and carbon emissions. However, this digital transformation inherently expands the maritime industry's exposure to cyber risks, creating a wider surface for malicious actors to attack. The integration of IT and OT systems presents a major vulnerability, as many shipboard OT infrastructures are older, designed for functionality rather than cyber resilience, and often lack basic security controls such as encryption or regular updates [2]. This leaves critical systems, such as navigation and propulsion, vulnerable to attacks such as GNSS spoofing, ransomware and malware injection. Efficiency gains from digitalization, such as real-time tracking and reduced downtime, are directly linked to increased exposure to cyber threats. This creates a crucial balance that requires proactive risk management rather than reactive responses. The full realization of **efficiency and sustainability benefits** depends on the **effective management** of these new cyber risks, meaning that maritime operations cannot fully benefit from digitalization **without a simultaneous and significant investment** in robust cybersecurity.

The maritime sector faces a diverse range of cyber threats, including unauthorized access and insider threats, ransomware attacks, social engineering and malware. Unauthorized access can occur due to inadequate security measures, allowing hackers or even insiders to manipulate or steal data. Ransomware, which encrypts a victim's files and makes them inaccessible until a ransom is paid, can lock down navigation systems or digital records, severely disrupting maritime operations. Social engineering, including phishing, smishing, and spoofing, targets human vulnerabilities to obtain sensitive information. Malware such as Remote Access Trojans (RATs) can allow attackers to remotely control systems. Recently, attacks on vessel navigation systems due to GPS spoofing have also been reported, as have remote cyberattacks exploiting vulnerabilities in wireless keyboards and printers. Cyberattacks by state actors have also been reported that resulted in the loss of propulsion and control on multiple vessels [2]. The economic and operational consequences of cyberattacks on ports and vessels highlight the critical need for robust cybersecurity measures. For example, the attack on the Port of San Diego in 2020 served as a warning. Similarly, the NotPetya malware attack on Maersk in 2020 cost hundreds of millions of dollars and disrupted global operations for weeks, demonstrating that cybersecurity is a safety, environmental, and business continuity issue.

With the rise of global political instability, cyberwarfare and the disruption of services have become the preferred weapons. Malicious states could potentially close ports and strategically use ships as tools to destroy critical infrastructure, risking not only port access but also leaving countries starving for food and energy.

International organizations such as IMO and BIMCO have developed guidelines for cyber risk management in the maritime sector. IMO Resolution [3] affirms that an approved safety management system (SMS) should consider cyber risk management in accordance with the objectives and functional requirements of the ISM Code. From 1 January 2021, all shipowners must address cyber risks during their Document of Compliance (DOC) reviews, making it mandatory to integrate cyber risk management into SMS documentation. The IMO Cyber Risk Management Model defines the process of identifying, analysing, assessing and communicating cyber risks and their acceptance, avoidance, transfer or mitigation to an acceptable level. The IMO Cyber Risk Management Guidelines provide high-level recommendations for cyber risk management to protect shipping from current and future cyber threats and vulnerabilities [4]. They encourage operators to integrate cyber security into their existing security management systems (SMS), ensuring that cyber risks are treated with the same rigor as traditional maritime hazards.

BIMCO's guidelines for cyber security on ships offer a practical five-step approach: **identification, assessment, protection, detection, response** and r**ecovery.** These guidelines emphasize the importance of crew training, securing systems and incident response planning [5]. In particular, **BIMCO's Shipboard Cyber Security Workbook** serves as a practical guide for owners, masters and crew, containing checklists for day-to-day cyber security management. Compliance with international standards such as ISO/IEC 27001:2022 and the NIST Cybersecurity Framework (CSF) provides a robust framework for information security management. These standards ensure that organizations manage risks proactively, not reactively, and have clear protocols for protection, detection, response and recovery [6].

Effective implementation of maritime cybersecurity requires a strategic and layered approach, known as **"defence in depth and breadth".** This involves a combination of protective and detection layers, from the physical security of the ship to network protection and intrusion detection, through periodic scanning and testing [7]. Key strategies include segmenting networks to contain potential breaches and make it more difficult for attackers to move laterally. Regular penetration testing and vulnerability assessments help identify weak spots before attackers can exploit them. Implementing advanced threat detection tools, such as those that use artificial intelligence and machine learning, can help detect unusual behaviour that may indicate a cyber threat. The United States Coast Guard (USCG) has moved **from encouraging cybersecurity best practices to enforcing them,** culminating in a new mandate that took effect on July 16, 2025. These final rules aim to protect the maritime transportation system from cyber threats by establishing minimum cybersecurity requirements, including the development and maintenance of a Cybersecurity Plan and the appointment of a Cybersecurity Officer. The requirements include automatic account lockouts, changing default passwords, multi-factor authentication, applying the principle of least privilege, maintaining separate user credentials and removing or disabling default credentials. It also requires segmentation of IT and OT networks, recording and monitoring of connections between them, and limiting physical access to IT and OT equipment [8].

3. GNSS Spoofing, Jamming, and Cyber Threats in Navigation

Cyber threats in navigation are especially devastating in **port operations** and port approaches due to a combination of o**perational complexity, critical infrastructure,** and **high interconnectivity.** Ports are busy environments with tight schedules, dense traffic, and restricted manoeuvring space. A cyberattack such as GNSS and GPS spoofing and jamming targeting vessel positioning systems and pilot navigation aids, disrupting pilotage or tug coordination, can lead to collisions, groundings, or blockages.

Ports are gateways for global trade, handling fuel, food, medical supplies, and military assets. Disruption can have national security and economic consequences. Unauthorized Access to Control Systems through remote manipulation of tugboat engines, thrusters, or pilotage systems targeting data collection and analysis, propulsion control, and automated mooring systems may pose high risks if systems are exposed to public networks or lack proper segmentation. Cyber-induced accidents in port approaches can result in loss of life, oil spills, or hazardous material exposure.

Port operations rely on integrated digital systems such as Port management systems, pilotage scheduling platforms, cargo tracking, vessel traffic services (VTS), customs, logistics etc. A breach in one system can cascade across others, amplifying the impact. Data breaches and espionage may have a direct impact on leakage of sensitive cargo data, schedules, or security protocols.

Other threats to navigation include manipulation or delay of pilot-tug-vessel communications by targeting VHF, AIS, and digital communication systems, and supply chain attacks Compromised through third-party software or hardware used in port operations that may help targeting navigation software, tugboat firmware, pilotage apps.

Ransomware attacks targeting administrative systems, digital logbooks, and communication platforms. may have a severe impact by disrupting pilotage scheduling, tug dispatching, and port logistics. Delays in pilotage or tug operations can cause missed berthing windows, demurrage costs, and supply chain disruptions. Unlike open sea operations, ports have limited fallback options. If a tugboat or pilot system fails, alternatives are scarce.

Ports are high-value targets for ransomware, espionage, and sabotage, particularly those located in strategic regions. To mitigate these risks, it is essential to implement robust cybersecurity protocols, enable real-time monitoring and anomaly detection, establish redundant communication systems, and provide targeted training to operational personnel. This training should foster **behavioural change** and preparedness for **cyber-physical incident response**.

One of the most effective ways to combat cyber threats is to have trained professional mariners (pilots/ship officers and crew) on a ship's bridge, who can override automatic systems in the event of a cyber-attack and use their skills to ensure ships and ports continue to operate safely and efficiently.

4. Crisis management and emergency response

In a digitized maritime environment, effective crisis management and emergency response is critical to minimizing the impact of cyber incidents and ensuring business continuity. Crisis management plans must include strategies for rapid detection, containment, eradication and recovery from cyberattacks.

IMO's cyber risk management guidelines recommend that organizations have clear incident response and recovery strategies. This includes establishing procedures for collation and retention of security records and periodic review by competent personnel as part of routine operational maintenance. Implementation of these guidelines helps ensure system and data resilience. An important aspect is also the establishment of an anonymous cyberattack reporting system to improve transparency in risk management and enable the generation of unique evidence on risk assessment and mitigation. It is critical that companies establish an internal threat team to assess new threats and regularly update response plans. This includes defining response roles and procedures, ensuring timely reporting of incidents to relevant national authorities within 24 hours of discovery, and detailed reports within 72 hours. In the US, significant cyber incidents must be reported to the National Centre for Cybersecurity and Communications Integration (NCCIC) and the captain of the port (COTP) within 12 hours from discovery. Proactive planning and regular testing of incident response protocols are key to minimizing impact and ensuring rapid recovery. Regular drills and crisis simulations are essential for testing response plans, ensuring that damage is minimized, and recovery is rapid when an attack occurs [9].

The role of technology in emergency response is multifaceted. Digital tools improve situational awareness and decision-making during emergencies, but they also introduce new dependencies. For example, DNV's Emergency Response Service (ERS™) provides 24/7 shore-based damage control support, using predictions of residual buoyancy, stability, strength and drift. This service provides rapid access to damage control support, understanding the criticality of a vessel's damaged condition and verifying intentions to make safe decisions. Similarly, Lloyd's Register's Ship Emergency Response Service (SERS) offers 24/7 access to experts, including naval architects and former seafarers, who provide proactive technical support and advice for scenarios such as structural damage, instability or pollution. These digital systems enable rapid and accurate situation analysis, but their effectiveness depends on the cyber resilience of the systems themselves. This means that while technology improves the ability to respond to traditional maritime emergencies, it also creates a new point of vulnerability if these systems become the target of a cyberattack. Therefore, emergency response plans must include scenarios related to compromised digital tools.

Business continuity and resilience are key to mitigating the impact of cyber incidents. This includes establishing strategies for data protection and recovery, including network segmentation to reduce the attack surface and ensure operations can continue even if the network is offline. The ability to revert to manual processes and maintain operations in a degraded state is a critical, but often untested, aspect of resilience. Lack of coordination before and during crises, unclear notification procedures, and inconsistent communication between government and private actors can hinder crisis response. This means that organizations must prepare for scenarios where digital systems are unavailable, ensuring that critical functions can continue to operate. The economic consequences of cyberattacks on ports and the global supply chain underscore the imperative of robust business continuity planning [10]. For example, the attack on the port of San Diego in 2020 and the Maersk incident in 2020 show how a cyberattack can paralyze operations and cause billions of dollars in damage.

International cooperation and information sharing are key to addressing growing cyber threats. Governments, port authorities and private stakeholders should work together to share intelligence, standardize security protocols and invest in collective defence mechanisms. Public-private partnerships can play a key role in funding advanced cybersecurity infrastructure, while international regulatory bodies such as the IMO must enforce stricter cybersecurity mandates across the industry. IMO's maritime digitalization strategy, which will be adopted by the end of 2027, aims to promote a fully interconnected, harmonized and automated global maritime sector, while recognizing the challenges of cyber security. The success of this strategy will depend on the contribution of member states and international organizations, especially in terms of safety and environmental protection.

5. Human factors and crew management

The human element is recognised as a key factor in the safety of life on board ships and a contributing factor to most accidents in the maritime sector. Digitalisation and automation are redefining the role of the human, requiring **new competencies beyond traditional maritime skills.** IMO emphasises that the human element must be considered when reviewing, developing and implementing new and existing requirements, including skills, education and training, and human capabilities, limitations and needs. The move towards autonomous and remotely operated processes is changing the structures of organisations and the way people work, introducing new safety challenges that affect crew and shore-based personnel. This means that safety in modern shipping increasingly relies on system robustness, resilience and the ability to continuously improve through the dynamic interaction between human, organisational and technical factors.

Training and awareness programs are essential to ensure that crew and shore-based personnel are equipped to cope with a digitalized environment. Effective cybersecurity training for seafarers is not just about acquiring technical skills, but also fostering a **culture of constant vigilance and responsibility**. Courses such as “Maritime Cyber Security Awareness for Seafarers” cover the definition of cybersecurity, existing cyber threats, vulnerabilities in shipboard IT and OT systems, and mitigation and defence measures. These courses emphasize that cybersecurity is everyone’s responsibility and must be integrated into the SMS. In addition to technical skills, digital maritime learning offers interactive, short courses that address specific skill gaps, including crew familiarization training, operational and emergency training, and troubleshooting training. The use of technologies such as virtual reality (VR) and digital twins can enhance crew competencies by allowing them to familiarize themselves with vessels and practice operations in a safe, virtual environment.

The development of autonomous shipping necessitates a reassessment of traditional training methodologies. Modern ship crews and pilots must possess conventional skills to operate effectively during system failures or cyber-attacks; additionally, they must be increasingly technologically proficient, with an emphasis on digital, operational, and interpersonal competencies. Research has identified "operational skills", "digital skills" and "maritime competence" as the most important skills and competencies for maritime autonomous surface ship (MASS) operations [11]. Interpersonal skills, such as communication, collaboration, teamwork, adaptability, leadership and emotional intelligence, are critical to aligning different interests and ensuring harmonious operations, especially in hybrid environments where human supervision remains vital.

Human-machine interaction in the maritime sector is becoming increasingly complex with the introduction of automation and artificial intelligence. In ports, semi-automation offers a middle ground between full automation and traditional human-operated systems, where machines perform repetitive or hazardous tasks, while human workers continue to supervise operations and make complex, high-risk decisions. This hybrid strategy is designed to increase efficiency and create a safer, healthier and more environmentally friendly work environment. Remote control of machinery from an enclosed space and ergonomically adapted chairs and monitors help to avoid the effects of poor posture and constant machine vibrations. However, this interaction between human operators and advanced autonomous systems requires careful design and training to ensure safety and prevent new forms of error. DNV’s AROS (Autonomous and Remotely Operated Ships) notations provide a framework for achieving equivalent or higher levels of safety for autonomous vessels compared to conventional vessels, taking into account human factors and remote-control centres. This includes assessing how human performance impacts the operating environment, including organizational aspects, and supporting clients through alternative design processes, for example, through the use of remote operations.

6. Conclusion

Digitalization is an inevitable and transformative process in the maritime industry, bringing significant benefits in efficiency and sustainability, but at the same time introducing complex cyber risks. The key insight is that the full potential of digitalization can only be realized through proactive and comprehensive cyber risk management, integrated into all aspects of maritime operations and safety management. This implies a shift from mere compliance with regulations to building a resilient cyber security culture.

The future of the maritime sector will depend on the industry's ability to adapt to these changes. This includes continued investment in advanced security technologies, the development of robust incident response and business continuity plans, and comprehensive training programs for crew and shore-based personnel. It is particularly important to **recognize the redefined role of the human factor** in a highly automated environment, where traditional skills are complemented by digital, operational and interpersonal competencies. International cooperation and information sharing remain key to building a collective defence against increasingly sophisticated cyber threats.

Cyber-induced accidents in port approaches can result in loss of life, oil spills, or hazardous material exposure. Ports are attractive targets for ransomware, espionage, or sabotage, especially in strategic locations. Therefore, establishing robust cybersecurity protocols, real-time monitoring and anomaly detection, redundant communication systems, and training of crew for behavioural change for cyber-physical incident response has utmost importance for safe and efficient port operations.

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Chapter 8 Supporting Material

1. Introduction

- Although **digitization** offers enormous benefits, it also widens the maritime industry's exposure to **cyber risks**, creating a wider surface for attacks
- **Cyber incidents** can result in **loss of life**, **loss of control** over ships or sensitive data, as well as **hijacking** of ships and/or cargo
- Effective **security procedures** and **robust crisis management** are fundamental aspects of maritime safety, environmental protection and business continuity

2. Security procedures for digitalized systems

- The integration of **information technology (IT)** and **operational technology (OT)** systems presents a major vulnerability, as many shipboard OT infrastructures are older, designed for functionality rather than cyber resilience, and often lack basic security controls such as encryption or regular updates
- This leaves critical systems, such as navigation and propulsion, vulnerable to attacks such as GNSS **spoofing**, **ransomware** and **malware injection**

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Security procedures for digitalized systems

- Efficiency gains from digitalization, such as **real-time tracking** and **reduced downtime**, are directly linked to increased **exposure to cyber threats**
- This creates a **crucial balance** that requires **proactive risk management** rather than reactive responses
- The full realization of efficiency and sustainability benefits depends on the **effective management of these new cyber risks** – maritime operations cannot fully benefit from digitalization without a simultaneous and significant investment in **robust cybersecurity**

Security procedures for digitalized systems

- International organizations such as **IMO** and **BIMCO** have developed **guidelines for cyber risk management in the maritime sector**
- The **IMO Cyber Risk Management Model** defines the process of identifying, analyzing, assessing and communicating cyber risks and their acceptance, avoidance, transfer or mitigation to an acceptable level
- **BIMCO's guidelines** for cyber security on ships offer a practical five-step approach: **identification, assessment, protection, detection, response and recovery**

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Security procedures for digitalized systems

- Effective implementation of maritime cybersecurity requires a strategic and layered approach, known as “defense in depth and breadth”
- This involves a combination of protective and detection layers, from the physical security of the ship to network protection and intrusion detection, through periodic scanning and testing: **segmenting networks, regular penetration testing and vulnerability assessments, advanced threat detection tools**

GNSS Spoofing, Jamming, and Cyber Threats in Navigation

Cyber threats in navigation are especially devastating in **port operations** and port approaches due to a combination of o**perational complexity, critical infrastructure,** and **high interconnectivity.**

Ports are busy environments with tight schedules, dense traffic, and restricted manoeuvring space.

A cyberattack such as GNSS and GPS spoofing and jamming targeting vessel positioning systems and pilot navigation aids, disrupting pilotage or tug coordination, can lead to collisions, groundings, or blockages.

3. Crisis management and emergency response

- In a digitized maritime environment, **effective crisis management** and **emergency response** is critical to minimizing the impact of cyber incidents and ensuring business continuity
- **Crisis management plans** must include strategies for rapid detection, containment, eradication and recovery from cyberattacks
- IMO's cyber risk management guidelines recommend that organizations have **clear incident response** and **recovery strategies**

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Crisis management and emergency response

- This includes **establishing procedures for collation and retention of security records** and **periodic review by competent personnel** as part of **routine operational maintenance**
- An important aspect is also the establishment of an **anonymous cyberattack reporting system** to improve transparency in risk management and enable the generation of unique evidence on risk assessment and mitigation
- It is critical that companies establish an **internal threat team** to assess new threats and regularly update response plans

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Crisis management and emergency response

- **Proactive planning** and **regular testing of incident response protocols** are key to minimizing impact and ensuring rapid recovery
- **Regular drills** and **crisis simulations** are essential for testing response plans, ensuring that damage is minimized and recovery is rapid when an attack occurs
- Lack of coordination before and during crises, unclear notification procedures, and inconsistent communication between government and private actors can **hinder crisis response**

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4. Human factors and crew management

- Digitalisation and automation are redefining the role of the human, requiring **new competencies beyond traditional maritime skills**

- IMO emphasises that the **human element** must be considered when reviewing, developing and implementing new and existing requirements, including skills, education and training, and human capabilities, limitations and needs

- The move towards **autonomous and remotely operated processes** is changing the structures of organisations and the way people work, introducing new safety challenges that affect crew and shore-based personnel

Human factors and crew management

- This means that safety in modern shipping increasingly relies on system robustness, resilience and the ability to continuously improve through the dynamic **interaction between human, organisational and technical factors**

- **Training and awareness programs** are essential to ensure that crew and shore-based personnel are equipped to cope with a digitalized environment

- **Effective cybersecurity training** for seafarers is not just about acquiring technical skills, but also fostering a culture of constant vigilance and responsibility

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Human factors and crew management

- Courses such as "**Maritime Cyber Security Awareness for Seafarers**" cover the definition of cybersecurity, existing cyber threats, vulnerabilities in shipboard IT and OT systems, and mitigation and defense measures

- These courses emphasize that cybersecurity is everyone's responsibility and must be integrated into the **safety/security management system** (**SMS**)

- In addition to technical skills, digital maritime learning offers interactive, short courses that address specific skill gaps, including **crew familiarization training, operational and emergency training, and troubleshooting training**

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Human factors and crew management

- The use of technologies such as **virtual reality** (**VR**) and **digital twins** can enhance crew competencies by allowing them to familiarize themselves with vessels and practice operations in a safe, virtual environment

- „**Operational skills**", "**digital skills**" and "**maritime competence**" as the most important skills and competencies for maritime autonomous surface ship (MASS) operations

- **Interpersonal skills**, such as communication, collaboration, teamwork, adaptability, leadership and emotional intelligence, are **critical** to aligning different interests and ensuring harmonious operations

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Human factors and crew management

- **Human-machine interaction** in the maritime sector is becoming increasingly complex with the introduction of **automation** and **artificial intelligence**
- In **ports**, semi-automation offers a middle ground between full automation and traditional human-operated systems, where machines perform repetitive or hazardous tasks, while human workers continue to supervise operations and make complex, high-risk decisions
- This **hybrid strategy** is designed to increase efficiency and create a safer, healthier and more environmentally friendly work environment

5. Conclusion

- **The key insight is that the full potential of digitalization can only be realized through proactive and comprehensive cyber risk management, integrated into all aspects of maritime operations and safety management**
- **This implies a shift from mere compliance with regulations to building a resilient cyber security culture**
- **It is essential to implement robust cybersecurity protocols, enable real-time monitoring and anomaly detection, establish redundant communication systems, and provide targeted training to operational personnel.**
- **This training should foster behavioral change and preparedness for cyber-physical incident response**

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Module 8 (Week 8)
COURSE NAME: Sustainable Maritime Operations and Green Ports

SECURITY PROCEDURES AND CRISIS MANAGEMENT IN A DIGITALIZED ENVIRONMENT

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Chapter 8 Assessment Questions

Security procedures and crisis management in a digitalized environment

1. **What is the primary goal of digitalization in the maritime industry?**
   a. Increasing the number of employees in the maritime sector.
   b. Improving efficiency, safety and environmental performance.
   c. Reducing the number of ships in traffic.
   d. Increasing the physical security of ports.
   e. Promoting fully autonomous vessels.

2. **What is one of the key vulnerabilities brought about by the integration of IT and OT systems in maritime?**
   a. Reduced fuel consumption.
   b. Increased resistance to physical attacks.
   c. Many shipboard OT infrastructures are older and lack basic security controls.
   d. Improved ship-to-shore communications.
   e. Easier software updates on ships.

3. **What is one of the economic and operational risks of cyberattacks on ports and vessels?**
   a. Increased transparency of the supply chain.
   b. Reduction of maintenance costs.
   c. Loss of life, loss of control over ships or sensitive data, as well as hijacking of ships and/or cargo.
   d. Improved efficiency of remote monitoring.
   e. Faster decision-making.

4. **Which international organization is requiring shipowners to consider cyber risks when reviewing their Document of Compliance (DOC) as of January 1, 2021?**
   a. BIMCO
   b. ISO
   c. NIST
   d. IMO
   e. USCG

5. **What approach do the IMO Cyber Risk Guidelines recommend protecting shipping from current and future threats?**
   a. Rely solely on physical security measures.
   b. Ignore cyber risks if they do not directly affect the safety of the vessel.

c. **Integrate cybersecurity into existing safety management systems (SMS).**
d. Fully automate all systems to eliminate human error.
e. Limit data exchange between ship and shore.

6. **What is the key aspect of a "defence in depth and breadth" approach to implementing maritime cybersecurity?**
   a. Completely isolating all digital systems from the outside world.
   b. A simple, single-layer security system.
   c. **A combination of protection and detection layers, from physical security to network protection.**
   d. Relying solely on antivirus software.
   e. Focusing solely on crew training.

7. **What is key to minimizing the impact and ensuring rapid recovery in the event of a cyberattack in a maritime environment?**
   a. Avoiding sharing information about the attack.
   b. **Proactively planning and regularly testing incident response protocols.**
   c. Relying solely on external experts to respond to incidents.
   d. Implementing only basic security measures.
   e. Waiting for the attack to resolve itself.

8. **How do digital tools like DNV's Emergency Response Service (ERS™) improve emergency response?**
   a. They increase reliance on manual processes.
   b. They reduce the need for human intervention.
   c. **They improve situational awareness and decision-making but introduce new dependencies.**
   d. They eliminate the possibility of cyberattacks.
   e. They limit access to information during a crisis.

9. **What are the three most important skills and competencies for Maritime Autonomous Surface Ship (MASS) operations?**
   a. Mechanical, navigational, and administrative skills.
   b. **Operational, digital, and maritime competencies.**
   c. Financial, legal, and marketing skills.
   d. Culinary, linguistic, and cultural skills.
   e. Physical, sports and artistic skills.

10. **Why is international cooperation and information sharing essential to confronting the growing cyber threats in the maritime sector?**
    a. It reduces the need for national security measures.
    b. It enables centralized control over all ships.
    c. **It helps share intelligence, standardize security protocols, and invest in collective defence mechanisms.**
    d. It limits access to new technologies.
    e. It increases competitiveness among ports.

CHAPTER 9

COURSE Module 9 (Week 9)

COURSE Module 9 (Week 9)

Review of Weeks 1 – 8 , Midterm Assessment and Feedback

Review of Weeks 1-8

Sustainability and **environmental policies**, although have some **common issues,** they are not the same and mistakenly used in the same meaning.

Sustainability is a broader concept that goes beyond protecting the environment alone. It refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission, 1987). Sustainability issues focus on; Social and Economic Dimensions, Corporate Sustainability and ESG criteria and Sustainable Development Goals (SDGs). On the other hand, Environmental Policies cover Legal and Regulatory Frameworks, Permitting and Compliance and Site-Specific Regulations. Topics such as Climate Change Mitigation, Resource Conservation, Pollution Control, Environmental Impact Assessments (EIAs) and Public Awareness and Education are covered in both policy approaches.

The UN Climate Change Conference COP26, held in Glasgow, United Kingdom, in 2021, was particularly notable for emphasizing the importance of **behavioural change** in addressing climate change and reducing carbon footprints through **Individual and societal behaviour change, public engagement and lifestyle changes**. While subsequent COPs (COP27 in Sharm El-Sheikh and COP28 in Dubai) continued to build on these themes, COP26 was a turning point in framing **behavioural change as a central pillar of climate strategy** alongside policy and technological innovation.

Vessels such as tugboats and pilot boats, and personnel such as harbour masters, carry out an essential role of ensuring the safety of port assets and vessels whilst in port. However, because of these service vessels' small size, in-port operations have not been included in the EU's emission reduction targets. The lack of enforced targets does not mean the sector is not polluting. Moreover, greener technology, whilst in development, is not yet ready for large scale commercial use.

GREENPORT posits that a **change in human behaviour** can reduce the environmental impact of in-port services in the short- to medium-term. Modifications can be made to day-to-day operations, with better use of existing digital technologies, that would contribute to a significant drop in emissions.
The behaviour change requires a change of education concepts in order to shape future professionals by Integrating knowledge, behaviour, and responsibility as well as maritime educators' commitment to sustainability.

One of the most essential conditions for sustainability is **raising awareness for behavioural change**. As society becomes more informed on various issues, the standards for sustainability will rise accordingly. If this awareness is embraced as a guiding principle, it can lead to long-term prosperity. In contrast, environmental policies primarily aim to correct negative externalities. **Policy coherence** involves the systematic promotion of mutually reinforcing policy actions across governments and agencies, thereby enabling broader progress toward the Sustainable Development Goals.

Tugboats are indispensable in port logistics, especially during piloting operations where they assist larger vessels in docking, undocking, and navigating confined waters. These tasks require high manoeuvrability and responsiveness, often resulting in inefficient fuel usage. With increasing environmental regulations and fuel costs, improving energy efficiency in tug operations has gained utmost importance.

Main energy-saving measures for behavioural change in pilotage and tugboat operations require holistic view on available technological innovations such as Hybrid Propulsion Systems (Electric-diesel hybrids are particularly effective in piloting operations, where low-speed manoeuvring dominates), Real-Time Monitoring (Energy management systems track fuel consumption and engine performance, enabling adaptive control strategies).

Certain port activities—such as **pilotage, mooring, and towage services**—are not yet directly covered by EU or IMO climate regulations. However, these services are increasingly expected to align with broader sustainability goals through:

- Voluntary adoption of low-emission technologies (e.g., electric or hybrid tugboats).
- Participation in green port initiatives and certification schemes.
- Integration into port-wide energy management systems**.**

A change in human attitude and behaviour is therefore needed. For that reason, the way how technology is used in practice needs to be considered as well. A collateral advantage of changing attitudes is that we can already initiate this today by changing maritime education and training approaches without the need of high investment costs, and without waiting for the greener technology that is still under development. By optimising the **interaction between humans and existing technology** in the short term and more efficient use of technology results in less fuel consumption (i.e., an economic incentive to change behaviour) and at the same time to less emission (i.e., an ecological incentive to change behaviour).

The relationship between environmental policies and sustainability is a dynamic and interdependent one. While environmental policies address specific ecological challenges, sustainability provides a broader framework that ensures long-term resilience by integrating economic and social dimensions. A holistic approach, combining both policy areas, is essential to ensure that development is both environmentally sound and socially inclusive, paving the way for a sustainable future.

Sustainability transcends ethical obligation to become a core enabler of port resilience and market leadership. Ports embedding sustainability into operational

DNA achieve efficiency gains, regulatory agility, and stakeholder trust—key pillars of long-term competitiveness. Sustainability is no longer a peripheral concern in port operations—it is central to achieving operational excellence and maintaining competitiveness. By embedding sustainability into pilotage, towing, and mooring services, ports can enhance safety, efficiency, and environmental performance simultaneously. The future of maritime logistics depends on the ability of ports to evolve into smart, green hubs that support both economic and ecological goals.

Industry Ecosystem and Technological Landscape: Ports are critical nodes in global trade, and their efficiency hinges on robust piloting, towing, and mooring services. These operations require a symbiotic relationship between industry stakeholders and cutting-edge technology.

Industry ecosystem requirements mainly focus on good stakeholder collaboration and workforce expertise. Piloting, towing, and mooring demand seamless coordination among diverse stakeholders. For instance, pilotage services rely on licensed mariners with localized knowledge of waterways, as mandated by their national legislation. Towing operations require agreements with tugboat operators for 24/7 availability. The International Tugowners Association (ITA) emphasizes standardized Service Level Agreements to prevent delays, as seen in Singapore's port, where tug dispatch times are capped at 15 minutes during peak hours. Mooring crews, meanwhile, must adhere to the International Mooring Equipment Guidelines, which prescribe tensile strength standards for mooring lines.

From the technological landscape perspective, the main requirement is an Advanced Navigation System. Modern piloting liaises with Vessel Traffic Services (VTS) integrated with AI-driven risk assessment tools. The Port of Antwerp's SEAONICS system, for instance, uses machine learning to predict collision risks in congested channels. Tugboats may employ Dynamic Positioning Systems (DPS), achieving millimetres-level precision during berthing. For mooring, IoT-enabled tension sensors provide real-time load data, reducing line failures by 30% according to research.

Digital integration and cybersecurity measures are another important issue to consider. Centralized platforms like Port Community Systems (PCS) streamline operations. Some blockchain platforms automates billing for towage services, cutting administrative costs by 18%. However, digitization introduces risks: a 2023 IBM Security Report noted a 220% rise in ransomware attacks on port systems, underscoring the need for zero-trust architectures.

Despite the costs, going green offers long-term advantages for emission reduction, operational efficiency, and market competitiveness. While cleaner vessels contribute to improved air quality and reduced carbon footprint in port areas, modern green technologies often enhance vessel performance and reliability and ports and operators that adopt sustainable practices may gain preferential access to funding, partnerships, and contracts.

The long-term savings from going green in tugboats, service vessels, and piloting operations are increasingly compelling in 2025, despite the high upfront costs such as Electric and Hybrid Vessels can reduce fuel consumption by up to 85%**,** especially when using hydrofoil or energy-optimized propulsion systems, Battery-powered tugs offer rapid charging and can operate multiple shifts without refuelling, cutting fuel costs significantly. From the maintenance and lifecycle costs aspects Electric motors have fewer moving parts than diesel engines, leading to lower maintenance costs and fewer breakdowns and longer service intervals. Hydrofoil pilot boats reduce hull drag, which minimizes wear and tear and extends vessel lifespan. By reducing emissions, operators can avoid paying up to €90 per ton of CO_2 under the EU Emissions Trading System and operators may earn tradable carbon credits, creating a new revenue stream or offsetting operational costs. While CAPEX for electric or hybrid tugs is higher, studies show that ROI can be achieved within 5–8 years due to Fuel savings, Reduced maintenance, and Lower regulatory costs.

Operational Strategies for Energy Saving and Emission Reduction
A port operational strategy focused on using existing resources to reduce energy consumption and emissions in port operations emphasizes **efficiency, collaboration**, and **technology**—without requiring major infrastructure overhauls.

Smarter, Cleaner and Leaner port operations require optimized equipment deployment at the first place. In a holistic approach to all respective operations, scheduling cranes, trucks, and yard equipment to minimize idle time will be important for an efficient collaboration**.** Using automated systems to track and manage energy consumption should be considered as well.

Implementing an onshore power supply system will encourage vessels to plug into shore-side electricity while docked, reducing emissions from onboard generators. Energy monitoring by installing smart meters and dashboards to monitor energy use in real time and identify areas for improvement and renewable energy integration through utilizing existing rooftops and open spaces for solar panels to power administrative buildings and lighting must be part of this holistic strategy.

Behavioural change for piloting operations for efficient navigation and fleet management must include route optimization using digital navigation tools to plan the shortest, safest routes for pilot transfers, which will help reduce fuel use.
Fleet scheduling coordinates pilot boat movements to avoid unnecessary trips and waiting times. Hybrid boat transition to gradually replace older pilot boats with hybrid or electric models, starting with high-usage routes will enhance operational efficiency.

Tug employment for collaborative and intelligent operations may include measures such as tug pooling for sharing tug resources across terminals to reduce redundancy and maximize utilization, dynamic dispatching by using AI-based systems to assign the most suitable tug based on vessel size, weather, and traffic conditions, and maintenance optimization by applying predictive maintenance to keep tugs running efficiently and avoid fuel-wasting breakdowns.

By leveraging what we already have—smart scheduling, digital tools, and collaborative practices—we can significantly reduce energy use and emissions. This strategy is not just environmentally responsible; it’s economically smart and operationally sound.

Collection and analysis of emissions and sustainability data is another important issue for decarbonization effort. With tightening environmental regulations and growing public scrutiny, ports and shipping companies must embrace data-driven strategies to minimize their ecological footprint. Therefore, understanding the connection between emissions data and sustainability objectives, navigating regulatory frameworks such as the IMO 2023 sulphur cap and the EU Emissions Trading System (ETS) (although applies to ships not port service craft it is important to become familiar for possible future applications) and evolving from reactive to predictive environmental management through digital innovation need to be considered for a holistic approach decarbonization.

Interpretation and use of data in operational decision-making has emerged as a critical enabler for optimizing vessel operations and port management. The modern maritime industry is undergoing a digital transformation, where vast amounts of data from digital sources, onboard sensors, and simulation models are reshaping operational decision-making. As shipping companies and port operators strive for greater efficiency, safety, and sustainability, the ability to interpret and utilize this data has become essential. From real-time engine performance analytics to predictive maintenance algorithms and route optimization models, data-driven insights are enabling smarter, more proactive management of maritime operations. Advanced data analytics and visualization tools are revolutionizing decision-making processes—from optimizing route efficiency and fuel consumption to enhancing risk management and port operations. By harnessing real-time data from IoT sensors, AIS, and predictive models, shipping companies can not only reduce costs and improve safety but also meet stringent IMO decarbonization targets.

However, the full potential of data-driven maritime operations can only be realized through seamless **integration of these technologies into daily workflows** and **organizational cultures**. Challenges such as data silos, risks, and crew adoption must be addressed to unlock the transformative power of digital solutions. Moving forward, the industry must prioritize investments in interoperable systems, user-friendly dashboards, and **continuous training** to ensure that data insights translate into actionable strategies. As the sector navigates toward a greener and more efficient future, the **synergy between data analytics, human expertise, and regulatory frameworks** will be critical in shaping sustainable and resilient maritime operations.

As the maritime industry advances toward decarbonization targets, simulator-based training has emerged as a critical tool for instilling **sustainable operational behaviours.** Structured feedback mechanisms within virtual training environments are reshaping decision-making paradigms in pilotage and tugboat operations, with measurable impacts on emissions reduction and operational efficiency.

Modern maritime simulators provide a controlled yet realistic platform for skill development, combining hydrodynamic modelling, port-specific scenarios, and real-time environmental variables. Key advantages include:

Risk Mitigation: Safe experimentation with low-emission techniques (e.g., tidal current utilization, optimized throttle curves).
Benchmarked Performance: Comparative analytics against IMO-aligned efficiency standards.
Global Standardization: Access to training modules reflecting diverse regulatory environments, from Singapore's port limits to EU Emission Control Areas.

A 2024 meta-analysis of 23 port authorities revealed that simulator-trained crews demonstrated 12–15% greater adherence to emission protocols during actual operations compared to traditionally trained counterparts.

The transition to sustainable maritime operations necessitates a dual focus: technological innovation and human behavioural adaptation. Simulator training, when coupled with structured feedback systems, provides a replicable framework for transforming abstract emission targets into concrete operational habits. As evidenced by the 17% reduction in harbour-side particulate matter achieved by early adopters, this approach converts regulatory compliance into competitive advantage.

For organizations committed to IMO 2050 objectives, the strategic imperative is clear: invest not only in cleaner engines but in data-fluent crews capable of translating simulation insights into real-world environmental stewardship.

Our intention is not to instruct pilots or tug captains on how to manoeuvre; rather, it is to enhance their existing skills with the aim of potentially adopting behaviours that could lead to reduced emissions, all while maintaining the same level of safety that is currently provided.

Advanced technology-based simulation tools play a critical role in the planning, management and decision-making processes in ports. These tools, developed specifically to increase operational efficiency and optimize resource use, provide strategic advantages in port management. Tools used various simulations in the world within the scope of port operations optimization. Terminal simulation software models operations in container terminals, ensuring that work is done in the optimum way and that the system is continuously improved. To increase the safety and efficiency of approaching, docking, and leaving manoeuvres of ships arriving at ports, Ship Traffic and Manoeuvring Simulations are used. Another type of simulation tool is port logistics and supply chain simulations. With this simulation tool, cargo flow within the port, warehouse usage, integration and optimization of port connection roads are simulated. In addition, digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data have also become widespread in recent years. Thanks to the digital twin, data at ports can be monitored instantly, corrective actions can be taken, when necessary, experiments that cannot be done in real life can be conducted and the results can be evaluated, and as a result, the digital twin prepares an infrastructure for automation.

Digitalization in the maritime sector encompasses the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning and automation in all maritime operations, logistics and management. This includes everything from remote monitoring of critical assets to autonomous vessel operations. **Although digitization offers enormous benefits, it also widens the industry's exposure to cyber risks, creating a wider surface for attacks.** The increasing reliance on interconnected digital systems, including information technology (IT) and operational technology (OT), introduces vulnerabilities that can disrupt global trade, threaten the safety of vessels, crews and lead to environmental disasters.

Cyber threats are especially devastating in **port operations** and **port approaches** due to a combination of **operational complexity**, **critical infrastructure**, and **high interconnectivity**. Ports are busy environments with **tight schedules**, **dense traffic**, and **restricted manoeuvring space**. A cyberattack disrupting pilotage or tug coordination can lead to **collisions**, **groundings**, or **blockages**.
Ports are gateways for **global trade**, handling fuel, food, medical supplies, and military assets. Disruption can have **national security** and **economic consequences**.

Port operations rely on **integrated digital systems** such as cargo tracking, vessel traffic services (VTS), customs, logistics etc. A breach in one system can cascade across others, amplifying the impact. For example, delays in pilotage or tug operations can cause **missed berthing windows**, **demurrage costs**, and **supply chain disruptions**. Unlike open sea operations, ports have **limited fallback options**. If a tugboat or pilot system fails, alternatives are scarce.

Digitalization is an inevitable and transformative process in the maritime industry, bringing significant benefits in efficiency and sustainability, but at the same time introducing complex cyber risks. The key insight is that the full potential of digitalization can only be realized through proactive and comprehensive **cyber risk management,** integrated into all aspects of maritime operations and safety management. This implies a shift from mere compliance with regulations to building a resilient cyber security culture.

The future of the maritime sector will depend on the industry's ability to adapt to these changes. This includes continued investment in advanced security technologies, the development of robust incident response and business continuity plans, and comprehensive training programs for crew and shore-based personnel. It is particularly important to **recognize the redefined role of the human factor** in a highly automated environment, where traditional skills are complemented by digital, operational, and interpersonal competencies. International cooperation and information sharing remain key to building a collective defence against increasingly sophisticated cyber threats.

Cyber-induced accidents in port approaches can result in loss of life, oil spills, or hazardous material exposure. Ports are attractive targets for ransomware, espionage, or sabotage, especially in strategic locations. Therefore, establishing robust cybersecurity protocols, real-time monitoring and anomaly detection, redundant communication systems, and training of crew for behavioural change for cyber-physical incident response has utmost importance for safe and efficient port operations.

As the maritime industry faces increasing scrutiny over its environmental impact, the role of maritime educators is emerging as a pivotal element in fostering sustainability among future professionals. Integrating sustainable practices into maritime education is of vital importance, as it equips students with the necessary knowledge and skills to navigate their future careers. Maritime educators should develop and implement curricula that not only focus on technical competencies but also include sustainability principles, thereby encouraging future professionals who would be aware of the ecological consequences of their actions.

Maritime educators' awareness of sustainability principles, especially in terms of port services sustainability, their capacity to incorporate behavioural change approaches into their courses, the challenges they face, and methods that would motivate learners to adopt sustainability into their behaviours has vital importance on the successfully implementation of the training programs developed. When evaluated within the framework of the COM-B model, the results provide inferences regarding the capability, opportunity and motivation levels of educators, offering important implications from both theoretical and practical perspectives. In this aspect, maritime educators need to understand and believe that integration of sustainability principles in maritime education has critical importance. Educators' belief in the necessity of integrating sustainability principles into their courses, combined with their high awareness of the importance of these principles create a strong ground for the "motivation". Finally, educators have to be open to incorporating behavioural change methods into their teaching materials, showing a positive indicator in terms of "motivation".

In that respect, these findings provide important clues for improving maritime education programs and increasing the competencies of instructors. Although educators have the motivation and are open to integrating behavioural change approaches into teaching methods, they need to improve their capability with more training and resources to incorporate sustainability principles more effectively into educational materials. With this consideration, a comprehensive sets of reference documents were provided for each curriculum and these documents were included in the repository on the project web site for a quick reference.

Additionally, various real time case studies were included in the repository together with educational materials as an open science document to the benefit of all interested parties besides project partners. Curricula also aimed at integrating practical training by simulations to the theoretical aspects, using a structured approach to develop participants' skills effectively. The curriculum design accounted for sequencing of activities and knowledge transfer, ensuring that related concepts are taught in a coherent manner. It has been understood that methods such as real case studies and interactive learning activities are effective in encouraging sustainable behavioural change in students. On the other hand, it has become clear that cooperation between academia and industry should be increased in order to produce solutions to sustainability issues in port services. With the pressing need to address sustainability challenges, the collaboration between maritime educators and industry stakeholders is crucial for equipping future professionals with the requisite tools to enact environmentally responsible practices.

Sustainability is becoming increasingly important in the maritime sector and education can be considered one of the cornerstones of this transformation. In the maritime world, education and training are vital and their importance extends far beyond shipping itself, as the safety and security of life at sea, the protection of the marine environment and the efficient movement of global trade depend on the professionalism and competence of seafarers. In that respect, the role of educators is very crucial to increase sustainability practices in maritime transportation. Supporting the capability, opportunity, and motivation levels of educators in a balanced way is critical for the future of a sustainable maritime sector, in terms of both environmental and economic sustainability. Sustainability education, especially in operational areas such as port services, can enable personnel to make more conscious decisions on issues such as energy efficiency, fuel savings, resource use, and equipment life. **This means reducing operating costs, increasing operational efficiency, and thus contributing to economic sustainability**. In addition, the quality of human resources developed through education is also the key to achieving **competitive advantage** in the sector. The sustainability awareness of the workforce would help port service providers adapt to international standards more quickly and achieve success in green port certification processes, allowing for not only short-term cost advantages but also long-term **reputation** and **strategic gains**. Thus, investing in **behavioural change** with sustainability education should be considered not only as part of environmental responsibility but also as part of economic performance.

Chapter 9 Supporting Material

Sustainability and **environmental policies**, although have some **common issues,** they are not the same and mistakenly used in the same meaning.

Sustainability is a broader concept that goes beyond protecting the environment alone. It refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission, 1987). Sustainability issues focus on; Social and Economic Dimensions, Corporate Sustainability and ESG criteria and Sustainable Development Goals (SDGs). On the other hand, Environmental Policies cover Legal and Regulatory Frameworks, Permitting and Compliance and Site-Specific Regulations. Topics such as Climate Change Mitigation, Resource Conservation, Pollution Control, Environmental Impact Assessments (EIAs) and Public Awareness and Education are covered in both policy approaches.

Review of Weeks 1-8

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The UN Climate Change Conference COP26, held in Glasgow, United Kingdom, in 2021, was particularly notable for emphasizing the importance of **behavioural change** in addressing climate change and reducing carbon footprints through **Individual and societal behaviour change, public engagement and lifestyle changes**. While subsequent COPs (COP27 in Sharm El-Sheikh and COP28 in Dubai) continued to build on these themes, COP26 was a turning point in framing **behavioural change as a central pillar of climate strategy** alongside policy and technological innovation.

Vessels such as tugboats and pilot boats, and personnel such as harbour masters, carry out an essential role of ensuring the safety of port assets and vessels whilst in port. However, because of these service vessels' small size, in-port operations have not been included in the EU's emission reduction targets. The lack of enforced targets does not mean the sector is not polluting. Moreover, greener technology, whilst in development, is not yet ready for large scale commercial use.

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GREENPORT posits that a **change in human behaviour** can reduce the environmental impact of in-port services in the short- to medium-term. Modifications can be made to day-to-day operations, with better use of existing digital technologies, that would contribute to a significant drop in emissions.

The behaviour change requires a change of education concepts in order to shape future professionals by Integrating knowledge, behaviour, and responsibility as well as maritime educators' commitment to sustainability.

Review of Weeks 1-8

One of the most essential conditions for sustainability is **raising awareness for behavioural change**.

As society becomes more informed on various issues, the standards for sustainability will rise accordingly. If this awareness is embraced as a guiding principle, it can lead to long-term prosperity. In contrast, environmental policies primarily aim to correct negative externalities.

Policy coherence involves the systematic promotion of mutually reinforcing policy actions across governments and agencies, thereby enabling broader progress toward the Sustainable Development Goals.

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Review of Weeks 1-8

Tugboats are indispensable in port logistics, especially during piloting operations where they assist larger vessels in docking, undocking, and navigating confined waters.

These tasks require high manoeuvrability and responsiveness, often resulting in inefficient fuel usage. With increasing environmental regulations and fuel costs, improving energy efficiency in tug operations has gained utmost importance.

Main energy-saving measures for **behavioural change in pilotage and tugboat operations** require holistic view on available technological innovations such as Hybrid Propulsion Systems (Electric-diesel hybrids are particularly effective in piloting operations, where low-speed manoeuvring dominates), and Real-Time Monitoring

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Certain port activities—such as **pilotage, mooring, and towage services**—are not yet directly covered by EU or IMO climate regulations. However, these services are increasingly expected to align with broader sustainability goals through:

- Voluntary adoption of low-emission technologies (e.g., electric or hybrid tugboats).
- Participation in green port initiatives and certification schemes.
- Integration into port-wide energy management systems.

A change in human attitude and behaviour is therefore needed. For that reason, the way how technology is used in practice needs to be considered as well. A collateral advantage of changing attitudes is that we can already initiate this today by changing maritime education and training approaches without the need of high investment costs, and without waiting for the greener technology that is still under development.

By optimising the **interaction between humans and existing technology** in the short term and more efficient use of technology results in less fuel consumption (i.e., an economic incentive to change behaviour) and at the same time to less emission (i.e., an ecological incentive to change behaviour).

Review of Weeks 1-8

The relationship between environmental policies and sustainability is a dynamic and interdependent one. While environmental policies address specific ecological challenges, sustainability provides a broader framework that ensures long-term resilience by integrating economic and social dimensions

Sustainability transcends ethical obligation to become a core enabler of port resilience and market leadership. Ports embedding sustainability into operational DNA achieve efficiency gains, regulatory agility, and stakeholder trust—key pillars of long-term competitiveness.

Sustainability is no longer a peripheral concern in port operations—it is central to achieving operational excellence and maintaining competitiveness. By embedding sustainability into pilotage, towing, and mooring services, ports can enhance safety, efficiency, and environmental performance simultaneously.

Review of Weeks 1-8

Industry Ecosystem and Technological Landscape: Ports are critical nodes in global trade, and their efficiency hinges on robust piloting, towing, and mooring services. These operations require a symbiotic relationship between industry stakeholders and cutting-edge technology.

Industry ecosystem requirements mainly focus on good stakeholder collaboration and workforce expertise. Piloting, towing, and mooring demand seamless coordination among diverse stakeholders.

The International Tugowners Association (ITA) emphasizes standardized Service Level Agreements to prevent delays, as seen in Singapore's port, where tug dispatch times are capped at 15 minutes during peak hours. Mooring crews, meanwhile, must adhere to the International Mooring Equipment Guidelines, which prescribe tensile strength standards for mooring lines.

From the technological landscape perspective, the main requirement is an Advanced Navigation System.

Operational Strategies for Energy Saving and Emission Reduction

A port operational strategy focused on using existing resources to reduce energy consumption and emissions in port operations emphasizes **efficiency, collaboration**, and **technology**—without requiring major infrastructure overhauls.

Smarter, Cleaner and Leaner port operations require optimized equipment deployment at the first place.

In a holistic approach to all respective operations, scheduling cranes, trucks, and yard equipment to minimize idle time will be important for an efficient collaboration**.**

Using automated systems to track and manage energy consumption should be considered as well.

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Behavioural change for piloting operations for efficient navigation and fleet management must include route optimization using digital navigation tools to plan the shortest, safest routes for pilot transfers, which will help reduce fuel use.

Fleet scheduling coordinates pilot boat movements to avoid unnecessary trips and waiting times. Hybrid boat transition to gradually replace older pilot boats with hybrid or electric models, starting with high-usage routes will enhance operational efficiency.

Tug employment for collaborative and intelligent operations may include measures such as tug pooling for sharing tug resources across terminals to reduce redundancy and maximize utilization, dynamic dispatching by using AI-based systems to assign the most suitable tug based on vessel size, weather, and traffic conditions, and maintenance optimization by applying predictive maintenance to keep tugs running efficiently and avoid fuel-wasting breakdowns.

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Collection and analysis of emissions and sustainability data is another important issue for decarbonization effort. With tightening environmental regulations and growing public scrutiny, ports and shipping companies must embrace data-driven strategies to minimize their ecological footprint. Therefore, understanding the connection between emissions data and sustainability objectives, navigating regulatory frameworks such as the IMO 2023 sulphur cap and the EU Emissions Trading System (ETS) **(although applies to ships not port service craft it is important to become familiar for possible future applications)** and evolving from reactive to predictive environmental management through digital innovation need to be considered for a holistic approach decarbonization.

Review of Weeks 1-8

Interpretation and use of data in operational decision-making has emerged as a critical enabler for optimizing vessel operations and port management.

As shipping companies and port operators strive for greater efficiency, safety, and sustainability, the ability to interpret and utilize this data has become essential.

From real-time engine performance analytics to predictive maintenance algorithms and route optimization models, data-driven insights are enabling smarter, more proactive management of maritime operations.

Advanced data analytics and visualization tools are revolutionizing decision-making processes—from optimizing route efficiency and fuel consumption to enhancing risk management and port operations. By harnessing real-time data from IoT sensors, AIS, and predictive models, shipping companies can not only reduce costs and improve safety but also meet stringent IMO decarbonization targets.

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Review of Weeks 1-8

Advanced technology-based simulation tools play a critical role in the planning, management and decision-making processes in ports.

Terminal simulation software models operations in container terminals, ensuring that work is done in the optimum way and that the system is continuously improved. To increase the safety and efficiency of approaching, docking, and leaving manoeuvres of ships arriving at ports, Ship Traffic and Manoeuvring Simulations are used.

Port logistics and supply chain simulation tools enhance cargo flow within the port, warehouse usage, integration and optimization of port connection roads.

Digital twin applications that enable the creation of a digital copy of the entire port within computer systems and continuous updating with real-time data have also become widespread in recent years..

Review of Weeks 1-8

Although digitization offers enormous benefits, it also widens the **industry's exposure to cyber risks, creating a wider surface for attacks.** The increasing reliance on interconnected digital systems, including information technology (IT) and operational technology (OT), introduces vulnerabilities that can disrupt global trade, threaten the safety of vessels, crews and lead to environmental disasters.

Cyber threats are especially devastating in **port operations** and **port approaches** due to a combination of **operational complexity**, **critical infrastructure**, and **high interconnectivity**. Ports are busy environments with **tight schedules**, **dense traffic**, and **restricted manoeuvring space**. A cyberattack disrupting pilotage or tug coordination can lead to **collisions**, **groundings**, or **blockages**.

Ports are gateways for **global trade**, handling fuel, food, medical supplies, and military assets. Disruption can have **national security** and **economic consequences**.

Review of Weeks 1-8

As the maritime industry faces increasing scrutiny over its environmental impact, the role of maritime educators is emerging as a pivotal element in fostering sustainability among future professionals.

Integrating sustainable practices into maritime education is of vital importance, as it equips students with the necessary knowledge and skills to navigate their future careers.

Maritime educators should develop and implement curricula that not only focus on technical competencies but also include sustainability principles, thereby encouraging future professionals who would be aware of the ecological consequences of their actions.

Review of Weeks 1-8

Maritime educators' awareness of sustainability principles, especially in terms of port services sustainability, their capacity to incorporate behavioural change approaches into their courses, the challenges they face, and methods that would motivate learners to adopt sustainability into their behaviours has vital importance on the successfully implementation of the training programs developed.

When evaluated within the framework of the COM-B model, the results provide inferences regarding the capability, opportunity and motivation levels of educators, offering important implications from both theoretical and practical perspectives. In this aspect, maritime educators need to understand and believe that integration of sustainability principles in maritime education has critical importance. Educators' belief in the necessity of integrating sustainability principles into their courses, combined with their high awareness of the importance of these principles create a strong ground for the "motivation".

Sustainability is becoming increasingly important in the maritime sector and education can be considered one of the cornerstones of this transformation.

Supporting the capability, opportunity, and motivation levels of educators in a balanced way is critical for the future of a sustainable maritime sector, in terms of both environmental and economic sustainability.

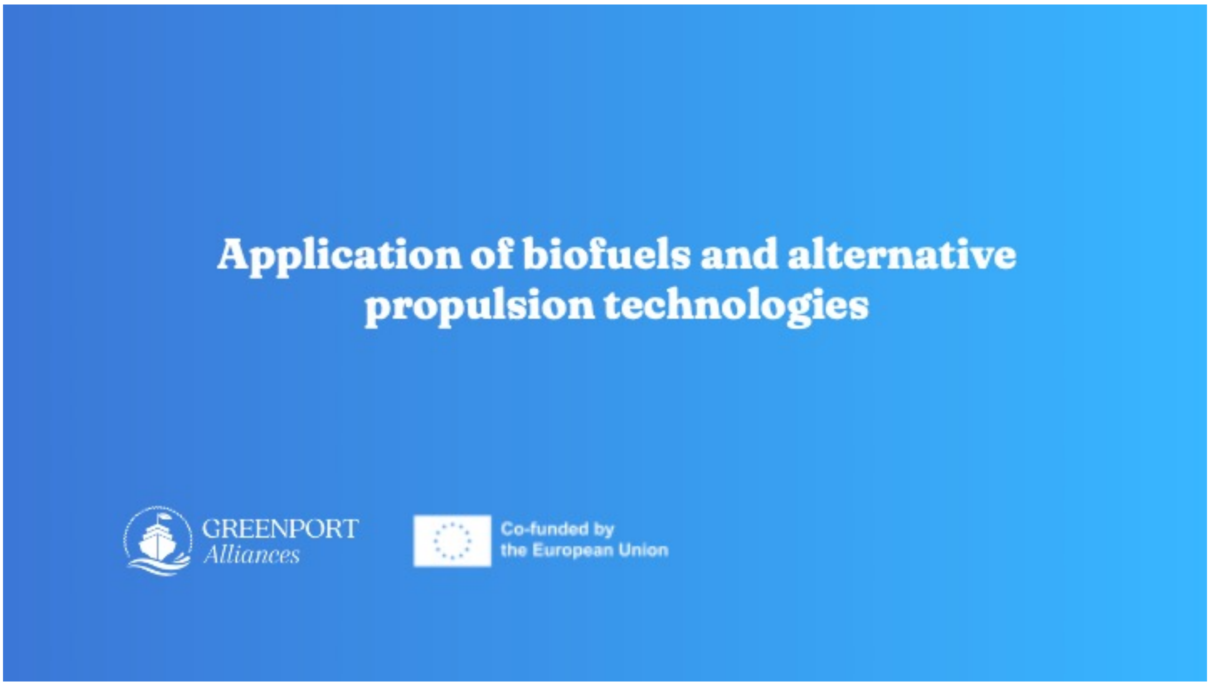
Sustainability education, especially in operational areas such as port services, can enable personnel to make more conscious decisions on issues such as energy efficiency, fuel savings, resource use, and equipment life. **This means reducing operating costs, increasing operational efficiency, and thus contributing to economic sustainability**. In addition, the quality of human resources developed through education is also the key to achieving **competitive advantage** in the sector.

The sustainability awareness of the workforce would help port service providers adapt to international standards more quickly and achieve success in green port certification processes, allowing for not only short-term cost advantages but also long-term **reputation** and **strategic gains**.

Thus, investing in **behavioural change** with sustainability education should be considered not only as part of environmental responsibility but also as part of economic performance.

CHAPTER 10

COURSE Module 10 (Week 10)



COURSE Module 10 (Week 10)

Application of biofuels and alternative propulsion technologies

1. Introduction

The maritime sector is under increasing pressure to reduce greenhouse gas (GHG) emissions and comply with international environmental regulations, such as the IMO's strategy to reach net-zero emissions by 2050 as well as the very ambitious EU Fit for 55 climate target which aims to cut EU emissions by 55% by 2030 and have Europe carbon neutral by 2050. This has led to the exploration of alternative fuels and propulsion technologies, including biofuels, hydrogen, ammonia, and hybrid-electric systems.

Tugboats, which operate intensively in port environments, are particularly well-suited for early adoption due to their short-range operations and frequent refuelling opportunities.

2. Fuel Conversion Technologies and Biofuel Systems

Biofuels are derived from renewable biological sources and include biodiesel, bio-LNG, and straight vegetable oil (SVO). Conversion technologies such as transesterification and anaerobic digestion are used to produce these fuels. Biodiesel can be used in low- to medium-speed marine engines with minimal modifications, offering reductions in particulate matter and carbon monoxide emissions.

In tugboat applications, hybrid propulsion systems combining diesel engines with electric motors or batteries have shown promising results. A study on tugboats operating in the Istanbul Strait demonstrated fuel savings of up to 72.4% using lithium iron phosphate batteries in hybrid configurations. Methanol is also gaining traction due to its liquid form, ease of storage, and compatibility with existing infrastructure.

Types of biofuels
Three types of biofuels are relevant for maritime shipping:

FAME (Fatty acid methyl ester) is produced from vegetable oils, animal fats or waste cooking oils by transesterification, where various oils (triglycerides) are converted to methyl esters. This is the most widely available type of biodiesel in the industry and is often blended with regular marine diesel. International standards: ISO 8217:2017, EN 14214, ASTM D6751, EN 590

BTL (Biomass to liquid) fuels are synthetic fuels that are produced from biomass by means of thermo-chemical conversion using the Fischer-Tropsch process or the methanol-to-gasoline process. The final product can be fuels that are chemically different from conventional fuels such as gasoline or diesel but can also be used in diesel engines. International standards: EN 16709, EN 15940

HVO/HDRD (Hydrogen vegetable oil / Hydrogenation derived renewable diesel) is the product of fats or vegetable oils – alone or blended with petroleum – refined by a hydrotreating process known as fatty acids-to-hydrocarbon hydrotreatment. Diesel produced using this process is often called renewable diesel to differentiate it from FAME biodiesel. HVO/HDRD can be directly introduced in distribution and refuelling facilities as well as existing diesel engines without any further modification. International standards: ASTM D 975

Currently, FAME is the most prominently used biofuel in marine applications. It is either used in blends with traditional petroleum fuels or as 100% biofuel

Biofuels and their effect on GHG regulations: EEDI/EEXI, CII, EU MRV

EEDI and EEXI

The EEXI and EEDI only consider the so-called tank-to-wake approach, meaning that only the carbon content of standard reference fuels the vessel is designed for is considered. For that reason, the usage of biofuels has no effect on the EEXI or the EEDI.

CII (Carbon Intensity Index)

In view of IMO DCS reporting as well as the CII calculation methodology – as per the interim guidance on the use of biofuels under regulations 26, 27 and 28 of MARPOL Annex VI (MEPC.1/Circ.905), biofuels certified by an international certification scheme, meeting sustainability criteria and providing a well-to-wake GHG emissions reduction of at least 65% compared to the well-to-wake emissions of fossil MGO of 94 gCO2e/MJ, may be assigned a Cf equal to its emissions intensity as confirmed through certification (Proof of Sustainability opr similar documentation), multiplied by its lower calorific value.

Cf value for fuel blends should be considered based on weighted average of the Cf for respective number of fuels by energy.

Biofuels that are not certified or exceed the well-to-wake GHG intensity criterion of 33 gCO2e/MJ (i.e., providing reduction of less than 65%) should be assigned the Cf of its fossil fuel equivalent.

The above-mentioned approach will be rescinded immediately upon operationalization of a well-to-wake GHG methodology through the IMO LCA Guidelines.

EU MRV

As per Regulation (EU) 2015/757, in case of alternative fuels, the monitoring plan shall contain "the methodologies for determining the emission factors, including the methodology for sampling, methods of analysis and a description of the laboratories used, with the ISO 17025 accreditation of those laboratories, if any". It is worth noting that Directive (EU) 2018/2001 (EU RED II), Annex V, Part C provides a methodology for greenhouse gas emissions from the production and use of transport fuels, whereas per point 13, the CO2 emissions of the fuel in use shall be taken to be zero for biofuels and bioliquids.

The proposed method for calculation of the CO2 emission factor for biofuel and biofuel blends should be included in the ship's MRV Monitoring Plan along with an addition to the list of fuel types used and method for determination of fuel density, with the revised plan being subject to acceptance from the Accredited Verifier, such as DNV.

In light of the upcoming revision of MRV Annexes, European legislation will enforce a specific approach addressing accounting of emissions from use of biofuels in MRV.

3. Adaptation of Operating Procedures for Alternative Fuels

Transitioning to alternative fuels requires significant changes in operational procedures, crew training, and safety protocols. The Nautical Institute has developed a training standard for handling ammonia, methanol, and hydrogen, emphasizing safe bunkering, storage, and emergency response.

For tugboats, these adaptations include:

- **Modified bunkering procedures** for methanol and hydrogen.
- **Enhanced ventilation and gas detection systems**.
- **Crew training** on fuel-specific hazards and emergency protocols.

These changes are essential to ensure safety and compliance with international regulations such as the IGF Code and MARPOL Annex VI.

Technical items to be observed and challenges on board
These are some of the possible consequences from the use of biofuels:

- **Microbial growth:** Bacteria and mould may grow, causing filters and piping to clog.
- **Oxygen degradation:** Biodiesel could form deposits in piping and engine, compromising operational performance.
- **Low temperature:** The higher cloud point may lead to the clogging of filters at lower temperatures.
- **Corrosion:** Some types of hoses and gaskets could degrade, leading to loss of integrity, and interact with some metallic material to form deposits.
- **Possible degeneration of rubber sealings, gaskets and hoses:** Important to verify that these components can be used together with biofuel.
- **Conversion:** When switching from diesel to biofuel, fuel filters can become clogged.

4. Collaboration with Engine Manufacturers and Suppliers

Collaboration between ship operators, engine manufacturers, and fuel suppliers is critical for the successful deployment of alternative propulsion technologies. Companies like **Caterpillar Marine** and **SAAM Towage** have signed MOUs to explore electrification and methanol-based propulsion for tugboats.

Engine manufacturers such as **MAN Energy Solutions** are developing dual-fuel engines that can operate on methanol and diesel, allowing for flexible fuel use and easier retrofitting. These partnerships accelerate innovation and ensure that new technologies are viable, scalable, and compliant with evolving regulations.

Several tugboat operators have pioneered the use of hybrid and electric propulsion systems to reduce emissions and improve operational efficiency:

- Foss Maritime's Carolyn Dorothy (USA): One of the first hybrid tugboats, launched in 2009, combining diesel engines with battery systems. It achieved a 73% reduction in particulate matter, 51% in NOx, and 27% in CO_2 emissions
- NYK Line's Sakigake (Japan): The first LNG-fueled tugboat in Japan, launched in 2015. It reduced SOx emissions by nearly 100%, NOx by 80%, and CO_2 by 30% compared to conventional heavy oil
- Hydrotug 1 (Belgium): Operating in the Port of Antwerp since 2024, this tug uses dual-fuel hydrogen engines developed by BeHydro. It supports the port's goal of becoming climate-neutral by 2050
- Seabulk's Spartan and Titan (USA): Hybrid diesel-electric tugs launched in 2022, offering high manoeuvrability and reduced fuel consumption. These tugs are part of a broader strategy to modernize towage operations
- Svitzer's Methanol Hybrid Fuel Cell Tug (Sweden): Expected to enter service in 2025 in the Port of Gothenburg, this tug combines methanol fuel cells with electric propulsion to meet the port's goal of 70% emission reduction by 2030

Methanol-Powered Tugboats

Methanol is gaining traction due to its liquid form, ease of storage, and compatibility with existing infrastructure:

- Methatug (Port of Antwerp-Bruges): Launched as the world's first methanol-powered tugboat, Methatug uses methanol-specific engines and demonstrates the feasibility of retrofitting existing vessels
- Rolls-Royce Power Systems: Developed propulsion concepts for tugboats using methanol internal combustion engines and hydrogen fuel cells, highlighting methanol's high energy density and low retrofit costs

Implementation of eco-friendly propulsion systems

GİSAŞ POWER, also called Zeetug, is a joint R&D project of GİSAŞ and NAVTEK and has been operating as 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.

GİSAŞ'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.

Lithium-ion battery packs are used to power electric tugboats. Utilizing robust electrically charged battery packs, the 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 centres 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 Centre's server. It utilizes pertinent data regarding performance to maximize electric power and provides feedback in the form of recommended actions to the operator.

It may be beneficial to consider the implementation of onshore power supply systems, as these could significantly reduce fuel consumption for tugs and pilot boats. Although port service craft are currently exempt from regulations such as the EU Maritime Fuel Regulation and the Emissions Trading System (ETS), there is increasing public expectation for ports to operate in a more sustainable and environmentally responsible manner.

As climate policy evolves, there is a growing likelihood that exemptions for port operations will be reconsidered. Future amendments to EU maritime legislation may extend emissions regulations to include service craft and auxiliary port activities.

Even in the absence of direct regulation, ports face increasing pressure from local communities, environmental groups, and industry stakeholders to adopt sustainable practices. OPS is viewed as a proactive measure that aligns with broader decarbonization goals. Investing in OPS infrastructure now may position ports favourably in anticipation of future compliance requirements. It also enhances environmental credentials, which can be advantageous in competitive and policy-driven funding environments.

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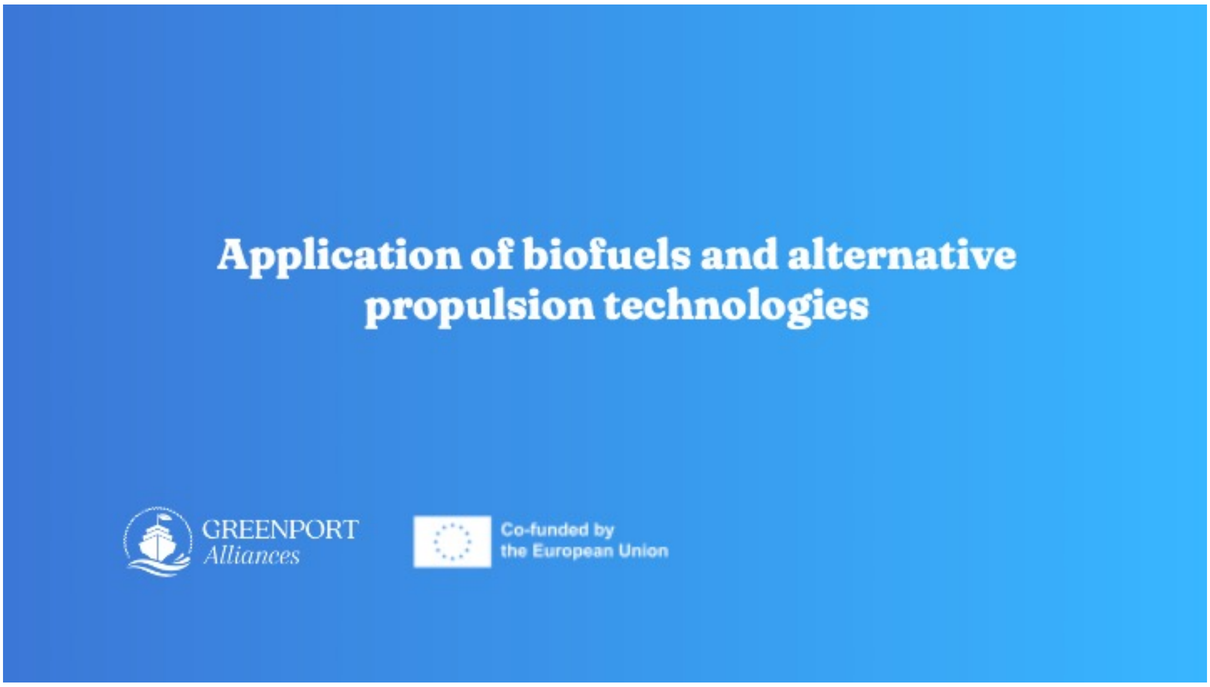
Application of biofuels and alternative
propulsion technologies
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1. Introduction

The maritime sector is under increasing pressure to reduce greenhouse gas (GHG) emissions and comply/align with international/local environmental regulations/expectations.

This has led to the exploration of alternative fuels and propulsion technologies, including biofuels, hydrogen, ammonia, and hybrid-electric systems.

Tugboats, which operate intensively in port environments, are particularly well-suited for early adoption due to their short-range operations and frequent refuelling opportunities.

2. Fuel Conversion Technologies and Biofuel Systems

- Biofuels are derived from renewable biological sources and include biodiesel, bio-LNG, and straight vegetable oil (SVO).
- Biodiesel can be used in low- to medium-speed marine engines with minimal modifications, offering reductions in particulate matter and carbon monoxide emissions.
- In tugboat applications, hybrid propulsion systems combining diesel engines with electric motors or batteries have shown promising results.
- A study on tugboats operating in the Istanbul Strait demonstrated fuel savings of up to 72.4% using lithium iron phosphate batteries in hybrid configurations.
- Methanol is also gaining traction due to its liquid form, ease of storage, and compatibility with existing infrastructure

Types of biofuels

FAME (Fatty acid methyl ester) produced from vegetable oils, animal fats or waste cooking oils is the most widely available type of biodiesel in the industry and is often blended with regular marine diesel.

BTL (Biomass to liquid) synthetic fuels that are produced from biomass by means of thermo-chemical conversion. The final product can be chemically different from conventional fuels such as gasoline or diesel but can also be used in diesel engines.

HVO/HDRD (Hydrogen vegetable oil / Hydrogenation derived renewable diesel) is the product of fats or vegetable oils – alone or blended with petroleum. The product is often called renewable diesel to differentiate it from FAME biodiesel. HVO/HDRD can be directly introduced in distribution and refuelling facilities as well as existing diesel engines without any further modification.

3. Adaptation of Operating Procedures for Alternative Fuels

Transitioning to alternative fuels requires significant changes in operational procedures, crew training, and safety protocols. For tugboats, these adaptations include:

- **Modified bunkering procedures** for methanol and hydrogen.
- **Enhanced ventilation and gas detection systems**.
- **Crew training** on fuel-specific hazards and emergency protocols.

Technical items to be observed and challenges on board

- **Microbial growth:** Bacteria and mould may grow, causing filters and piping to clog.
- **Oxygen degradation:** Biodiesel could form deposits in piping and engine,
- **Low temperature:** The higher cloud point may lead to the clogging of filters at lower temperatures.
- **Corrosion:** Some types of hoses and gaskets could degrade,
- **Possible degeneration of rubber sealings, gaskets and hoses:**
- **Conversion:** When switching from diesel to biofuel, fuel filters can become clogged

4. Collaboration with Engine Manufacturers and Suppliers

Collaboration between ship operators, engine manufacturers, and fuel suppliers is critical for the successful deployment of alternative propulsion technologies. Companies like **Caterpillar Marine** and **SAAM Towage** have signed MOUs to explore electrification and methanol-based propulsion for tugboats.

Engine manufacturers are developing dual-fuel engines that can operate on methanol and diesel, allowing for flexible fuel use and easier retrofitting.

Several tugboat operators have pioneered the use of hybrid and electric propulsion systems to reduce emissions and improve operational efficiency:

5. Implementation of eco-friendly propulsion systems

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.

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Module 10 | Application of biofuels and alternative propulsion technologies

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Chapter 10 Assessment Questions

Application of biofuels and alternative propulsion technologies

EXAM QUESTIONS

1. **Mark the wrong option: Tugboats, which operate intensively in port environments, are particularly well-suited for biofuels and alternative propulsion technologies**
   a. Early adoption due to their short-range operations
   b. Frequent refuelling opportunities
   c. Advances in hybrid tugboat applications
   d. Transitioning to alternative fuels without significant changes in operational procedures
   e. All of the above

2. **Mark the wrong option: For tugboats, adaptation of operating procedure for alternative fuels require**
   a. Modified Bunkering Procedures
   b. Enhanced ventilation System
   c. IMO mandating for hybrid tugboats
   d. Enhanced gas detection system
   e. Crew Training

3. **Which one below is <u>NOT</u> one of the technical items to be observed onboard?**
   a. Oil-based pollution
   b. Microbial growth
   c. Oxygen degradation
   d. Low temperature
   e. Possible degeneration

4. **Which example illustrates the contribution of sustainability to operational excellence in ports?**
   a. Banning private construction along coastlines
   b. Reducing ship emissions via shore-side electricity (OPS)
   c. Mandatory ESG training for maritime personnel
   d. Increasing penalties for ballast water discharge
   e. All of them

5. **Which of the following is not a type of biofuel?**
    a. FAME
    b. BTL
    c. HVO
    d. EEDI
    e. HDRD

6. **Which one of the following is a primary benefit of using biofuels in port operations?**
    a. Increased greenhouse gas emissions
    b. Higher operational costs
    c. Decreased Fuel Efficiency
    d. Increased noise pollution
    e. Reduced air pollution

7. **What is one of the main challenges associated with implementing alternative propulsion technologies?**
    a. Lack of available technology
    b. Decreased safety standards
    c. High initial investment costs
    d. Limited fuel supply options
    e. Increased maintenance requirements

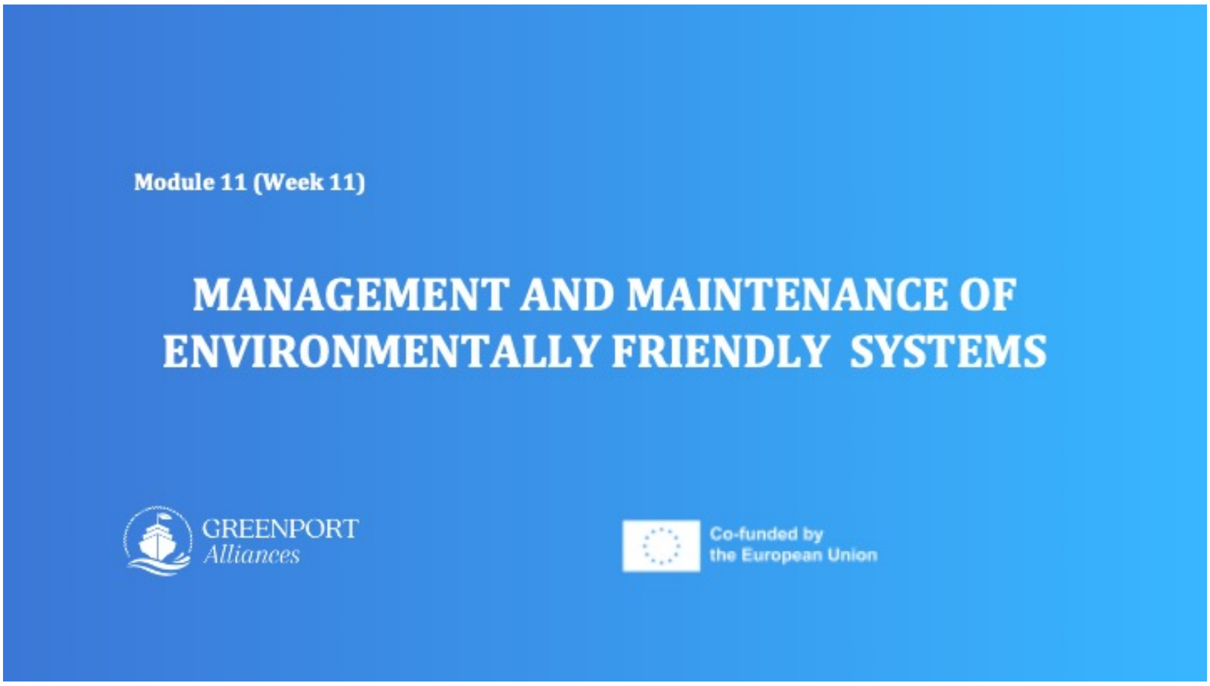
8. **How can the use of biofuels impact the carbon footprint of port activities?**
    a. It increases the carbon footprint significantly.
    b. It has no impact on the carbon
    c. It reduces the carbon footprint by replacing fossil fuels
    d. It doubles the carbon footprint due to production processes.
    e. All of them are correct

9. **Which alternative propulsion technology is commonly used for reducing emissions in port equipment?**
    a. Nuclear Power.
    b. Coal Powered engines
    c. Hydrogen Fuel Cells
    d. Diesel Generators.
    e. Gasoline Engines

10. **What role do government regulations play in promoting biofuels and alternative propulsion technologies in ports?**
    a. They have no influence on adoption rates.
    b. They provide subsidies for fossil fuel usage
    c. They mandate specific emission reduction targets
    d. They discourage innovation through strict policies
    e. They limit research and development fund

CHAPTER 11

COURSE Module 10 (Week 10)



Management and Maintenance of Environmentally Friendly systems

1. Introduction

The maritime industry is undergoing a significant transformation driven by technological innovation and the need to increase efficiency, safety and environmental sustainability. Traditional ship maintenance methods, which have mainly relied on manual inspections and reactive measures after failures occur, are gradually giving way to advanced technologies that enable a proactive approach to maintenance. This paradigm shift is particularly important for ship operators facing increasing demands for operational reliability and economic efficiency [1].

Advanced methods for the maintenance of ship systems and equipment encompass a wide range of technologies and approaches, from schedule-based preventive maintenance to sophisticated predictive systems using artificial intelligence and the Internet of Things (IoT). These methods not only enable the reduction of unplanned downtime and repair costs, but also significantly contribute to the safety of maritime traffic and the protection of the marine environment. The implementation of advanced maintenance methods has become crucial to achieving sustainability goals in the maritime industry, where the focus is on optimizing fuel consumption, reducing emissions and extending the lifespan of ship equipment [2].

The modern approach to ship maintenance is based on the principles of asset life cycle management, as defined in the ISO 55000 series of standards, which emphasize the importance of a systematic approach to managing assets throughout their entire life cycle. This holistic approach enables organizations to optimize asset utilization, improve financial performance, and manage the risks associated with owning and operating ships. In the context of the maritime industry, this means integrating the various aspects of maintenance - from routine inspections to complex predictive analytics - into a single system that supports the operational objectives of ship operators [3].

The implementation of advanced maintenance methods on tugboat engines provides a practical example of applying theoretical principles to real-world operating conditions. Due to their intensive port use and continuous high-load operation, tugboats require a rigorous approach to engine maintenance to ensure operational reliability and minimize downtime.

2. Maintenance and calibration of ship engines and systems

The maintenance and calibration of ship engines and systems are vital to the safety and operational efficiency of ships (Simion et al., 2024). Maintenance and calibration encompass a wide range of processes, from routine inspections and component replacements to complex diagnostic tests and precise adjustments and aim to maintain the optimal performance of shipboard machinery (Piotrovsky et al., 2021). Maintenance and calibration on ships are considered essential tools for improving overall efficiency and ensuring operational and environmental assurance (Abbas & Shafiee, 2020). Effective maintenance and calibration protocols directly reduce the risk of unexpected equipment failures, which can lead to costly delays, environmental hazards, and potentially catastrophic accidents at sea

(Ganesh et al., 2020). Given that a significant portion of maritime accidents are caused by technical equipment failures, implementing effective fault detection and diagnostic methods is crucial (Simion et al., 2024). The integration of digital technologies with traditional systems has paved the way for advanced monitoring approaches that facilitate the continuous assessment of machinery health and performance (Liu et al., 2022). On the other hand, inadequate maintenance can increase ship operating costs by 20 to 540%. Therefore, effective maintenance strategies should be considered not only for their environmental benefits but also as an economic imperative. Today, the adoption of advanced maintenance management systems that integrate artificial intelligence allows for the prediction and significant improvement of necessary maintenance and repairs, which in turn helps prevent environmental damage (Durlik et al., 2024; Lim et al., 2025).

Considering that the maritime industry will grow further in the future, a comprehensive approach to reducing its environmental impacts should focus on increasing energy efficiency and complying with strict emission regulations (Wu and Lin, 2021; Spinelli et al., 2022). Given this backdrop, the maintenance and calibration of ship engines and systems emerge as a critical area of focus, holding significant potential for reducing GHG emissions, particularly in and around seaports (Yang & Zou, 2023). Regular maintenance, including the calibration of critical engine components, ensures that the engine operates within its design parameters, leading to improved combustion efficiency and reduced emissions of harmful pollutants such as nitrogen oxides and particulate matter).

Tugboats, although play a crucial role in port operations, assisting larger vessels during docking, undocking, and manoeuvring within confined spaces, their engines and systems contribute significantly to emissions and fuel consumption, raising environmental concerns.
Regular maintenance ensures that tugboat engines operate at optimal performance levels. Key maintenance activities include regular oil changes to reduce friction and wear for improved engine efficiency, replacements of air and fuel filters periodically to prevent clogging and ensure proper fuel combustion, and cooling system checks to prevent overheating, which can lead to engine damage and inefficiencies.

A tugboat engine preventive maintenance program begins with establishing a comprehensive maintenance schedule based on manufacturer guidelines and operating conditions. This program includes regular cleaning and lubrication of engine components, which can result in a reduction in energy consumption and a significant reduction in wear-related failures. Key activities include regular checks and replacement of engine oil, filters, checking the condition of the cooling system, and inspecting the drive belt.

3. Performance monitoring and use of predictive algorithms

Performance monitoring involves the continuous assessment of engine performance, fuel consumption, emissions, and operational efficiency. This process is essential for identifying inefficiencies, optimizing maintenance schedules, and ensuring compliance with environmental regulations.

To effectively monitor performance, several key performance indicators (KPIs) should be tracked:

Fuel Consumption Rate: Measures the amount of fuel used per hour of operation, providing insights into efficiency.

Engine Load: Indicates the percentage of engine capacity being utilized, helping to identify under or overloading.
Emission Levels: Regular monitoring of NOx, SOx, and PM emissions to ensure compliance with regulatory standards.
Operational Hours: Tracking the number of hours the tugboat operates helps in scheduling maintenance and assessing wear and tear.
Maintenance Intervals: Keeping records of maintenance activities to identify patterns and optimize schedules.

Implementing an efficient performance monitoring systems depends on **sensor technology** and **data acquisition systems**. Modern tugboats are equipped with various sensors that collect real-time data on engine performance and operational parameters with fuel flow meters which measure fuel consumption in real-time, engine temperature sensors to monitor engine and exhaust temperatures to prevent overheating and pressure sensors to track oil and coolant pressure levels to ensure proper engine function.
Data acquisition systems aggregate data from various sensors and provide a centralized platform for monitoring performance. These systems can visualize data to present real-time data in user-friendly dashboards that highlight key metrics. Systems also store historical data to maintain records of performance data for trend analysis and reporting.

Predictive algorithms leverage historical and real-time data to forecast future performance and maintenance needs. These algorithms are part of predictive maintenance strategies **that aim to minimize downtime** and reduce operational costs.

4. Maintenance documentation management

Effective maintenance documentation management is critical for ensuring the reliability, safety, and efficiency of tugboat operations. It involves the systematic organization, storage, and retrieval of maintenance records, procedures, and compliance documents. Proper documentation not only facilitates regulatory compliance but also enhances operational efficiency and aids in decision-making.

Tugboats must adhere to various maritime regulations, including safety and environmental standards. Proper documentation helps demonstrate compliance during inspections and audits. Well-organized maintenance records enable quick access to historical data, facilitating informed decision-making regarding repairs, replacements, and maintenance schedules for operational efficiency

Accurate records of maintenance activities help identify patterns that may indicate potential safety risks, allowing for proactive measures to mitigate them. Detailed documentation aids in tracking the performance and condition of equipment over time, supporting effective asset management strategies.

Key Components of Maintenance Documentation

Maintenance Logs
Maintenance logs are essential records that capture all maintenance activities performed on tugboat engines and systems. Key elements include:
Date and Time: When the maintenance was performed.
Description of Work: A detailed account of the tasks completed (e.g., oil changes, filter replacements).

Personnel Involved: Names of the crew members or technicians who performed the maintenance.
Parts Used: Inventory of parts replaced or repaired, including part numbers and quantities.

Inspection Reports
Regular inspections are vital for ensuring the safety and functionality of tugboats. Inspection reports should include:
Inspection Date: When the inspection took place.
Findings: A summary of the condition of the equipment and any issues identified.
Recommendations: Suggested actions based on the inspection findings, including immediate repairs or future maintenance needs.

Service Manuals and Procedures
Service manuals provide detailed instructions for maintenance tasks and repairs. These documents should include:
Manufacturer Specifications: Guidelines for maintaining and servicing specific engine models and systems.
Step-by-Step Procedures: Clear instructions for performing maintenance tasks, including safety precautions.
Troubleshooting Guides: Information on diagnosing and resolving common issues.

Compliance Documents
Compliance documentation is crucial for meeting regulatory requirements. This includes:
Certificates of Compliance: Documentation proving adherence to environmental and safety regulations.
Emission Reports: Records of emissions testing and compliance with local and international standards.
Safety Audits: Results from safety audits conducted to assess operational practices and adherence to safety protocols.

Implementing a centralized documentation system allows for easy access and retrieval of maintenance records. This can be achieved through Digital Document Management Systems utilizing software solutions to store and organize documents electronically, making them searchable and easily accessible as well as cloud storage solutions ensuring that documentation is stored in a secure cloud environment, allowing for remote access and collaboration among team members.

Establishing standardized procedures for documenting maintenance activities ensures consistency and completeness. Key practices include:
Uniform Templates: Creating standardized templates for maintenance logs, inspection reports, and service manuals to ensure all necessary information is captured.
Training for Personnel: Providing training for crew members on the importance of documentation and how to use the established systems effectively.
Conducting regular audits of maintenance documentation helps ensure accuracy and compliance. This can involve:
Periodic Reviews: Assessing documentation for completeness and accuracy, identifying any gaps or discrepancies.
Feedback Mechanisms: Encouraging crew members to provide feedback on the documentation process to continuously improve practices.

Integrating maintenance documentation with performance monitoring systems enhances data accuracy and accessibility. This can include:

Real-Time Updates: Allowing maintenance logs to be updated in real-time, ensuring that records reflect the current status of equipment.
Data Analytics: Utilizing analytics tools to extract insights from maintenance data, helping to inform decision-making and optimize maintenance schedules.

The volume of data generated can be overwhelming, making it difficult to maintain organized records. Variability in documentation practices among crew members can lead to incomplete or inaccurate records. Keeping up with changing regulations requires continuous updates to compliance documentation.

5. Predictive and preventive maintenance techniques

In the marine industry, maintenance strategies have evolved from simple reactive approaches to sophisticated predictive models, with the goal of maximizing operational efficiency and minimizing costs. Corrective Maintenance (CM) is a traditional approach which involves repairs that are carried out only after a failure occurs. Although it may seem like the cheapest option because it does not require an initial investment in planning or monitoring, it often results in unexpected downtime, significant financial losses, and disruptions to global logistics networks. The average downtime per failure can be as long as 14 days, which poses a significant challenge in maintaining schedules within global supply chains [4].

Preventive Maintenance (PM) is based on scheduled servicing or maintenance after a certain number of operating hours, regardless of the actual condition of the equipment. The aim is to prevent failures and extend the life of the equipment. Although PM reduces unexpected failures and downtime compared to corrective maintenance, it often leads to unnecessary repairs and over-scheduling of maintenance, resulting in increased costs and extended downtime. Despite these limitations, preventive maintenance brings significant benefits: it reduces unplanned downtime, reduces repair costs, increases asset reliability and longevity, ensures compliance with regulatory standards (such as SOLAS, ISM Code and MARPOL), and contributes to sustainability by improving fuel efficiency and reducing emissions. However, challenges include high initial costs, higher labour intensity and the potential for excessive maintenance [1].

Predictive Maintenance (PdM) represents a transformative approach that uses real-time data, analytics and machine learning to optimize the maintenance process. Unlike corrective and preventive maintenance, PdM proactively predicts potential equipment degradation or failures based on operational data from the vessel. Its high efficiency is reflected in the reduction of downtime, optimization of maintenance efficiency and compliance with industry practices. This approach significantly reduces unplanned downtime, extends machine life and lowers costs, while improving overall fleet availability and safety. PdM is an integral part of the fourth generation of shipping, known as Shipping 4.0, which integrates advanced technological innovations such as the Internet of Ships (IoS) and artificial intelligence (AI) to transform traditional ships into "smart ships" [5]. The implementation of predictive maintenance relies on sophisticated methodologies and advanced tools, such as Reliability-Centered Maintenance (RCM), Condition-Based Monitoring (CBM) and the application of data analysis and machine learning (ML).

6. Use of digital tools for maintenance management

Computerized Maintenance Management Systems (CMMS) are software solutions designed to plan, perform and document vessel maintenance in accordance with the requirements of classification societies and manufacturers. These systems offer centralized data management, enabling efficient data synchronization between ship and shore, which improves communication and optimizes time. Key features of CMMS include fault reporting, document management, fleet monitoring, spare parts inventory management and electronic management of job lists. The benefits of implementing a CMMS are multiple: it simplifies the planning, documentation and execution of maintenance tasks, ensures compliance with all applicable regulations (in particular with the International Safety Management Code - ISM Code, which prescribes a mandatory Planned Maintenance System - PMS). Furthermore, CMMS protects assets and optimizes their management, reducing manual data entry and operating costs.

The Internet of Things (IoT) is revolutionizing the approach to maritime logistics and vessel monitoring, enabling real-time data collection and improving operational efficiency. IoT devices, such as sensors, are placed at critical points on a ship (e.g. engines, generators, cooling systems, hull) to continuously monitor metrics such as temperature, vibration, pressure and fuel efficiency. These sensors enable technical teams to respond quickly to anomalies, providing early detection of potential problems. IoT applications include continuous monitoring of fuel consumption, exhaust emissions and energy consumption, enabling optimization and compliance with international environmental standards. IoT also helps in early detection of hazards such as fires or floods, sending immediate alerts to the crew and emergency response teams on shore. Despite challenges such as signal attenuation in the complex steel structures of ships, multi-hop wireless networks and advanced protocols enable efficient communication [6].

Digital twins (DT) are virtual replicas of physical assets that enable continuous monitoring, simulation and prediction of the condition of ship systems and components. This technology enables operators to monitor, analyze and optimize their assets, providing a comprehensive overview of operations and facilitating predictive maintenance. DT's integration with IoT is key to improving predictive maintenance capabilities; The IoT network collects real-time data through sensors, communication protocols and IoT gateways, which are then transferred to the digital twin model. By using digital twins, maritime companies can optimize maintenance processes, improve decision-making, increase operational efficiency, reduce downtime and extend asset life [7].

Big data and analytics are key to optimizing logistics processes and improving overall efficiency in shipping. This involves collecting, processing, and analysing complex data sets from diverse sources such as sensors, RFID tags, GPS devices, and ERP systems. The application of big data analytics enables real-time shipment tracking and visibility, accurate demand forecasting and optimization of inventory levels, route optimization and fleet management, risk mitigation, and continuous improvement and cost reduction. Big data analytics can predict equipment failures and maintenance needs, thereby reducing downtime and extending the life of assets. Technologies such as machine learning and artificial intelligence within the big data framework enable process automation, predictive analysis, and operations optimization.

7. Life cycle management of ship equipment

Effective Life cycle Management (ELM) of ship systems and equipment is essential for the sustainability, safety and economy of maritime operations. This process encompasses all phases, from planning to disposal, considering regulatory requirements.

ELM is usually divided into five phases: planning, procurement, use, maintenance and disposal. For effective management, some best practices are recommended: maintaining a comprehensive inventory of all valuable equipment, tracking problems with an easy failure reporting mechanism (preferably an automated system), monitoring daily equipment usage to detect over- or under-utilization, creating a procurement plan based on usage data, establishing a maintenance cycle to evenly distribute equipment wear, optimizing equipment distribution, automating the procurement process (e.g., end-of-life alerts), and applying quality controls through customized checklists [3],[8].

Integrating Reliability and Maintainability Engineering (R&ME) early in the design process is essential to avoid prohibitive maintenance costs throughout the system life cycle. R&ME treats reliability and maintainability as performance parameters from the outset, directly impacting operating and maintenance costs and total life cycle costs. This includes reliability prediction, failure physics analysis, failure mode and effects and criticality analysis (FMECA), fault tree analysis (FTA), parts selection and stress analysis. R&ME focuses on controllable design elements such as system reliability, system architecture (including redundancy) and system maintainability through design for reliability and design for maintainability activities [9].

The maritime sector is subject to strict regulations, including SOLAS, the ISM Code and MARPOL. Preventive maintenance ensures compliance by maintaining up-to-date certificates, inspection logs and maintenance records, and meeting safety and environmental standards required for audits and inspections. According to DNV, ships with robust maintenance systems reduce audit preparation time by up to 50%, simplifying compliance processes and avoiding penalties. Lifecycle management of marine equipment also supports sustainability goals by improving energy efficiency through well-maintained engines and reducing emissions and preventing pollution from equipment failures.

8. Conclusion

The transformation of the maritime industry towards sustainability is inextricably linked to advanced methods of maintaining ship systems and equipment. The shift from reactive to proactive and predictive maintenance strategies is not only an operational necessity, but a strategic imperative that enables safer, more efficient and more environmentally friendly maritime operations. Regulatory pressure, embodied in conventions such as MARPOL and initiatives such as the EU Green Deal, acts as a strong driver for the adoption of innovative technologies and practices.

Digital tools, including Computerized Maintenance Management Systems (CMMS), the Internet of Things (IoT), digital twins (DT), artificial intelligence (AI) and big data analytics, are key to this transformation. They enable real-time condition monitoring, failure prediction, optimization of maintenance schedules and efficient resource management, leading to reduced unplanned downtime, extended equipment life and significant cost savings. Maintenance is thus positioned as a fundamental element of the business model, ensuring supply chain continuity and strengthening competitiveness.

Furthermore, integrating the principles of equipment lifecycle management into maritime operations ensures long-term sustainability. Design for sustainability, responsible recycling and component reuse reduce waste and promote resource efficiency. Classification societies and IMO resolutions play an indispensable role in setting standards and ensuring compliance, thereby supporting the overall framework for advanced maintenance.

Ultimately, the maritime industry is moving towards a future where intelligent technologies and sustainable practices are deeply integrated. Advanced maintenance is not just a technical discipline, but a comprehensive strategy that enables the industry to meet its economic objectives while protecting the environment and ensuring safety. Continued research, development and implementation of these methods will be key to building a more resilient, efficient and greener maritime sector.

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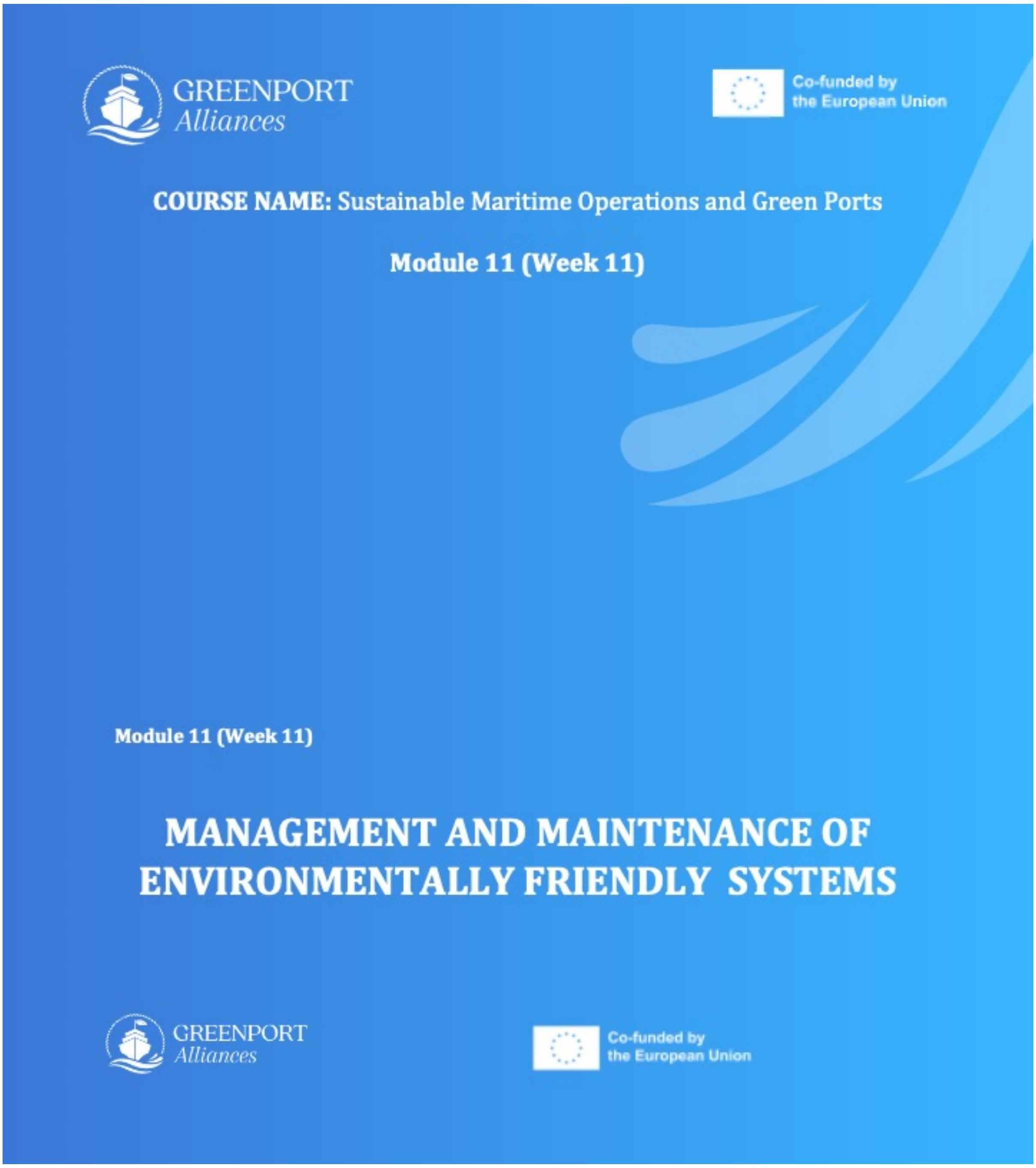
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Module 11 (Week 11)
Module 11 (Week 11)
MANAGEMENT AND MAINTENANCE OF ENVIRONMENTALLY FRIENDLY SYSTEMS
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1. Introduction

- **Traditional ship maintenance methods**, which have mainly relied on manual inspections and reactive measures after failures occur, are gradually giving way to advanced technologies that enable a proactive approach to maintenance

- **Management and maintenance of ship systems and equipment** encompass a wide range of technologies and approaches, from **schedule-based preventive maintenance** to sophisticated **predictive systems using artificial intelligence (AI) and the Internet of Things (IoT)**

- The implementation of advanced maintenance methods on **tugboat engines** provides a practical example of applying theoretical principles to real-world operating conditions. Due to their **intensive port use** and **continuous high-load operation, tugboats** require **a rigorous approach** to engine maintenance to ensure **operational reliability** and **minimize downtime.**

2. Maintenance and calibration of ship engines and systems

Tugboats assisting larger vessels during docking, undocking, and manoeuvring within confined spaces, their engines and systems contribute significantly to emissions and fuel consumption, raising environmental concerns.

Regular maintenance ensures that tugboat engines operate at **optimal performance** levels. Key maintenance activities include **regular oil changes** to reduce friction and wear for improved engine efficiency, **replacements of air and fuel filters periodically** to prevent clogging and ensure **proper fuel combustion, and cooling system** checks to prevent **overheating**, which can lead to engine damage and inefficiencies.

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Maintenance and calibration of ship engines and systems

A tugboat engine preventive maintenance program begins with establishing a comprehensive maintenance schedule based on manufacturer guidelines and operating conditions. This program includes regular cleaning and lubrication of engine components, which can result in a reduction in energy consumption and a significant reduction in wear-related failures. Key activities include regular checks and replacement of engine oil, filters, checking the condition of the cooling system, and inspecting the drive belt.

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3. Performance monitoring and use of predictive algorithms

- **Preventive Maintenance (PM)** is based on scheduled servicing or maintenance after a certain number of operating hours, regardless of the actual condition of the equipment
- Although PM reduces unexpected failures and downtime compared to CM, it often leads to unnecessary repairs and over-scheduling of maintenance, resulting in increased costs and extended downtime
- It reduces repair costs, increases asset reliability and longevity, ensures compliance with regulatory standards and contributes to sustainability by improving fuel efficiency and reducing emissions

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4. Maintenance documentation management

Key Components of Maintenance Documentation

Maintenance Logs
- Date and Time: When the maintenance was performed.
- Description of Work: A detailed account of the tasks completed (e.g., oil changes, filter replacements).
- Personnel Involved: Names of the crew members or technicians who performed the maintenance.
- Parts Used: Inventory of parts replaced or repaired, including part numbers and quantities.

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Maintenance documentation management

Key Components of Maintenance Documentation

- **Maintenance Logs**
- **Inspection Reports**
- **Service Manuals and Procedures**
- **Compliance Documents**

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5. Predictive maintenance techniques

- **Predictive Maintenance (PdM)** represents a transformative approach that uses real-time data, analytics and machine learning to optimize the maintenance process

- PdM proactively predicts potential equipment degradation or failures based on operational data from the vessel

- This approach significantly reduces unplanned downtime, extends machine life and lowers costs, while improving overall fleet availability and safety

- PdM integrates advanced technological innovations to transform traditional ships into "smart ships"

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6. Use of digital tools for maintenance management

- Computerized Maintenance Management Systems (CMMS) are software solutions designed to plan, perform and document vessel maintenance in accordance with the requirements of classification societies and manufacturers

- These systems offer centralized data management, enabling efficient data synchronization between ship and shore, which improves communication and optimizes time

- Key features of CMMS include fault reporting, document management, fleet monitoring, spare parts inventory management and electronic management of job lists

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Use of digital tools for maintenance management

- The Internet of Things (IoT) is revolutionizing the approach to maritime logistics and vessel monitoring, enabling real-time data collection and improving operational efficiency
- IoT devices, such as sensors, are placed at critical points on a ship (e.g. engines, generators, cooling systems, hull) to continuously monitor metrics such as temperature, vibration, pressure and fuel efficiency
- These sensors enable technical teams to respond quickly to anomalies, providing early detection of potential problems

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Use of digital tools for maintenance management

- IoT applications include continuous monitoring of fuel consumption, exhaust emissions and energy consumption, enabling optimization and compliance with international environmental standards
- IoT also helps in early detection of hazards such as fires or floods, sending immediate alerts to the crew and emergency response teams on shore
- Despite challenges such as signal attenuation in the complex steel structures of ships, multi-hop wireless networks and advanced protocols enable efficient communication

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Use of digital tools for maintenance management

- Digital twins (DT) are virtual replicas of physical assets that enable continuous monitoring, simulation and prediction of the condition of ship systems and components
- This technology enables operators to monitor, analyze and optimize their assets, providing a comprehensive overview of operations and facilitating predictive maintenance
- By using digital twins, maritime companies can optimize maintenance processes, improve decision-making, increase operational efficiency, reduce downtime and extend asset life

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Use of digital tools for maintenance management

- Big data and analytics are key to optimizing logistics processes and improving overall efficiency in shipping – this involves collecting, processing, and analyzing complex data sets from diverse sources such as sensors, RFID tags, GPS devices, and ERP systems
- In particular, big data analytics can predict equipment failures and maintenance needs, thereby reducing downtime and extending the life of assets
- Technologies such as machine learning and artificial intelligence within the big data framework enable process automation, predictive analysis, and operations optimization

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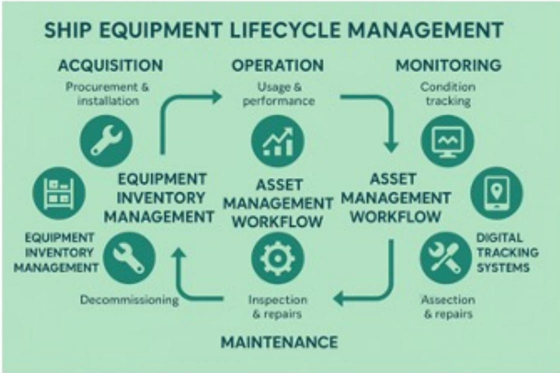
7. Life cycle management of ship equipment

- Effective Life cycle Management (ELM) of ship systems and equipment is essential for the sustainability, safety and economy of maritime operations – this process encompasses all phases, from planning to disposal, considering regulatory requirements
- ELM is usually divided into five phases: planning, procurement, use, maintenance and disposal
- Integrating Reliability and Maintainability Engineering (R&ME) early in the design process is essential to avoid prohibitive maintenance costs throughout the system life cycle



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Life cycle management of ship equipment

- R&ME treats reliability and maintainability as performance parameters from the outset, directly impacting operating and maintenance costs and total life cycle costs
- This includes reliability prediction, failure physics analysis, failure mode and effects and criticality analysis (FMECA), fault tree analysis (FTA), parts selection and stress analysis
- R&ME focuses on controllable design elements such as system reliability, system architecture (including redundancy) and system maintainability through design for reliability and design for maintainability activities

8. Conclusion

- **The shift from reactive to proactive and predictive maintenance strategies is not only an operational necessity, but a strategic imperative that enables safer, more efficient and more environmentally friendly maritime operations**

- **Digital tools are key to this transformation**

- **Integrating the principles of equipment lifecycle management into maritime operations ensures long-term sustainability**

Chapter 11 Assessment Questions

Management and maintenance of environmentally friendly ship systems

EXAM QUESTIONS

1. **What is the main difference between corrective and predictive maintenance in the marine industry?**
    a. Corrective maintenance is more expensive, while predictive maintenance is cheaper.
    b. Corrective maintenance includes repairs before failure, and predictive maintenance after failure.
    c. Corrective maintenance is carried out after failure, while predictively predicts potential equipment degradation or failure based on operational data.
    d. Predictive maintenance does not require any investment, unlike corrective maintenance.
    e. Corrective maintenance reduces unplanned downtime, and predictive maintenance increases it.

2. **What is the primary purpose of Computerized Maintenance Management Systems (CMMS)?**
    a. Exclusively monitoring fuel consumption.
    b. Planning, performing and documenting vessel maintenance in accordance with classification societies and manufacturers' requirements.
    c. Remote control of navigation systems.
    d. Automation of all ship operations.
    e. Exclusively managing spare parts inventories.

3. **How does the Internet of Things (IoT) contribute to advanced maintenance of ship systems?**
    a. It increases manual labour and reduces automation.
    b. It prevents real-time data collection.
    c. It enables real-time data collection via sensors, leading to early detection of potential problems and optimization.
    d. It limits ship-to-shore communication.
    e. It increases energy consumption on board.

4. **What are digital twins (DT) in the context of ship maintenance?**
    a. Physical replicas of ships for crew training.

  b. **Virtual replicas of physical assets that enable continuous monitoring, simulation and prediction of the condition of ship systems and components.**
  c. Software tools for financial reporting.
  d. Automated cargo management systems.
  e. Methods for reducing engine noise.

5. **What is one of the key challenges of preventive maintenance (PM) despite its benefits?**
  a. Extended unplanned downtime.
  b. Increased fuel consumption.
  c. **High initial costs, higher labour intensity, and potential for excessive maintenance.**
  d. Inability to reduce repair costs.
  e. Lack of compliance with regulatory standards.

6. **What is one of the objectives of equipment life cycle management (ELM) in maritime operations?**
  a. Exclusively extending the life of the ship.
  b. Minimizing the cost of equipment acquisition.
  c. **Covering all phases of equipment, from planning to disposal, considering regulatory requirements, for sustainability, safety and economy.**
  d. Focusing exclusively on repairs after failure.
  e. Increasing waste and reducing resource efficiency.

7. **How does a large amount of data (Big Data) and analytics contribute to the optimization of processes in shipping?**
  a. By reducing the amount of available data.
  b. By disabling the tracking of shipments in real time.
  c. **By enabling real-time shipment tracking, accurate demand forecasting, inventory level optimization, route optimization and fleet management, and risk reduction.**
  d. Increasing manual data processing.
  e. By limiting the application of artificial intelligence and machine learning.

8. **What is the purpose of integrating Reliability and Sustainability Engineering (R&ME) into the early design process?**
  a. Increasing total life cycle costs.
  b. Postponing maintenance until the end of the life cycle.
  c. Reducing system reliability.
  d. **Avoiding excessive maintenance costs throughout the system life cycle by treating reliability and sustainability as performance parameters from the start.**
  e. Focusing exclusively on parts selection without stress analysis.

9. What are the three key technologies that predictive maintenance (PdM) integrates?

a. Satellite communications, radar and sonar.
b. GPS, weather forecasting and cartography.
c. Real-time data, analytics and machine learning.
d. Physical inspections, manual repairs and preventive maintenance schedules.
e. Paper records, telephone communication and fax.

10. Why is the maritime sector subject to strict regulations in the context of maintenance?

a. To limit the number of ships in service.
b. To reduce the need for qualified crew.
c. To ensure compliance with safety and environmental standards, maintaining up-to-date certificates, inspection records and maintenance records.
d. Purely for financial reasons.
e. To encourage reactive maintenance methods.

CHAPTER 12

COURSE Module 12 (Week 12)

Reporting and document management according to ESG and regulatory requirements

1. Introduction

The increasing importance of Environmental, Social and Governance (ESG) compliance and regulatory reporting has changed the way organisations collect, manage and disclose key sustainability data [1]. In today's rapidly evolving regulatory landscape, companies must not only understand the complex international and national environmental regulations, but also implement efficient systems to ensure accurate and timely reporting. This module provides a comprehensive examination of modern approaches to ESG documentation and regulatory compliance, with a focus on utilising digital transformation to address these challenges.

A key component of effective ESG management lies in the ability to utilise advanced technologies for data collection and analysis [2]. Companies are increasingly utilising automated reporting tools, AI-powered analytics platforms and integrated document management systems to track sustainability metrics, monitor emissions and assess energy efficiency. These technological solutions enable more accurate measurement of environmental impact while significantly reducing the administrative burden associated with manual reporting processes.

2. ESG (Environmental, Social, and Governance) standards and reporting requirements

While **sustainability** is the **vision** and Corporate Social Responsibility **(CSR)** is a **voluntary approach** to achieving sustainability, **ESG** is a framework for measuring and reporting progress toward sustainability. It translates CSR and sustainability efforts into measurable metrics. CSR is more about values and voluntary actions, ESG is about accountability and performance. The integration of ESG principles into corporate operations has transformed how organizations measure, manage, and communicate their sustainability performance [3]. At the core of this transformation lies the need for robust data collection, analysis, and reporting mechanisms that align with both voluntary standards and mandatory regulations. Modern businesses are increasingly adopting digital tools and advanced technologies to streamline these processes, ensuring accuracy, efficiency, and compliance. Automated systems for tracking emissions, energy consumption, and other sustainability metrics have replaced manual methods, reducing errors while providing real-time insights into environmental impact. Cloud-based platforms and AI-driven analytics enable organizations to process large datasets, identify trends, and generate comprehensive reports that meet stakeholder expectations.

Simultaneously, the regulatory landscape surrounding ESG disclosures continues to evolve, with international and national frameworks setting increasingly stringent requirements. From the Global Reporting Initiative’s comprehensive standards to the EU’s Corporate Sustainability Reporting Directive, companies must navigate a complex web of guidelines that dictate what information must be collected, how it should be verified, and when it needs to be disclosed [4]. Understanding these frameworks is critical not only for compliance but also for maintaining credibility with investors, customers, and regulators. Proper documentation management ensures that all reported data is traceable, auditable, and securely stored, forming a reliable foundation for both internal decision-making and external verification.

The intersection of technology and regulation in ESG reporting creates opportunities for organizations to go beyond mere compliance. By leveraging digital solutions, companies can turn sustainability data into strategic assets, identifying areas for improvement, optimizing resource use, and demonstrating long-term value creation. This proactive approach not only mitigates risks associated with regulatory non-compliance but also enhances corporate reputation and competitive positioning in an increasingly sustainability-driven market. As reporting requirements continue to expand in scope and complexity, the ability to efficiently manage ESG data and documentation will remain a key differentiator for businesses committed to transparency and sustainable growth.

The reporting process must deliver measurable environmental benefits such as tracking, developing digital platforms for stakeholder communication, and implementing regular sustainability audits to drive continuous improvement, and emphasize sustainability reporting as a strategic tool for ports and maritime operators to systematically measure, manage, and communicate their environmental performance while maintaining operational efficiency.

3. Management and archiving of compliance documentation

In today's complex regulatory environment, effective management and archiving of compliance documentation has become a critical component of corporate governance. As ESG reporting requirements grow increasingly stringent, organizations must establish systematic approaches to handle the vast amounts of data and documentation required to demonstrate compliance with both voluntary standards and mandatory regulations. This process goes beyond simple record-keeping - it represents a strategic function that ensures business continuity, mitigates legal risks, and supports transparent stakeholder communication.

The foundation of robust compliance documentation management lies in implementing digital archiving systems that can handle diverse data types while maintaining strict version control. Modern organizations are transitioning from traditional paper-based systems to cloud-based platforms that offer secure storage, advanced search capabilities, and automated retention policies. These systems must be designed to accommodate everything from emissions data and energy audits to board meeting minutes and supply chain certifications. A well-structured digital archive serves multiple purposes: it facilitates efficient internal audits, enables quick responses to regulatory inquiries, and provides the evidentiary basis for all sustainability claims made in public reports.

Advanced technologies are transforming how compliance documentation is processed and maintained. Artificial intelligence and machine learning algorithms are being deployed to automatically classify documents, flag inconsistencies, and identify missing information in reporting packages. Blockchain solutions are emerging as a powerful tool for creating immutable audit trails, particularly for carbon credit transactions and supply chain due diligence [5]. These technological solutions not only improve efficiency but also significantly enhance the reliability of compliance documentation - a crucial factor as regulators increasingly scrutinize the accuracy of corporate sustainability disclosures.

The management of compliance documentation must also address the challenge of evolving regulatory requirements. Organizations need to implement flexible systems that can adapt to new reporting standards and expanded disclosure obligations. This requires establishing clear protocols for document versioning, approval workflows, and periodic reviews. Cross-functional collaboration is essential, with legal, compliance, and sustainability teams working together to ensure all documentation meets current standards while remaining adaptable for future changes. Regular training programs help maintain organizational awareness of documentation requirements and ensure consistent practices across all business units.

Effective archiving strategies must consider both accessibility and security. While compliance documents need to be readily available for audits and reporting purposes, they also contain sensitive business information that requires protection. Role-based access controls, encryption protocols, and multi-factor authentication help balance these competing needs. Organizations are increasingly adopting hybrid archiving solutions that combine the scalability of cloud storage with the security of on-premises systems for particularly sensitive documents.

The lifecycle management of compliance documentation represents another critical consideration [6]. Organizations must establish clear retention policies that comply with legal requirements while avoiding unnecessary data hoarding. Automated purge mechanisms help maintain archive efficiency by systematically removing obsolete documents, reducing storage costs, and minimizing privacy risks. At the same time, special provisions must be made for documents that may be needed in legal proceedings or that have historical significance for the organization.

Looking forward, the management of compliance documentation is becoming increasingly integrated with broader enterprise risk management systems. By analysing patterns in compliance documentation, organizations can identify emerging risks, spot process inefficiencies, and make data-driven decisions about resource allocation. The most forward-thinking companies are treating their compliance archives not just as regulatory necessities, but as valuable organizational assets that can provide insights for strategic planning and continuous improvement.

As ESG reporting expectations continue to evolve, the ability to efficiently manage and archive compliance documentation will remain a key differentiator for organizations committed to sustainability and good governance [7]. Those that invest in robust systems and processes today will be better positioned to meet tomorrow's reporting challenges while maintaining stakeholder trust and competitive advantage in an increasingly transparency-driven business environment.

4. Preparation of reports for regulatory bodies

The preparation and submission of accurate, timely reports to regulatory authorities has become a critical competency for organizations operating in today's complex compliance landscape [8]. As environmental and sustainability reporting requirements grow more detailed and frequent, companies must develop streamlined processes to transform raw operational data into compliant disclosures that meet exacting regulatory standards. This function has evolved from a routine administrative task to a strategic process that requires cross-departmental coordination, specialized technical knowledge, and rigorous quality controls.

At the core of effective regulatory reporting lies a well-designed data governance framework. Organizations must establish clear protocols for data collection, validation, and transformation to ensure all reported information is accurate, complete, and traceable to source documents. Modern reporting teams are implementing automated data pipelines that pull information directly from operational systems – energy management platforms, emissions monitoring equipment, and supply chain databases – minimizing manual intervention and reducing the risk of transcription errors. These systems increasingly incorporate artificial intelligence to flag anomalies, validate calculations, and ensure consistency across different reporting periods and formats.

The complexity of regulatory reporting demands careful attention to the specific requirements of each governing body and jurisdiction. Reporting teams must maintain up-to-date knowledge of evolving frameworks such as the EU's CSRD, the SEC's climate disclosure rules, or various national emissions reporting schemes [9]. This requires not only understanding the explicit data requirements but also interpreting how these apply to the organization's specific operations and industry context. Many companies are developing internal playbooks that translate regulatory language into concrete data needs and reporting templates, ensuring consistency across reporting cycles and geographical locations.

Structured approval workflows represent another critical component of the reporting process. As regulatory submissions carry significant legal implications, organizations are implementing multi-tiered review processes involving technical experts, legal counsel, and senior management. Digital workflow platforms help track revisions, document approvals, and maintain audit trails of all changes made during the report preparation process. Version control systems ensure that all stakeholders are working with the most current information while preserving historical iterations for reference and audit purposes.

The presentation and formatting of regulatory reports requires equal attention to detail. Many authorities now mandate specific digital reporting formats, such as XBRL (extensible Business Reporting Language) for financial data or XML schemas for environmental disclosures [10]. Reporting teams must master these technical requirements while ensuring the reports remain accessible and understandable to human reviewers. Visualization tools are increasingly being employed to present complex sustainability data in clear, standardized formats that facilitate regulatory review and analysis.

Quality assurance processes form the final safeguard before report submission. Leading organizations conduct pre-submission audits that verify data accuracy, check compliance with reporting requirements, and assess the overall coherence of the disclosure. Some are establishing internal "quality gates" where reports must meet predefined accuracy thresholds before progressing to the next stage of review. These controls are particularly important as regulators increase their scrutiny of corporate sustainability claims and impose stricter penalties for misreporting.

Post-submission processes complete the reporting cycle. Forward-thinking organizations systematically document regulator feedback and questions, using these insights to improve future reporting processes. They maintain comprehensive submission archives that include not just the final reports but all supporting documentation, calculations, and internal review comments. These archives serve as vital references during regulatory inquiries or audits and provide valuable institutional knowledge as reporting teams evolve over time.

As reporting requirements continue to expand in scope and complexity, organizations are recognizing the need to build specialized reporting competencies. This includes investing in training programs to develop staff expertise in both regulatory requirements and reporting technologies, as well as establishing centres of excellence to maintain consistency across different reporting obligations. The most sophisticated reporters are beginning to apply predictive analytics to anticipate future reporting demands and prepare their data collection systems accordingly.

The preparation of regulatory reports has emerged as a strategic function that goes beyond basic compliance. Organizations that excel in this area gain multiple advantages: they reduce compliance risks, build credibility with regulators and stakeholders, and derive valuable operational insights from their reporting processes. In an era of increasing transparency demands, the ability to efficiently produce high-quality regulatory reports represents both a compliance necessity and a competitive differentiator for responsible businesses.

5. Conclusion

The comprehensive examination of reporting and document management in accordance with ESG and regulatory requirements underscores a fundamental shift in how organizations approach sustainability and compliance. Generally, the digital transformation of data collection and reporting processes has enabled organizations to meet growing regulatory demands while deriving valuable business insights from sustainability metrics.

Effective management of compliance documentation now serves as both a legal safeguard and a foundation for transparent stakeholder communication. Meanwhile, the preparation of regulatory reports has become a specialized function requiring cross-departmental collaboration and rigorous quality controls. Organizations that successfully integrate these elements gain more than just compliance; in other words, they build trust with stakeholders, uncover operational efficiencies, and position themselves as leaders in sustainable business practices. As regulations continue to evolve, robust ESG reporting, and documentation systems will remain critical for organizations committed to long-term value creation in an increasingly transparency-driven business environment.

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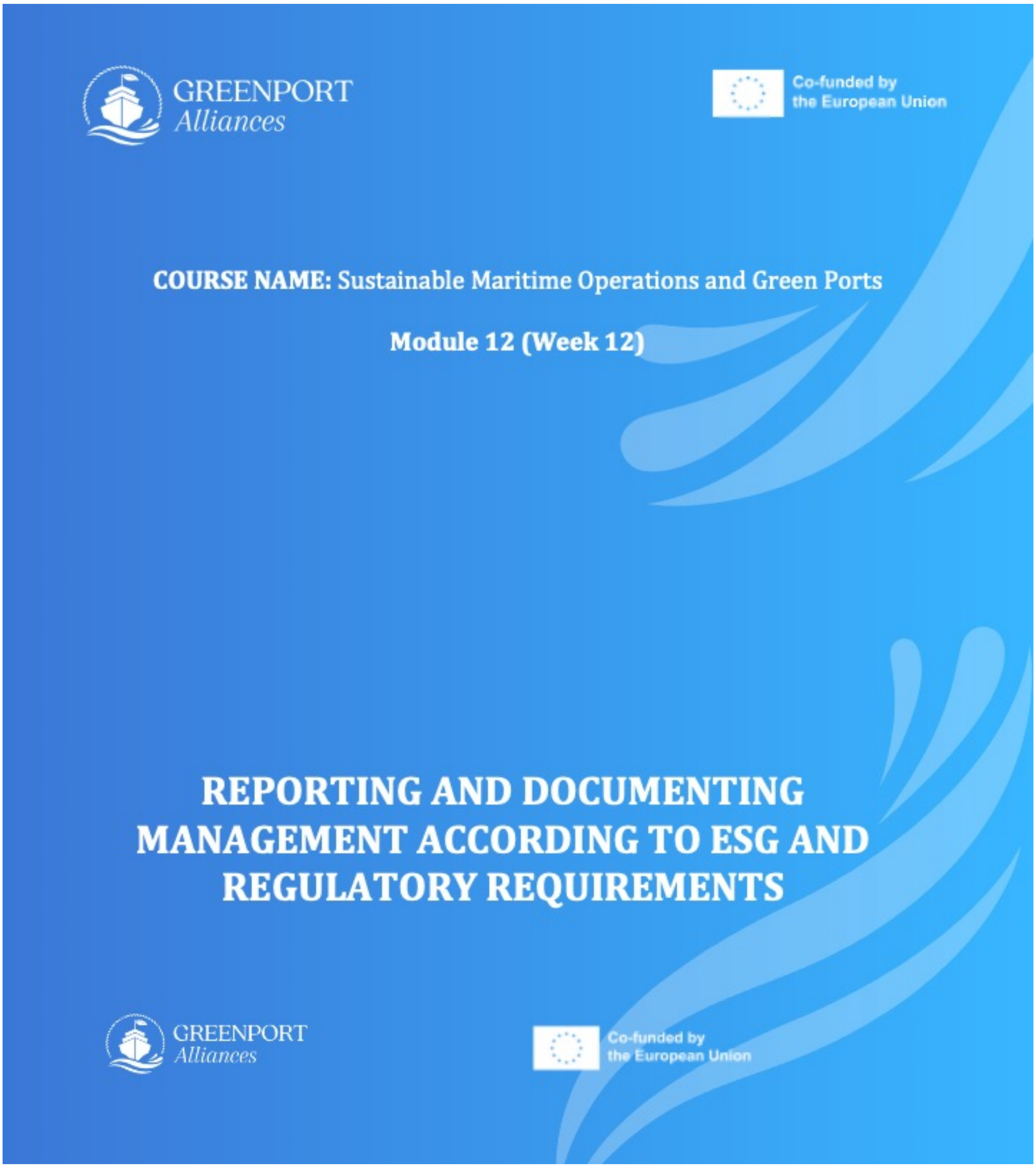
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COURSE NAME: Sustainable Maritime Operations and Green Ports
Module 12 (Week 12)
REPORTING AND DOCUMENTING MANAGEMENT ACCORDING TO ESG AND REGULATORY REQUIREMENTS
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1. Introduction

- Growing importance of ESG compliance and regulatory reporting
- Digital Transformation in ESG Management
- Regulatory challenges and solutions

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 001

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2. ESG standards and reporting requirements

- **Role of ESG Principles in Industry**
  - ESG integration is transforming how sustainability is measured and communicated.
- **Digital Transformation of ESG Processes**
  - Adopting advanced technologies to automate ESG data tracking and reporting.
- **Evolving Regulatory Landscape**
  - Stricter international and national ESG reporting standards
- **ESG as a Strategic Advantage**
  - Efficient ESG management drives improvement, and strengthens market position.

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3. Management and archiving of compliance documentation

- **Compliance Documentation as Strategic Governance**
  - Effective documentation management is essential for ensuring compliance, and transparent stakeholder communication.

- **Digital Archiving Systems**
  - Cloud-based platforms with version control and automated retention policies are replacing traditional record-keeping systems.

- **Advanced Technologies in Compliance Management**
  - AI, machine learning, and blockchain enhance accuracy, detect inconsistencies, and create immutable audit trails.

- **Flexibility for Evolving Regulations**
  - Compliance systems must adapt to changing reporting standards through clear workflows, versioning, and cross-functional collaboration.

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3. Management and archiving of compliance documentation

- **Secure and Accessible Archiving**
  - Balancing audit-readiness and data protection with encryption, role-based access, and hybrid storage models.

- **Lifecycle Management of Compliance Data**
  - Retention policies and automated purging reduce storage costs, mitigate privacy risks, and ensure legal preparedness.

- **Integration with Enterprise Risk Management**
  - Analyzing compliance data reveals operational risks and informs strategic, data-driven decision-making.

- **Competitive Advantage Through Robust Systems**
  - Strong compliance infrastructure sets companies apart in ESG reporting and strengthens stakeholder trust.

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4. Preparation of reports for regulatory bodies

- **Regulatory Reporting as a Strategic Function**
  - The preparation of timely, accurate reports has evolved into a strategic, cross-functional process with legal and reputational stakes.

- **Strong Data Governance Framework**
  - Clear protocols for data collection, validation, and traceability are essential for high-quality, auditable reporting.

- **Automation and AI in Data Processing**
  - Automated data pipelines and AI tools reduce manual errors, validate outputs, and enhance consistency across reporting cycles.

- **Adapting to Complex Regulatory Frameworks**
  - Organizations must interpret and apply jurisdiction-specific rules (e.g., CSRD, SEC climate rules) through internal playbooks and templates.

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4. Preparation of reports for regulatory bodies

- **Structured Approval and Workflow Controls**
  - Multi-level reviews, digital workflow platforms, and version control ensure legal oversight and process transparency.

- **Compliance with Technical Reporting Standards**
  - Managing digital formats and use visualization tools to meet submission standards and improve clarity.

- **Pre- and Post-Submission Quality Assurance**
  - Quality gates, audits, and feedback tracking support continuous improvement and regulator trust.

- **Building Specialized Reporting Competencies**
  - Investing in training, centers of excellence, and predictive analytics helps organizations stay ahead of evolving reporting demands.

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Conclusion

- **Digital transformation** is central to meeting ESG and regulatory reporting demands efficiently.
- **Compliance documentation** is now both a legal requirement and a tool for transparent stakeholder engagement.
- **Regulatory reporting** has evolved into a strategic, cross-functional discipline with high standards for accuracy and quality.
- **Integrated ESG systems** drive not only compliance but also operational insights, trust, and competitive advantage.
- **Long-term success** depends on robust, adaptable ESG frameworks aligned with evolving transparency expectations.

Chapter 12 Assessment Questions

Reporting and document management according to ESG and regulatory requirements

EXAM QUESTIONS

1. What is a key benefit of using automated reporting tools for ESG compliance?

a. reducing the need for any human involvement
b. increasing the administrative burden for companies
c**. enabling more accurate measurement of environmental impact**
d. eliminating all regulatory requirements
e. focusing only on financial data

2. Which of the following is a major challenge in ESG regulatory reporting?

a. lack of interest from investors
b. decreasing number of sustainability frameworks
c. navigating complex international and national regulations
d. reduced need for data accuracy
e. fewer requirements for transparency

3. What role do AI and machine learning play in compliance documentation?

a. they replace all human decision-making
b. they automatically classify documents and flag inconsistencies
c. they eliminate the need for regulatory audits
d. they only work with paper-based systems
e. they reduce the need for any documentation

4. Why is digital archiving important for ESG compliance?

a. it allows companies to avoid all reporting requirements
b. it ensures documents are only accessible to external regulators
c. it provides secure storage, version control, and quick audit responses
d. it removes the need for any compliance checks
e. it focuses solely on financial records

5. What is a critical step in preparing reports for regulatory bodies?

a. ignoring data validation processes
b. using only manual data entry methods
c. implementing structured approval workflows
d. avoiding any digital tools

e. submitting reports without internal reviews

6. How does blockchain technology support compliance documentation?

a. by making all data publicly editable

b. by creating immutable audit trails for transactions

c. by eliminating the need for any documentation

d. by reducing the importance of ESG standards

e. by focusing only on social governance

7. What is a key advantage of cloud-based platforms in ESG reporting?

a. they prevent any external audits

b. they limit access to only senior management

c. they enable processing large datasets and generating comprehensive reports

d. they remove the need for compliance with any regulations

e. they only store financial records

8. Why is cross-functional collaboration important in ESG documentation?

a. It ensures only one department handles compliance

b. It eliminates the need for digital tools

c. It helps legal, compliance, and sustainability teams align on requirements

d. It reduces transparency with stakeholders

e. It focuses only on short-term reporting

9. What is a key feature of effective regulatory report submission?

a. avoiding any pre-submission checks

b. using only paper-based formats

c. maintaining comprehensive submission archives

d. ignoring regulator feedback

e. submitting reports without supporting data

10. How can companies turn ESG compliance into a strategic advantage?

a. by avoiding all sustainability disclosures

b. by using data only for internal purposes

c. by leveraging compliance insights for risk management and decision-making

d. by reducing transparency with investors

e. by focusing only on short-term financial gains

CHAPTER 13

COURSE Module 13 (Week 13)

COURSE Module 13 (Week 13)

Communication and Stakeholder Engagement

1. Introduction

Maritime transport and port operations are at the heart of global trade and, in the modern context, face increasing demands for sustainability, digitalization, and cross-sector collaboration. The transition toward green ports involves not only technical innovations and environmentally friendly technologies but also a fundamental change in the way complex systems is managed and a large number of stakeholders are coordinated. In this process, **port authorities, operators, shipowners, customs services, local communities**, and **technology partners** play a key role, with their cooperation determining the success of implementing sustainable solutions. To achieve greater efficiency and transparency, it is essential to rely on digital platforms and tools that enable real-time information exchange, precise operational planning, and reduction of the environmental footprint. The introduction of systems such as Port Community Systems, PortCDM, blockchain technologies, digital twins, emissions tracking platforms, and Just-in-Time solutions represents an important step toward process optimization and increasing port resilience. Beyond the technical component, the transformation requires **changes in behaviours of individuals, organizational culture** and **management,** including systematic **involvement of all stakeholders**, clearly defined **communication protocols**, and **change management strategies**. It is precisely this integration of technological, regulatory, and social elements that enables the development of green ports that are competitive, adaptable, and sustainable in the long term.

2. Roles of various stakeholders in sustainable port operations

Port authorities are central coordinating entities connecting various actors in port operations. Their role includes regulating the planning and development of port infrastructure, decision-making, enforcing regulations, and financing projects. In the context of green ports, port authorities take the lead in initiatives such as shore power systems, coordinating the diverse interests of stakeholders and ensuring implementation that is environmentally, economically, and socially sustainable.

Pilots and tug operators form the core operational actors in port services. Their collaboration is crucial for safe and energy-efficient operations, requiring clear communication and coordination before and during port activities. **The European Tugowners Association (ETA)** and the **European Maritime Pilots' Association (EMPA)** have developed recommendations based on three principles: **planning, cooperation,** and **communication**.

Shipowners and vessel operators are users of port services whose demands for efficiency and reliability influence operational decisions. Their cooperation with port authorities and service providers is key to implementing green technologies and procedures.

Customs and regulatory agencies are responsible for controlling the flow of goods across borders and ensuring compliance with international regulations. In the context of green ports, these agencies play an important role in enforcing environmental standards and regulations.

Technology providers enable the digital transformation of port operations through the development and implementation of advanced communication and management systems. Their cooperation with port authorities and operators is crucial for successful digitalization.

Local communities represent an important stakeholder group as they are directly affected by port activities, especially concerning emissions and environmental impact. Port authorities must involve local communities in projects and maintain transparency about green port initiatives.

Stakeholders can be categorized along several dimensions.

According to **influence and power**, we distinguish high influence groups including port authorities, major shipowners, and regulators; medium influence groups encompassing pilots, tug operators, and technology providers; and low influence groups consisting of local communities and small service providers.

Based on **proximity to operations**, stakeholders can be internal such as port employees, pilots, and tug operators; boundary stakeholders including shipowners, freight forwarders, and customs agencies; and external stakeholders like regulators, local communities, and NGOs.

By **interest type,** stakeholders can be commercial, including shipowners, terminal operators, and service providers; regulatory, which covers customs agencies, maritime administrations, and environmental regulators; and social, comprising local communities and NGOs.

This structured approach to categorization enables a clear understanding of the complex network of relationships among different actors in port operations and their specific roles in the context of sustainable maritime activities.

3. Behavioural change: The role of training, leadership, and peer influence

Ports serve as vital hubs for international trade and transportation, but their operations can significantly impact the environment and local communities. As the demand for sustainable practices grows, port authorities and stakeholders must adopt strategies that promote environmental stewardship and social responsibility. Behavioural change among stakeholders is essential to this transition, and it can be effectively facilitated through targeted training, strong leadership, and positive peer influence.

Stakeholder management involves **identifying, engaging**, and **collaborating** with individuals and groups that have an interest in port operations. Effective stakeholder management is crucial for:

Building Trust: Establishing transparent communication channels fosters trust and collaboration among stakeholders.

Enhancing Compliance: Engaging stakeholders helps ensure adherence to environmental regulations and sustainability initiatives.

Raising Awareness: Educating stakeholders about the environmental impacts of port operations and the importance of sustainability.

Skill Development: Providing practical skills for implementing sustainable practices, such as waste management, energy efficiency, and pollution control.

Types of Training for a behavioural change at various levels may include;

Higher Education Modules for future personnel such as ship and port managers, and pilot candidates in their respective curricula at maritime higher education institutes

Vocational Short courses for industry and trainers for skilling, reskilling/upskilling

Workshops and Seminars: Interactive sessions that engage stakeholders in discussions about sustainability challenges and solutions.

On-the-Job Training: Practical training that allows employees to learn sustainable practices to adopt for behavioural change in real-world scenarios.
E-Learning Modules: Online courses that provide flexible access to training materials, enabling stakeholders to learn at their own pace.

To ensure that training programs lead to meaningful behavioural change, it is essential to evaluate their effectiveness through:
Pre and Post Training Assessments: Measuring knowledge and skill improvements before and after training sessions.
Feedback Surveys: Gathering stakeholder feedback to identify areas for improvement in training content and delivery.

Effective leadership is crucial for fostering a culture of sustainability within port operations. Leaders can influence behavioural change by:
Setting a Vision: Articulating a clear vision for sustainability that aligns with organizational goals and stakeholder interests.
Modelling Behaviour: Demonstrating commitment to sustainable practices through personal actions and decision-making.
Empowering Stakeholders: Encouraging stakeholders to take ownership of sustainability initiatives and providing them with the resources needed to succeed.

Different leadership styles can impact stakeholder engagement and behavioural change. **Transformational Leadership** by inspiring and motivating stakeholders to embrace sustainability through a shared vision and collaborative efforts and **Servant Leadership**, prioritizing the needs of stakeholders and fostering a supportive environment for sustainable practices can be considered as the most effective leadership styles for behavioural change.

Leaders should establish accountability mechanisms to ensure that sustainability goals are met. This can include performance metrics such as setting measurable sustainability targets and regularly assessing progress. Acknowledging and rewarding stakeholders who demonstrate exemplary commitment to sustainability is also important to maintain motivation.

Peer influence plays a significant role in shaping behaviour and attitudes toward sustainability among stakeholders. In the context of social learning, stakeholders often look to their peers for guidance on acceptable behaviours and practices. Positive examples can encourage others to adopt sustainable practices. When stakeholders work together towards common sustainability goals, it fosters a sense of community and shared responsibility in a collective action approach.

Strategies to enhance peer influence may include peer mentorship programs. Pairing experienced stakeholders with those new to sustainability initiatives can facilitate knowledge transfer and skill development. Collaborative projects engaging stakeholders in joint sustainability projects encourages teamwork and reinforces positive behaviours.

Creating a culture that values sustainability requires open communication to encourage dialogue among stakeholders about sustainability challenges and successes. Celebrating achievements by recognizing collective efforts and milestones in sustainability initiatives reinforce positive behaviours.

Training, leadership, and peer influence are essential components for driving behavioural change in stakeholder management for sustainable port operations. By investing in training programs, fostering effective leadership, and leveraging peer influence, ports can create a culture of sustainability that engages all stakeholders. As the maritime industry continues to evolve, embracing these elements will be crucial for achieving long-term sustainability goals and minimizing the environmental impact of port operations.

4. Good planning of effective communication with all players involved

Communication protocols in port operations must be carefully designed. Effective communication involves pre-defined planning of towing operations, coordination among involved parties during the creation of operational plans, and sharing all relevant information such as pilot availability, tugs, and berth time windows. Precise and clear communication between pilots, captains, and tug operators during all phases of port operations is crucial. Managing resistance to change in this context includes developing business cases tailored to the specific goals of each stakeholder, ensuring early involvement in change processes, promoting collaboration within the entire ecosystem, and maintaining transparency about all initiatives and their benefits. Continuous improvement and evaluation of communication and collaboration effectiveness play an important role in system stability and adaptability. Monitoring mechanisms include regular performance analysis of all stakeholders, systematic collection and analysis of feedback, and dynamic strategy adjustment based on practical insights. Platforms for sharing best practices facilitate knowledge exchange among port authorities and learning from successful projects, while workshops and forums enable informal networking and experience transfer among actors from different sectors and geographical areas. Innovation and multidisciplinary approaches are key to preparing future professionals who will lead sustainability processes in the maritime industry. Collaboration with industry partners allows educational institutions to keep curricula aligned with current trends and equip students with knowledge and skills adapted to real-world challenges.

Successful communication and collaboration with all relevant stakeholders in green port operations require a systematic approach combining traditional methods and modern digital technologies. Clear identification of all stakeholders, effective communication channels, and structured change management must become integral parts of daily operational processes rather than additional activities. Digital transformation brings new solutions but also challenges such as the need for interoperability, high levels of cybersecurity, and management of complex information systems. Successful implementation of green technologies and practices can only be achieved through continuous dialogue, clearly defined roles and responsibilities for all involved, and flexible mechanisms for adapting to changing conditions.

In modern logistics and maritime environments, digitalization plays a crucial role in enhancing efficiency, safety, and transparency. Port systems increasingly rely on advanced information technologies that enable better coordination and data exchange among all participants in the supply chain. Among the most important technological solutions in this context are Port Community Systems (PCS), Port Collaborative Decision Making (PortCDM), blockchain technology, digital twins, emissions tracking platforms, as well as advanced communication standards and digital tools.

Port Collaborative Decision Making (PortCDM) is a digital system designed to enhance situational awareness and coordination between port and inland operators. Developed under the auspices of the International PortCDM Council (IPCDMC), this methodology enables the transparent exchange of plans, assessments, and updates in real time, leading to better synchronization of all activities and a significant reduction in vessel and cargo traffic delays. PortCDM enables all stakeholders in the port call process to collaborate and share data by using a standardized port call message format, driving the creation of common situational awareness for enhanced and synchronized planning.

Pre-arrival notification systems and ETA sharing platforms form the backbone of efficient port operations. These systems enable vessels to submit arrival notifications well in advance, allowing port authorities to anticipate vessel requirements and optimize resource allocation. The accuracy and reliability of ETA predictions are crucial for implementing Just-in-Time operations, as they enable vessels to adjust their sailing speed to arrive exactly when port services are available. Modern arrival systems integrate AI-powered ETA prediction services that leverage historical vessel movement data, live traffic information, weather conditions, and routing data to generate accurate forecasts. These systems support real-time information sharing and coordination between authorities, port community systems, and logistics operators.

Digital twins create virtual replicas of physical port assets, including terminals, cranes, warehouses, and transport networks. These digital models continuously update with real-time data from sensors and IoT devices, providing a dynamic view of port operations. Digital twins enable port operators to simulate scenarios, optimize resource allocation, and reduce energy consumption by facilitating Just-in-Time operations. Emissions tracking platforms provide comprehensive monitoring and reporting of vessel emissions in port areas. These platforms combine AIS vessel movement data with sophisticated emissions calculations to identify emission sources and opportunities for reduction. Real-time emissions monitoring enables ports to benchmark operations, develop reduction strategies, and ensure regulatory compliance.

The integration of PortCDM, arrival systems, and emissions tracking creates a synergistic effect that significantly reduces both emissions and operational delays through several key mechanisms:

Enhanced Predictability: Shared timestamp data and collaborative planning enable more accurate ETA predictions, allowing vessels to optimize their sailing speed and arrive Just-in-Time. This eliminates the "hurry up and wait" mode of operation, where vessels sail at full speed only to anchor outside ports for extended periods.

Coordinated Resource Allocation: Real-time data sharing through PortCDM enables better coordination of port services including pilots, tugs, berths, and cargo handling equipment. This coordination reduces waiting times and ensures optimal utilization of resources. Optimized Sailing Operations: By sharing reliable RTA (Requested Time of Arrival) information, vessels can adjust their speed to arrive precisely when port services are available, reducing fuel consumption by up to 10-15% and corresponding emissions. Reduced Anchorage Time: Collaborative planning and shared data enable ports to minimize vessel anchoring time, which directly translates to reduced emissions from auxiliary engines and improved air quality in port areas. Improved Operational Efficiency: Studies show that ports implementing collaborative decision-making report improved work procedures, reduced time spent on information gathering, and reduction of administrative workload by over 80%.

Digital coordination tools such as Just-In-Time (JIT) platforms enable ship agents, tugboat operators, and fuel suppliers to exchange key data on vessel arrivals and required services, resulting in better coordination of pilotage, towing, and supply services, reduced waiting times at anchorages, and increased operational efficiency by minimizing delays. Navigation aids and supportive tools provide pilots with enhanced situational awareness using official, local, and bathymetric data. These digital navigation aids serve as supportive tools to complement traditional navigation methods. These digital tools should never be relied upon solely - they are navigation aids designed to support, not replace, proper seamanship and compliance with collision regulations.

5. Eliciting the required information for smooth operations

Efficient port operations rely heavily on accurate and timely information. Eliciting the required information from various stakeholders—such as port authorities, shipping companies, customs officials, and local communities—is essential for ensuring smooth operations.

Structured interviews involve predetermined questions that guide the conversation, ensuring that all relevant topics are covered comprehensively. It provides uniformity in responses, making it easier to compare data in a consistent way. Allows for follow-up questions to clarify responses.

Surveys and questionnaires can be distributed to a larger audience to gather quantitative and qualitative data. From a scalability perspective it can reach a wide range of stakeholders quickly and anonymity encourages honest feedback, especially on sensitive topics.

Surveys can be distributed through online platforms (e.g., Google Forms, SurveyMonkey), and may include both closed ended (quantitative) and open-ended (qualitative) questions.

Focus Groups involve guided discussions with a small group of stakeholders to gather diverse perspectives on specific topics. Interactive feedback can be received as participants can build on each other's ideas, leading to richer discussions. It provides immediate clarification facilitating real-time clarification of points raised during discussions. A diverse group of stakeholders to participate must be carefully selected and a skilled facilitator will be required to guide the discussion and keep it focused.

Workshops and Collaborative Sessions bring together stakeholders for collaborative problem-solving and information sharing. Collective knowledge harnesses the expertise of multiple stakeholders to identify challenges and solutions and encourages active participation and buy-in from all parties. Workshops can be organized around specific operational challenges or initiatives. Use brainstorming sessions, breakout groups, and presentations to encourage participation.

Observational studies involve monitoring operations and interactions among stakeholders to gather information on processes and behaviours. Real-time data provides insights into actual practices rather than reported behaviours and contextual understanding helps identify discrepancies between policy and practice. This may include site visits to observe operations in real-time.

Data Analysis of existing data from various sources (e.g., operational logs, performance metrics) can provide valuable insights. Objective insights provide reliance on factual data rather than subjective opinions. Trend identification helps identify patterns and trends over time. Data can be collected from operational systems, databases, and reports. Data analytics tools can be used to interpret the information and generate actionable insights.

Stakeholder Meetings, regular meetings with stakeholders provide a platform for sharing information, updates, and addressing concerns. Open communication fosters transparency and encourages dialogue among stakeholders. Relationship Building strengthens relationships and trust between parties. Scheduling regular meetings (e.g., monthly or quarterly) with key stakeholders can be considered that focus on operational updates, challenges, and feedback.

Utilizing technology, such as mobile apps and collaboration platforms, can facilitate information sharing and communication. Real-time updates allow for immediate sharing of information and notifications and ensures that stakeholders can access information anytime and anywhere.

Eliciting the required information for smooth port operations is crucial for enhancing efficiency, safety, and stakeholder satisfaction. By employing a combination of structured interviews, surveys, focus groups, workshops, observational studies, data analysis, stakeholder meetings, and technology, port authorities can gather the necessary insights to inform decision-making and optimize operations. Adopting these approaches fosters a culture of collaboration and continuous improvement, ultimately contributing to the success of port operations.

6. Clarifying the role of digital aids (e.g. PPU, VR)

Digital aids, such as Portable Pilot Units (PPUs) and Virtual Reality (VR) technologies, play a transformative role in enhancing the efficiency, safety, and decision-making processes in port operations. These tools leverage advanced technology to improve communication, training, and operational effectiveness.

Portable Pilot Units (PPU) are electronic devices used by maritime pilots to assist in navigating vessels safely in and out of ports. These units provide real-time data and situational awareness to enhance decision-making during critical navigation phases.

PPUs provide pilots with access to forecasted weather conditions, predicted tides, currents, and vessel traffic through AIS. This data is crucial for making informed navigation decisions.

By integrating data from various sources, such as AIS (Automatic Identification System) and radar, PPU helps pilots visualize their surroundings more effectively, allowing for better situational awareness.

Pilots can use PPUs to plan optimal routes, different scenarios, and assess potential risks before executing manoeuvres. By providing accurate and timely information, PPUs contribute to safer navigation, reducing the risk of accidents and grounding incidents.

Virtual Reality (VR) technology immerses users in a simulated environment, allowing them to experience and interact with 3D representations of real-world scenarios. In port operations, VR can be used for training, planning, and operational simulations.

VR provides a safe and controlled environment for training port personnel, including pilots, dockworkers, and emergency responders. Trainees can practice handling various scenarios, such as vessel arrivals, cargo handling, and emergency situations, without the risks associated with real-life operations. The immersive nature of VR enhances engagement and retention of information. Trainees can visualize complex processes and understand the spatial relationships between different elements in the port environment.

VR can be utilized to simulate port layouts and operations, allowing stakeholders to visualize changes, assess potential impacts, and optimize workflows before implementation.

VR training can prepare personnel for emergency situations, such as spills or accidents, by simulating crisis scenarios and allowing trainees to practice response strategies in a risk-free setting.

VR can facilitate remote collaboration among team members, allowing stakeholders to meet in a virtual environment to discuss plans, review operations, and make decisions without the need for physical presence.

Digital aids like Portable Pilot Units (PPUs) and Virtual Reality (VR) technologies significantly enhance port operations by improving safety, efficiency, and training effectiveness. PPUs provide pilots with critical real-time data and situational awareness, while VR offers immersive training experiences that prepare personnel for real-world challenges. By integrating these digital tools into port operations, stakeholders can better navigate the complexities of modern maritime logistics, ultimately leading to smoother and safer port operations.

7. Conclusion

Successful communication and collaboration with all relevant stakeholders in green port operations require a systematic approach combining traditional methods and modern digital technologies. The integration of PortCDM, arrival systems, ETA sharing, digital twins, and emissions tracking platforms creates a comprehensive ecosystem that significantly reduces both emissions and operational delays through enhanced planning, cooperation, and shared data.

Clear identification of all stakeholders, effective communication channels, and structured change management must become integral parts of daily operational processes rather than additional activities. Digital transformation brings new solutions but also challenges such as the need for interoperability, high levels of cybersecurity, and management of complex information systems. The implementation of Just-in-Time operations, supported by collaborative planning and real-time data sharing, has proven to reduce fuel consumption, emissions, and waiting times while improving overall port efficiency. Successful implementation of green technologies and practices can only be achieved through continuous dialogue, clearly defined roles and responsibilities for all involved, and flexible mechanisms for adapting to changing conditions.

Change management and communication represent key factors for achieving sustainability and efficiency in port operations. Given the growing need for environmentally friendly solutions and digital transformation, ports must adopt an integrated approach that combines strategic management, cross-sector collaboration, and modern technologies. Key success factors include strong leadership and senior management support, active involvement of all relevant stakeholders in change planning, careful and gradual implementation of changes through clearly defined phases, and continuous education and training of employees to adapt to new demands and technologies.

A review of the Long Beach and Port of Los Angeles case study is particularly instructive, as it demonstrates how the strategic use of digital technologies to facilitate information sharing can lead to measurable reductions in emissions. This example also highlights how ports can proactively address environmental concerns, anticipating future regulatory pressures that may extend to currently exempt operations.

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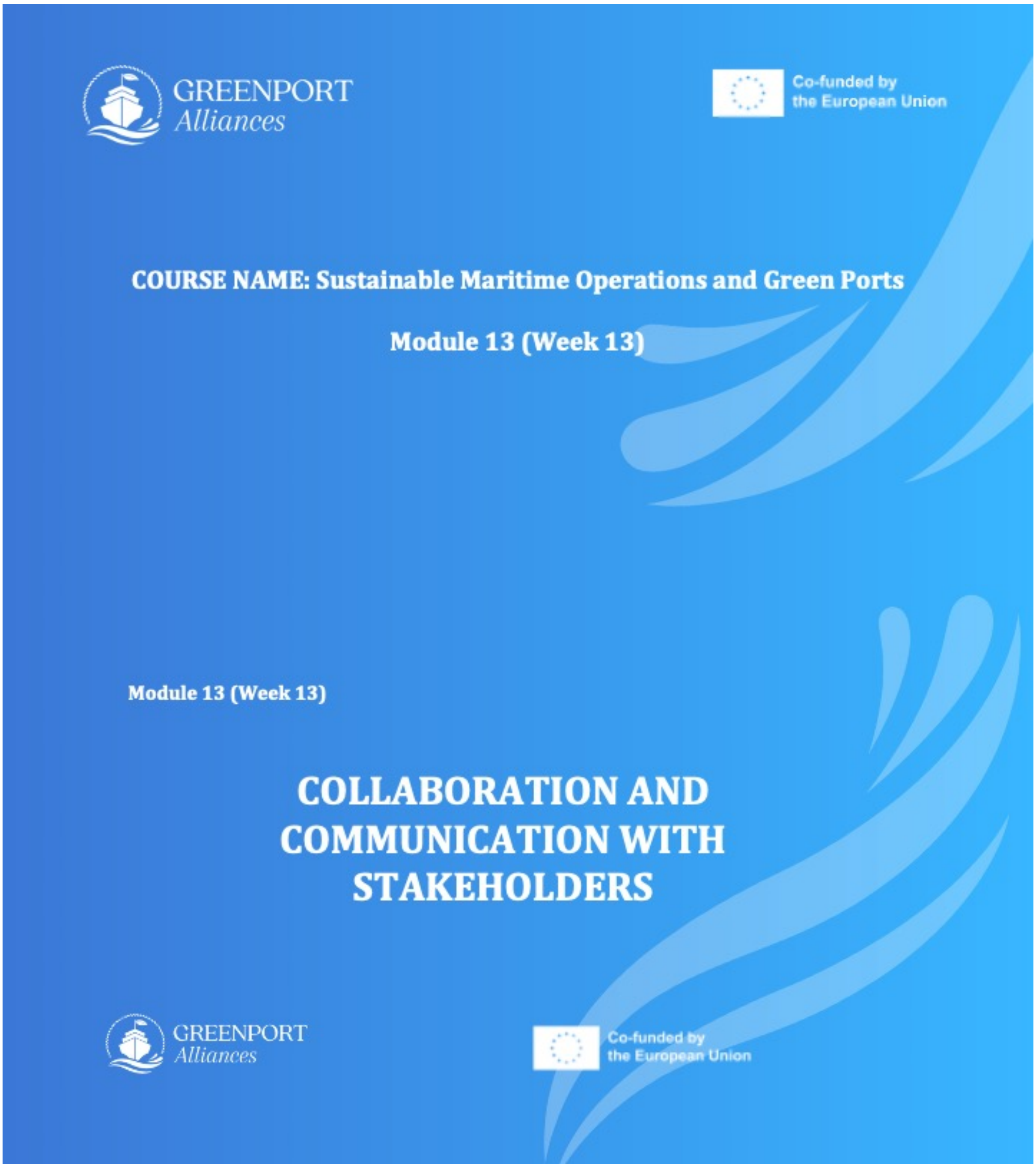
Chapter 13 Supporting Material



1. Introduction

- Maritime transport and port operations lie at the heart of global trade and are facing growing demands for sustainability, digitalization, and cross-sector collaboration.
- The transition to green ports requires not only technical innovations and environmentally friendly technologies but also a fundamental change in how complex systems are managed and multiple stakeholders are coordinated.

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Roles of various stakeholders in sustainable port operations

•**Port authorities** act as central coordinators, connecting various port operation actors.

- Regulate planning and development of port infrastructure
- Decision-making and enforcing regulations
- Financing port projects

•In green port initiatives, **Port authorities** :

- Lead projects like shore power systems
- Coordinate diverse stakeholder interests
- Ensure solutions are environmentally, economically, and socially sustainable

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Key Operational and Stakeholder Actors in Ports

•**Pilots and tug operators**: Core to safe, efficient port services; require close collaboration, planning, and clear communication.

•**Shipowners and vessel operators**: Drive demand for efficiency; their cooperation is vital for adopting green technologies.

•**Customs and regulatory agencies**: Oversee cross-border goods flow; enforce international and environmental regulations.

•**Technology providers**: Enable digital transformation by implementing advanced management and communication systems; crucial partners for port authorities.

•**Local communities**: Directly impacted by port activities (emissions, environment); need transparent communication and involvement in green projects

3. Behavioural change: The role of training, leadership, and peer influence

Stakeholder management: identifying, engaging, and collaborating

- Building Trust
- Enhancing Compliance
- Raising Awareness
- Skill Development

Training for a behavioural change

- Higher Education Modules
- Vocational Short courses,
- Workshops and Seminars,
- On-the-Job Training
- E-Learning Modules

4. Good planning of effective communication with all players involved

•**Digitalization** boosts efficiency, safety, and transparency in logistics and maritime environments.

•**Port Community Systems (PCS):**

- Centralized information platforms connecting all logistics chain actors (freight forwarders, terminal operators, customs, land/sea transport, authorities).
- Provide 40+ services for seamless, secure data exchange, optimizing cargo flow and reducing processing time.

•**Blockchain & Distributed Ledger Technology (DLT):**

- Decentralized databases record transactions transparently and immutably across multiple sites.
- Main benefits: automated transactions, fewer manual processes, real-time tracking, high data security.

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•**Port Collaborative Decision Making (PortCDM):**

- Digital methodology for real-time information sharing and activity synchronization between ports and inland operators.
- Results: less vessel/cargo delay, improved situational awareness.

•**Advanced Communication Standards & Tools**:

- Technologies: Digital Selective Calling (DSC), Automatic Identification System (AIS), VHF/UHF/MF/HF radio, satellite comms, NAVTEX.
- Enable interoperability and system modularity, adapting to varied port needs.

•**Best Practices & Innovations**:

- Maritime and Port Authority of Singapore sets standardization benchmarks.
- Just-In-Time (JIT) platforms and apps like Wärtsilä Pilot PRO improve coordination and navigation.
- IoT sensors enable real-time analytics: cargo tracking, predictive maintenance, route optimization, and fleet management.

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5. Eliciting the required information for smooth operations

- **Integrated approach essential**: Combines strategy, technology, and cross-sector collaboration for sustainability and efficiency.
- **European port development stages**:
  - Reactive
  - Proactive
  - Transactional
  - Interactive
  - Sustainable port
- **Key success factors:**
  - Strong leadership
  - Stakeholder involvement
  - Step-by-step implementation
  - Employee training and education
- **Barriers to change**:
  - Poor coordination and unclear procedures
  - Public-private communication gaps
  - Risk during digital system outages → need for continuity plans

- **Cross-sector cooperation:**
  - Horizontal collaboration optimizes resources and assets
  - EU CO3 Project: Clear rules and structures enable sector connectivity
  - Public-private partnerships drive infrastructure, especially cybersecurity
- **Communication essentials:**
  - Pre-planned towing operations and berth scheduling shared among stakeholders
  - Continuous, clear communication between pilots, captains, and tug operators
- **Key tools & practices:**
  - Performance monitoring and feedback systems
  - Forums, workshops, and best practice platforms for knowledge transfer
  - Dynamic curricula through industry–education partnerships
- **Sustainable ports require:**
  - Systematic stakeholder engagement using both traditional and digital tools
  - Defined roles, flexible strategies, and high-level cybersecurity
  - Ongoing collaboration supporting green corridor initiatives and digital innovation

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6. Clarifying the role of digital aids (e.g. PPU, VR)

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Portable Pilot Units (PPUs) are electronic devices used by maritime pilots to assist in navigating vessels safely in and out of ports. These units provide real-time data and situational awareness to enhance decision-making during critical navigation phases.

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7. Conclusion

Communication and **collaboration** with all relevant stakeholders in green port operations require a systematic approach combining traditional methods and modern digital technologies.

Integration of PortCDM, arrival systems, ETA sharing, digital twins, and emissions tracking platforms creates a comprehensive ecosystem that significantly reduces both emissions and operational delays through enhanced planning, cooperation, and shared data.

Key success factors include strong leadership and senior management support, active involvement of all relevant stakeholders in change planning, careful and gradual implementation of changes through clearly defined phases, and continuous education and training of employees to adapt to new demands and technologies

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Module 13 (Week 13)
COURSE NAME: Sustainable Maritime Operations and Green Ports

Communication and Stakeholder Engagement

Co-funded by the European Union

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Chapter 13 Assessment Questions

Communication and Stakeholder Engagement

EXAM QUESTIONS

1. **What is the main goal of introducing digital platforms and tools in green ports?**
   a. Increasing the number of employees
   b. Enabling real-time information exchange and reducing the environmental footprint
   c. Reducing safety
   d. Increasing customs duties

2. **Which group has the highest influence on port processes according to level of influence and power?**
   a. Local community
   b. Small service providers
   c. Port authorities, major shipowners, and regulators
   d. Technology partners

3. **What is the main function of Port Community Systems (PCS) platforms?**
   a. Transmission of satellite signals
   b. Integration and data exchange among all participants in the port logistics chain
   c. Management of the local community
   d. Ship maintenance

4. **What is the key advantage of applying blockchain technology in ports?**
   a. Reduction of workforce
   b. Transparency and data security
   c. Introduction of paper documentation
   d. Reduction of digitalization

5. **What are the basic elements of successful change management in ports?**
   a. Ignoring feedback
   b. Strong leadership, involvement of all stakeholders, and continuous education
   c. Avoiding communication

d. Lack of planning

6. **Which communication technology is NOT listed as a standard in port digital systems?**
   a. VHF radio
   b. NAVTEX
   c. Telegram
   d. AIS

7. **What do Just-in-Time (JIT) platforms enable in maritime operations?**
   a. Reduced efficiency
   b. Better coordination of pilotage, towing, and supply
   c. Increased waiting at anchorages
   d. Reduced safety

8. **What is the role of the local community in the context of green ports?**
   a. No role
   b. Participates in projects and influences transparency of initiatives
   c. Only finances projects
   d. Manages customs procedures

9. **What is the goal of horizontal cooperation among different maritime companies?**
   a. Increasing costs
   b. Optimization of resource use and increased efficiency
   c. Reduced safety
   d. Avoiding innovation

10. **What is an example of innovation that requires close cooperation of multiple stakeholders for developing alternative fuel infrastructure?**
   a. Green corridors
   b. Traditional ship engines
   c. Paper procedures
   d. Increasing CO_2 emissions

CHAPTER 14

COURSE Module 14 (Week 14)

Development and Implementation of Sustainable Port and Shipping Strategies

1. Introduction

Within the European Union, the Green Deal sets an ambitious target of reducing transport emissions by 55% by 2030 and achieving net-zero emissions by 2050. To meet these goals, ports must adopt comprehensive sustainable strategies encompassing planning, operational efficiency, impact measurement, and investment in innovation.
The **EU Green Deal** aims to transform Europe into a climate neutral and circular economy by 2050. One of the goals in the roadmap is to create a toxic-free environment by preventing the generation of pollutants.
For that reason, transport should become drastically less polluting: the **'Sustainable and Smart Mobility Strategy'** which is part of the Green Deal aims to reduce transport emissions by 90% until 2050.

The European Shipping Industry is and remains a significantly polluting sector, responsible for 3-4% of the EU's total CO2 emissions (European Commission). Efforts are being made EU-wide by policymakers, industry, academia, research, and civil society alike to mitigate the impact of marine vessels and their operators on the environment. The shipping industry in general is committed to reach its emission reduction targets by 2030 and subsequently 2050 (this has been declared on a number of occasions by the World Shipping Council - WSC - and the European Community Shipowners Association - ECSA). The **'Fit for 55 Package'** clearly delineates the targets that shipping in general needs to reach, specifically through the **FuelEU Maritime** and the **Monitoring, Reporting and Verification (MRV)** regulations. Also, the **Emissions Trading Scheme (ETS)** has been updated to include shipping.

In all cases the size of the vessels that fall under these regulations are those of **5000 gross tonnes (GT)** and over. The ETS contemplates smaller vessels but does not include working boats. The rationale behind omitting smaller vessels was that the larger vessels make up 80% of the shipping pollution, and also an impact assessment for vessels under 5000GT had not been carried out.

Being omitted from the regulation does not mean that shipowners of vessels under 5000GT keep on polluting, rather many shipowners want to do their part in decarbonisation. A specific category of the omitted smaller vessels is working boats that carry out port services. Vessels such as tugboats, mooring boats, pilot boats, carry out an important role in ports. Their goal is to ensure the safety of the port assets, the safety of the vessels entering and exiting the port and the overall safety of the environment (land and sea). The mission of these port services is indeed safety. In some specific cases, such as tugboats, there is not a clear technology that will be the innovation that will lead the sector to zero emissions. Most of the innovation available is seen as interim solutions to reduce emissions, however no technology has currently been seen as the long-term solution that can be invested in by shipowners.

What is clear to the sector is that emissions can be reduced in the short term by **changes in behaviour of the various categories of people involved in port services.** The imperative of reducing emissions within the maritime port services sector without waiting for stricter legislation, more elaborate compliance monitoring, or more environmentally friendly technologies to become available. Behavioural change strategy can optimise the **interaction between humans and existing technology** in the short term so that port services use less fuel (i.e., an economic incentive) and thus become more sustainable (i.e., an ecological incentive). This needs a behavioural and attitude change in current and future workers in the sector.

Technology that would mitigate these vessels' environmental impact is being developed, e.g., hydrogen, methanol, ammonia or synthetic drop-in fuels from renewable energy, as well as electric engines. Sustainable supply of new fuels is still a problem. Unfortunately, these technological advancements are either not yet ready for commercial use at a large scale or are not convincing to be long term solutions, being still at a conceptual level or being piloted in test contexts. Although there are several attempts for electric engines, the desired power level is not at the satisfactory level especially for larger ships (and their towage) and for use during severe weather conditions. Moreover, the boats in question have a long lifecycle of 30 years or more. Consequently, the 2050 goals are hard to achieve because many ships operating today will still be sailing by then, even if more efficient ships come onto the market at a later point. The viable technological solution to reach the goals would then be to retrofit ships with transition technologies. However, the extra cost of cleaner technology over one that emits more greenhouse gases (the 'green premium') is a barrier that slows down the introduction of transition technologies. Additionally, it is a fact that **investing in new technology without changing people's attitudes will not solve the climate crises**.

A change in human attitude and behaviour is therefore needed. For that reason, the way how technology is used in practice needs to be considered as well. A collateral advantage of changing attitudes is that we can already initiate this today by changing maritime education and training approaches without the need of high investment costs, and without waiting for the greener technology that is still under development. In addition, a more efficient use of technology results in less fuel consumption. GREENPORT Alliance targeted the unaddressed societal problem of emissions in the port services sector and posits that an immediate mitigating solution can be found through wide **cross-sectoral co-creation** and flow of knowledge and collaboration for innovation in education. The project bridges the existing divide within the different workers/areas of work in port services, as well as the silos that exist between academia/research and industry.

All these sectors on their own are aware of the problem of needing to reduce emissions in the maritime sector and are working in their own fields to provide solutions. By bringing these different areas of work together, will be strengthening Europe's capacity to innovate and to develop and test out new ideas to address the climate crises. This solution proposed cannot be undertaken by any one partner acting alone and will require the concentrated input of all involved to achieve the targeted aim and objectives. The approach is also an innovative one since until now, there have only been fragmented efforts to address behavioural change in terms of emissions reduction.

This strategic approach is the industry's sense of its own initiative, seeking to address a problem that is overlooked by **current regulatory targets** to the detriment of our shared environment, and promoting the understanding that individual actions in port services matter and can contribute to mitigating the climate crises. The sector is thus displaying a sense of initiative in jointly confronting the socio-economic challenge of climate change through educational innovation. This will push the industry and allow it to be pre-emptive and forward-looking, instead of reactive to eventual regulatory obligations, and puts it in a better position for the green transformation.

In the field of HEIs, the project created educational material that can be incorporated into the existing programmes provided by HEIs to prospective maritime personnel. This will develop new skills in the **incoming generation of seafarers** - the ability to understand how daily operations impact emissions, and how to do their work in a more sustainable manner than previously done. Such green skills are growing in demand, and the HE institution needs to be able to innovate so as to prepare its students for the maritime sector of the future, rather than that of the past. This contributes to key goals for European cooperation in higher education identified in the Renewed EU Agenda for Higher Education, namely ‘Ensuring higher education institutions contribute to innovation’ and ‘Tackling skills mismatches and promoting excellence in skills development’.

As has been emphasised, the driving ethos of this innovative approach is to re-frame the education and training framework of port services, seeking behavioural change that better integrates green skills into existing and new curricula. Digital skills will be integrated in the training and education content - digital tools and technology already at hand can support workers’ efforts to be more sustainable, and they need to be supported in understanding how to utilise these new technologies for their increased effectiveness and sustainability at work.

Investing in the industry workers’ green and digital skills in turn links to the increased resilience of the sector. It will ensure that current and future workers are prepared for the changes that are coming - be it from the industry, as both clients and service providers increasingly request or seek to provide services that are ever-more sustainable, or from future EU/national/regional regulations and targets. Moreover, it makes them more accountable to the wider European community, instilling a dedication and understanding of joint action to address the climate crises.

Many market operators in the port service industry are aware that their clients (i.e. ports) are increasingly **implementing ambitious strategies** to reduce their emissions or to reach neutrality. This will mean that eventually the more sustainable port services providers will have a **competitive edge.**
This chapter elaborates in detail on four key areas: planning and implementing sustainability strategies, optimizing port logistics, impact measurement systems with continuous improvement, and the role of innovation and new technologies in port development.

2. Planning and implementation of sustainability strategies

Effective sustainability planning begins with a comprehensive assessment of environmental, social, and economic impacts. Key steps include:

- **Stakeholder Engagement**: Involving port authorities, shipping companies, local communities, and regulators to align goals.
- **Sustainability Frameworks**: Adopting international standards such as ISO 14001 or the UN Sustainable Development Goals (SDGs).
- **Strategic Roadmaps**: Defining short- and long-term objectives, such as reducing carbon emissions, improving waste management, and enhancing biodiversity.

Implementation requires integrating these strategies into port governance, budgeting, and daily operations, supported by policy instruments and performance incentives.

The first step in strategic planning involves a detailed **analysis** of relevant legal and institutional frameworks at the international, European, and national levels. This includes reviewing regulations set by the International Maritime Organization, the EU regulations on ship engine emissions, legislative initiatives like the "Fit for 55" package, and national strategies for sustainable transport development. **Legal alignment** ensures that port authorities and shipping service operators meet minimum standards and secure incentives, including subsidies for adopting low-carbon technologies.

Following the legal analysis, the port authority should formulate a clear **sustainability vision and mission** that encompass environmental, economic, and social aspects of development. The vision should be based on the idea of transforming the port into a green energy hub for integrated systems of electricity, hydrogen, and other low-carbon fuels.

Engaging key stakeholders, government bodies, ancillary service operators, the local community, and academia is crucial for developing a cohesive strategy and securing support and funding.

Implementation requires integrating these strategies into port governance, budgeting, and daily operations, supported by policy instruments and performance incentives.

The implementation of the sustainability strategy proceeds through four phases. In the conceptualization phase, the strategic framework is defined, and the Port Energy Transition Master Plan is prepared. This is followed by detailed planning, which includes developing technical and financial plans for low-carbon infrastructure projects such as shore-side electricity supply and hydrogen storage. The third phase covers the execution of concrete projects, including the construction of alternative fuel refuelling stations, modernization of loading and unloading machinery, and digitization of emission monitoring systems. The final phase involves evaluation and adjustment of the strategy through regular reviews of achieved results against key performance indicators and the adaptation of plans according to new technologies and changes in the regulatory framework.

The most recent European regulatory framework significantly accelerates decarbonisation in maritime transport and port operations. The following acts are particularly relevant:

FuelEU Maritime Regulation (EU 2023/1805): This regulation sets mandatory greenhouse gas (GHG) intensity reduction targets for the energy used by ships, with stepwise implementation up to 2050. It includes a strong focus on Onshore Power Supply (OPS), mandating that from 2030, passenger and container ships must use shore-side electricity in major EU ports, thereby reducing emissions at berth.

EU ETS Directive (EU 2023/959): The revised EU Emissions Trading System (ETS) has been extended to cover the maritime sector from 2024 onwards, initially for CO_2 (and later also for N_2O and CH_4). This obliges ship operators of vessels larger than 5,000 GT to monitor, report, and pay for their emissions on relevant voyages, thus internalising environmental costs into the shipping sector.

Alternative Fuels Infrastructure Regulation (AFIR, EU 2023/1804): AFIR requires the establishment of adequate infrastructure for alternative fuels, such as OPS connections, hydrogen, and e-fuel bunkering facilities in both sea and inland ports. For instance, all major EU ports must be equipped with sufficient OPS infrastructure for container and passenger ships by 2030.

OPS Directive (Directive 2014/94/EU, as amended): This directive sets technical standards and minimum requirements for the deployment of OPS at EU ports, ensuring interoperability and safety.

Implementing these regulations requires port authorities, terminal operators, and vessel owners to strategically invest in alternative energy sources, digital monitoring, and shore power infrastructure. Furthermore, alignment with these regulations is often linked to eligibility for EU funding mechanisms and innovation support instruments hence ports must establish specific, measurable, achievable, relevant, and time-bound (SMART) targets aligned to regulations.

3. Operational efficiency in ports and optimizing port logistics.

Increasing operational efficiency in ports and optimizing port logistics is based on the digitization and automation of key processes such as traffic flow, berth scheduling, truck traffic control, and inventory management. The application of intelligent transport systems enables real-time tracking of vessel arrivals and departures, reducing waiting times and avoiding unnecessary fluctuations in operations. Lean logistics and just-in-time operations also contribute to minimizing resource use and waste

Digital platforms for managing cargo flows connect the port with its logistics hinterland, optimize vehicle routing, and contribute to reducing emissions caused by inefficient operations. Auxiliary vessels, such as tugboats and pilot boats, are often not included in national emission reduction targets, although their cumulative fuel consumption significantly impacts local air quality.

Slow steaming strategies, which include optimizing speed and route planning within the port area, enable fuel consumption reductions of up to 15% per operation. Establishing standardized manoeuvring procedures, combined with the use of digital seabed maps, increases safety and allows for more precise vessel movements, while simultaneously reducing unnecessary turns.

Including auxiliary services in emission reduction targets is both feasible and economically beneficial, especially when supported by close collaboration with technology providers and access to EU funding.

4. Measuring impact and continuous improvement

Effective monitoring of the progress of sustainability strategies in ports is based on the application of multidimensional key performance indicators (KPIs) grouped into four main dimensions: economic, environmental, social, and governance. Within the environmental dimension, particularly important indicators include total emissions of carbon dioxide, nitrogen oxides, and sulphur oxides, as well as fuel consumption per individual operation.

In the social aspect, key indicators include the number of safety incidents and air quality levels in the port hinterland, reflecting the impact of port activities on the local community and public health. Digital platforms play a crucial role in modern monitoring and reporting systems. Additionally, the integration of meteorological data and information on sea conditions provides a comprehensive overview of the operational and environmental status of the system. These systems generate clear and interactive dashboards tailored to the needs of different teams within the organization, accelerating decision-making, increasing efficiency, and reducing the need for external support.

To ensure continuous adaptation of the strategy to changing conditions, regular annual audits are conducted, enabling the reassessment of goals, analysis of possible deviations, and identification of new opportunities for improvement.

Continuous improvement is driven by feedback loops, benchmarking, and adaptive management practices. Benchmarking against leading European and global ports, provides a foundation for adopting best practices and continually adjusting key performance indicators in line with global standards and trends.

5. The role of innovation and new technologies in port development

Innovation is a catalyst for sustainable transformation. Emerging technologies are reshaping port operations:

- **Green Technologies**: Shore power systems, electric vehicles, and alternative fuels reduce emissions.
- **Smart Ports**: IoT, blockchain, and automation and digital twins enhance efficiency, security, and traceability.

Digital twins represent virtual replicas of physical port infrastructures and equipment based on data collected through sensors, as well as geographic information systems (GIS) and building information models (BIM). Using digital twins, it is possible to simulate various terminal load scenarios, test new logistics solutions, and conduct predictive maintenance of cranes and transport vehicles, thereby reducing unexpected downtime and the related repair costs. The Internet of Things (IoT) and automation play a key role in modernizing port operations. It is possible to demonstrate how green digital investments can simultaneously increase operational efficiency and reduce the ecological footprint of ports.

The implementation of customized IoT systems and artificial intelligence can optimize truck movements within the port area, reduce waiting times by up to 30%, and lower carbon dioxide emissions by 10%. The introduction of energy storage systems, along with automated monitoring of machine pressure and temperature, enables more energy-efficient resource management, applying machine learning for dynamic real-time load management. The use of clean energy and alternative fuels is increasingly common in ports aiming for sustainability. The introduction of hydrogen-based dual-fuel technology in port transporters in Antwerp resulted in a reduction of diesel fuel consumption by up to 70%, creating the conditions for a complete transition to a hydrogen-only fleet. Renewable energy sources such as solar panels installed on terminal roofs and wind turbines in coastal areas enable decentralized energy production used to power ships and onshore logistics systems. The development of digital twins has been further enhanced by simulation models within the Docks-the-Future concept, allowing the testing of entire supply chains in a controlled virtual environment. This approach increases the port's ability to respond to sudden changes in demand and disruptions in the global supply chain, minimizes operational risks, and shortens the time required for implementing new protocols and technological solutions.

The human element plays a pivotal role in the success of sustainable port strategies, especially from a behavioural change perspective, to adopt and implement innovative approaches and new technologies. While technology and infrastructure are essential, the attitudes, decisions, and actions of individuals—port workers, managers, stakeholders, and community members—ultimately determine the effectiveness of sustainability initiatives.

Creating a culture of sustainability to embrace innovation and new technologies requires a good leadership commitment. When leaders model sustainable behaviour, it sets a tone that influences the entire organization.

Employee Engagement - workers who understand the purpose and benefits of sustainability are more likely to adopt innovative eco-friendly practices**.**

Training and Education including regular workshops and awareness campaigns help shift mindsets and build skills for sustainable operations.

Behavioural change in daily operations may start with introducing operational practices such as simple actions like reducing idling time, proper waste sorting, or reporting leaks that can have a cumulative impact. **Incentives and recognition** such as rewarding sustainable behaviour on energy-saving suggestions or safety improvements reinforces positive habits. **Social norms and peer pressure** can encourage individuals to conform to sustainable practices.

6. Conclusion

All strategic approaches, particularly those aimed at enhancing sustainability in port operations, inevitably lead to fundamental changes in organizational structures, processes, and mindsets. These changes often require individuals at all levels to adopt new behaviours, attitudes, and ways of working. To ensure that the desired behavioural shifts are successfully achieved, it is essential to incorporate effective change management practices into the strategy implementation process. This involves anticipating resistance, communicating the purpose and benefits of the changes clearly, engaging stakeholders early, and providing the necessary support and training. By managing change proactively and empathetically, organizations can foster a culture that embraces sustainability and innovation,

Through inclusive planning, involving employees in the design and implementation of strategies increases buy-in and reduces resistance. Clear, honest communication about goals, benefits, and progress builds trust and motivation.

Behavioural change is the bridge between strategy and execution. By fostering a culture of sustainability, empowering individuals, and aligning incentives, ports can ensure that their sustainability strategies are not only implemented but embraced. The human element is not a barrier—it's the engine of transformation.

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COURSE NAME: Sustainable Maritime Operations and Green Ports
Module 14 (Week 14)
DEVELOPMENT AND IMPLEMENTATION
OF SUSTAINABLE PORT AND SHIPPING
STRATEGIES
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1. Introduction

•Port operations and shipping are at the heart of global trade and represent a significant source of greenhouse gas emissions and air pollution.
•The **European Union Green Deal** sets ambitious targets:

- 55% reduction in transport emissions by 2030
- Net-zero emissions by 2050

•To meet these goals, **ports must adopt** comprehensive sustainable strategies including:

- Planning
- Operational efficiency
- Impact measurement
- Investment in innovation

2. Planning and implementation of sustainability strategies

•Planning and Implementation of Sustainability Strategies in Ports begins with **alignment to international and EU regulations**, including the Green Deal targets and the Directive on Alternative Fuels Infrastructure.
•Key legislative documents define the **ultimate emission reduction goals** and conditions for the use of renewable energy sources within the port system.
•Ports must establish **specific, measurable, achievable, relevant, and time-bound (SMART) targets** (e.g., reducing CO_2 emissions by 30% within the next five years).

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- **The first step** in strategic planning involves a detailed analysis of relevant legal and institutional frameworks at the international, European, and national levels:
  - Includes reviewing regulations set by the International Maritime Organization, EU regulations on ship engine emissions, legislative initiatives like the "Fit for 55" package, and national strategies for sustainable transport development.
  - Legal alignment ensures that port authorities and shipping service operators meet minimum standards and secure incentives, including subsidies for adopting low-carbon technologies.

- The port authority should then **formulate a clear sustainability vision and mission** that encompass environmental, economic, and social aspects of development, based on transforming the port into a green energy hub for integrated systems of electricity, hydrogen, and other low-carbon fuels.

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•**Engaging key stakeholders** - government bodies, ancillary service operators, the local community, and academia - is crucial for developing a cohesive strategy and securing support and funding.

•The implementation of the sustainability strategy proceeds through four phases:

- **Conceptualization Phase**: Define the strategic framework; prepare the Port Energy Transition Master Plan.
- **Detailed Planning Phase**: Develop technical and financial plans for low-carbon infrastructure projects, such as shore-side electricity supply and hydrogen storage.
- **Execution Phase**: Construct alternative fuel refueling stations, modernize loading and unloading machinery, and digitize emission monitoring systems.
- **Evaluation and Adjustment Phase**: Regularly review achieved results against key performance indicators and adapt plans according to new technologies and changes in the regulatory framework.

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3. Operational efficiency in ports and optimizing port logistics.

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•Increasing operational efficiency in ports relies on the digitization and automation of key processes such as berth scheduling, truck traffic control, and inventory management.

•The application of intelligent transport systems enables real-time tracking of vessel arrivals and departures, reducing waiting times and avoiding unnecessary fluctuations in turbine operations.

•Digital platforms for managing cargo flows connect the port with its logistics hinterland, optimize vehicle routing, and contribute to reducing emissions from inefficient operations.

•Auxiliary vessels, such as tugboats and pilot boats, are often excluded from national emission targets, even though their collective fuel consumption significantly impacts local air quality.

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- Slow steaming strategies; optimizing speed and route planning within the port; reduce fuel consumption by up to 15% per operation.
- Establishing standardized maneuvering procedures and using digital seabed maps increase safety, allow more precise vessel movements, and reduce unnecessary turns.

Best practice examples:

- **The Port of Rotterdam's** shore power project enables ships to turn off auxiliary engines in port, reducing nitrogen oxide and carbon dioxide emissions by up to 20% within one year.
- **The Port of Málaga's Green Port Initiative** combines local renewable energy with digital air quality monitoring, achieving a 25% reduction in particulate matter emissions.
- **EmissionInsider Carbon Insight Suite** offers real-time emission monitoring for ports such as Houston and Rotterdam, enabling rapid management responses and continual operational optimization to better protect the environment.

4. Measuring impact and continuous improvement

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- Multidimensional KPIs: economic, environmental, social, governance
- Important indicators: CO_2, NO_x, SO_x emissions; fuel use
- Social focus: safety incidents, air quality
- Digital platforms enable automatic data collection (IoT sensors)
- Integration: meteorological and sea condition data
- Dashboards support fast, informed decisions
- Regular audits allow strategy updates

5. The role of innovation and new technologies in port development

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- Digital twins: virtual replicas of port infrastructure, created using sensor data, GIS, and BIM.
- With the iTwin® platform, simulate terminal load scenarios, test logistics solutions, and enable predictive maintenance for cranes and vehicles.
- IoT and automation modernize port operations; projects like NON-STOP show that green digital investments improve efficiency and reduce ecological footprints.

- Customized IoT and AI optimize truck movements, cutting waiting times by up to 30% and CO_2 emissions by 10%.
- Energy storage, automated monitoring, and machine learning allow real-time, efficient resource management.
- Hydrogen dual-fuel technology in Antwerp: up to 70% less diesel use, paving the way for hydrogen fleets.
- Solar panels and wind turbines provide renewable energy for ships and logistics.
- Simulation models (Docks-the-Future) allow virtual supply chain testing, improving response to disruptions and speeding up protocol implementation.

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Conclusion

- Strategic approaches lead to fundamental changes in **organizational structures, processes, and mindsets**.
- These changes often require individuals at all levels to adopt new **behaviours, attitudes, and ways of working**.
- To ensure incorporate effective change management practices into the strategy implementation process. This involves anticipating resistance, communicating the purpose and benefits of the changes clearly, engaging stakeholders early, and providing the necessary support and training.
- By managing change proactively and empathetically, organizations can foster a culture that embraces sustainability and innovation,
- Through inclusive planning, increases buy-in and reduces resistance.
- Clear, honest communication about goals, benefits, and progress builds trust and motivation.

Conclusion

Behavioural change is the bridge between strategy and execution.

By fostering a culture of sustainability,
empowering individuals,
aligning incentives,
ports can ensure that their sustainability strategies are not only implemented but embraced.

The human element is not a barrier—it's the engine of transformation.

Chapter 14 Assessment Questions

Development and implementation of sustainable port and shipping strategies

EXAM QUESTIONS

1. **What is the main purpose of the Port Energy Transition Master Plan?**
   a. Increasing the number of berths
   b. Building infrastructure for low-carbon fuels
   c. Reducing the number of employees
   d. Introducing new customs procedures

2. **What percentage reduction in emissions was achieved in the Port of Rotterdam by implementing shore-side power for ships?**
   a. 5%
   b. 15%
   c. 20%
   d. 30%

3. **What does the acronym SMART stand for in the context of sustainability goals?**
   a. System for Monitoring Activities in Real Time
   b. Specific, Measurable, Achievable, Relevant, Time-bound
   c. Strategy for Noise Reduction
   d. Software for Ship Route Management

4. **Which technology enables simulation of different terminal load scenarios?**
   a. Blockchain
   b. Digital twins
   c. Artificial intelligence for traffic management
   d. 3D printing

5. **By applying which strategy did the Port of Málaga achieve a 25% reduction in particulate emissions?**
   a. Introduction of solar panels
   b. Green Port Initiative (combination of renewable energy and digital air quality monitoring)
   c. Complete transition to electric trucks
   d. Restructuring customs procedures

6. **What is the EU Green Deal target for transport emission reduction by 2030?**
   a. 30%
   b. 45%
   c. 55%
   d. 70%

7. **Why do auxiliary vessels (e.g., tugboats) present a challenge in emission reduction?**
   a. They do not have alternative fuels
   b. They are often not included in national emission reduction targets
   c. They consume more energy than cargo ships
   d. They lack sensors for consumption monitoring

8. **What is the purpose of the Emission Insider Carbon Insight Suite system?**
   a. Human resource management
   b. Automatic collection of emission data through IoT sensors
   c. Optimization of ship routes
   d. Warehouse safety monitoring

9. **Which port uses hydrogen-based dual-fuel technology to reduce diesel consumption?**
   a. Port of Singapore
   b. Port of Antwerp
   c. Port of Los Angeles
   d. Port of Hamburg

10. **What is the main goal of the GREENPORT Alliances initiative in the Port of Aveiro?**
    a. Increase the number of cargo operations
    b. Reduce fuel consumption through crew education
    c. Introduce robotic trucks
    d. Build a new oil terminal

FINAL REMARKS

The global maritime industry plays an important role in international trade, transporting more than 80% of the world's merchandise by volume, while also accounting for approximately 3% of global greenhouse gas (GHG) emissions. Because of this dual significance—facilitating global trade while contributing to climate change—the maritime sector occupies a critical position in advancing worldwide sustainability efforts.

The question of why change is needed finds its clearest answer in legislation: society, through international and regional bodies, is deliberately steering shipping towards a sustainable future. The International Maritime Organization (IMO) has committed to reducing total annual GHG emissions from international shipping by at least 20%, with an ambition for 30% by 2030, and further aiming to cut emissions by at least 70%, striving for 80% by 2040, both compared to 2008 levels. The ultimate target is to achieve net-zero GHG emissions by or around 2050. These targets are **not optional but are becoming embedded** in binding regulations that shape ship design, fuel use, and operational practices.

In other words, the **need for change** is not merely ethical or economic—it is being codified into rules that drive the sector forward. Legislation ensures that sustainability is no longer a choice but a necessity, creating the framework within which the maritime industry must operate, innovate, and contribute to the global transition towards a sustainable community.

The GREENPORT methodology catalyses change by optimising the interaction between humans and machines, ensuring that vessels—particularly tugboats—perform the same activity with less fuel consumption and thereby reduce emissions. This dual effect is both environmentally beneficial and economically attractive, as lower fuel use translates directly into cost savings.

GREENPORT enables organisations to **move beyond compliance** and achieve ecological and financial gains in parallel. At its core, the methodology recognises that a change in human behaviour can substantially reduce the environmental impact of in-port services in the short to medium term. Through modifications to day-to-day operations and better use of existing digital technologies, significant drops in emissions can be achieved without waiting for large-scale technological overhauls.

Assessing progress involves systematic measurement of the relevant indicators over time and comparing them against threshold values. Trends in these indicators reveal whether performance is improving, stagnating, or deteriorating. Broadly speaking, two methods for assessing progress can be distinguished.

The first method is compliance with fixed rules using clear thresholds. For exhaust gas emissions, such thresholds are set in environmental legislation and standards.

For example, regulations may prescribe maximum emission levels, minimum energy efficiency requirements, or limits on resource use. These rules define a boundary that distinguishes acceptable ("good") from unacceptable ("bad") performance. Compliance therefore involves measuring the relevant property (e.g. CO_2 emissions, fuel consumption per nautical mile) and verifying that it remains below the prescribed limit. The distance to the legal threshold provides a quantitative measure of how well a situation aligns with regulatory expectations. Importantly, these thresholds are not static: they evolve over time as legislation tightens in response to technological advances and societal demands. Ecological footprint assessments based on fixed rules are thus anchored in compliance yet remain dynamic as standards rise.

The second method is continuous improvement relative to past performance. In situations where no absolute definition of "good" exists, the focus shifts from meeting fixed targets to demonstrating incremental gains—each step being "better" than the last. This perspective aligns with the guiding principle of radiation safety ALARA principle (As Low As Reasonably Achievable), which recognises that although a perfect "zero footprint" may not be attainable, organisations can and should continually reduce their impact. Examples include reducing energy consumption, minimising waste streams, or enhancing circular use of materials. Here, progress is benchmarked against previous results, ensuring measurability even in the absence of formal thresholds. Demonstrating year-on-year efficiency gains, such as lower emissions per voyage or improved fuel intensity, falls squarely under this category.

The GREENPORT methodology relies on real-time optimisation of the input–output balance of ship energy flows and is designed as a process of gradual, step-by-step fuel reduction. By continuously aligning energy demand with efficient machine operation and informed human decision-making, vessels can shave off unnecessary consumption in small increments that accumulate into substantial savings. Each improvement cycle strengthens the interaction between crew and technology, making the vessel slightly more efficient than before. This incremental approach ensures that fuel savings and emission reductions are achieved without disruption to daily operations, while still building a compelling business case for adoption. Every tonne of fuel avoided is an immediate cut in greenhouse gas emissions, showing that operational efficiency—improved step by step—is the fastest and most cost-effective route to regulatory compliance and sustainable competitiveness.

Changing human behaviour is often more difficult than changing technology. While facts and technical arguments are important, they are rarely enough on their own to convince someone to act differently. **Persuasion** requires a careful balance of rational arguments, emotional appeal, and practical incentives. At the heart of this process lies the need for a driving force that stimulates people to strive for improvement—or, in other words, to increase their performance. This driving force can take many forms: economic rewards such as fuel savings, social recognition from peers, or the personal satisfaction of contributing to a more sustainable future. Without such a catalyst, people may acknowledge the value of change but fail to act.

To strengthen persuasion and make change sustainable, several models offer structured approaches to influencing behaviour. Aristotle's rhetoric highlights the interplay of **logos (rational argument), ethos (credibility of the speaker)**, and **pathos (emotional appeal)**, which together create a compelling message. When these three elements are combined effectively, they create a message that is rationally sound (logos), trustworthy (ethos), and emotionally engaging (pathos). This balance is what makes communication in teaching truly persuasive The **Knoster model for managing complex change** shows that successful transformation requires a combination of vision, skills, incentives, resources, and an action plan; if one of these elements is missing, resistance or confusion is likely. The **COM-B model (Capability, Opportunity, Motivation → Behaviour)** emphasises that behaviour only changes when people not only know how to act but also can act within their environment and want to act because they are motivated. Finally, approaches like nudging illustrate how subtle adjustments in the way choices are presented can encourage people to adopt better habits without removing their freedom of choice.

Persuasion therefore involves more than presenting the case for change: it is about **creating the conditions**—through arguments, incentives, skills, and supportive environments—in which individuals feel inspired, motivated, and enabled to continuously push their behaviour toward better outcomes.

As the maritime industry faces increasing scrutiny over its environmental impact, the role of maritime educators is emerging as a pivotal element in fostering sustainability among future professionals. Integrating sustainable practices into maritime education is of vital importance, as it equips students with the necessary knowledge and skills to navigate their future careers. Maritime educators should develop and implement curricula that not only focus on technical competencies but also include sustainability principles, thereby encouraging future professionals who would be aware of the ecological consequences of their actions.

Maritime educators' awareness of sustainability principles, especially in terms of port services sustainability, their capacity to incorporate behavioural change approaches into their courses, the challenges they face, and methods that would motivate learners to adopt sustainability into their behaviours has vital importance on the successfully implementation of the training programs developed. When evaluated within the framework of the COM-B model, the results provide inferences regarding the capability, opportunity and motivation levels of educators, offering important implications from both theoretical and practical perspectives. In this aspect, maritime educators need to understand and believe that integration of sustainability principles in maritime education has critical importance. Educators' belief in the necessity of integrating sustainability principles into their courses, combined with their high awareness of the importance of these principles create a strong ground for the "motivation". Finally, educators have to be open to incorporating behavioural change methods into their teaching materials, showing a positive indicator in terms of "motivation".

In that respect, these findings provide important clues for improving maritime education programs and increasing the competencies of instructors. Although educators have the motivation and are open to integrating behavioural change approaches into teaching methods, they need to improve their capability with more training and resources to incorporate sustainability principles more effectively into educational materials. With this consideration, a comprehensive sets of reference documents were provided for each curriculum and these documents were included in the repository on the project web site for a quick reference.

Additionally, various real time case studies were included in the repository together with educational materials as an open science document to the benefit of all interested parties besides project partners. Curricula also aimed at integrating practical training by simulations to the theoretical aspects, using a structured approach to develop participants' skills effectively. The curriculum design accounted for sequencing of activities and knowledge transfer, ensuring that related concepts are taught in a coherent manner. It has been understood that methods such as real case studies and interactive learning activities are effective in encouraging sustainable behavioural change in students. On the other hand, it has become clear that cooperation between academia and industry should be increased in order to produce solutions to sustainability issues in port services. With the pressing need to address sustainability challenges, the collaboration between maritime educators and industry stakeholders is crucial for equipping future professionals with the requisite tools to enact environmentally responsible practices.

Sustainability is becoming increasingly important in the maritime sector and education can be considered one of the cornerstones of this transformation. In the maritime world, education and training are vital and their importance extends far beyond shipping itself, as the safety and security of life at sea, the protection of the marine environment and the efficient movement of global trade depend on the professionalism and competence of seafarers. In that respect, the role of educators is very crucial to increase sustainability practices in maritime transportation. Supporting the capability, opportunity and motivation levels of educators in a balanced way is critical for the future of a sustainable maritime sector, in terms of both environmental and economic sustainability. Sustainability education, especially in operational areas such as port services, can enable personnel to make more conscious decisions on issues such as energy efficiency, fuel savings, resource use, and equipment life. This means reducing operating costs, increasing operational efficiency, and thus contributing to economic sustainability. In addition, the quality of human resources developed through education is also the key to achieving competitive advantage in the sector. The sustainability awareness of the workforce would help port service providers adapt to international standards more quickly and achieve success in green port certification processes, allowing for not only short-term cost advantages but also long-term reputation and strategic gains. Thus, investing in behavioural change with sustainability education should be considered not only as part of environmental responsibility but also as part of economic performance.

The developed curriculum intended to raise awareness on environmental issues covering the subjects of training a new generation of maritime professionals compatible with global sustainability obligations. Insights into how academic institutions can develop environmentally conscious and globally competent maritime professionals, emphasize that academic institutions should shape professionals who are not only skilled in their technical roles but also responsible for sustainable practices.

The European Green Deal underscores the essential role of education in achieving Europe's ambitious goal of becoming carbon-neutral by 2050. It promotes the integration of environmental topics into all levels of education and emphasizes the development of key competencies such as critical and systems thinking (European Commission, 2019). Although there is consensus that incorporating sustainability topics into curricula enhances understanding of the interconnections between social, economic, and environmental systems, integrating these topics into higher education are still limited in scope and impact.

This challenge offers an opportunity for the industry to take a leadership role in sustainability through innovation and advanced technologies, while maritime education is tasked with equipping future professionals with the knowledge, skills, and behaviours required to address these challenges. In this context, maritime educators bear a vital responsibility for fostering sustainability principles among students, shaping their ability to implement environmentally and socially responsible practices in the workplace.

This integration of sustainability principles demands a transformative approach to curriculum design, teaching methodologies, and institutional strategies. However, designing transformative educational experiences is challenging within entrenched educational paradigms and structures that often remain untransformed and lack critical reflexivity.

Within this context, restructuring training programs to include sustainability principles to achieve behavioural change emerges as an important requirement. Despite its potential, the application of behavioural change approaches to foster sustainability within maritime education has been largely overlooked. Grounded in social and behavioural sciences, such approaches offer valuable insights into how educators and students can adopt sustainable practices and overcome barriers to implementation. However, the lack of empirical studies in this area highlights a pressing need for research on embedding sustainability principles into maritime education.