Linking operational decision making to vessel emissions

MSc Marine Technology Thesis

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Delft University of Technology

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by

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Preface

In writing this preface, I realise that it symbolises the end of my academic career, marking the end of my time as a Marine Technology student. During my time at Technische Universiteit Delft, I pursued my enthusiasm for technology and the ocean. This thesis allowed me to delve deeper into this subject, expanding my knowledge while pushing the limits of my intellectual horizon.

I want to express my gratitude to my supervisor, Dr.ir. J.F.J. (Jeroen) Pruijn, for his guidance and support throughout the MSc graduation process. In addition, I am grateful to the marine engineers working at Jumbo Maritime for their guidance and valuable insight throughout this graduation project, sharing their experience, pointing out the potential pitfalls, and brainstorming session on how to handle and tackle problems. Among these, I owe a special debt of gratitude to my main supervisor at Jumbo Maritime, ir. M. (Martijn) Witvoet and second supervisor ir. B. (Bas) Milatz for introducing me into the Jumbo community, granting me full autonomy to explore my most preferred topic, and equipping me with all the tools required for my research. The atmosphere in the Schiedam office resulted in a truly enjoyable and enriching experience throughout. Lastly, I want to thank Dr. A. Abeer from the UMC Utrecht for her guidance in qualitative research.

It goes without saying that this thesis would not have been possible without the full support of my family and friends. The process underscored the importance of a secure and supportive environment, allowing me to dedicate myself wholeheartedly to this graduation project.

With respect to the great challenge we face as humans in reducing the effects of the climate crisis, I hope that this work serves as a source of inspiration for future researchers in the maritime sector, highlighting that, in addition to technological solutions, it starts with the willingness and a shift in priorities of clients and contractors to reduce human dependence on fossil energy.

T.J. van Groeningen
Rotterdam, May 2025

Abstract

Offshore construction vessels produce significant greenhouse gas (GHG) emissions, which led to the need to understand how operational decisions can mitigate their environmental impact. This thesis investigates the link between operational decision making and vessel emissions, focussing on Jumbo Maritime's offshore installation projects. A mixed methods approach was adopted, which combined quantitative analysis of vessel operational data with qualitative insights from stakeholder interviews. Detailed analysis of daily progress reports, energy system models, and fuel consumption records allowed the quantification of emissions for each operational activity. Meanwhile, interviews with on- and offshore managers showed how factors such as contract requirements and project complexity influence decision-making in practice.

The results identify which activities drive the highest emissions and why. Dynamic positioning (DP) during offshore operations and transits emerged as the major contributor to fuel use and emissions, whereas periods at anchor or in port resulted in minimal fuel consumption. Unplanned downtime, especially waiting on weather and technical breakdowns, contributed substantially to emissions.

Crucially, the study found that certain operational strategies can noticeably reduce emissions without compromising project performance. Key recommendations include using anchoring instead of continuous DP whenever conditions allow, and implementing proactive maintenance programmes to minimise breakdowns and associated downtime. In addition, it is recommended to align contractual terms and planning processes with emission reduction goals to empower crews to choose more sustainable operating modes. By linking day-to-day operational choices with their emission outcomes, this research provides practical guidelines for offshore vessel operators to reduce their carbon footprint while maintaining efficiency and safety.

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Nomenclature

Abbreviations

Abbreviation	Definition
AMP	Alternative Marine Power
BSFC	Brake Specific Fuel Consumption
CBA	Cost Benefit Analysis
CII	Carbon Intensity Index
DP	Dynamic Positioning
DPR	Daily Progress Reports
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operating Index
EEXI	Energy Efficiency Existing Ship Index
EIAPP	Engine International Air Pollution Prevention Test
ETS	European Trading System
EU	European Union
FAT	Factory Acceptance Test
GHE	GreenHouse Effect
GHG	GreenHouse Gas
GT	Gross Tonnage
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IMO	International Maritime Organisation
KPI	Key Performance Indicator
MCR	Maximum Continuous Rating
MCDA	Multi-Criteria Decision Analysis
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MBM	Market Bases Measure
MEPC	Marine Environment Protection Committee
MPC	Model Predictive Control
NPV	Net Present Value
OCV	offshore construction vessel
OPS	Onshore Power Supply
RoI	Return on Investment
SEEMP	Ship Energy Efficiency Management Plan
TTW	Tank-to-Well
UNCTAD	United Nations Conference for Trade and Development
UNFCCC	United Nation Framework Convention on Climate Change
VLSFO	Very Low Sulfer Fuel Oil (VLSFO)
WSM	Weighted Sum Model
WTW	Well-to-Wake

1 Introduction

Greenhouse gases (GHGs) play a crucial role in regulating Earth's climate by trapping heat in the atmosphere. This process is known as the Greenhouse Effect (GHE). Although this effect is crucial for maintaining a habitable climate, as without this effect the Earth's average temperature would be 30°C lower (Charles Langmuir, 1999). An excess of GHG, especially due to human activities such as burning fossil fuels, deforestation, and industrial processes, has significantly increased the concentration of these gases leading to global warming and climate change. According to International Chamber of Shipping (2025), the maritime sector is crucial to global trade, handling approximately 90% of world commerce by volume. Despite its importance, shipping contributes significantly to environmental degradation, notably through greenhouse gas (GHG) emissions, air pollutants, and marine pollution. The International Maritime Organisation (IMO), recognising these adverse environmental impacts, has set stringent goals aimed at a substantial reduction in GHG emissions from shipping by 2030 and beyond. Consequently, the maritime industry faces significant pressure to evolve its operational and technological practices toward sustainability.

Within the maritime sector, offshore vessels, such as those used by Jumbo Maritime, a company specialising in heavy-lift operations and offshore contracting, represent a unique subset. In regular shipping, effective work is measured in tons of cargo carried per mile sailed. Offshore vessels float at a specific location. Due to this unique operational profile, companies like Jumbo Maritime are actively looking for ways to reduce their impacts on GHG emissions, as standard emissions reduction measures are often difficult to apply to their operational context.

The shift towards sustainability in maritime operations requires not only technological advancements, but also optimised decision-making processes at an operational level. Decisions made during vessel operation profoundly affect fuel consumption, emissions output, and overall operational efficiency. Although technological interventions such as alternative fuels, hybrid propulsion systems, and integration of renewable energy are crucial, optimising operational practices can provide immediate and substantial reductions in emissions.

Building upon previous research within the domain, notably examining the intersection of operational decisions and environmental impact, this thesis delves deeper into the operational strategies available to vessel operators. The purpose of this project is to clearly establish the connection between operational decisions and emissions performance, providing tangible recommendations for improved environmental outcomes without compromising operational effectiveness or profitability.

This research, conducted in close cooperation with Jumbo Maritime, leverages real operational data and industry insights to ensure practical relevance and applicability. The results of this study are intended to inform maritime stakeholders, enhancing their decision-making capabilities in the pursuit of environmental and operational excellence, thus contributing to the industry's broader sustainability objectives.

This chapter further outlines the scope, significance, and detailed structure of the thesis. In addition, a brief overview of Jumbo Maritime, the company collaborating that provides operational insights and data for this research, is presented.

1.1. Jumbo Maritime

This master's thesis represents a collaborative effort between the author and Jumbo Maritime. Jumbo Maritime is a global heavy-lift shipping and offshore transportation & installation company, aimed at improving overall vessel efficiency and reducing emissions. The Schiedam-based company operates eight in-house designed heavy-lift vessels with a lifting capacity ranging from 800 to 3,000 tons. These ships are equipped to efficiently load and unload a wide range of complex cargo at berths around the world. Two of them are also capable of performing offshore installation scopes. Jumbo's philosophy is that engineering, safety awareness, and environmental care are at the forefront of reliable operation (Jumbo Maritime, 2025). Therefore, the thesis is a consequence of Jumbo's drive to invest in projects that enhance these objectives.

1.2. Greenhouse gases

According to the University of Michigan, there are 10 primary GHGs of which a few are present only due to industrial processes; water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are naturally occurring. Perfluorocarbons (CF_6, C_2F_6), hydrofluorocarbons (CHF_3, CF_3CH_2F, CH_3CHF_2) and sulphur hexafluoride (SF_6) (Center for Sustainable Systems, 2024). The table below, also from the University of Michigan, gives an overview of the concentration of these gases in the atmosphere.

Compound	Pre-industry Concentration	Concentration in 2019	Atmospheric Lifetime (years)	Main Human Activity Source	GWP (100-years)
Carbon dioxide (CO_2)	278 ppm	417.9 ppm	Variable	Fossil fuels, cement production, land use change	1
Methane (CH_4)	729 ppb*	1923 ppb*	12	Fossil fuels, rice paddies, waste dumps, livestock	30 (fossil fuel), 27 (non-fossil fuel)
Nitrous Oxide (N_2O)	270 ppb*	335.8 ppb*	109	Fertilizers, combustion industrial processes	273
HFC-134a (CF_3CH_2F)	0 ppt**	108 ppt**	14	Refigerant	1526
HFC-32 (CH_2F_2)	0 ppt**	20 ppt**	5	Refigerant	771
CFC-11 (CCl_3F)	0 ppt**	226 ppt**	52	Refigerant	6226
PFC-14 (CF_4)	34 ppt**	86 ppt**	50000	Aluminium production	7380
SH_6	0 ppt**	9.95 ppt**	3200	Electrical insulation	25200

Table 1.1: The main Greenhouse Gases (Center for Sustainable Systems, 2024)
** ppb = parts per billion, ** ppt = parts per trillion*

In the last column, the Global Warming Potential (GWP) is shown. The GWP indicates the relative effectiveness of GHGs in trapping the Earth's heat over a period of 100 years. CO_2, being the primary anthropogenic GHG, is set as the reference gas with a GWP of 1. The data in Table 1.1 can be divided into 4 groups of GHGs: carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Fluorinated Gases. Although almost every source, for example (Rotmans and Den Elzen, 1992), uses a different GWP for each compound, they are all of the same order of magnitude.

1.2.1. Carbon dioxide equivalents (CO_2eq)

As there are huge differences in each concentration and GWP's, the industry uses the so-called carbon dioxide equivalents CO_2e or CO_2eq. The CO_2eq is calculated by multiplying the mass of emissions by the GWP of the gas (Center for Sustainable Systems, 2024). By doing this, the influence on the global warming of the gases can be compared with each other. Figures 1.1 (IPCC, 2022) show that 75% of GHG emissions is CO_2, of which 64% is due to fossil fuels and industry.

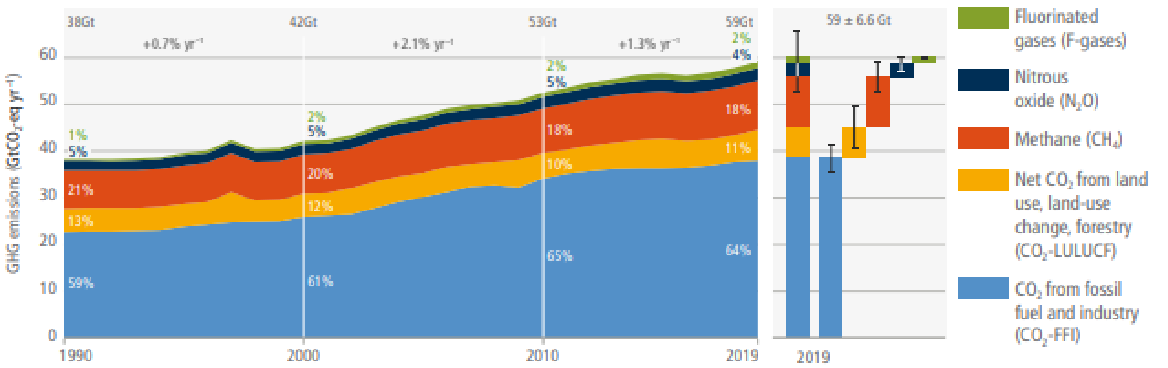


Figure 1.1: Global net anthropogenic GHG emissions 1990-2019 (IPCC, 2022)

1.2.2. Nitrogen oxides (NO_x), Sulfur oxides (SO_x) and Particulate matter (PM)

According to J. Zhao et al. (2021), the main harmful gases emitted by ships are CO_2 (carbon dioxide), NO_2 (Nitrogen oxides), SO_2 (sulfur oxides) and PM (particulate matter). NO_2, SO_2 and PM are not considered direct GHGs. All three of them are considered indirect GHGs. An indirect GHG is a gas that, while not directly trapping heat in the atmosphere, contributes to GHE by influencing the concentration or effectiveness of direct GHG. They do this by contributing to the formation of direct GHGs or helping to extend their useful atmospheric life (Lasek and Lajnert, 2022). However, the problem with these indirect GHGs is that the GWP is very difficult to determine and depends on many different factors. Therefore, calculations of the CO_2eq, as described in Section 1.2.1, for these three gases are not within the scope of this thesis.

For bunkering their fleet, Jumbo Maritime sometimes uses biodiesel. Masera and Hossain (2023) states that the fuel properties of biodiesels are very important. The use of low-quality biodiesels can harm engine components and lead to unstable engine operation. In addition, compared to fossil diesels, such as Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO), high-quality biodiesels produce higher NOx emissions when used in diesel engines, which is known as the NOx penalty. Based on National Biodiesel Education Program (2018), engines that use 100% biodiesel (B100) usually emit 4 to 13% more NO_x before after treatment and 2 to 4% for 20% biodiesel (B20).

1.3. Shipping industry

The next question that arises is: What is the influence of the shipping industry, compared to other sectors, on global greenhouse gas emissions? According to Ritchie (2020), shown in figure 1.2, 16.2% of all CO_2eq is due to transport and 1.7% due to the shipping industry.

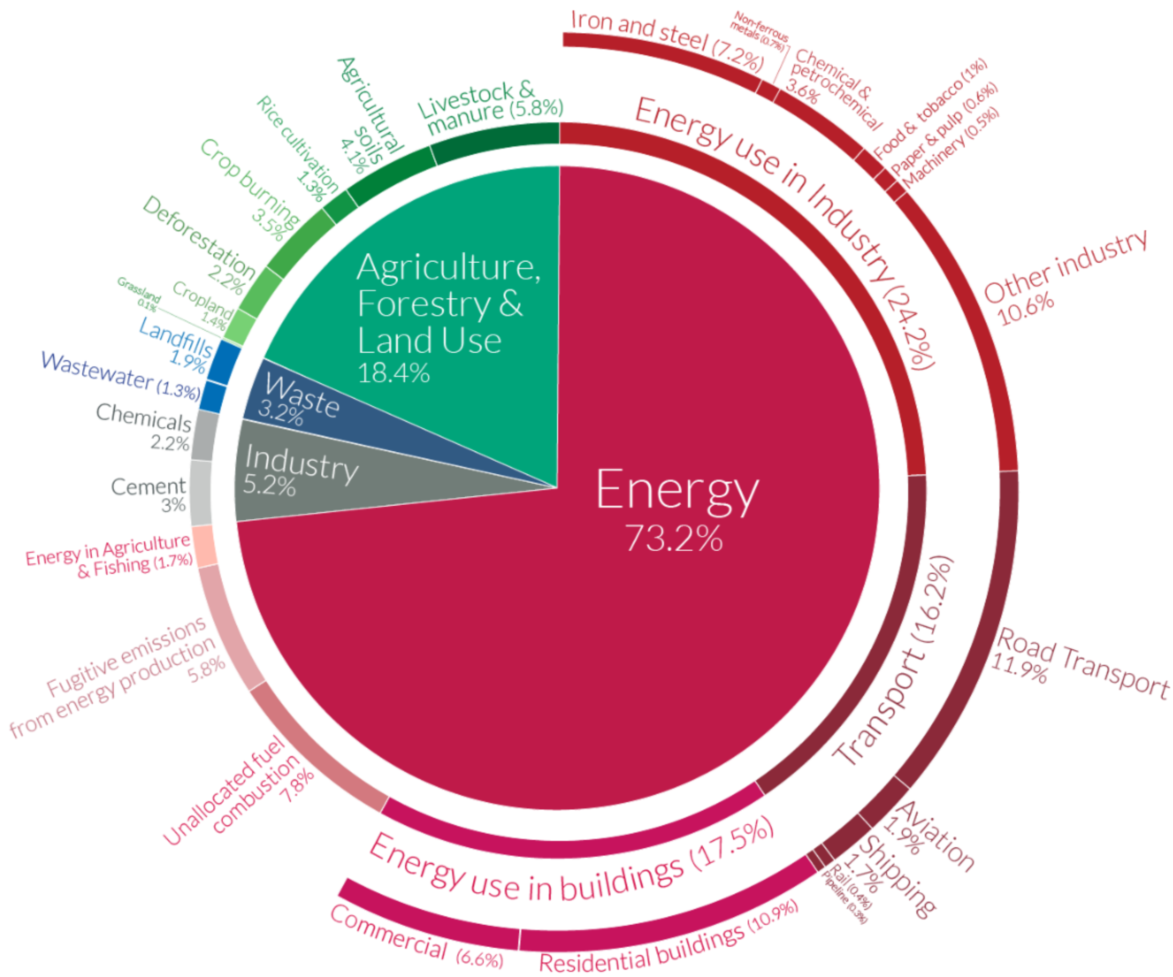


Figure 1.2: Global greenhouse gas emissions by sector in 2016 [CO_2eq] (Ritchie, 2020)

But how does this compare to other countries? In Figure 1.3 (Ritchie, Rosado, and Roser, 2023) it can be seen that the international shipping industry emits $\pm$ 6 times the amount of GHG compared to the Netherlands and is equal to approximately 25% of the total GHG emissions of the European Union in 2022.

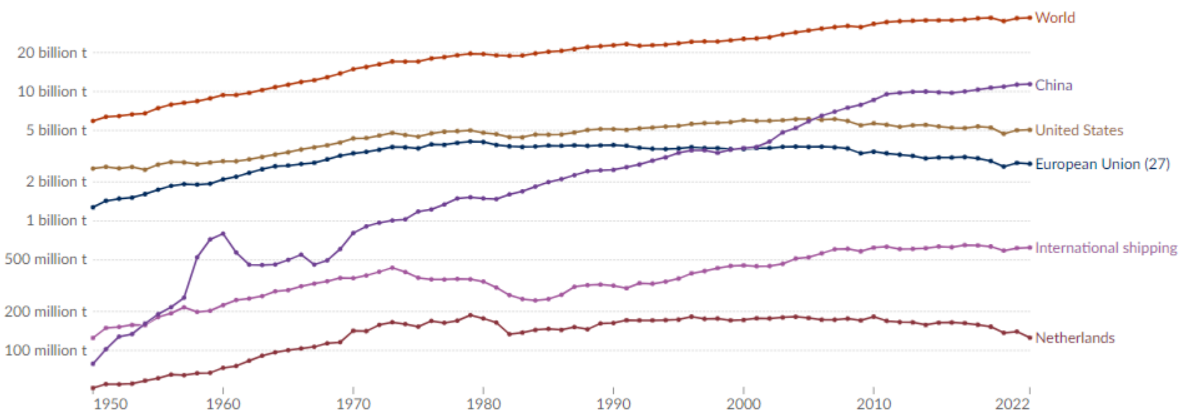


Figure 1.3: Annual CO_2 emissions (Ritchie, Rosado, and Roser, 2023)

Both figure 1.2 and figure 1.3 are from *Our World in Data* ((Ritchie, 2020) and (Ritchie, Rosado, and Roser, 2023)) and thus are based on the same data source. In the literature *Our World in Data* and the IMO are referred to a lot when it comes to the data used for figures and graphs. However, there is a significant difference in the numbers all the different sources come up with. All emission calculations are performed indirectly, which leads to uncertainty in the number. For comparison, the International Maritime Organisation (IMO) claims that in 2007 international maritime activity represented 843 Mt of CO_2 Crist, 2009 and represents 2.7% of the world's GHG emissions.

For the remainder of this review, the IMO data will be prioritised over data from *Our World in Data* due to the IMO's status as the official United Nations agency responsible for regulating maritime activities. As the primary global authority, the IMO reports are derived directly from member states and industry sources, providing specialised and authoritative information on maritime policy and environmental regulations. This also means that it is politically influenced; however, the political influence is mainly on the decision-making regarding regulations, not on providing the data itself. *Our World in Data* offers accessible and valuable summaries of global trends by aggregating data from multiple sources, including the IMO. The example above shows that it lacks the specificity required for a detailed analysis of international maritime regulations.

Looking at, the GHG emissions from the maritime industry can be categorised according to the type of vessel. Large cargo vessels such as container ships, bulk carriers, and tankers are responsible for the largest part of GHG emissions due to their sheer size, fuel consumption, and extensive global operations. In contrast, specialised vessels, such as offshore construction vessels, have a more specific but still significant impact on overall emissions.

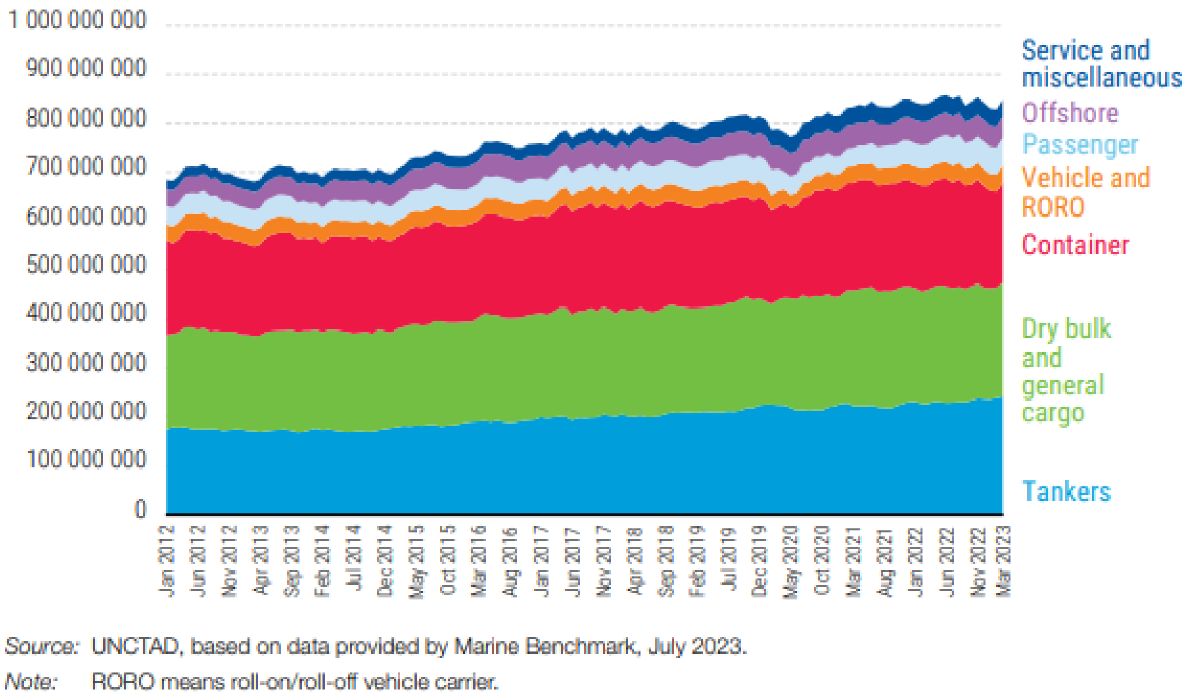


Figure 1.4: Total carbon dioxide emissions by vessel types, tons, January 2012—March 2023 (United Nations, 2023)

This review of the literature will focus primarily on offshore vessels, as they play a critical role in Jumbo Maritime operations. Understanding the emission profile of these vessels is particularly relevant to the company's environmental sustainability goals and its efforts to optimise operations in a sector that is increasingly focused on reducing its carbon footprint. By focussing on offshore vessels, this research aims to provide targeted insights that can inform the company's strategies in this specific niche of the maritime industry. However, the other types of vessels will also be considered if relevant studies have been conducted in the context of operational decision-making. Insights from sectors such as container shipping, bulk carriers, or tankers can provide valuable parallels or best practices that can be adapted to offshore vessels, particularly in areas such as fuel efficiency, route optimisation, or other emissions reduction strategies.

1.4. Problem statement

The global shipping industry significantly contributes to greenhouse gas emissions, mainly due to its dependence on fossil fuels. Offshore construction vessels, such as those operated by Jumbo Maritime, represent a specialised niche within this broader industry, characterised by unique operational profiles involving stationary operations, dynamic positioning, and irregular voyages. These operational conditions make standard emission reduction strategies, frequently described in the literature (Chapter 3), difficult to apply directly. Moreover, regulatory frameworks (Chapters 2) are increasingly stringent, aiming to drive maritime sectors toward greater sustainability.

Thus, the problem addressed in this research is how operational decision-making in offshore maritime projects can effectively balance environmental objectives, regulatory compliance, and practical project constraints. Specifically focussing on operational measures, this study highlights immediate and actionable strategies to improve environmental performance, addressing the pressing challenge of decarbonising the maritime industry. The findings will provide a valuable foundation for the design of effective tools and methods in the subsequent phases of the research, helping Jumbo Maritime to align with international sustainability goals and regulatory compliance while improving overall operational efficiency. This thesis aims to identify opportunities to optimise vessel operations to reduce emissions without compromising operational effectiveness.

1.5. Research outline

This research seeks to establish a comprehensive understanding of how operational decisions influence environmental impacts in offshore maritime activities, setting the stage for a data-driven framework. By synthesising existing knowledge on operational measures, emission reduction strategies, and regulatory challenges, this work aims to pinpoint critical gaps and opportunities in the offshore installation sector. This is done according to the following research question:

Main: How can data-driven decision making contribute to a cost-effective reduction in greenhouse gas emissions in offshore maritime operations while maintaining performance and compliance with regulations?.

The main objective of this thesis is to find out whether there is the possibility to reduce greenhouse gas emissions from offshore operations conducted by Jumbo Maritime. To find a satisfactory answer to this objective, the main research question is subdivided into several sub-questions, which will be addressed in different chapters.

The initial phase of the thesis provides background information and is divided into two chapters. This phase will explore current studies and theories to establish a solid foundation for research. The first chapter discusses the regulatory frameworks that offshore companies have to comply with. This chapter sets the limits for the research that will follow. The second chapter explores existing operational emission reduction measures found in scientific literature. The initial phase will be addressed through a thorough literature review and provide an answer to the first sub-question.

1. What existing operational measures are available in the offshore industry to reduce greenhouse gas emissions?

With the literature review as a foundation, the main part of this thesis is to define a decision-making framework to reduce emissions from offshore operations. Through real performance data collected from the dynamic positioning computer, fuel consumptions and emissions per operational activity are calculated. This quantitative analysis has the goal of finding out which operational parameters have the biggest influence on the emission footprint, which answers the second sub-question.

2. What is the influence of each offshore activity on greenhouse gas emissions carried out by offshore construction vessels based on data analysis?

From the quantitative analysis, several possible areas of improvement will be listed. Offshore contractors operate in a commercial environment, so to get the complete picture, a financial analysis has to be done. This leads to the fifth sub-question.

3. How can emission reduction be a cost-effective operational strategy that incorporates allowances from the EU emission trading system, to optimise both compliance with emissions and overall costs?

Next, a qualitative analysis in the form of conducting interviews is done to find a better understanding of the force field offshore operators have to operate in. In addition, experience from people directly involved in offshore operations helps to better understand possible areas of improvement and the effect of possible savings on daily/routine work procedures. Therefore, the third sub-question is formulated as follows.

4. How do the preparatory project decisions impact the operational choices related to the reduction of emissions on offshore vessels?

The quantitative analysis highlighted possible areas of improvement and the qualitative analysis resulted in a better understanding of offshore operations. The combination of both makes it possible to identify key areas of improvement. These are crucial to be able to establish a decision-making framework. This leads to the fourth sub-question.

5. What are the key areas of improvement based on quantitative and qualitative analysis to minimise emissions in offshore maritime operations?

To conclude the research, the information collected in sub-question 2 to 5 is combined to form a collaborative decision-making framework to align stakeholders, to reduce emissions, and optimise offshore operations.

6. What collaborative decision-making frameworks can align stakeholders to improve operational practices for emission reduction?

The focus will be on offshore vessels because of their unique operational profiles compared to other ocean going vessels. The operational profile of offshore vessels is dominated by heavy lifting operations on dynamic positioning (DP), which causes fluctuating power demands. In addition to that, multiple stakeholders are involved, each having their own priorities. Misalignment can lead to high downtime and inefficient operations. The consumption data and operational profile of a vessel in current offshore operation will be used as a reference.

1.5.1. Scope of thesis

This research focusses on optimising the sustainability of offshore maritime operations by examining operational decision making and its environmental impacts. It will primarily address key operational parameters such as the energy distribution on board vessels and the influence of organisational limitations on emissions reduction. The approach emphasises data-driven analysis and decision-making frameworks while aligning with international regulations and targets to reduce greenhouse gases.

This study is confined to operational measures on a single vessel and does not explore alternate fuel types, changes in vessel design, or other technological innovations. These measures, while impactful, require long-term investments and are outside of immediate operational adjustments that can drive short-term sustainability improvements. By narrowing the focus to actionable operational measures, this research aims to provide Jumbo Maritime with practical strategies to achieve its sustainability objectives without compromising operational efficiency. In addition to that, stakeholder participation was limited to the contractor’s internal perspective

Part I

Literature review

2 Regulatory framework

Chapter 2 reviews (upcoming) regulations that could impact operational emissions and their cost. Due to the significant impact the maritime industry has on global warming, it is under increasing pressure to reduce its environmental impact. During the United Nations Climate Change Conference (COP21) in Paris, France, on 12 December 2015, the Paris Agreement was signed. In line with the Paris Agreement, the European Union and organisations such as the Internation Maritime Organisation (IMO) developed strategies to comply with the Paris Agreement. As a result, indicators such as the Ship Energy Efficiency Management Plan (SEEMP), Energy Efficiency Existing Ship Index (EEXI), and the Carbon Intensity Indicator (CII) aim to drive improvements in vessel efficiency and reduce emissions. These measures shape the future of the industry, pushing for innovation and more sustainable practices in all types of vessels. But what are these regulations exactly? This section will elaborate on that.

2.1. Global agreements and IMO strategy

At COP 21 in Paris, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a landmark agreement to combat climate change to accelerate, intensify the actions, and investments needed for a sustainable low-carbon future. The aim of the Paris Agreement is to strengthen the global response to the threat of climate change by keeping a global temperature increase in this century well below 2 degrees Celsius above pre-industrial levels and to continue efforts to limit the temperature increase even further to 1.5 degrees Celsius (UNFCCC, 2015). The Agreement entered into force on 4 November 2016 and aims for climate neutrality (net zero emissions) by the second half of the century. The first global stocktake is scheduled for 2023 (UNFCCC, 2015)

The 2023 IMO Strategy for Reducing Ship GHG Emissions, adopted by the 80th Marine Environment Protection Committee (MEPC80, (IMO, 2023b)), represents a significant step in the efforts of the maritime sector to decarbonise. The IMO strategy sets ambitious goals for international shipping to achieve net zero GHG emissions "by or around 2050," IMO (2023b) aligning the shipping industry with global climate goals set by the Paris Agreement. This establishes environmental impact as a non-negotiable criterion for evaluating operational strategies, and any proposed measure must contribute to GHG reduction to align with these regulations. To achieve this, introduce intermediate goals, with the aim of reducing carbon intensity by at least 20% and striving for 30% by 2030 and at least 70% and striving for 80% by 2040 compared to 2008 levels. (IMO, 2023b) By setting these intermediate targets, the IMO encourages the adoption of cleaner technologies, alternative fuels, and operational efficiencies to reduce the environmental impact of shipping as soon as possible.

The 2023 strategy is a revised strategy that builds on the initial 2018 framework but with more aggressive goals, to comply with the growing pressure to decarbonise. It emphasises market-based measures (MBMs), the development of zero- and low-emission fuels, and improved international cooperation to ensure equitable access to technology. With this holistic approach, the IMO intends to support the transition of the maritime sector while addressing economic disparities, especially for developing countries (IMO, 2023b).

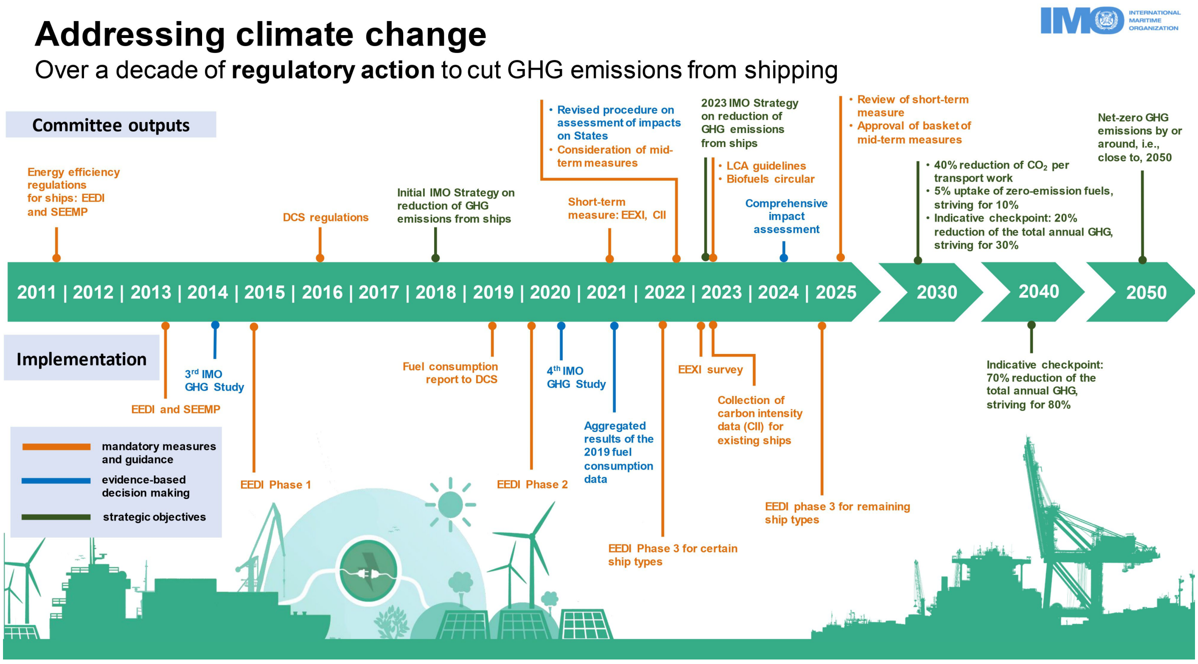


Figure 2.1: IMO timeline (IMO, 2023a)

2.2. IMO measures

2.2.1. Ship Energy Efficiency Management Plan (SEEMP)

The Ship Energy Efficiency Management Plan (SEEMP) is a mandatory framework under IMO MARPOL Annex VI to improve the energy efficiency of ships. SEEMP consists of four key elements: planning, implementation, monitoring, and self-evaluation. Ships must optimise operations through strategies such as speed optimisation, voyage optimisation, and hull maintenance, while also considering technological upgrades (IMO, 2022b). For ships over 5,000 GT, SEEMP includes additional mandatory data collection on fuel consumption (Part II) and compliance with the Carbon Intensity Indicator (CII) ratings (Part III). Certain elements of the SEEMP framework, such as the Energy Efficiency Existing Ship Index (EEXI) and the CII, do not apply to all vessels. This depends on the size, type, and operational profile of the ship. In general, SEEMP ensures that ships regularly assess and improve their energy efficiency to reduce fuel consumption and emissions (IMO, 2022b).

2.2.2. Energy Efficiency Existing Ship Index (EEXI)

The Energy Efficiency Existing Ship Index (EEXI) is a measure to assess the energy efficiency of existing ships. Similarly to the EEXI there is the Energy Efficiency Design Index (EEDI), which applies to new-built ships. The Energy Efficiency Existing Ship Index (EEXI) calculates a ship's theoretical CO_2 emissions per ton-mile, considering factors such as engine power, fuel type, and ship speed (IMO, 2022a). EEXI and EEDI are used for compliance and as estimates of emissions. The Energy Efficiency Operational Indicator (EEOI) is used to monitor performance and continuously improve. Due to the complex operational profile of offshore vessels, the EEXI is not yet mandatory for these types of vessels. However, this will be reevaluated in 2027.

2.2.3. Carbon Intensity Index (CII)

The CII quantifies the intensity of carbon of vessel operations, that is, the amount of CO_2 emitted per unit of cargo carried and distance travelled. Ships above 5,000 gross tonnage (GT) are assigned a rating based on their CII value, from "A" (best) to "E" (worst). Ships rated "D" for three consecutive years or "E" in one year must submit corrective plans (IMO, 2022c). Similarly to the EEXI, the CII does not yet apply to offshore vessels as they are still debating on a correct way to calculate these indexes for these type of vessels.

Taken together, SEEMP, EEXI and CII are intended to incentivise annual efficiency improvements, but, as noted, the segment of the reference vessel currently falls outside of its scope. This influences which measures are considered in this study. In practice, the following impact assessment focusses on regulations with direct economic, operational, or organisational effects. As measures such as EEXI and CII are not yet mandatory for the reference vessel, they therefore have limited to no immediate impact.

2.2.4. Nitrogen oxides (NO_x), Sulfur oxides (SO_x) and Particulate matter (PM)

Besides above measures the IMO also set strict limits to certain emissions, due to their pollutive impact in coastal and port regions. To mitigate these impacts, the IMO introduced regulations under the International Convention for the Prevention of Pollution from Ships (MARPOL), specifically in MARPOL Annex VI. These regulations set strict limits on key pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter (PM). Over time, these limits have been tightened in a tiered fashion, reflecting progressive environmental objectives and technological advancements within the shipping industry.

The following sections detail the tiered limits for SO_x and NO_x, discuss their impact on PM, and present compliance strategies.

Sulfur Oxides (SO_x) Emission Limits

Sulphur oxide emissions (SO_x) from shipping are mainly the result of the combustion of sulphur-containing marine fuels. In Regulation 14 of MARPOL Annex VI, the IMO established global limits on the sulphur content of marine fuel:

Time Period	**Global Cap**
Before 1 January 2020	3.50% m/m
On and after 1 January 2020	0.50% m/m

Table 2.1: Global Cap Changes (International Maritime Organization (IMO), 2008)

This significant reduction in the global sulphur content of the fuel was aimed at reducing SOx emissions worldwide. Ship operators can comply by using low sulphur fuels (e.g., Very Low Sulphur Fuel Oil, VLSFO) or by installing approved Exhaust Gas Cleaning Systems (EGCS), commonly known as scrubbers, which remove SOx from the exhaust gas stream.

Sulfur Emission Control Areas (SECAs)

In addition to the global sulphur limit, certain regions have been designated as Emission Control Areas (ECAs). Sometimes, specifically referred to as sulphur emission control areas (SECAs), where more stringent sulphur limits apply. According to Regulation 14.4 of MARPOL Annex VI, the maximum sulphur content in these areas is 0.10% m/m. These areas include (but are not limited to):

- The Baltic Sea Area
- The North Sea Area
- The North American ECA
- The United States Caribbean Sea ECA

Compliance within ECAs typically involves the use of marine gas oil (MGO) or ultralow sulphur fuel oil (ULSFO), although many ships opt to use scrubbers. Violations of these limits can result in fines, vessel detention, and other penalties imposed by local port states.

Nitrogen Oxides (NO_x) Emission Tiers

Regulation 13 of MARPOL Annex VI sets out the tiered approach to reducing NO_x emissions from marine diesel engines. The tier level depends on the date of construction of the vessel (or the date of engine installation) and the location where the vessel is operating. The limits of NO_x are expressed in grammes of NO_x per kilowatt hour (g / kWh) and are related to the rated speed of the engine (revolutions per minute, rpm).

Tier	Ship Built	rpm <130	130 $\leq$ rpm <2000	rpm $\geq$ 2000
Tier I	$\leq$ 2010	17.0 g/kWh	$45 \times$ rpm$^{-0.23}$	9.8 g/kWh
Tier II	$\geq$ 2011	14.4 g/kWh	$44 \times$ rpm$^{-0.23}$	7.7 g/kWh
Tier III	$\geq$ 2016 (NECAs only)	3.4 g/kWh	$9 \times$ rpm$^{-0.23}$	1.96 g/kWh

Table 2.2: NO_x tiers

Designated NECAs currently include the North American ECA and the US Caribbean ECA for NO_x control, and the Baltic Sea and North Sea also enforce Tier III for new builds. Ongoing discussions at the IMO may lead to additional NECAs worldwide.

Particulate Matter (PM) Restrictions

Although Particulate Matter (PM) does not have a direct numerical limit under MARPOL Annex VI, it is inherently affected by the sulphur content of the fuel. High-sulphur fuels tend to generate higher PM emissions because of the formation of sulphates. Consequently, global and ECA-specific fuel sulphur limits indirectly reduce PM emissions.

As emission reduction technologies evolve, systems such as diesel particulate filters (DPFs) are being tested, but widespread adoption is currently limited in the maritime context due to operational and practical challenges.

2.2.5. Compliance Strategies

Shipowners and operators employ several strategies to comply with the SO_x, NO_x and (indirectly) PM regulations.

1. **Fuel Switching**: Using low-sulphur fuels such as Very Low Sulphur Fuel Oil (VLSFO), Ultra Low Sulphur Fuel Oil (ULSFO), Marine Gas Oil (MGO) or Marine Diesel Oil (MDO).
2. **Exhaust Gas Cleaning Systems (Scrubbers)**: Wet or dry scrubbers can reduce SOx levels in exhaust gases to meet the equivalent of operation of 0.50% or 0.10% sulphur fuel.
3. **Aftertreatment Systems**: SCR (Selective Catalytic Reduction) and EGR (Exhaust Gas Recirculation) are used to control NO_x emissions, particularly for Tier III compliance.
4. **Alternative Fuels**: Liquefied natural gas (LNG), methanol, biofuels and other emerging fuel alternatives generally have lower sulphur and nitrogen content, thus reducing both SO_x and NO_x emissions, as well as PM.
5. **Operational Measures**: Slower steaming (reducing the engine load), voyage optimisation, optimised route planning, and improved engine maintenance can also help to reduce overall emissions.

2.3. EU initiatives

Besides the regulations that come from the IMO, the EU has decarbonisation initiatives for the shipping industry. They comply with the targets set by the IMO and/or have more ambitious targets for the EU area. According to the European Climate Law, the EU has committed to reduce its net GHG emissions by at least 55% by 2030. This programme is called 'Fit for 55'. The two initiatives that directly influence the maritime sector are the Emission Trading System (ETS) and FuelEU.

2.3.1. Monitoring, Reporting and Verification (MRV)

From January 1, 2025, offshore ships of 400 gross tonnage (GT) and above are required to monitor, report, and verify their greenhouse gas (GHG) emissions under the EU MRV regulation. This initiative aims to improve the transparency and accuracy of data on the emissions of these vessels. The European Commission has specified that the MRV regulation applies to ships designed or certified for offshore activities, such as offshore support vessels, pipe layers, and drilling ships. This definition ensures that vessels engaged in offshore construction are included in the MRV requirements.

2.3.2. EU Emissions Trading System (ETS)

The EU Emission Trading System (EU ETS) is the European Union's primary tool for reducing GHG emissions, particularly carbon dioxide (CO_2), from the main industrial sectors through a cap-and-trade approach. As of January 1st EU ETS applies to commercial ships of 5,000 GT and above transporting cargo or passengers and calling at EU ports, regardless of their flag or the owner's jurisdiction. Shipping companies are required to buy and surrender emissions allowances for tank-to-well CO_2 emissions within the EU and European Economic Area (EEA) ports (DNV, 2024). The EU sets a limit on total emissions that decreases over time. Companies can trade these allowances, companies that reduce emissions can sell excess allowances, while those that exceed their limits must buy more. By doing this, the system encourages investment in cleaner technologies as part of the EU's goal of carbon neutrality by 2050 (European Union, 2016) (European Union, 2023). EU ETS effectively commercialises emissions, meaning that emission reductions also yield cost savings by avoiding allowance purchases. This introduces a clear financial criterion for decision-making, strategies will be judged not only by emissions reduced but also by their cost-effectiveness. From January 1, 2027, offshore vessels are set to be included in the EU ETS.

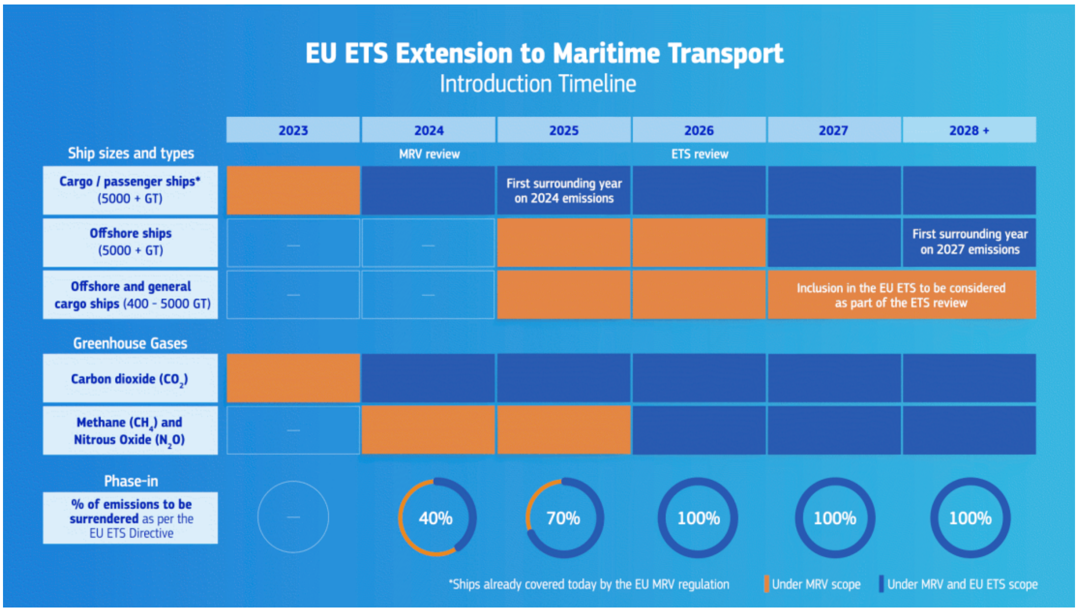


Figure 2.2: EU ETS extension to Maritime Transport timeline

Marker Stability Reserve (MSR)

The Market Stability Reserve (MSR) is a mechanism introduced to keep the supply of emission allowances in the EU Emission Trading System (EU ETS) in line with demand and avoid extreme price fluctuations. Essentially, it absorbs surplus allowances from the market when too many are in circulation and reinjects them if there is a shortfall.

Each year, regulators calculate the total volume of allowances in circulation, the surplus. If that surplus exceeds a certain threshold, set at 833 million tonnes of CO_2, a percentage of the surplus is placed in the reserve. This reduces the number of allowances auctioned in the following year and helps to support the carbon price. In contrast, if the total volume of allowances in circulation goes below a lower threshold, 400 million tonnes of CO_2, the MSR releases additional allowances back into the market. The mechanism became operational in 2019, with an initial higher absorption rate of 24% of the surplus each year, scheduled to fall to 12% after 2030. Additional rules allow specific amounts of allowances to be 'backloaded' into the reserve. That is, withheld from earlier auctions to prevent an oversupplied market. In general, by tightening or loosing allowance availability, the MSR helps to maintain a stable carbon price signal and promote ongoing investment in low carbon technologies (Gabin Mantulet, Aurélien Peffen, and Sylvain Cail, 2023).

2.3.3. FuelEU

The FuelEU Maritime initiative sets limits on the annual average intensity (GHG) for ships over 5,000 GT visiting EU ports, regardless of their flag. These limits are designed to gradually reduce the intensity of maritime fuel GHG, starting with a reduction of 2% by 2025 and aiming for a decrease of 80% by 2050. This will be split up into several steps:

- 2.00% from 1 January 2025
- 6.00% from 1 January 2030
- 14.5% from 1 January 2035
- 31.0% from 1 January 2040
- 62.0% from 1 January 2045
- 80.0% from 1 January 2050

(Office of the European Union, 2023)

The targets cover not only CO_2, but also methane (CH_4) and nitrous oxide (N_2O) emissions, based on a full life cycle assessment of the fuels, known as the Well-to-Wake (WtW) approach. The regulation also introduces zero-emission requirements for ships at berth, specifically for passenger and container ships, which must use onshore power supply (OPS) or other zero-emission solutions to reduce air pollution in ports.

By adopting a technology-neutral and goal-based approach, FuelEU Maritime encourages innovation, allowing operators to choose the most suitable fuels or energy technologies based on their ships' needs. It also includes flexibility mechanisms to help existing fleets comply and rewards early adopters of clean energy solutions. The regulation will take effect on January 1, 2025, with some monitoring requirements beginning on August 31, 2024 (Office of the European Union, 2023). However, currently offshore vessels are excluded from the scope of the FuelEU Maritime Regulation. This exclusion is subject to future reviews, and the regulation's scope may be expanded to include more vessel types pending such evaluations. As most of these regulations will be revised before 2030, it becomes difficult for companies such as Jumbo Maritime to adjust their long-term strategies.

2.4. Relevance to Jumbo Maritime

Among the various regulations discussed, the EU ETS emerged as the dominant driver of operational changes in this study due to its direct cost impact on CO_2 emissions. However, the FuelEU Maritime scope and IMO efficiency indices, while important for long-term efficiency, did not impose immediate operational constraints on the case vessel. From 2024 onwards, maritime shipping emissions are gradually incorporated into the EU ETS, which means that vessel operators will need to obtain allowances for their CO_2 output. This effectively adds a cost dimension to fuel consumption and therefore influences operational decision making. Therefore, this thesis will focus primarily on the EU ETS as the regulatory driver in subsequent analyses.

To conclude, the following regulations are shown in Table 2.3, are applicable to the reference vessel.

Regulation	**Applicable to reference vessel**	**Remarks / Suggested Adaptations**
IMO EEXI	No	Offshore construction vessels currently exempted; future adaptations needed for DP activities
IMO CII	No	No current rating for offshore vessels; suggest adapting metrics (e.g., emissions per operational day or activity)
IMO SEEMP	Yes	Mandatory annual fuel consumption reporting to IMO
IMO NO_x/SO_x	Yes	Tier I NO_x engines; compliant via fuel management (sulphur ≤0.50% globally, ≤0.10% in ECAs)
EU MRV	Yes (from 2025)	Requires detailed per-voyage CO_2 emissions monitoring and reporting for EU voyages
EU ETS	Yes (from 2027)	Future obligation to purchase CO_2 allowances for EU-related emissions
FuelEU Maritime	No	Currently exempt; future inclusion possible. Would require adapting metrics to project-based fuel usage

Table 2.3: Overview of Regulatory Applicability for reference vessel

In summary, Jumbo Maritime faces the challenge of reducing emissions, to meet the IMO / EU mandates while maintaining profitability. Thus, both environmental performance and financial viability will be critical in assessing any operational changes.

Having established the regulatory context for maritime emissions, the next chapter will examine academic literature on operational decision making and emissions reduction strategies.

3

Operational emission reduction strategies

To comply with the regulations and indices highlighted in Chapter 2, the industry must take action. The decarbonisation of the maritime industry will require primarily new fuels, but also greater energy efficiency, better logistics, and uptake of carbon capture and storage onboard. Digitalisation will be a key enabler for decarbonising the maritime industry and improving ship design, operations, and fleet utilisation (DNV, 2024). However, as it is a commercial environment, the financial impact has a significant influence on the implementation of decarbonisation measures. DNV provided a high-level overview of different categories of measures to reduce emissions or improve efficiency in shipping, each with an associated cost and savings potential.

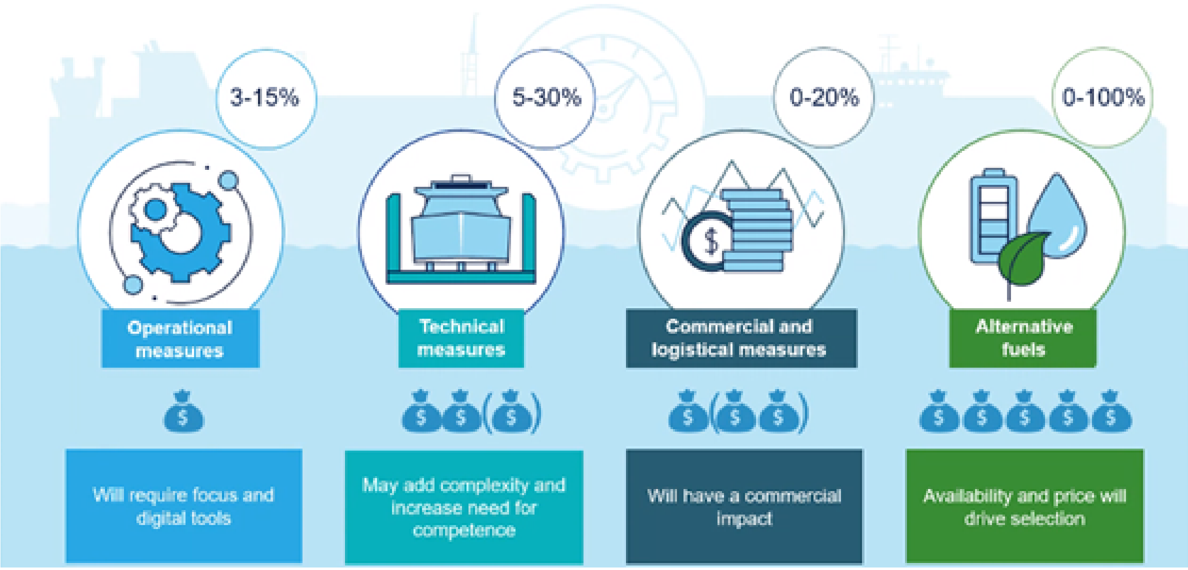


Figure 3.1: cost and savings potential decabonisation measures (DNV, n.d.[a])

Although Jumbo Maritime is also looking into technical measures and alternative fuels, it is difficult to achieve this in the near future. Operational and logistic measures, on the other hand, can have an impact tomorrow. This chapter will highlight current operational measures that are being used in the maritime industry, found in the literature. It will provide an answer to Sub-question 2:

1: What existing operational measures are available in the offshore industry to reduce greenhouse gas emissions?

3.1. Energy distribution

If you want to improve energy efficiency or reduce energy use in general, the first step is to understand how all the energy produced onboard a vessel is distributed. In this section, the breakdown of the energy distribution will be explained. According to Xing, Spence, and Chen (2020), internal combustion engines and oil-fired boilers are currently widely used on board merchant ships to provide propulsion (main engine), electricity generation (auxiliary engine), and steam generation (auxiliary boiler). These depend mainly on fossil fuel combustion and, in particular, on marine residual oils to produce energy. This can be proven by DNV (2024) when looking at Figure 3.2. It shows that as of June 2024, 98% of all ships ran on conventional fuels and 72.9% of the order book consists of vessels that will run on conventional fuels.

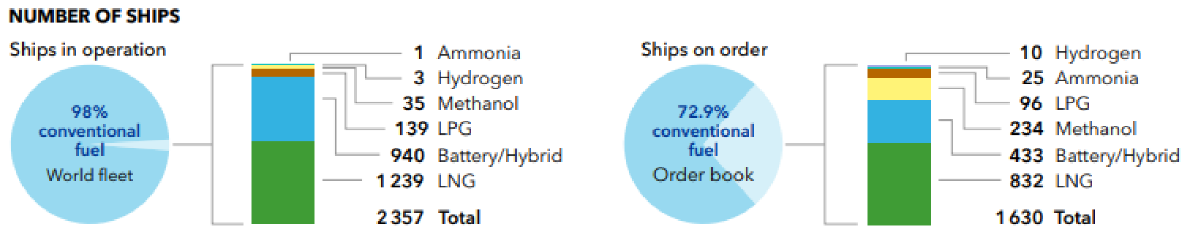


Figure 3.2: Alternative fuel uptake in the world fleet in number of ships as of June 2024 (DNV, 2024)

The three categories described by (Xing, Spence, and Chen, 2020), the main engine, the auxiliary engine, and the boilers, are used by many other scientific sources and institutions to explain the total fuel consumption and / or the breakdown of the energy of a vessel. Figure 3.3 shows that the main engine is responsible for $\pm$ 75%, the auxiliary engine for $\pm$ 17%, and the boiler for $\pm$ 8% of the total fuel consumption. It should be stated that the boilers are located primarily in tankers and very large container carriers. However, these percentages cannot be taken as standard for all types of vessel. The total fuel consumption does not provide the full picture. In figure 3.3 the total fuel consumption is also shown per type of vessel.

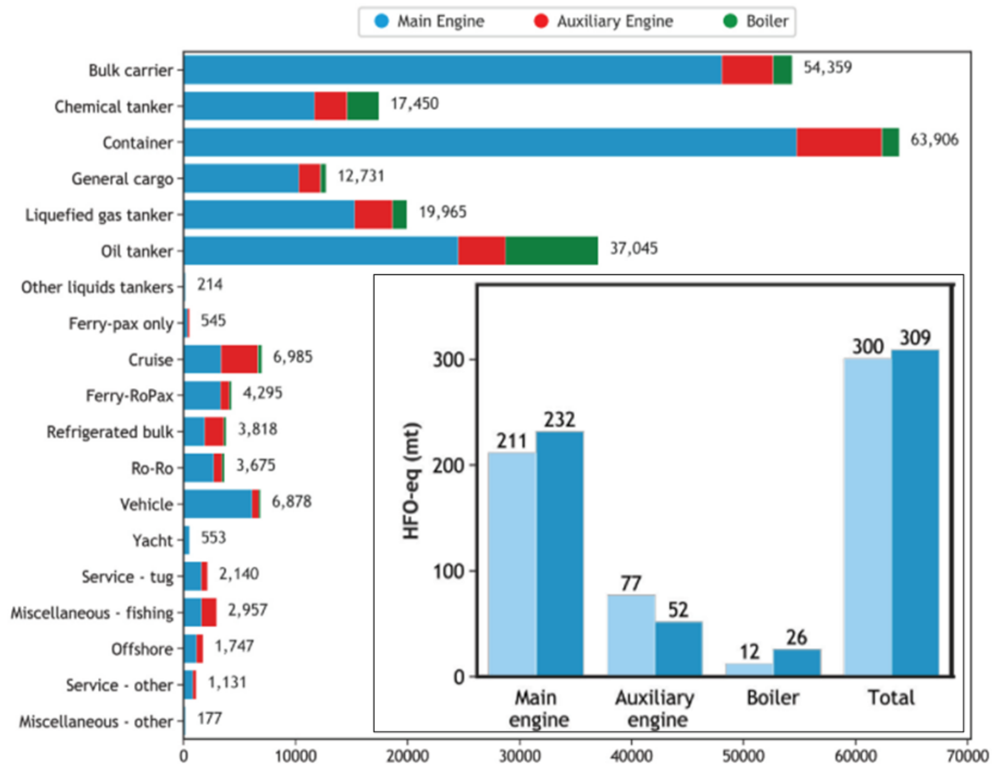


Figure 3.3: Total fuel consumption per engine category (per vessel) [HFOeq], (lightblue 2012, darkblue 2018) (IMO, 2021)

In IMO (2021) exact numbers and percentages can be found for this figure. The figure shows that for each type of vessel the energy distribution is specific to its operational profile. Section 3.2 highlights a few measures to reduce consumption.

3.2. Operational measures

This section will highlight a few possible operational measures for the decarbonisation of the maritime industry found in a literature review prior to this research (Groeningen, 2024). Operational measures include strategies that optimise ship performance, navigation, maintenance, and port activities, focussing on improving efficiency and reducing emissions through coordinated practices. Many of these measures aim to reduce fuel use by improving operational efficiency. However, it is crucial that such changes do not indirectly compromise project schedules or safety. This highlights that operational performance must be maintained even as emissions are reduced. In addition to the topics found in the following section, the literature review also covered shore-to-ship power, alternative routing, operating resistance optimisation, and maintenance optimisation (Groeningen, 2024). However, while conducting the research these theories were not applied and therefore left out of this report.

3.2.1. Slow steaming

According to Lindstad and Eskeland (2015), slow steaming can be explained as the operation of commercial vessels at a speed lower than their design speed. Slow steaming was adopted to save fuel costs and was performed by almost all global shipping companies after the economic crisis of 2008 (Xing, Spence, and Chen, 2020). The general assumption is of a cubic relationship between the required power and the speed of the ship. For example, a 10% speed reduction yields approximately a 27% reduction of the required power (Faber, Huigen, and Nelissen, 2017). Slow steaming has proven to be the most energy-efficient operational measure for individual vessels. Fuel savings and reductions in CO_2 emissions can be achieved in the range of 20 to 40% or even more than 60%, depending on the extent of the speed reduction (Xing, Spence, and Chen, 2020). According to Corbett, H. Wang, and Winebrake (2009) on individual container ship routes, depending on operating conditions, a reduction in fuel consumption and CO_2 emissions of up to 70% can be achieved if the speed is reduced to approximately half the intended speed.

However, there are some things to consider. According to Pelić et al. (2023), marine diesel engines have the lowest specific fuel consumption (SFC) in the range of 85% Maximum Continuous Rating (MCR). The SFC increases significantly if the MCR decreases, especially below 50%. At extremely slow steaming speeds, with a load less than 40% MCR, other problems, such as increased engine fouling and the need for continuous operation of the auxiliary blowers, may occur. In addition to that, slow steaming will increase travel time, weaken just-in-time delivery service, and reduce the number of trips per year of the ship. The increase in travel time could lead to a deterioration in product quality and increased consumption of refrigeration energy for cold chain logistics, such as fresh fruit, vegetables, and meats (C.-Y. Lee, H. L. Lee, and Zhang, 2015).

Source	**Methods**
(Halim et al., 2018)	International freight model (IFM)& “ASIF” (Activity, Structure, Intensity, Emission Factor) method
(Chang and C.-M. Wang, 2014) & (Lindstad and Eskeland, 2015)	Scenario based modeling
(Faber, 2012)	Scenario based modeling & Cost benefit analysis

Table 3.1: Slow steaming methods and sources

3.2.2. Voyage optimisation

Voyage optimisation is a very large concept. According to Zaccone et al. (2018), the main objective of optimisation of the voyage can be explained as: reducing the total resistance of the ship, reducing the financial cost, or making the maximum profit during a voyage by selecting the optimal path and speed profile for a given weather forecast. For liner services, this includes slow steaming, weather (alternative) routing, speed optimisation, and operating resistance optimisation. For offshore construction vessels, this can be extended to DP operations, optimised downtime handling, and reduce equipment breakdowns. As said, voyage optimisation is a large concept that contains several smaller topics. Ship particulars, sailing speed, sea and weather conditions are the basic variables. Origin-destination, seaworthiness, safe handling, service contract time, time in ports, and minimum fuel consumption are the main constraints (S. Wang, Meng, and Z. Sun, 2013). According to Sen and Padhy (2015), the combining factor is that they are all concerned with distance, time, and minimisation of resistance under the constraints defined above.

Speed optimisation

Speed optimisation involves adjusting the speed of a ship along a specific route, or individual segments of a route, while considering uncertainties such as variable service times at sea or in ports, time constraints and weather conditions (Li, B. Sun, Q. Zhao, et al., 2018). Its primary objective is typically to reduce fuel consumption or maximise efficiency. Although often mistaken for slow steaming, speed optimisation is a distinct concept. The key difference is that slow steaming involves consistently operating a ship at reduced speeds to save fuel, while speed optimisation adjusts speed dynamically based on route conditions, schedules, and operational constraints to achieve specific efficiency or timing goals (Li, B. Sun, Guo, et al., 2020). In a study conducted by Li, B. Sun, Q. Zhao, et al. (2018), a 48000DWT oil tanker was used to simulate the effects of speed optimisation compared to the use of continuous punctual speed sailing and the design speed sailing. The results of the fuel consumption simulation show that the fuel savings in a single voyage by speed optimisation is 1.07% compared to the punctual speed sailing in time, and compared to the design speed sailing, the optimised speed achieves a single voyage fuel savings of 32.63%. Highlighting the financial impact, the results of the cost simulation show that the cost reductions after speed optimisation for a single voyage operation of the ship are up to $86,000 and $95,000, respectively. (Li, B. Sun, Q. Zhao, et al., 2018). Another research by K. Wang et al. (2018) states that the optimisation results show that the proposed method can improve the energy efficiency of the ship, lower the fuel consumption and therefore reduce CO_2 emissions by approximately 28% in ideal cases.

Another part of speed optimisation, known as virtual arrival (or just-in-time arrival), combines elements of speed optimisation and ship scheduling. Today, under the traditional first-come, first-served berthing system, ships rush to their destination and then remain idle awaiting berth assignment. In this approach, a ship adjusts its speed to reach the port at the precise time that a berth becomes available, avoiding unnecessary waiting at anchor due to known delays in berth allocation. A study carried out by Jia et al. (2017) shows that fuel savings can range from 7.26% with only a 25% reduction in the 'excess' port time to 19% if all apparent inefficiencies can be removed.

Virtual arrival requires coordinated agreements between ship operators and port authorities to determine an agreed-upon arrival time (Jia et al., 2017). However, this is also the catch of this caution. According to Jia et al. (2017), its widespread implementation faces challenges such as the commercial priorities of stakeholders, the need for improved communication, and possible impacts on crew workload and rest periods.

Source	**Methods**
(K. Wang et al., 2018)	Model Predictive Control (MPC)
(Li, B. Sun, Q. Zhao, et al., 2018)	multi-variable nonlinear programming (Matlab & Simulink)
(Li, B. Sun, Guo, et al., 2020)	Constrained optimization by linear approximation (python)
(Jia et al., 2017)	bottom-up approach
(Poulsen and Sampson, 2019)	semi-structured interviews & non-participant observation

Table 3.2: Speed optimization methods and sources

3.2.3. Organisational factors

Non-technological operational measures are highly based on human effort and the judgment of key stakeholders, such as ship operators, managers, crew members, governments and port operators. This underscores that organisational factors critically affect operational emissions. Consequently, organisational factors are critical for both the adoption and successful implementation of these measures, directly influencing their effectiveness in achieving fuel savings (Rasmussen, Lützen, and Jensen, 2018).

According to Banks (2015), the concepts of organisational factor management that can be considered to improve energy efficient ship operations included the following: human resource management, accountability, behavioural management, and personal engagement. Part of that is equipping operators with a deeper understanding of energy-efficient practices, which enables them to make better decisions that positively impact fuel consumption and operational efficiency.

In addition, implementing effective management structures and incentive programmes is essential. These measures are designed to create a collaborative environment in which the benefits of fuel savings are shared among operators. When operators see tangible benefits, they are more likely to be motivated and engaged in energy-saving practices. By fostering a sense of shared responsibility and mutual gain, these incentives encourage positive behaviour changes that contribute to sustainable energy management onboard (Banks, 2015). For two case study ships, the savings in fuel oil consumption achieved by a reduction in fuel consumption and an increase in transported cargo were 3% and 7%, which corresponded to a decrease in EEOI of 15% and 22% (Banks, 2015). Transporting more cargo with lower consumption also increases the profitability of a trip.

Source	Methods
(Rasmussen, Lützen, and Jensen, 2018) e.g.	qualitative methods especially focusing on the ”why” and ”How” questions and interview were done in a semi-structured manner.

Table 3.3: Organisational factor power methods and sources

3.3. Evaluation and Selection of Research Methods

The previous literature review revealed three key limitations in existing research approaches that informed the selection of research methods for this thesis.

First, scenario-based models and simulations tend to oversimplify real operational constraints, failing to capture the complex and dynamic realities of offshore vessel projects. For example, slow-steaming scenarios typically assume flexible transit schedules that rarely apply to the rigid schedules characteristic of offshore construction operations. Thus, effective methods in general cargo liner shipping contexts become less valid for highly constrained offshore environments.

Second, theoretical optimisation and economic models, such as advanced fuel optimisations or cost-benefit analyses, rely heavily on idealised assumptions and comprehensive datasets, neither of which is typically available in offshore construction contexts. Offshore projects involve multiple stakeholders with competing priorities, irregular operations, and fragmented or uncertain data. Consequently, purely theoretical or long-term economic evaluations, such as Net Present Value (NPV) analyses, become unreliable due to inherent uncertainties.

Third, qualitative insights can be derived through methods such as structured surveys or observational case studies. However, structured surveys restrict respondents to predefined categories, limiting deeper explorations of the underlying motivations or context-specific considerations. Observational case studies, though insightful, require significant time and resources and may inadequately capture the subjective reasoning behind operational decision making. Therefore, these approaches are less flexible and less effective compared to semi-structured interviews, which allow for nuanced, context-rich exploration relevant to operational decision-making.

Given these limitations, this thesis adopts a mixed-method approach that combines quantitative operational data analysis with qualitative insights from semi-structured stakeholder interviews. Analysing actual operational records, such as daily progress reports (DPR) and real-time performance data, grounds the research in reality and accurately captures the operational complexities, irregular activities, and downtime characteristic of offshore projects. Currently, semi-structured interviews with stakeholders illuminate the context behind quantitative findings, highlighting decision-making dynamics, safety considerations, contractual priorities, and other organisational influences not readily visible through data analysis alone.

To effectively integrate and evaluate the diverse data and insights derived from these methods, a Multi-Criteria Decision Analysis (MCDA) is used. MCDA offers a structured, yet flexible framework explicitly designed to incorporate both numerical and qualitative information, accommodating stakeholder priorities and operational constraints. Alternative methods, such as purely qualitative narrative comparisons or traditional cost-benefit analysis (CBA), were considered, but deemed less suitable. Purely qualitative approaches lack the structured clarity required for systematic and transparent comparisons, while CBA's focus on monetary valuations inadequately addresses essential qualitative criteria such as safety, compliance, and stakeholder satisfaction. The Weighted Sum Model (WSM) was chosen as the MCDA technique because of its simplicity, transparency, and ability to clearly reflect trade-offs across criteria through easily interpretable weighted scores, making it well suited to contexts where criteria can be normalised and weighted according to stakeholder priorities. More complex alternatives like the Analytic Hierarchy Process (AHP) or TOPSIS were considered but were judged to be unnecessarily elaborate for the scope and data requirements of this analysis.

In summary, traditional modelling and analysis approaches either oversimplify offshore operational complexities or demand idealised assumptions unsuitable for this research context. The adopted mixed-method approach, complemented by MCDA, addresses these gaps by combining empirical quantitative analysis with qualitative stakeholder insights, providing a robust, comprehensive, and context-sensitive methodology. This integrated approach ensures that the research remains aligned with its main objective: achieving cost-effective emissions reduction in offshore operations without compromising operational performance or regulatory compliance.

3.4. Key decision criteria

Based on the literature it can be concluded that successful emission reduction in vessel operations is a multifaceted challenge. The environmental impact is paramount, as strategies must demonstrably reduce greenhouse gas emissions to meet regulatory and societal goals. Secondly, operational performance remains critical. Any emission saving measure should not excessively impede the efficiency or success of the operation. In addition to those organisational factors, Section 3.2.3 frequently determines whether emission reduction practices can be adopted in daily operations. Finally, the financial impact cannot be ignored. Cost-effectiveness and economic feasibility decide whether the measures will be implemented on a scale. These four impact criteria appear throughout the literature and practice and will serve as evaluation criteria for the decision-making framework of this study in Chapter 8.

These insights from scientific literature inform the design of our analytical approach where we develop the multi-criteria decision framework. In the following chapters, we will analyse Jumbo's operations through this lens. Chapter 4 next describes the research methodology adopted to collect and analyse the data.

4 Methodology

Based on the findings of Chapter 2 and Chapter 3, four factors were identified as critical to evaluate operational emissions decisions: environmental impact, operational performance, financial impact, and organisational factors. Consequently, this research adopts a multi-criteria decision analysis (MCDA) approach centred on these four criteria. Each criterion reflects a theme highlighted in the literature. For example, industry studies stress the need to balance emissions reduction with operational efficiency and cost, see Chapter 3, while organisational support and culture are cited as pivotal for implementing sustainable measures. By structuring the MCDA around these factors derived from the literature, we ensure that the framework addresses all relevant dimensions identified in previous research.

First, this chapter details how the data and insights were gathered to evaluate the operational strategies under those criteria. The study was conducted in multiple phases, combining literature review, quantitative analysis, and qualitative analysis into an MCDA. The general approach ensures that all four key criteria, as identified in the literature review, are taken into account and sets the stage for creating a practical decision-making framework.

Quantitative analysis consisted of two parts. First, calculate the emissions of each specific offshore activity (Chapter 5, sub-question 2). Secondly, a financial analysis (Chapter 6, sub-question 3).

The emissions of operational activities were calculated using real operational data from a reference project and a vessel. Detailed operational logs, specifically Daily Progress Reports and data from the vessel's Dynamic Positioning (DP) computer, were collected throughout the project. These data included time-stamped records of vessel activities, transit legs, power usage parameters, and location data. The goal was to calculate fuel consumption and emissions for each type of operational activity. The quantitative analysis was carried out in several steps :

1. Data Processing and Activity Clustering: Operational events in the DPR's were categorised into clusters, main clusters, and operational mode to allow analysis of emissions per activity type.
2. Component Definition: The propulsion and power generation configuration of the vessel was defined and their technical characteristics were identified.
3. Fuel Consumption Estimation: Fuel consumption was calculated for each cluster, main cluster, and operational mode. The engine load data was converted to fuel consumption using fuel curves provided by the manufacturer and standard formulas. For example, the relationship between electrical load and engine brake power was used to estimate fuel use on generators, and specific fuel consumption (in g / kWh) was applied for different engine load percentages. Assumptions such as minimum engine load thresholds were applied to reflect operational practices. All of this was done in the so-called bollard pull condition, which is not applicable during transits. Therefore, transit consumption has been estimated and validated based on historical data.
4. Emissions Calculation: The fuel consumption for each activity was then translated into emissions (CO_2, NO_x, SO_x, PM) based on the emission factors per ton of fuel for the fuel type used.
5. Sensitivity analysis: A sensitivity study was conducted to test how different time intervals affected the results. This helped evaluate the robustness of the findings. The outcome is a breakdown

of fuel consumption, time spent and GHG emissions by operational activity, identifying which activities had the greatest impact on the emission footprint of the vessel (Section 5.7).

The second part, the financial analysis, is carried out to evaluate the cost effectiveness of possible operational changes. Using the results of the quantitative analysis, the study estimated the financial impact of emissions and fuel consumption. This included calculating the day rates, fuel costs, port fees, and the cost of CO_2 emissions under the EU ETS. This economic perspective ensured that the recommendations and decision framework would not only be environmentally sound but also economically viable for stakeholders. By quantifying costs and, therefore, possible savings, research could prioritise measures that offer a favourable balance between emissions reduction and cost, which is a critical consideration for industry adoption.

Qualitative analysis (Chapter 7, sub-question 4) is performed to understand why certain operational decisions were made and how organisational factors come into play. Thus, a qualitative analysis was conducted in the form of semi-structured interviews. A purpose-sampling strategy was used to select interviewees who were directly involved in or knowledgeable about the case project's operations. Participants included project managers, vessel managers, and offshore operations managers. By choosing these roles, the study captured the perspectives of on-the-ground decision-makers to higher-level operational planners. An interview protocol was prepared covering topics such as decision-making processes during operations, awareness of emission reduction, constraints faced, and opinions on various efficiency measures. Each interview was conducted in person and lasted approximately 45 minutes. With consent, the interviews were recorded and later transcribed verbatim. For analysis, the interview transcripts were examined using a thematic coding approach. Using ATLAS.ti, initially open-coding was used to mark any relevant concepts or remarks line-by-line. Then axial coding grouped these initial codes into higher-level themes and patterns. Emerging categories included contractual factors, external pressures, organisational factors, decision making, and stakeholder influences. The result of this process was a set of key themes (Section 7.2) that describe how organisational factors and decision-making behaviour influence operational decisions related to emissions. In essence, the qualitative phase provided insight into why certain high-emission activities occur and what practical considerations govern the operators' behaviour.

Key operational factors (sub-question 5) The quantitative analysis highlighted several potential areas of improvement to reduce fuel consumption and emissions. The qualitative analysis provided insight into why certain operational decisions were made and how organisational factors come into play. By overlaying these results, a set of key areas of improvement was identified. These profiles are the target use cases for the decision framework. This integrative step is not a separate chapter, but a conceptual bridge that leads to the development of the framework.

Decision-making framework (Chapter 8, sub-question 6) To conclude the research, all the information collected was synthesised into a decision-making framework. The framework was developed using a Weighted Sum Model (WSM) approach, a Multi-Criteria Decision Analysis (MCDA) technique, to systematically evaluate operational choices.The criteria in this framework were directly informed by the research: Environmental impact, operational performance, organisational factors, and financial impact, reflecting quantitative data, qualitative themes, and financial analysis, respectively. Each criterion can be weighted according to stakeholder priorities or regulatory importance. The framework guides decision makers through the comparison of alternatives. In building the framework, care was taken to ensure that it aligns with the real-world decision processes at Jumbo Maritime. The insights of the interviews on how decisions are currently made and what barriers exist were used to shape the usability of the framework. The framework was refined through an iterative discussion with the participants to validate that the criteria and their interpretation make sense in practice. The end product is a structured decision support tool that can help align stakeholders on the most sustainable course of action, given all the trade-offs. It serves as a blueprint for data-driven and collaborative decision-making aimed at reducing emissions without compromising operability or violating constraints.

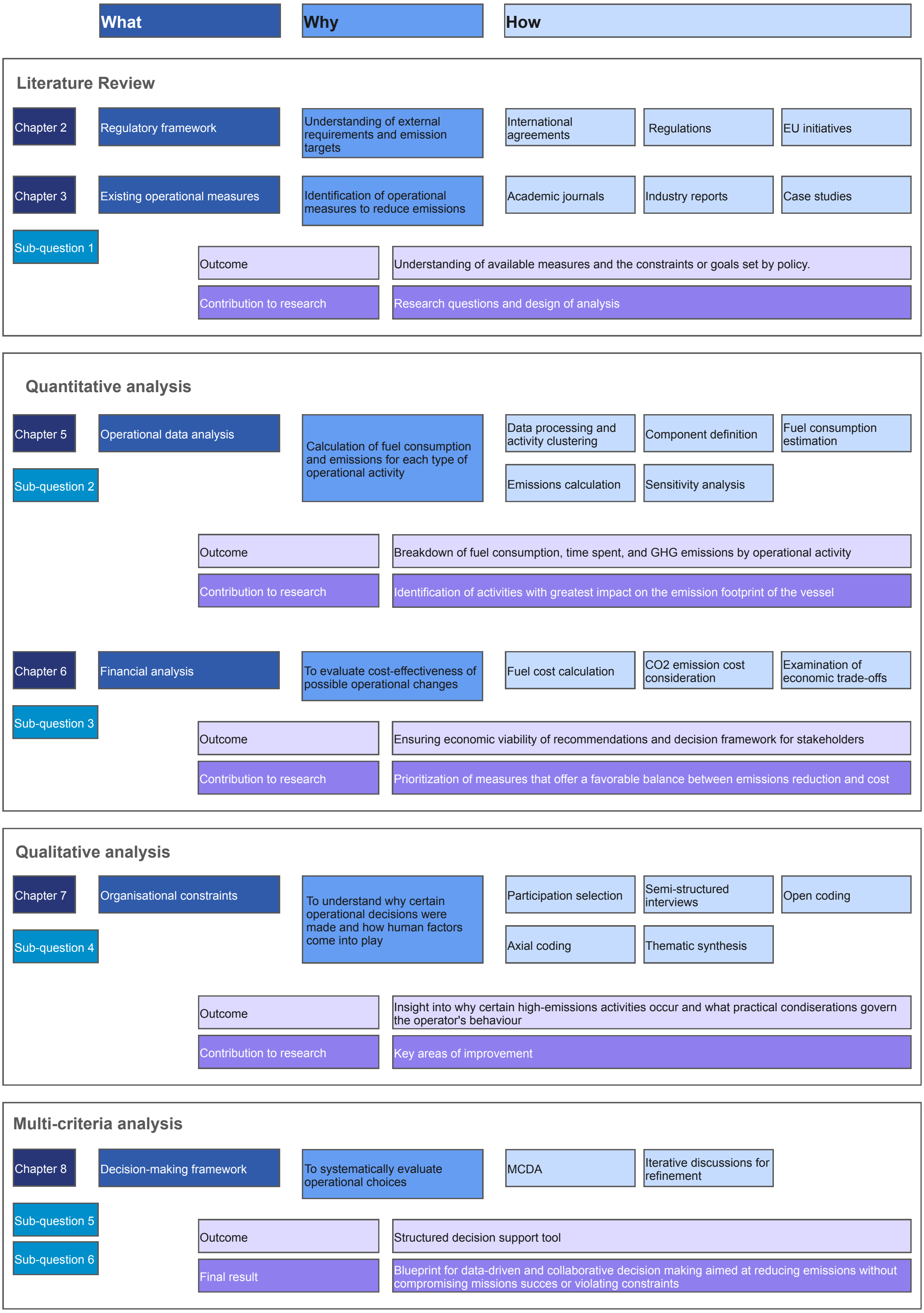


Figure 4.1: Methodology visualised

Part II

Quantitative analysis

5
Operational Data Analysis of Vessel Emissions

Data analysis plays a crucial role in evaluating performance, identifying inefficiencies, and optimising operational processes. This chapter presents a comprehensive data-driven evaluation. The analysis integrates multiple data sets to extract meaningful information, offering a structured approach to understanding key performance metrics. The quantitative analysis will provide an answer to the following sub-question.

2: What is the influence of each offshore activity on greenhouse gas emissions carried out by offshore construction vessels based on data analysis?

The chapter is divided into several sections. Daily Progress Reports provide a structured record of daily tasks and operational time, enabling trend identification and anomaly detection. The definition of components establishes the specific elements of the vessel that influence overall fuel consumption and efficiency, clarifying where the numbers come from. Fuel consumption estimation applies analytical calculations to predict energy consumption. Finally, a Sensitivity Study evaluates the impact of various time intervals on overall accuracy.

By integrating these analytical components, this chapter provides a data-driven foundation for optimising operations and improving predictive capabilities. The methodologies applied here will support informed decision making and contribute to the broader objectives of this research.

5.1. Power- and Energy systems

To get a proper estimate of fuel usage and emissions per activity, the first step is to know the machinery on board. Table 5.1 gives an overview of the energy sources that are currently installed in the reference vessel.

Although engines can operate on several different fuel types. During the reference project, Jumbo made use of Marine Gas Oil (MGO) and Bio-Fuel. Where the Bio-fuel is used in the main engines and the MGO in the auxiliary engines.

No.	Emission source	Technical description	Potential Fuel types
1	Main engine PS: Make: Caterpillar Type: 9M32C	Rated Power: 4500 kW@600 rpm SFOC: $187\ \mathrm{g/kWh}$	Heavy Fuel Oil (HFO) VLSFO Marine Diesel/Gas Oil Bio-Fuel
2	Main engine SB: Make: Caterpillar Type: 9M32C	Rated Power: 4500 kW@600rpm SFOC: $187\ \mathrm{g/kWh}$	Heavy Fuel Oil (HFO) VLSFO Marine Diesel/Gas Oil Bio-Fuel
3	Auxiliary engine FWD: Make: Caterpillar Type: 3516B	Rated Power: 1901 kW@1800rpm SFOC: $215\ \mathrm{g/kWh}$	Marine Diesel/Gas Oil
4	Auxiliary engine AFT: Make: Caterpillar Type: 3516B	Rated Power: 1901 kW@1800rpm SFOC: $215\ \mathrm{g/kWh}$	Marine Diesel/Gas Oil
5	Emergency generator: Make: Caterpillar Type: C18	LSA 49.1 S4 AREP Rated Power: 465 kW SFOC: $214\ \mathrm{g/kWh}$	Marine Diesel/Gas Oil

Table 5.1: Energy sources onboard the reference vessel

Internal Combustion engines

Table 5.1 shows that there are 3 types of engines on board. The main propulsion configuration of the vessel consists of two turbocharged 9-cilinder, four-stroke MAK 9M 32C diesel engines in line, 600 rpm rated with output power of 4500 kW. Both main engines drive a Controllable Pitch Propeller (CPP) directly through a gearbox and each engine drives a shaft generator of the AEM, type SE 630 M4. Although the main engines are capable of delivering 4500 kW, a maximum of 3750 kW can be used for the generation of electric power.
Both sets of auxiliary diesel generators are powered by 16 cilinder, four-stroke turbocharged Caterpillar engines, type 3516B.

Electric generators

The electric generators are coupled to diesel engines and convert mechanical shaft power into electric power. Electric alternators are categorised into a half dozen different types, but the generators in Table 2.2 are all synchronous machines.

Generator	Manufacturer	Amount	Tag plate Output
Shaft	AEM SE 630 M4	2	3∼ 690VAC/60Hz/1800rpm/3750kVA
Auxiliary	AEM generator SE 500M4	2	3∼ 690VAC/60Hz/1800rpm/2280kVA
Emergency	Leroy Somer LSA 49.1 S4 AREP	1	3∼ 440VAC/60Hz/1800rpm/550kVA

Table 5.2: Electric generators

DP system

The vessel is fitted with a dynamic positioning (DP) system, which is essential for the offshore installation contracts it undertakes. To address this, it is crucial to develop a more comprehensive understanding of the function and requirements of the system.

There are three levels of dynamic positioning, each with distinct requirements, primarily concerning redundancy. The International Maritime Organisation (IMO) defines these three primary DP Equipment Classes as follows:

- **Equipment Class 1**: Loss of position may occur in the event of a single fault.
- **Equipment Class 2**: The loss of position should not occur in the event of a single fault in any active component or system. Generally, static components are not considered susceptible to failure if they are adequately protected against damage and their reliability meets the standards set by the relevant administration. The single failure criterion encompasses any active component or system, as well as any normally static component that lacks proper documentation regarding protection and reliability.

- **Equipment Class 3**: In addition to the failures outlined for Class 2, this classification assumes that any normally static component may also fail. Furthermore, all components located within a single watertight compartment are considered vulnerable to failure due to fire or flooding, as are all components within a single fire subdivision.

Following this, the reference vessel is classified as Equipment Class 2 under DNV-GL. Consequently, only the requirements of this classification will be considered within the scope of this thesis. This classification also covers the IMO DP Class 2 requirements. However, additional requirements for the DP system are stipulated by the classification bureaus. Since classification societies differ to some extent in their requirements, this thesis is focused solely on the class guidelines established by DNV-GL.

The classification requirements require that any systems that could potentially compromise the vessel's ability to maintain its position must be configured and installed in such a manner that any malfunction in an active component or system does not result in a loss of position. These systems include technical components such as main engines, auxiliary generators and their excitation equipment, reduction gearing, appendages, electrical components, control gear, and thrusters.

Furthermore, systems that are not directly part of the DP system, but could affect its proper functioning in the event of a malfunction, such as fire suppression systems, engine ventilation systems, and shutdown systems, are incorporated into the Failure Mode and Effects Analysis (FMEA).

Operating philosophy DP2

In operational terms, the dynamic positioning class 2 (DP2) system facilitates accurate and reliable positioning so that the vessel can provide a stable platform for offshore construction operations. During offshore installation on DP, all 4 generators are online. Then both main engines with shaft generators and both auxiliary engines are running. For the shaft generators to be synchronised with the grid, the main engines operate on a fixed rotational speed. The propellers are loaded by alternating the pitch angle of the blades. The DP2 vessel operation manual describes a low-power configuration (Green DP) that meets the DP2 redundancy requirements. Both main engines with shaft generators, yet one auxiliary engine is then running. Weather workability limits and other limiting factors are not mentioned as to when this configuration is technically feasible. But it is solely used during waiting on weather.

5.2. Daily Progress Reports

During projects, Jumbo keeps track of progress with a so-called Daily Progress Report (DPR). These DPR's are a standard format which have to be signed by both the contractor and the clients as they are used as official documentation. The DPR's include, besides weather and general project information, various sections such as: Log of main events, planned activities for the next 24 hours, safety activities, crew & subcontractors on board, consumables, and a section of remarks. The project lasted over a period of 135 days, resulting in 135 DPR's.

Log of main events

The log of main events section can be split into two parts. First, the so-called critical path, this is the mean event during that day for instance, ”Waiting on Weather”. The second part consists of the activities that were performed during the ”Waiting on Weather”. This is done to show the client that, although planning had to be thrown overboard, the time was still used as useful as possible. These activities sometimes overlap, complicating the data analysis with, for instance, fuel consumption estimation. Therefore, it was decided to only consider the critical path for this research. This resulted in a contiguous critical path over 135 days. During these 135 days, 1973 individual activities were recorded with varying timestamp durations. Table 5.3 shows the 5 shortest durations, all of 120 seconds.

Date	Start Time	Stop Time	Time Difference (s)
23-5-2023	17:23:00	17:25:00	120
23-5-2023	22:58:00	23:00:00	120
6-6-2023	06:00:00	06:02:00	120
28-7-2023	16:15:00	16:17:00	120
28-7-2023	16:17:00	16:19:00	120

Table 5.3: Shortest activities in DPR's

Consumables

The consumables section shows the start quantity, bunkered, used, and actual resources on board. Table 5.4 shows the total consumed for each fuel type.

Fuel Type	Bunkered (tons)	Used (tons)
Bio (mt)	1202.1	1579.9
MGO(mt)	378.4	503
Total	1580.5	2082.9

Table 5.4: Total consumed fuel according to DPR

However, these consumables are copied by hand every day. Resulting in a lack of accuracy per day. In some DPR's it is noted that errors have been made and corrected later on, resulting in highly fluctuating and some absurd daily consumptions. The daily fuel consumption based on the DPR's is shown in Figure 5.1.

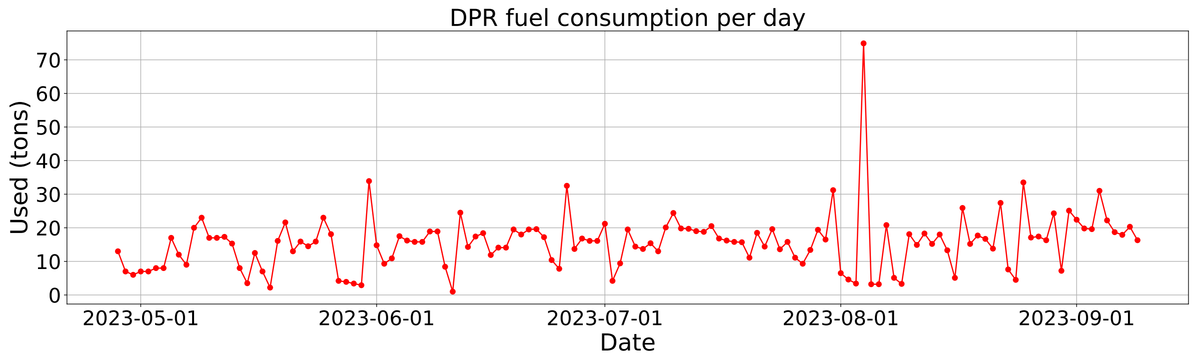


Figure 5.1: Daily fuel consumption based on DPR's

5.2.1. Cluster activities

Altough the description section of the DPR's have pre-selected activities from a dropdown menu and a comments section to elaborate on that, during projects there will always be unforseen activities and or reasons why the DPR's are not filled correctly. To make sure the activity descriptions in the DPR's have all been post-processed by the project manager to identify the critical path and select the right (main) clusters. Figure 5.2 shows the final (main) clusters that were used can be found.

Shift infield / move in to MP is special. In most cases, it is past the execution where it moves from one monopile to another by just resetting the DP location. However, in some cases, the vessel had to move around the wind farm to start working on the other side; these specific situations are labelled as transit instead of execution on DP. The line to Port from Transit in/out is due to (Un)mooring, which happens in port and has a different engine usage.

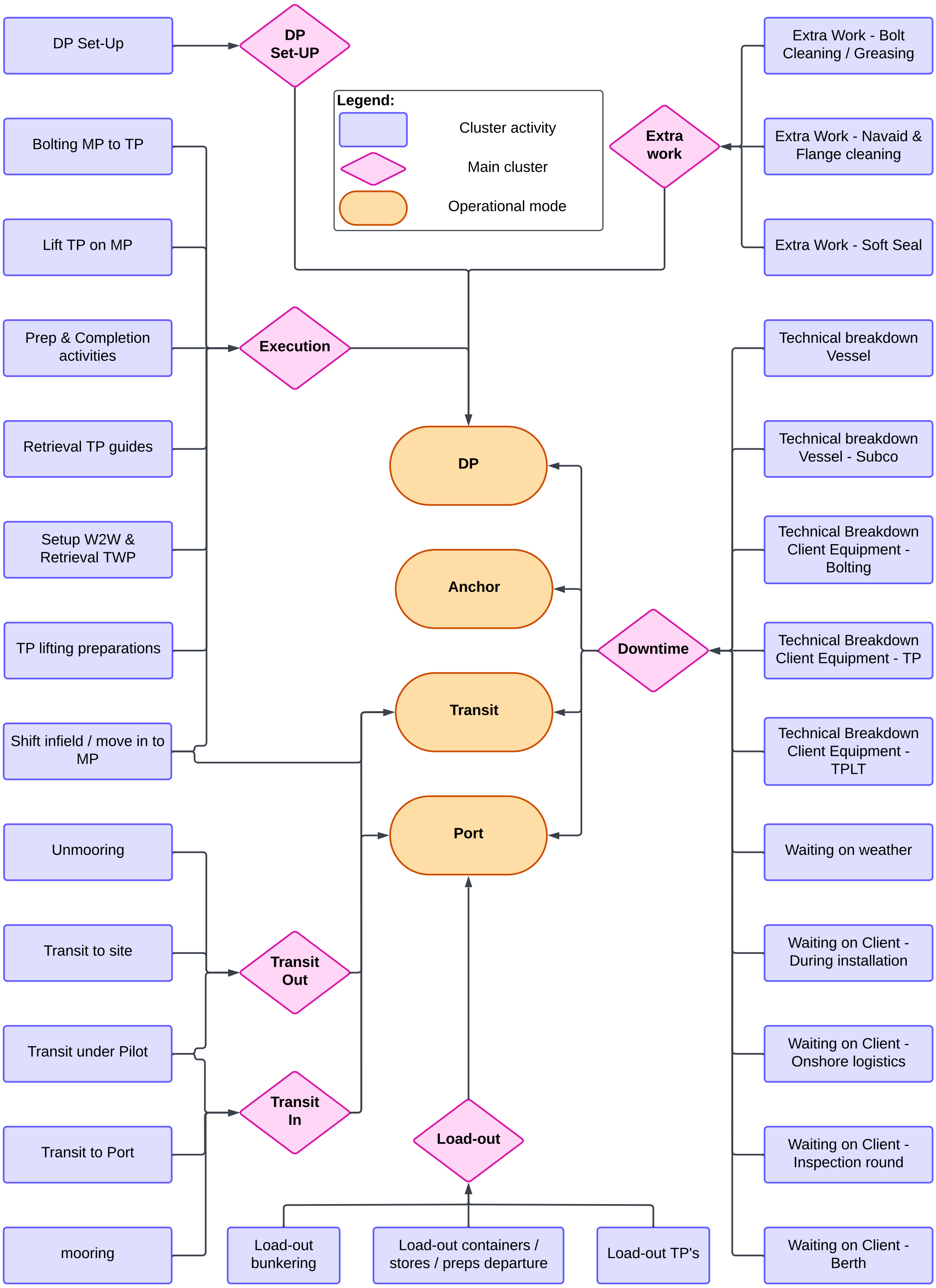


Figure 5.2: The defined clusters for the DPR's

5.3. Component Definition

Various components within the energy and power system convert and distribute chemical energy into electrical power and thrust. The data obtained from the DP computer, which is used in this thesis, consist of the pitch angle (α_{pitch}) of both controllable pitch propellers, the electrical output of two shaft generators and two auxiliary generators (P_e), and the corresponding time referenced to Coordinated Universal Time (UTC) (t). Using these input variables, along with fixed conversion factors and efficiencies, it is possible to determine the brake power of the engines and the associated emissions. In the current technical configuration, the energy flows as depicted in Figure 5.3

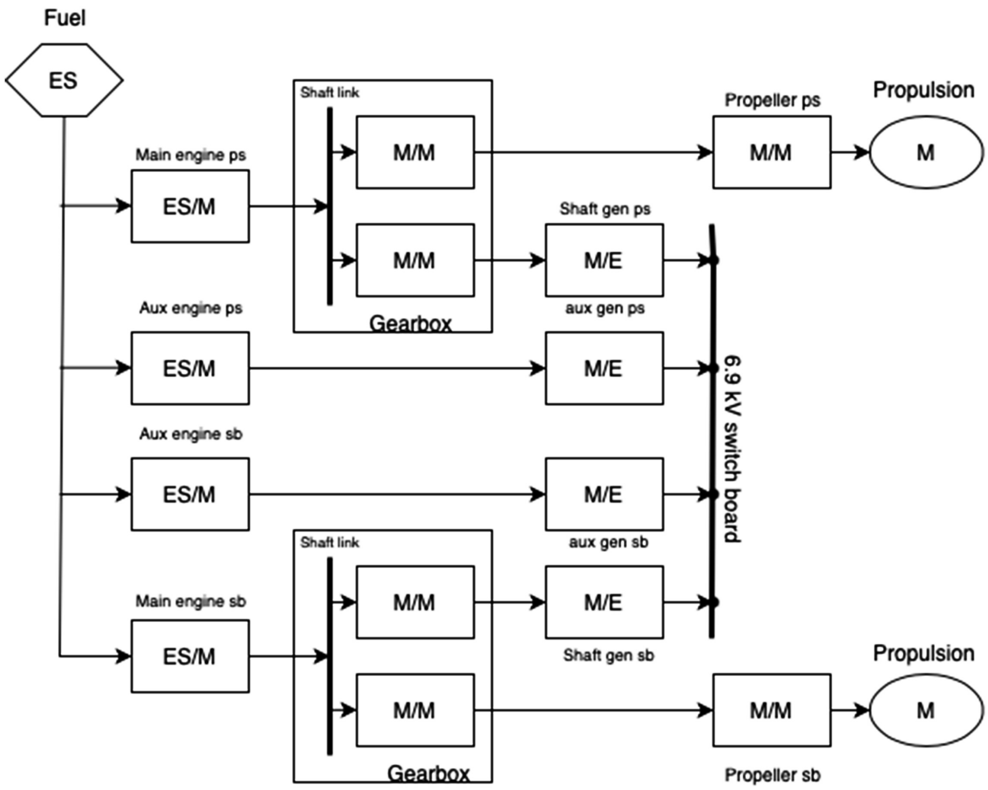


Figure 5.3: Energy flow diagram of the power system on board the reference vessel

In this figure, the loads are calculated from right to left, with six outer components on the right-hand side for which variables are known. The conversion of one form of energy to another results in inherent losses. These losses are expressed in terms of efficiency, which are employed to determine the contributions of all components. Various conversion efficiencies must be taken into account when estimating the load profile. In theory, engine dynamics can be estimated by following the steps proposed by Klein Woud and Stapersma (2002), as illustrated in Figures 5.4a and 5.4b.

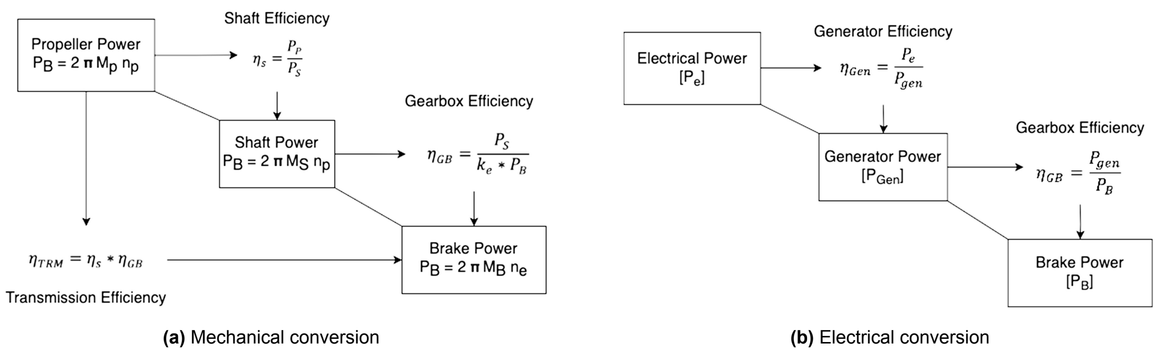


Figure 5.4: Power chain conversion

The conversion efficiencies are defined in Table 5.5. Efficiencies related to mechanical losses, such as η_S and η_{GB}, originate from the vessel manual. The generator efficiencies were determined by analysing the difference between electrical output and rated engine power.

Efficiency	Symbol	Quantity	Unit
Shaft	η_s	98	%
Gearbox	η_{GB}	98	%
Generator	η_{Gen}	96	%

Table 5.5: Assumed efficiencies throughout the calculations

5.4. Fuel consumption estimation

To better understand the emissions per operation, it is essential to estimate the emissions generated by the engines. The objective of the model for this is to combine the electrical load on the generators, in conjunction with the absorbed power on the propellers, to determine the engine power at the crankshaft. With power at any moment in time, fuel consumption is estimated. Subsequently, the emissions can be calculated. In estimating the load, many differences between the auxiliary and main engines are counted, such as appendages, specific fuel consumption, and maximum output. In addition, the main engines are connected to both controllable pitch propellers and shaft generators. For that reason, the estimation of brake engine power differs.

5.4.1. Main Engines

To estimate the power absorbed by the propeller, Figure 5.5 is used. This figure illustrates the relationship between pitch angle, required power, and thrust delivered. It is important to note that this figure is only valid under bollard pull conditions. Based on the recorded data, it was determined that the vessel remained stationary during the installation process, confirming that the propeller operated under bollard pull conditions.

During the design phase of the vessel, the decision was made to prioritise optimisation for long-distance sailing. As a result, in this specific condition, the thrust-to-power ratio does not achieve its maximum potential. Although controllable pitch propellers exhibit improved bollard pull performance compared to fixed pitch propellers of the same dimensions, pitch is restricted to 70% due to limited water inflow.

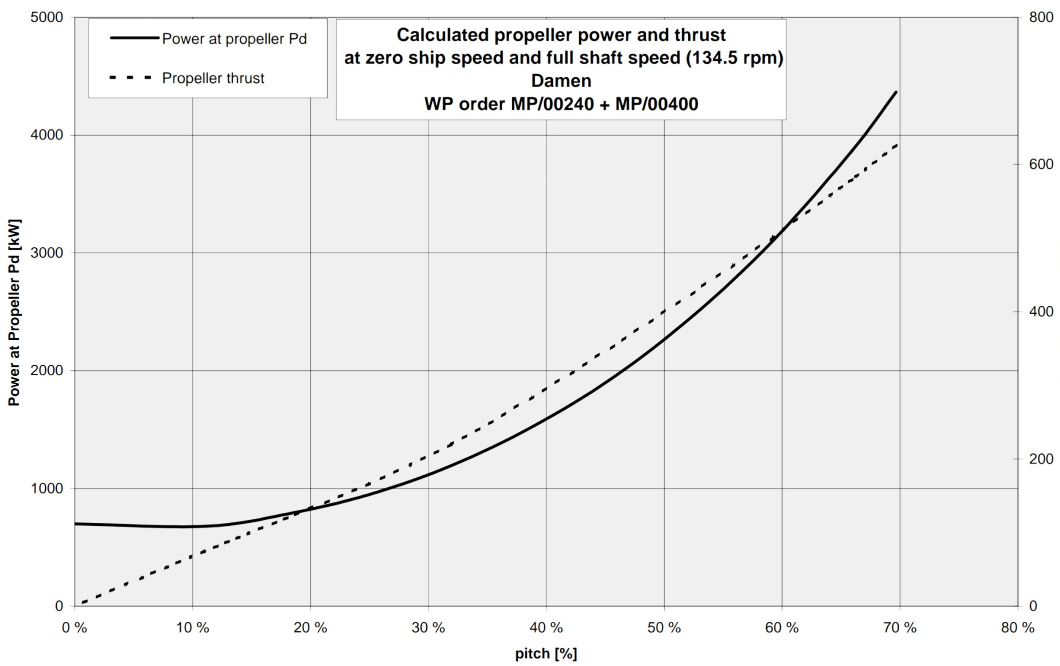


Figure 5.5: Propeller Power, Thrust and pitch in bollard pull conditions

The black line representing the power of the propeller (P_p) in Figure 5.5 is plotted using formula 5.1.

$$P_p(t) = 0.0051 * \alpha^3_{\text{pitch}(t)} + 0.4754 * \alpha^2_{\text{pitch}(t)} - 5.1058 * \alpha_{\text{pitch }(t)} + 701.22 \tag{5.1}$$

With:

- $\alpha_{\text{pitch}(t)}$ is the pitch angle as a percentage of the maximum pitch range.
- P_p is the power absorbed by the propeller at the shaft [kW]

The effective power of the main engine is calculated by adding the absorbed power of the propeller to the electrical load of the generator, taking into account the mechanical losses. For the shaft generator to be synchronised with the grid, the engine operates at a constant rpm of 600 to maintain a proper electrical frequency. The load curve can be found in A. Figure 5.5 in combination with pitch at any time is used to calculate the power that the propellers absorb. This includes rotational and mechanical losses in the propeller, shaft seals, bearings, and gearbox. With formula 5.2 the actual load is then determined by adding the electrical load of the 3000 kWe AEM generator to the load resulting from the propellers.

$$P_b(t) = \frac{P_e(t)}{\eta_{GB} * \eta_{Gen}} + \frac{P_P(t)}{\eta_{GB} * \eta_S} \tag{5.2}$$

With:

- P_b is the brake power of the auxiliary engine a the shaft [kW]
- P_e is the electrical loading of the shaft generator [kWe]
- P_p is the power absorbed by the propeller at the shaft [kW]
- η are the efficiencies defined in table 5.5

In the data it was found that when the reference vessel was in port or at anchor the pitch angle remained around 0%, resulting in a $P_P(t) = 701$ [kW]. For both operational modes, the main thrusters are not in operation and should not give a load; therefore, it is assumed that $P_P(t) = 0$ [kW] when the operational mode is 'Anchor' or 'Port'.

5.4.2. Auxiliary Engines

The power of the auxiliary engine is the electrical load divided by the efficiency of the mechanical and electrical components of the generator. In table 5.5 the mechanical and electrical losses (η_{Gen}) are assumed to be 96% when combined.

$$P_b(t) = \frac{P_e(t)}{\eta_{Gen}} \tag{5.3}$$

With:

- P_b is the brake power of the auxiliary engine at the shaft [kW]
- P_e is the electrical loading of the shaft generator [kWe]
- η_{Gen} is the generator efficiency defined in table 5.5

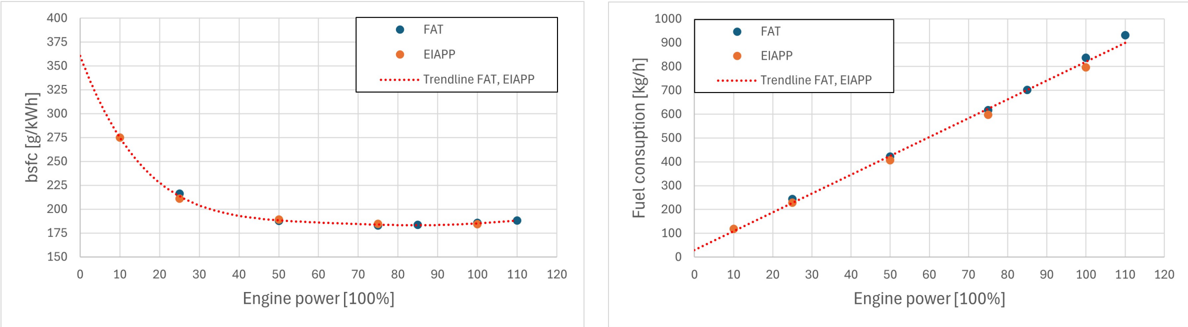
5.4.3. Specific fuel consumption

The specific fuel consumption and total fuel consumption of the main engines are illustrated in Figures 5.6a and 5.6a. The horizontal axis represents a percentage of the maximum engine power delivered, which quantifies the amount of fuel consumed by the engines to generate the required power output.

As Jumbo vessels are equipped with controllable pitch propellers, the rotational speed of the engine is maintained at a constant 600 rpm, with the power delivered to the engine varying according to load.

The vertical axis indicates the brake-specific fuel consumption in grammes per kilowatt hour (g/kWh). The increased specific fuel consumption at lower loads is attributed to reduced temperatures and pressures, which leads to lower engine efficiency. The engine data used for these graphs originate from the Factory Acceptance Test (FAT) and the Engine International Air Pollution Prevention (EIAPP) certificate.

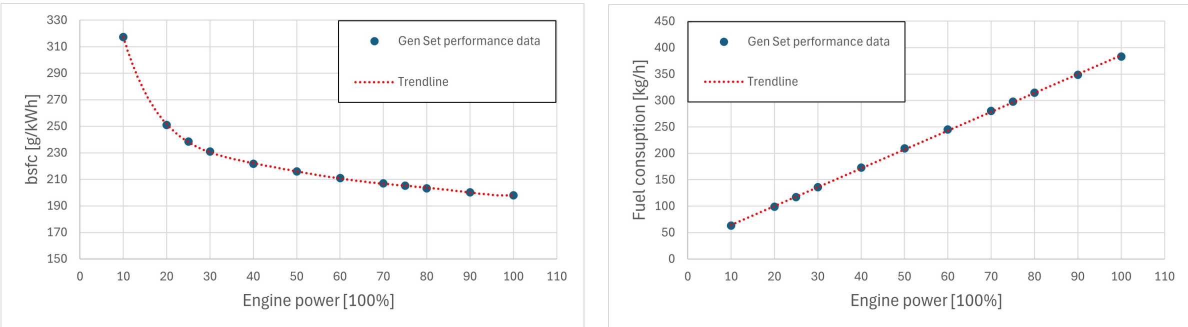
In all calculations involving these graphs, it is assumed that the load on any running and synchronised engines does not fall below 10%. This minimum load is essential to ensure continued engine operation.



(a) Brake Specific Fuel Consumption **(b)** Fuel consumption

Figure 5.6: Main engine: MAK 9M32C

The engine consumption graphs 5.7a and 5.7a for the auxiliary engines are similar to those for the main engine. Data originate from a factory acceptance test. Although the main engines operate more efficiently at load 80%, the auxiliary engines are more efficient close to their rated power.



(a) Brake Specific Fuel Consumption **(b)** Fuel consumption

Figure 5.7: Auxiliary engine: CAT3516B

$$b_e = \frac{\dot{m}_b}{P_b} \quad \left[\frac{g}{kWh}\right] \tag{5.4}$$

With:

- b_e is the specific fuel consumption [$\frac{g}{kWh}$]
- m_b is the mass of fuel [t]
- P_b is the engine's brake power, meaning the effective power at the crank [kW]

Applying these equations to the data results in a total fuel consumption of all the engines. In section 5.2, Figure 5.1 shows the daily fuel consumption based on DPR's. Dividing this by 24 gives the average in tons/h during that day. Figure 5.8 shows the calculated fuel consumption and the averaged fuel consumption from the DPR's.

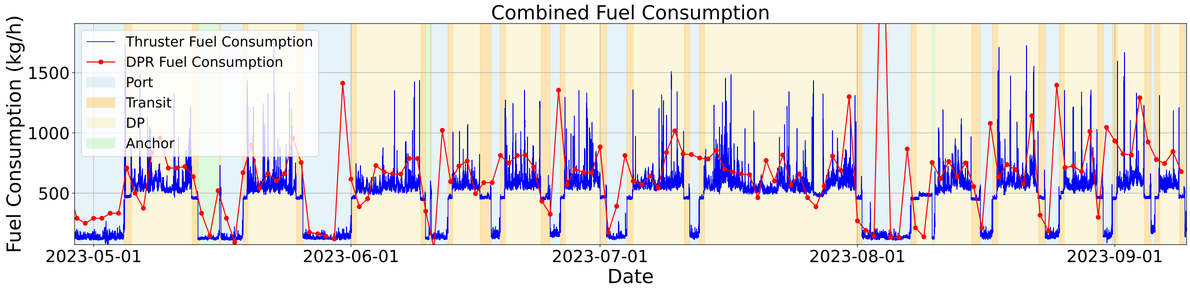


Figure 5.8: Total fuel consumption calculated and from DPR's

To get better insights in the fuel consumption and emissions of offshore activities, a daily consumption is too generic. In addition to that, as explained in Section 5.2 errors have been made while filling in these DPR's. Therefore, it is more interesting to look into the calculated distribution of the fuel consumption. and zoom in on each specific engine.

Looking at each specific engine, several things stand out. Firstly, the auxiliary engines, shown in Figure 5.9 and Figure 5.10. It can be seen that during the transits, both auxiliary engines are always turned off. In addition to that, during DP operations, at least one auxiliary engine is running. If there is only one running, then most likely the vessel is on green DP, as described in section 5.1, during waiting on weather. Lastly, in port and at anchor, only one of the auxiliary engines is operating, to cover the hotel load and port operations.

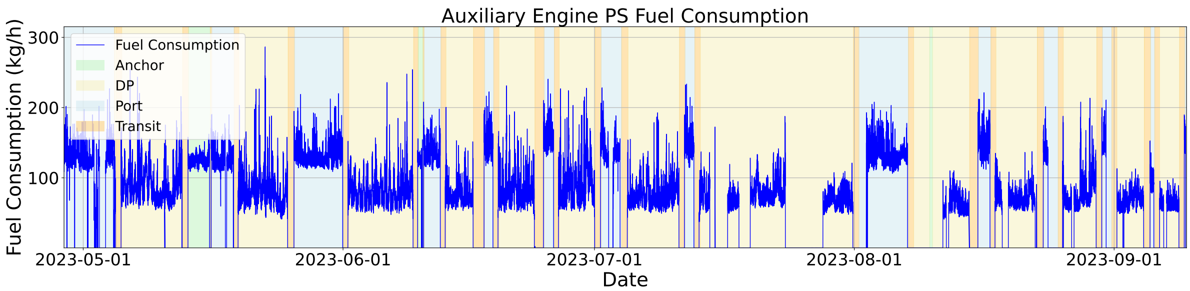


Figure 5.9: Fuel consumtion portside auxiliary engine

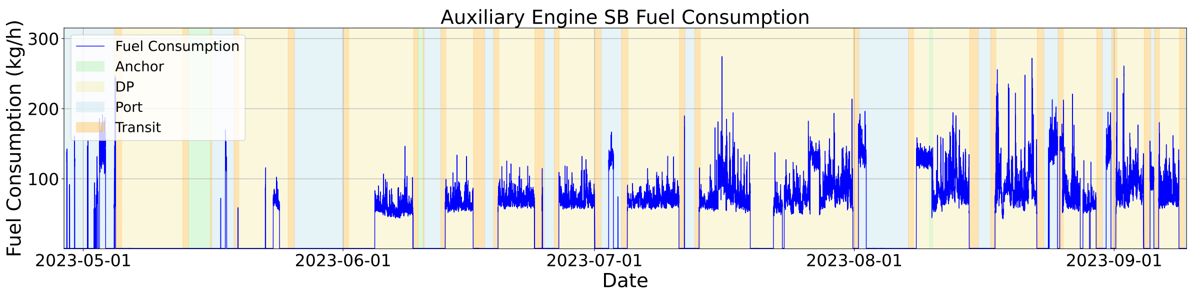


Figure 5.10: Fuel consumtion starboard auxiliary engine

Secondly, the main engines, shown in Figure 5.11 and Figure 5.12. During DP operations, both main engines are always on, which is in line with section 5.1. In port and on anchor, in most cases they are off, except for a few situations where the main engines were used between switching from one auxiliary engine to the other to cover the hotel load. During transits, at least one of the main engines is turned on. When only one is in operation, the vessel is 'slow steaming'. Two examples are transit 8 (16-06-2023 → 17-06-2023) and 10 (23-06-2023 → 25-06-2023).

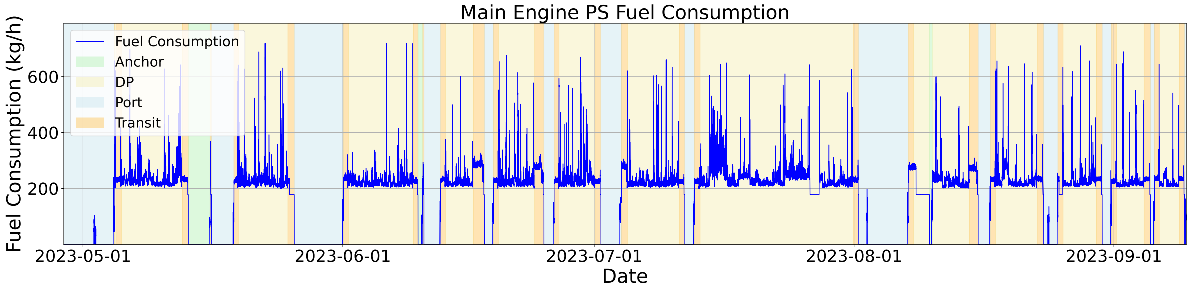


Figure 5.11: Fuel consumtion portside main engine

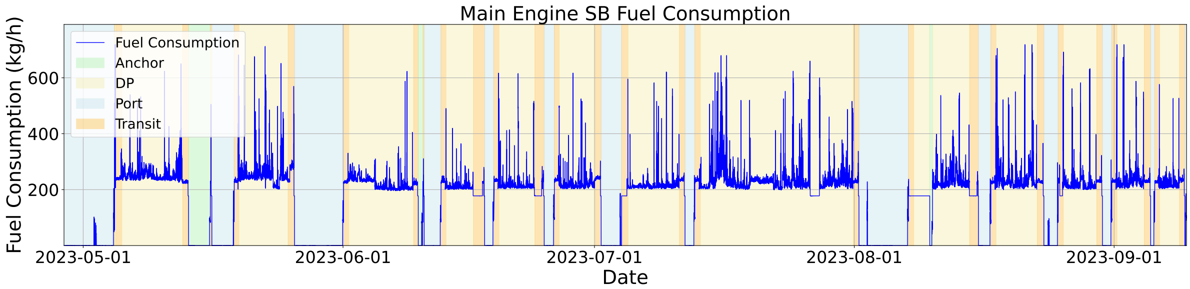


Figure 5.12: Fuel consumtion starboard main engine

As explained in section 5.4.1 currently the fuel consumption is calculated in Bollard Pull condition. This therefore does not apply for the transits. Hence, the following clusters, as defined in section 5.2.1, should be subtracted from the total fuel consumption: Transit to port, transit to site, and transit under pilot.

5.4.4. Transit fuel consumption

As described in section 5.1, the main engines are run on Bio-Fuel and the auxiliary engines run on MGO. This implies that on DP both Bio-Fuel and MGO are used and during transit only bio-fuel is used. However, with the available data it requires a lot of assumptions to guesstimate the portion of Bio-Fuel that was used during transits and the portion used while on DP. During the course of the reference project, the vessel made 13 return trips, which is 26 individual trips to and from the installation site. In total, the vessel covered 5576 nautical miles with an average of 214.46 nautical miles per trip, depending on where the vessel had to be/was in the field.

In the past, the vessel has also been used for shipping projects; during these projects, fuel consumption is recorded on WE4Sea. According to WE4Sea, fuel consumption ranges from 69 to 140 kg per nautical mile, averaging approximately 100 kg per nautical mile. With an consumption of 100 kg per nautical mile, the total fuel consumption during transits is 557.6 tons.

According to people in the office, a fuel consumption of 35 tons per day is used for calculations. The reference vessel has two given speeds, the 'transit average' and 'economical' speed. This results in the following fuel consumption in kg per nautical mile:

Fiel consumption	@ 14 kts (Economical)	@ 15.5 kts (Transit average)
tons/day	35	35
nm/day	336	372
tons/nm	0.104	0.094
kg/nm	104.17	94.08

Table 5.6: Transit consumption based on office information

According to the EU MRV regulation, trips and their distance and fuel consumptions had to be reported. If these are aligned with the DPR's the transit times can be calculated and therefore the average speed. This information can be found in Table 5.7.

Actual transit time	Mileage in miles	Average speed kts	Actual transit time	Mileage in miles	Average speed kts
18:00:00	214	11.89	15:38:00	205	13.11
16:32:00	172	10.40	16:00:00	225.1	14.07
13:50:00	225.1	16.27	16:02:00	201	12.54
18:20:00	221	12.05	15:18:00	225.1	14.71
15:09:00	225.1	14.86	25:34:00	201.7	7.89
16:09:00	188.5	11.67	14:24:00	225.1	15.63
14:10:00	225.1	15.89	18:35:00	214.4	11.54
14:00:00	225.2	16.09	14:30:00	225.1	15.52
15:06:00	225.1	14.91	16:02:00	212	13.22
14:00:00	205	14.64	14:25:00	225.1	15.61
14:20:00	225.1	15.70	18:10:00	208	11.45
16:35:00	205	12.36	13:50:00	225.1	16.27
18:15:00	225.1	12.33	15:06:00	202	13.38
Average speed (kts)				**13.62**	

Table 5.7: MRV transit times

The average speed of the entire transit is 13.62 knots. However, this includes several slow transits and the transit time includes (un)mooring and transit under pilot operations, which are at a relatively low speed.

Therefore for the remainer of this research a transit fuel consumption of 100 kilogrammes or 0.1 tonnes per nautical mile will be used.

5.5. Sensitivity study

The data provided by Jumbo consisted of more than 16 million rows with mainly 1 second steps. However, in some cases, multiple steps per second were recorded. Due to some practical limitations such as excel, only capable reading files up to a maximum 1,048,576 rows and 16,384 columns. Therefore, calculations, error handling, and other adjustments become difficult to validate. In addition to that, with the available hardware, the processing time was quite extensive. Therefore, the database had to be reduced in size. This required several cleaning steps to ensure accuracy. First, data points recorded within the same second were merged into single entries, significantly reducing the size of the data set. Next, 38 time gaps caused by the DP computer were identified, mostly small (2 to 3 seconds), with a few larger than 100 seconds, up to a maximum of 6000 seconds. These were filled using the average values of the corresponding activity clusters to maintain consistency. Additionally, when engines were turned off, sometimes sensor errors occurred, resulting in unrealistic negative power values. These were corrected by setting the values to zero, which prevented false indications of fuel consumption. After that, the data set still contained 11 million rows. To reduce this, time intervals can be taken. However, this might influence the accuracy of the data. Therefore, a sensitivity study is conducted. This section will elaborate on how the sensitivity study is performed.

5.5.1. Time intervals

To conduct the sensitivity study, the data is handled accordingly:

- Numeric data: the average was calculated over a certain time interval
- Non-numeric data: the one that occurs most often within the time interval

For the non-numeric data, this resulted in completely excluding some clusters at intervals of 1 hour or more. As can be imagined, adding all these averages results in a deviating total fuel consumption. For all (main) clusters, the sum of the fuel consumption is calculated for every time interval. The values shown in Table 5.8 are the maximum absolute deviation of a certain (main) cluster or operational mode for that time interval.

Time interval	Total	Cluster activities	Main cluster	Activity	Processing time (s)
1 s	-	-	-	-	1023.16
10 s	0.05%	0.33%	0.18%	0.06%	98.37
20 s	0.10%	0.67%	0.38%	0.12%	56.90
30 s	0.15%	1.09%	0.50%	0.18%	34.15
1 min	0.23%	1.48%	0.88%	0.27%	21.31
2 min	0.32%	4.53%	1.88%	0.37%	9.29
5 min	0.45%	12.46%	1.77%	0.69%	4.74
10 min	0.57%	60.23%	5.88%	1.41%	2.61
20 min	0.74%	18.24%	9.20%	1.49%	1.72
1 hour	1.23%	59.75%	34.82%	8.38%	0.82
12 hours	3.63%	$\gg$ 100%	48.85%	52.52%	0.46
1 day	5.55%	$\gg$ 100%	79.61%	$\gg$ 100%	0.45

Table 5.8: Largest offset of a specific cluster compared to the 1 second time interval

Table 5.3, in section 5.2, shows the shortest DPR activities. Based on the combination of the shortest DPR activities of 120 seconds and the information provided by Table 5.8, it was decided to continue all calculations from now on with the 30-second time interval. By doing this, the loss accuracy is minimised and the processing time is reduced significantly.

5.5.2. Efficiencies

In Section 5.3 assumed efficiencies were introduced for the gearbox (η_{GB}), shaft (η_S) and generators (η_{Gen}) used throughout the power transmission chain. These efficiencies were obtained from the vessel manual. To assess the sensitivity of the model to these assumed values, several variations were tested to evaluate their effect on total calculated brake power and, ultimately, fuel consumption.

Table 5.9 presents the results of the sensitivity analysis in a range of efficiencies for the gearbox, shaft, and generator. The base case, where $\eta_{GB} = 0.98$, $\eta_S = 0.98$, and $\eta_{Gen} = 0.96$, was compared with slightly lower and higher values to simulate real-world variabilities in mechanical performance.

Eta_gearbox	Eta_shaft	Eta_generator		
		0.9	**0.96**	**1**
0.95	**0.95**	5.23%	2.96%	1.57%
	0.98	3.97%	1.69%	0.30%
	1	3.17%	0.89%	-0.50%
0.98	**0.95**	3.48%	1.23%	-0.14%
	0.98	2.25%	**0.00%**	-1.38%
	1	1.47%	-0.79%	-2.16%
1	**0.95**	2.37%	0.14%	-1.23%
	0.98	1.16%	-1.08%	-2.44%
	1	0.39%	-1.85%	-3.22%

Table 5.9: Sensitivity of efficiencies

These results indicate that the greatest sensitivity is observed when all components perform below the expected efficiency (e.g. $\eta = 0.95$), leading to an over 5% increase in calculated brake power. In contrast, as the efficiency of the components approaches 100%, the calculated load and, consequently, fuel use drop slightly. Resulting in negative deviations compared to the base scenario. This makes sense as higher efficiency leads to lower consumption.

This sensitivity study highlights the importance of accurate efficiency assumptions, especially for operational evaluations and fuel/emissions reporting. Although deviations from ± 0.02 in efficiency values may seem minor, they can translate into significant cumulative differences over extended operations.

5.5.3. Fuel consumption

Combining all the information from Section 5.1 to Section 5.5.2 the final fuel consumption can be calculated. As explained in section 5.4, this was done using the bollard pull conditions of the engine. The brake power of the auxiliary engines is calculated with equation 5.3 and the brake power of the main engines in calculated with equation 5.2. Using equation 5.4 and the brake power of the engines, the total fuel consumption could be calculated for each cluster. This is shown in Table 5.10.

Clusters	**Sum (t)**	**Avg (t/h)**	**Max (t/h)**	**Min (t/h)**
Bolting MP to TP	128,19	0,59	0,70	0,53
DP Set-Up	15,29	0,65	1,10	0,52
Extra Work - Bolt Cleaning / Greasing	19,84	0,58	0,69	0,52
Extra Work - Navaid & Flange cleaning	20,75	0,60	0,76	0,50
Extra Work - Soft Seal	29,07	0,58	0,66	0,53
Lift TP on MP	32,19	0,59	0,72	0,54
Load-out Bunkering	1,51	0,14	0,14	0,13
Load-out containers / stores / preps departure	10,38	0,16	0,19	0,12
Load-out TP's	27,04	0,15	0,20	0,13
Mooring	1,07	0,51	0,54	0,50
Prep & Completion activities	134,83	0,62	0,78	0,49
Retrieval TP guides	25,71	0,58	0,64	0,53
Setup W2W & Retrieval TWP	26,38	0,59	0,71	0,46
Shift infield / move in to MP	50,46	0,58	0,67	0,45
Technical Breakdown Client Equipment - Bolting	27,98	0,60	0,73	0,52
Technical Breakdown Client Equipment - TP	11,33	0,58	0,63	0,53
Technical Breakdown Client Equipment - TPLT	51,93	0,36	0,61	0,13
Technical breakdown Vessel	6,18	0,22	0,55	0,13
Technical breakdown Vessel - Subco	13,41	0,51	0,68	0,15
TP lifting preparations	50,24	0,59	0,82	0,54
Transit to Port	70,44	0,46	0,47	0,45
Transit to Site	75,17	0,49	0,54	0,45
Transit under Pilot	15,15	0,48	0,51	0,45
Unmooring	1,09	0,47	0,56	0,45
Waiting on client - Berth	15,75	0,31	0,48	0,14
Waiting on client - During installation	40,65	0,35	0,60	0,13
Waiting on client - Inspection round	43,38	0,54	1,16	0,14
Waiting on client - Onshore logistics	28,24	0,14	0,16	0,12
WoW	457,39	0,50	0,68	0,13

Table 5.10: Fuel consumption per cluster

The total fuel consumption according to the four engine calculations is 1432 tons. As explained in section 5.4.4 the clusters "Transit to Port, Transit to Site, and Transit under Pilot" should be removed, as these are not estimated accordingly. In table 5.11 the final calculation for the total fuel consumption is shown.

Variable	Fuel consumption (t)	
Calculated in bollard pull	1432	
Transit clusters in bollard pull	161	-
Total (minus transit)	1271	
Transit estimation	557.60	+
Total	**1827.7**	

Table 5.11: Total calculated fuel consumption

This can be compared to the fuel consumption sent to Lloyds for the MRV data and the fuel consumption according to the DPR's, as shown in section 5.2. This is done in Table 5.12.

	MRV	DPR's	Calculated
Total fuel consumption	2075.1	2082.9	1827.7
Offset	-	0.38%	11.76%

Table 5.12: Comparison fuel consumption MRV, DPR and calculated

The offset between the DPR's and MRV can be explained by the difference in start and end time. The project data are recorded from 28-04-2023 17:00 and end on 09-09-2023 13:22. However, the DPR includes the fuel consumption for both complete days.

The calculations seem to be quite far off from the MRV and DPR reports. This can be explained by the assumption made from Section 5.1 to Section 5.5.2. Looking at table 5.10, it can be seen that it makes sense how each cluster compares with each other. To give some examples, Waiting on Weather (WoW) happens in port, on anchor, and on DP. This causes a relatively large difference in the min and max consumption. However, during WoW, no machinery is operative; compare this to clusters on DP with machinery in operation, such as 'bolting', 'lifting', and 'Set-up W2W' these averages are all higher due to the operative machinery. Port operations such as 'load-out' or 'waiting on client - onshore logistics' are much lower compared to DP operation and are in the same order of magnitude with other port operations. The offset and the assumptions taken will be discussed in more detail in Section 5.8

5.6. Emissions

This section explains how fuel consumption data is converted into various types of emissions. By applying standardised emission factors for each fuel and emission type, good estimates of greenhouse gas output can be made.

5.6.1. (CO_2) Emissions Conversion Factors

An accurate estimate of carbon dioxide (CO_2) emissions is essential to evaluate the environmental impact of the use of marine fuels. Each fuel type possesses a distinct chemical composition, leading to variable CO_2 emissions when combusted. The following conversion factors are used within Jumbo, expressed in kilogrammes of CO_2 emitted per ton of fuel consumed, reflecting this variation.

Fuel	**Conversion Factor**	**Unit**
Heavy Fuel Oil (HFO)	3.114	kg CO_2/ton
Marine Gas Oil (MGO)	3.206	kg CO_2/ton
Light Fuel Oil (LFO)	3.151	kg CO_2/ton
Biofuel-100	0.000	kg CO_2/ton
Biofuel-30 (30% Biofuel Blend)	2.244	kg CO_2/ton
Liquefied Natural Gas (LNG)	2.750	kg CO_2/ton
Methanol	1.375	kg CO_2/ton

Table 5.13: CO_2 Emissions conversion factors per Ton

These conversion factors demonstrate significant differences among fuels. Biofuels notably reduce net CO_2 emissions due to their biogenic carbon content, with Biofuel-100 being considered fully carbon neutral. Methanol also presents lower emissions compared to traditional fossil fuels, positioning it as an intermediate viable option. As described in section 5.1, during the reference project only biofuel and MGO have been used.

5.6.2. (NO_x)

A former Jumbo graduate student conducted research to predict NO_x emission from a 4-stroke marine diesel engine. As a reference, the same type of engine, the 9M32C caterpillar, is used as installed in reference vessel. Accurate NO_x simulations reach beyond the scope of this thesis and depend on more parameters than this thesis has access to. For example, combustion temperature, air temperature, fuel consumption, and oxygen ratio. Therefore, the NO_x emission estimates are simplified proportional to engine load.

Power/Torque (%)	10	25	50	75	100
NO_x mass flow (kg/h)	7.8	9.4785	21.98	31.799	39.575
NO_x specific (g/kWh)	18.634	9.018	10.479	10.157	9.55

Table 5.14: NO_2 emission data Van Riet (2018)

The NO_x specific can be taken linearly between 10 and 25%, between 25 and 100% the average is 9.8 g/kWh. For the NO_x mass flow a curve fit has been made, the equation 5.5 shown in Figure 5.13

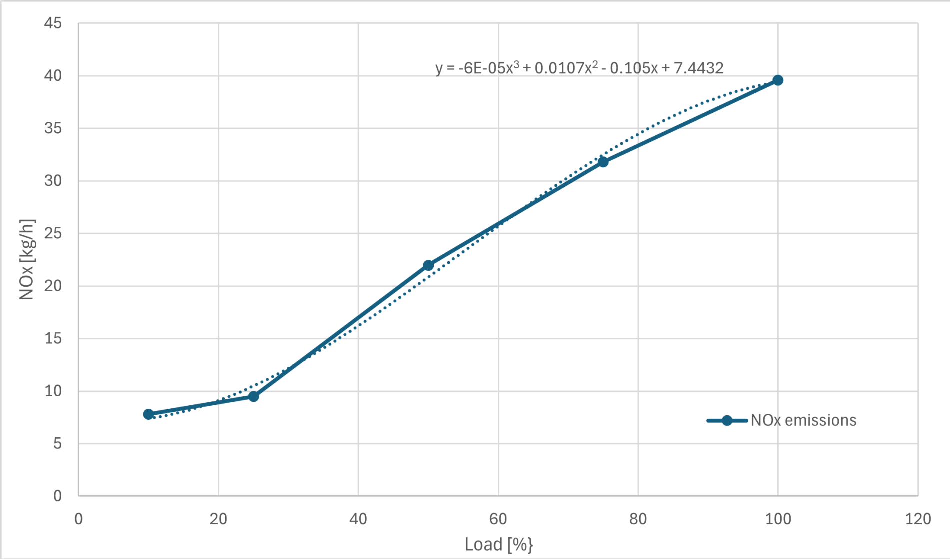


Figure 5.13: NO_2 emission performance test data Van Riet (2018)

$$NO_x[kg/h] = -0.00006 * Load^3 + 0.0107 * Load^2 - 0.105 * Load + 7.4432 \quad (5.5)$$

A constant factor proportional to the engine power was used to determine NO_x emissions for the auxiliary engines. The Caterpillar 3516B data sheet does not specify NO_x values, but the ship complies with IMO Tier I regulations. At a constant speed of 1800 rpm, the NO_x limit is 10.05 g/kWh. Therefore, a simplified conversion factor of 10.05 g/kWh is used, with a minimum synchronised power limit of 180 kW to account for the fuel required to keep the engine running, even when the load is nearly zero.

5.6.3. (SO_x), and Particulate Matter (PM) Emissions

SO_x emissions can be estimated based on the sulfur content of the fuel. A common approach is to multiply the mass of sulphur in the consumed fuel by the ratio of molecular weights of SO_2 to sulphur. Marine Gas Oil (MGO) can have varying sulphur content depending on regulatory requirements and where it is used. Historically, MGO sulphur levels could reach 1.0-1. 5% by weight, but international regulations, as explained in 2.2.4 (MARPOL Annex VI), now limit it to a maximum of 0.5% in most waters around the world. Within emission control areas (ECAs), the sulphur content of MGO is restricted to 0.1% by weight or lower. For these cases, Very Low Suphur Fuel Oil (VLSFO) and Ultra Low Sulphur Fuel Oil (ULSFO) are used.

Like CO_2 and NO_x, PM emissions are generally estimated using emission factors such as grammes per kg of fuel or per kWh). The complicated thing about PM is that it is dependent on the sulphur content within the fuel. In addition, the exact factor can vary based on engine design, operational load, combustion technology, and whether there are after-treatment systems.

5.7. Results

The results section presents a detailed analysis of operational efficiency and fuel consumption based on updated time-based and fuel-based Sankey diagrams. The objective is to identify critical areas of inefficiency and potential improvements to reduce emissions and optimise operational performance. The analysis is supported by the quantitative details discussed earlier in Chapter 5.

5.7.1. Time

The time-based Sankey diagram, Figure 5.14, reveals clear distributions of operational time between various activities and main clusters. Downtime dominates operational time, representing 50.5% of the total. This downtime is mainly observed in dynamic positioning mode (DP), contributing significantly at 58.5%. Within downtime, Waiting on Weather (WoW) constitutes a major portion at 28.6%, followed by Technical Breakdown Client Equipment (TPLT) at 5.1%, and waiting on client during installation (5.0%). Furthermore, waiting on client during inspection rounds represents 3.0% of downtime, underscoring client-related delays as significant inefficiencies.

Execution represents 23.7% of the total operational time, indicating considerable potential for efficiency enhancements. Within the execution, key activities include bolting MP to TP (6.8%), preparation and completion activities (6.7%), and onshore logistics (6.7%). Extra work and TP lifting preparations contribute moderately but consistently, highlighting areas where procedural improvements may enhance operational speed and efficiency.

Port activities, which account for 24.9% of the time, significantly exceed other stationary operations, suggesting substantial periods at port facilities where procedural optimisations could substantially impact overall efficiency. Transit activities include Transit in (7.1%) and Transit out (6.1%). The impact of transit time is significantly lower compared to that of fuel.

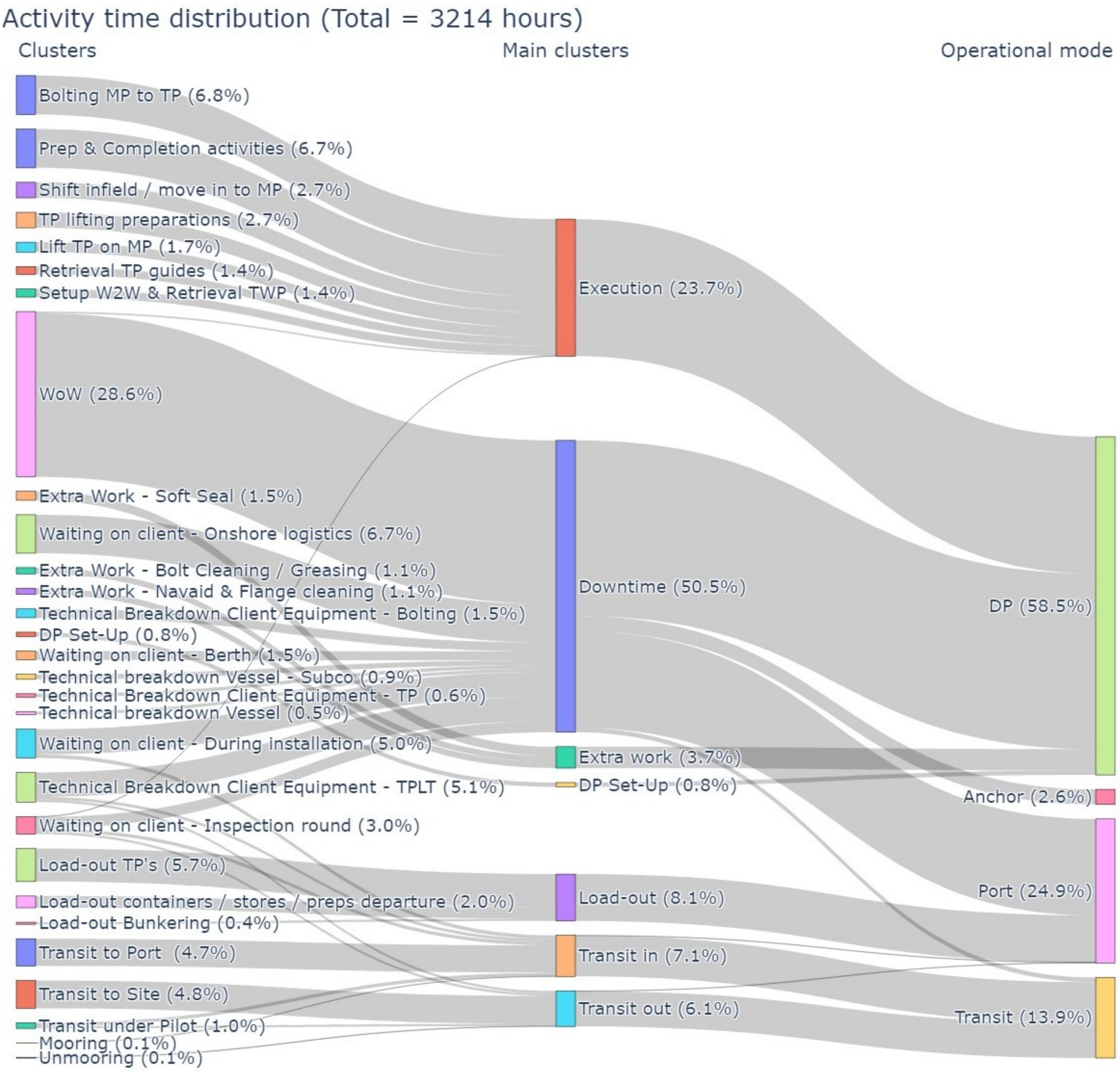


Figure 5.14: Sankey diagram time distribution

5.7.2. Fuel

The fuel-based Sankey diagram, Figure 5.15, clearly demonstrates operational fuel consumption patterns. Downtime remains the major contributor to fuel use at 37.7%, mainly from DP operations at 61.6%. Waiting on weather (WoW) is the main activity in downtime fuel consumption, accounting for 26.6%, making it a priority area for operational management improvements. The technical breakdown client equipment (TPLT) also contributes significantly at 4.3% of total fuel consumption, indicating notable inefficiencies due to technical disruptions.

The execution-related clusters constitute 25.6% of the total fuel use, mainly driven by gluing MP to TP (7.2%), and preparation and completion activities (7.6%). These figures emphasise the need to improve the efficiency of specific execution tasks to achieve meaningful fuel savings.

Transit activities represent a significant proportion of total fuel usage (31.4%), transit in (15.7%) and transit out (14.0%) underscore the importance of transit optimisation to achieve better fuel economy.

Port operations and anchoring activities account for 6.4% and 0.6%, respectively, representing relatively minor but still relevant fuel consumption areas that could benefit from procedural or technological improvements.

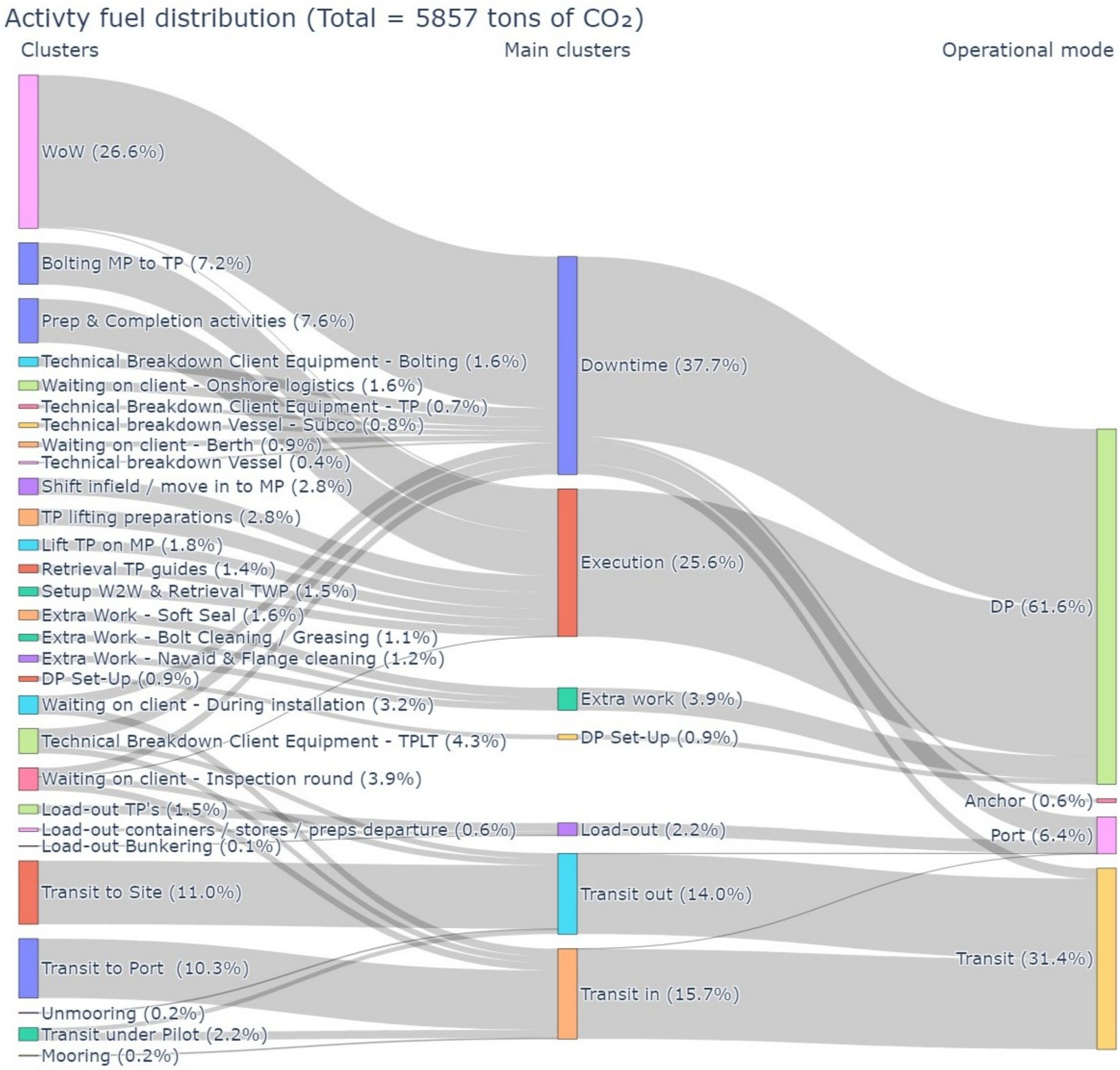


Figure 5.15: Sankey diagram fuel consumption distribution

The quantified emissions by activity will later feed into the environmental criterion of the decision model.

5.8. Discussion

The quantitative analysis relies on several key assumptions that affect the reliability and applicability of the results. Data gaps in the DPRs were filled using average operational values, assuming typical conditions during missing intervals, which may overlook short-term variations (Section 5.2). The engine efficiency assumptions used fixed values for the shaft line, gearbox, and generators (Table 5.5), potentially underestimating actual power losses. Real-world variations due to engine load, maintenance state, or environmental conditions were not considered, which may influence absolute fuel estimates, although relative comparisons between clusters remain valid.

In addition to that, the critical path of the DPR's is used to set the clusters. However, during for instance 24 hours of waiting the vessel isn't doing nothing. Things like maintenance or testing are done. This causes extra inaccuracy in the consumptions of each cluster.

Operational modes were simplified by classifying activities as transit or bollard pull conditions (Section 5.4). This binary approach overlooks intermediate scenarios, but effectively captures the dominant operational modes. Fuel consumption estimates were based on manufacturer-provided SFC curves (Figures 5.6 and 5.7), assuming optimal engine performance. Real-world deviations due to maintenance or fuel quality were not explicitly modelled, introducing potential inaccuracies.

The emission calculations used standardised conversion factors (Table 5.13), assuming uniform fuel types. Actual fuel blends, such as biofuels, would significantly alter the emission figures. Thus, while the model accurately identifies inefficiency "hot spots," precise emission quantities should be viewed as indicative rather than exact.

Future research should focus on reducing these assumptions' uncertainties by integrating real-time fuel flow measurements, detailed engine-specific efficiency curves, and environmental monitoring data. Expanding data sets across different vessels and operational profiles would further enhance the robustness and practical relevance of the methodology.

5.9. Conclusion

The analysis in this chapter addresses the sub-question: *"What is the influence of each offshore activity on greenhouse gas emissions carried out by offshore construction vessels based on data analysis?"* The results clearly highlight that certain activities disproportionately impact emissions. Downtime, particularly waiting on weather and technical breakdowns, became major inefficiencies, significantly influencing both time and fuel consumption. This shows substantial potential for operational optimisation and emission reduction.

The data revealed that downtime accounted for approximately 50.5% of total project time, with waiting on weather alone representing 28.6%. In terms of fuel, downtime contributed 37.7% of overall consumption, largely due to continuous dynamic positioning (DP) operations. Transit, although only 13% of the duration of the project contributed a notable 31.4% of the total fuel use, underscoring its high intensity of fuel. Additional operational activities such as bolting, preparation, and transit were also identified as areas with room for efficiency improvements (Figures 5.14 and 5.15).

These findings provide a direct answer to the sub-question by quantifying the emissions associated with each key operational activity and clarifying their relative impact on overall emissions. They underline the crucial need for proactive downtime management, streamlined execution, and optimised transit strategies. Targeted improvements, such as reducing unnecessary DP operations during idle periods, refining task execution, and adjusting transit speeds, present significant opportunities for both sustainability and cost-effectiveness. These insights form a solid empirical foundation for operational decision-making that aims to reduce emissions without compromising the project objectives.

It is important to note that understanding the emissions profile of each operational activity offers only part of the picture. Offshore contractors operate within a commercial framework, making financial evaluation an essential component of strategic decision making. Chapter 6 will elaborate further on the economic aspects of offshore projects.

6
Financial analysis

The second part of the quantitative analysis consists of a financial analysis, to obtain a complete quantitative picture regarding offshore operational emissions. This chapter answers the following sub-question.

3: How can emission reduction be a cost-effective operational strategy that incorporates allowances from the EU emission trading system, to optimise both compliance with emissions and overall costs?

The cost calculations here form the basis of the financial criterion in the MCDA. This chapter will dive into the costs and, therefore, possible savings of offshore activity and highlight some secondary benefits.

6.1. Cost

To find out how much money can be saved for both a client and a contractor, the first step is to get a general overview of the costs related to offshore installation scopes. This includes day rates, fuel costs, port dues, and emission allowances,as discussed in Chapter 2, the EU ETS will introduce carbon costs for vessels.

6.1.1. Day rate

The selected vessel for the offshore project has an established day rate of approximately € 150k. This rate covers expenses for crew salaries, vessel maintenance, insurance, onboard facilities, and essential operational support. However, it explicitly excludes fuel costs, which will be accounted for separately based on actual consumption and prevailing market prices. Therefore, it should be in the best interest of the client as well to limit this as much as possible. Accurate tracking and reporting of fuel usage will be essential for effective budget management and cost control throughout the project's duration.

6.1.2. Fuel costs

As explained in Section 6.1.1 fuel prices are not included in the day rates of the vessel and are usually invoiced to the client. Table 6.1 shows the current bunker prices (March 2025) with a conversion rate of $1.00 to €0.88.

Location	MGO €/mt	VLSFO €/mt
Global average bunker price	696	529
Americas average	793	573
Europe, Middle East & Africa average	649	496
Asia-Pacific average	702	527
Rotterdam	559	442

Table 6.1: Bunker prices (Ship & Bunker, 2025)
(based on € 1,- to $ 1.13)

The prices of a B30 biofuel blend containing 30% biodiesel delivered to Rotterdam were at an average premium of € 116 /mt to VLSFO, so € 558 / mt.

6.1.3. Port calls

During a project, an offshore vessel repeatedly has to go back to port to resupply, TP's in this case, to continue installation. Each port has a different way to calculate port dues depending on many parameters. During the reference project, the Port of Rotterdam was used to resupply.

Port of Rotterdam

Below is an illustrative example to calculate port-related costs for an offshore vessel using the structure and steps set out in the General Terms and Conditions of Port of Rotterdam. This example assumes the following.

- A single port call
- No Environmental Ship Index (ESI) or Green Award discounts claimed
- Standard waste-fee assessment (no additional discounts)

To calculate port dues, the Port of Rotterdam has a step-by-step approach.

1. **Identify vessel type:** The reference vessel is an "offshore vessel", this gives a GT tariff of €0.303 and a sustainability component rate of €0.065.
2. **Vessel component:** The reference vessel has a Gross Tonnage of 15027 GT
3. **Cargo component:** This depends on the load, in this case TP's ("Other general cargo") at a rate of €0.576 per tonne (T). Per trip 4 TP's of 540 tons are transported
4. **Efficiency discount:** The exact weight is unknown but falls under the category: 'General cargo ships (no liner service)' having a ratio of 133.3%

$$\text{Max Cargo Fees Before Discount} = (GT) \cdot (1.333) \cdot (\text{Cargo Rate}) \quad (6.1)$$

   - If the Raw Cargo Fee (Step 3) is less than the "max cargo fees before discount", there is no discount applied.
   - If the Raw Cargo Fee (Step 3) is greater than "Max cargo fees before discount", everything above that amount is zero rated.

5. **Sustainability component:** For offshore vessel €0.065 per GT and as no ESI and Green Award discount applies, the pull amount is due.
6. **Total Seaport Dues:** The sum of the steps above

$$\text{Seaport Dues} = \text{Vessel Fee} + \text{Cargo Fee} + \text{Sustainability} \quad (6.2)$$

7. **Waste Fee:** The fixed amount is €210,- and the rate per GT is €0.037

$$\text{Waste Fee} = \text{Fixed Amount} + (\text{Rate per GT} \cdot \text{GT}) \quad (6.3)$$

8. **Berth costs:** The reference vessel used public quays for load-out. This rate is € 3.73 per metre (LOA) per 24 hours. The reference vessel is $\approx$ 144 metres. During the reference project, the vessel stayed in port on average for 61 hours. (Havenbedrijf Rotterdam, 2025)

Table 6.2 sums up all these steps and reaches a grand total of approximately € 10k per call. Of course, real costs can differ depending on the actual operation (cargo amount, stay duration, bunkering, ESI score, etc.).

Step	Cost
2: Vessel component	€ 4553
3: Cargo component	€ 1244
4: Efficiency discount	€ 1244
5: Sustainability component	€ 977
6: Total seaport dues	€ 8018
7: Waste fee	€ 766
8: Berth costs	€ 1365
Total	$\approx$ **€ 10000**

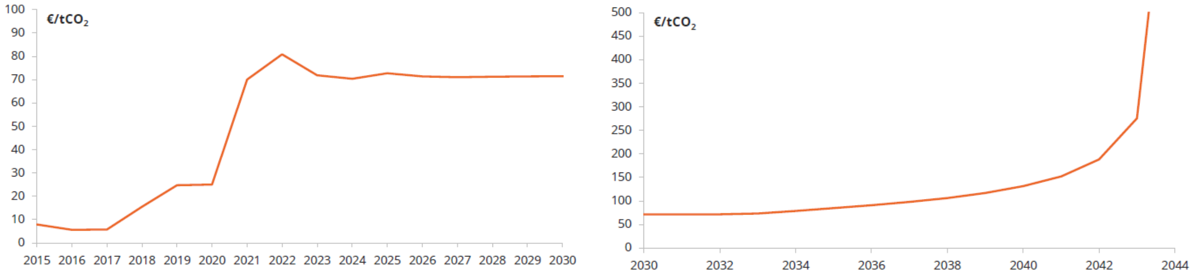
Table 6.2: Port dues estimation

6.1.4. Emission rights

As explained in Chapter 2 from January 1, 2025, offshore ships of 400 gross tonnage (GT) and above are mandated to monitor, report, and verify their greenhouse gas (GHG) emissions under the EU's MRV regulation. Starting January 1, 2027, offshore vessels over 5,000 GT will be incorporated into the EU ETS. This means that these vessels will be required to hold and surrender emission allowances corresponding to their verified emissions, effectively placing a carbon price on their operations.

EU ETS price

Out of the regulations reviewed in Chapter 2, the EU ETS was identified as the most directly relevant to Jumbo Maritime operations (Section 2.4), as it introduces a carbon cost. Therefore, in this financial assessment, we focus on the impacts of the ETS. Currently (2025), the EU ETS carbon price is around €70 to 75 per tonne of CO_2. This relatively stable range is partly due to overlapping climate policies, such as renewable and efficiency targets, reducing the reliance on the carbon price alone to drive emissions cuts. By 2030, tightening emissions caps and growing pressure on heavier industries mean the EU ETS price could begin a gradual rise, eventually exceeding € 130 per tonne by 2040, and potentially spiking further if no structural reforms are made to accommodate deep decarbonisation.



(a) Until 2030 **(b)** From 2030

Figure 6.1: EU ETS allowances price evolutions (Gabin Mantulet, Aurélien Peffen, and Sylvain Cail (2023))

Other upcoming regulations such as FuelEU, IMO EEXI, and CII currently do not impose direct financial costs on Jumbo's operations. Offshore construction vessels are currently excluded from these measures. Thus, financial analysis centres on the EU ETS as the primary regulatory cost driver.

Penalties

under the European Union Emission Trading System (EU ETS), companies that emit more CO_2 than their allocated allowances face significant penalties. Specifically, for each excess tonne of CO_2 emitted without a corresponding allowance, a company is fined € 100. This fine is adjusted annually for inflation. Importantly, paying the fine does not absolve the company from the obligation to surrender the necessary allowances; they must still obtain and surrender the missing allowances in the subsequent year. In addition, the names of non-compliant operators are publicly disclosed, adding reputational consequences to the financial penalties. Failure to comply for two or more consecutive periods may result in the ships of the company being banned from trading in the EU. Member states may also impose further penalties for other forms of non-compliance to ensure adherence to the system's regulations.This framework promotes investment in energy efficiency and low-carbon technologies, aligning with the EU's broader climate goals. (DNV, n.d.[b])

In summary, exceeding CO_2 emission allowances under the EU ETS results in substantial financial penalties and requires the surrender of the necessary allowances, thereby encouraging companies to proactively manage and reduce their greenhouse gas emissions.

6.2. Secondary benefits

Implementing fuel-saving and environmentally responsible practices in offshore construction not only reduces direct operational costs such as fuel expenditures, carbon taxes. It also generates secondary financial benefits through enhanced market reputation, increased client demand, and long-term competitiveness. In particular, demonstrating a strong commitment to sustainability can improve corporate image and brand value, helping a firm stand out in a market where environmental concerns are increasingly salient. This can translate into two key financial advantages.

Attracting New Clients and Retaining Existing Ones

Many organisations, especially those operating under strict environmental, social and governance (ESG) criteria, are now actively seeking partners with robust sustainability credentials (Surroca, Tribo, and S. Waddock, 2010). By adopting fuel-efficient technologies and showcasing verifiable emission reductions, offshore construction firms not only comply with emerging regulations but also appeal to environmentally conscious clients. This reputational advantage can lead to an expanded customer base: Some companies may even choose to pay a premium to work with suppliers who help them meet their own sustainability goals (Berry and Rondinelli, 1998).

Strengthening Competitive Differentiation

Greener operations can serve as a unique selling proposition, differentiating an offshore construction business from competitors that have yet to integrate sustainability into core operations (Linde et al., 1996). Studies have shown that firms with stronger environmental performance often experience better market share and profitability (S. A. Waddock and Graves (1997); Orlitzky, Schmidt, and Rynes (2003)). This is particularly true in industries subject to considerable public and governmental scrutiny, such as offshore or marine construction, where negative environmental impacts can damage both corporate reputation and client trust. Being “ahead of the curve” in the implementation of greener practices signals corporate responsibility and fosters stakeholder loyalty, which can generate repeat business and new project opportunities (Delmas and Toffel, 2008).

Overall, while the primary financial benefits of sustainability measures focus on immediate cost savings (e.g., lower fuel usage, reduced downtime, improved operational efficiency), the secondary benefits stem from the strengthened competitive position that sustainability confers. These benefits often accumulate over time, as the firm’s environmental reputation becomes more widely known, helping to secure higher value contracts, maintain long-term client relationships, and reduce risk exposure to fluctuations in fuel prices or tightening environmental regulations.

6.3. Conclusion

The financial analysis demonstrates several cost factors and therefore possible constraints regarding offshore operations. Emission reduction can in fact be a cost-effective operational strategy by, for instance, strategically integrating allowances from the EU Emissions Trading System (ETS). By proactive management of vessel emissions, significant financial savings can be achieved through reduced fuel consumption, lower emission-related expenses, and reduced downtime. All of these aspects can have a significant impact on fuel costs, port fees, number of operating days, and emission allowances.

Given the increasing cost trends observed for EU ETS allowances, proactive emission management becomes increasingly financially advantageous. Fuel cost reductions achieved through operational adjustments directly translate into fewer emissions, subsequently lowering the cost burden of purchasing ETS allowances. In addition, secondary financial benefits, such as the attraction of new clients and the strengthening of competitive differentiation, are also in play.

This chapter explicitly answers the sub-question: *”How can emission reduction be a cost-effective operational strategy that incorporates allowances from the EU Emissions Trading System to optimise both compliance with emissions and overall costs?”*. The findings confirm that aligning operational practices with emission reduction goals within the framework of the EU ETS presents a compelling financial strategy. By prioritising emissions-conscious decisions, companies like Jumbo Maritime can optimise their compliance strategies, achieve significant operational cost savings, and effectively navigate the evolving regulatory landscape.

Part III

Qualitative analysis

7
Organisational constraints

Efforts to reduce greenhouse gas (GHG) emissions have focused primarily on technological solutions, operational optimisations, and regulatory mandates. Although these measures are critical to achieve meaningful reductions, there is growing recognition that organisational influence, through decision-making behaviours, plays an equally important role in the pursuit of greener operations. Data-driven approaches can offer valuable evidence and recommendations, but their success often depends on how people interpret and act on this information. Hence, addressing these organisational influences in decision-making processes becomes imperative to ensure that data-based recommendations are not only adopted but also sustained over time. In maritime environments, where safety, efficiency, and compliance often coincide, understanding how different stakeholders make decisions can reveal opportunities to improve GHG mitigation strategies. This chapter addresses the research sub-question:

4: How do preparatory project decisions impact operational choices related to the reduction of emissions on offshore vessels?

The chapter presents a qualitative investigation into how organisational influence shapes emission reduction strategies and outcomes. The objective is to obtain a deeper understanding of the potential areas of improvement found in Chapter 5 and concluded in Section 5.9. By gaining a deeper understanding of the potential areas of improvement; Wainting in Weather, Technical breakdowns, Bolting MP to TP, prep & completion activities, and transit, the goal is to select three key areas of improvement to highlight in a decision-making model.

7.1. Defining project complexity and influential factors

Project complexity has increasingly become an important topic within project management research, particularly due to its impact on project success. The influential theory of David Baccarini Baccarini (1996) is the cornerstone for defining and understanding the complexity of the project. His work, along with insights from contemporary studies, provides an integrated view of the nature and implications of complexity in project environments.

7.1.1. Project Complexity: The Baccarini theory

Baccarini (1996) introduced a systematic approach to defining the complexity of the project. He proposed that complexity could be understood through two core dimensions: differentiation and interdependency. Differentiation refers to the number of varied elements within a project (e.g., tasks, disciplines, teams), while interdependency concerns the degree to which these elements are interconnected and reliant upon each other. According to Baccarini, complexity can be categorised into two principal types:

- Organisational Complexity: Defined by differentiation within project organisation structures, both vertical (levels of hierarchy) and horizontal (number of distinct units or specialisations).
- Technological Complexity: Defined by differentiation in tasks, materials, technologies, and processes required to achieve project goals, along with the degree of interdependencies of tasks.

Baccarini emphasises that managing complexity fundamentally involves effective integration across these differentiated and interdependent elements.

Building on Baccarini's foundational ideas, further studies have enriched our understanding of complexity. Mikkelsen (2021) highlights perceived complexity as subjective and influenced by the role and context of the individual involved in project management. Thus, the complexity of the project can significantly vary according to the perspectives of the stakeholders. More recent literature (Lafhaj et al., 2024) describes complexity as a systemic and organisational phenomenon. Lafhaj et al. (2024) identifies project complexity as closely related to the number and interrelation of stakeholders, scope, objectives, and managerial structures. This is complementary to Baccarini's emphasis on differentiation and interdependency.

Several critical factors significantly influence the degree of complexity of the project. The complexity increases notably with the number and diversity of stakeholders involved, as the different stakeholders bring different perspectives, interests, and expectations to the project. Broad and ambiguous project scopes and objectives further enhance complexity, often leading to misalignment and conflicting interests among stakeholders. Complex management hierarchies and detailed communication protocols can elevate complexity, underscoring the importance of streamlined communication structures. Furthermore, external conditions, such as political unrest or economic volatility, can amplify the complexity of the project, introducing layers of unpredictability and risk, especially evident in sectors such as construction, as highlighted by Alashwal and Al-Sabahi (2018).

But how do these critical factors influence the complexity? Complexity influences all the core elements of project management. Increased complexity requires more sophisticated planning, control, and adaptive management mechanisms. It requires more specialised resources and enhanced coordination efforts, often complicating resource management. Elevated complexity correlates directly with increased risk, necessitating comprehensive risk identification and management strategies. In addition, effective complexity management requires transparent, structured, and inclusive communication channels among stakeholders, thus promoting collaboration and ensuring project alignment.

To manage this complexity, the insights from Baccarini (1996) original concepts and contemporary perspectives can be integrated. Effective complexity management strategies involve the promotion of strong integrative processes across organisational and technological boundaries. It is crucial to promote clarity, transparency, and frequent stakeholder engagement to enhance communication and collaboration. Employing flexible and adaptive project management methodologies capable of responding dynamically to unforeseen complexities is essential. In addition, proactively identifying, analysing and mitigating risks arising from complex interactions and external environments are fundamental to effectively managing complexity.

Project complexity, grounded in differentiation and interdependency per Baccarini's model, significantly impacts project outcomes. Contemporary research reinforces and expands these core concepts, providing deeper insights into complexity's subjective and systemic dimensions. Recognising and managing these elements proactively is essential for enhancing project performance and achieving successful outcomes within complex environments.

7.1.2. Application of the Baccarini Theory

In this research, the Baccarini Baccarini (1996) complexity framework is used as an analytical tool to assess how various aspects of project complexity influence operational decision making. By applying the concepts of differentiation and interdependency, the theory provides a structured way to classify the complexities encountered in offshore projects, such as the number of stakeholders involved, the diversity in objectives, and the level of technical and organisational coordination required.

The framework helps interpret the qualitative data collected during interviews, especially in identifying patterns of how project complexity affects the flexibility of operational choices. For example, it highlights how highly differentiated projects with many specialised actors tend to create rigid decision-making processes that can limit opportunities for emission reduction. In contrast, projects with lower interdependencies may offer more room to adapt operational strategies in real time.

This theoretical lens ensures that the analysis is not only descriptive but also explanatory, linking organisational and technical complexities to practical barriers and enablers for implementing sustainable operational measures. Hence, it supports a deeper understanding of why certain decisions are made and how complexity can constrain or facilitate environmentally beneficial actions.

7.2. Methodology

To capture the complexity of these processes, a qualitative research design was conducted, using semi-structured interviews and thematic data analysis. This approach allowed for an in-depth examination of the subjective experiences, perceptions, and organisational contexts that shape decision-making on board offshore vessels.

Data collection: Data were collected primarily through semi-structured interviews, guided by a semi-structured protocol that covered topics such as perceived barriers and drivers of emission reductions, organisational culture, contractual constraints and regulatory influences. Each interview lasted between 30 minutes and an hour, allowing participants to expand on specific areas of importance or relevance. The interviews were conducted in person, recorded with the informed consent of the interviewees, and transcribed verbatim to maintain precision.

Using semi-structured interviews, the study could go beyond predetermined categories, uncovering emerging themes related to individual motivations, organisational challenges, and real-world applications of environmental regulations. The interviews were held by the writer of this report and the interviewees are Jumbo Maritime employees who have experience with either the reference project or a similar project and know the challenges.

Participant Selection: Purposive sampling was used to identify and recruit participants who directly participate in day-to-day operations and strategic planning on offshore vessels. The sample included project managers, vessel managers, and offshore operations managers with experience in offshore projects, specifically the one used as a base case. This deliberate inclusion of professional roles ensured that the study captured a comprehensive spectrum of perspectives: from those making operational decisions on the ground to those overseeing broader sustainability objectives.

Data Analysis: After transcription, the interview data was imported into ATLAS.ti for systematic analysis. The analytical process was iterative and consisted of three core stages:

1. **Open Coding:** Each transcript is examined line by line to identify and label recurring ideas, phrases, or concepts related to emission reduction practices and decision-making behaviours. This initial stage aimed to capture all potentially relevant data without imposing predetermined categories.
2. **Axial Coding:** In the second phase, related codes were grouped and restructured to form broader categories or subthemes. For example, codes related to fuel consumption, communications and finance were reviewed to see how they interacted and influenced each other within decision-making
3. **Selective Coding and Thematic Synthesis:** Finally, the most significant categories were synthesised into overarching themes that directly addressed the central research question. These themes shed light on how organisational factors and decision-making processes can facilitate or hinder the adoption of emission reduction measures.

This resulted in the following code tree shown in Figure 7.1

Previous quatitative research: In Chapter 5 the quantitative analysis is explained. To give the interviewees a good understanding of some of the results found, every interview started with a short introduction by the interviewer on the results coming from the quantitative analysis. As this prior knowledge is important to both the interviewee and the interviewer, it has also been coded. It has been split up into two sub-codes: Explanation and Daily Progress Report (DPR).

- **Explanation:** Covers everything under explaining the research steps and the results that were found from the quantitative analysis.
- **DPR:** One of the main sources of quantitative analysis was the Daily Progress Reports (DPR). However, due to some unclarities regarding these DPR's they were mentioned a significant amount, causing a separate code for the DPR's.

Contracts: Captures how formal agreements and contractual stipulations shape operational behaviour, incentives, and constraints in offshore projects.

- **Clauses:** Focusses on specific provisions (e.g., waiting on weather clauses, operational availability terms) that can drive or hinder emission reduction practices. Clauses are often pivotal because they spell out what actions are financially rewarded or penalised, thus guiding vessel operations.

Decision-Making: Encompasses the processes by which offshore personnel (on-board and onshore) evaluate and select a course of action, taking multiple factors into account.

- **Financial:** Pertains to the cost implications of various choices (e.g., whether to remain on standby, transit slowly, or anchor). These considerations include budget constraints, the potential for financial penalties, and economic drivers that can promote or discourage efficient fuel use.
- **Communications:** Deals with how information exchange (or its absence) influences decisions. Poor communication can lead to inaction or conflicting directives, while clear coordination among stakeholders often facilitates fuel-saving and emission-reducing measures.
- **Time:** Relates to scheduling pressures, deadlines, and the urgency to keep the vessels active. Tight timelines can overshadow environmental considerations, whereas more flexible schedules might allow slower transits or less waiting time on DP, thus reducing emissions.
- **Uncertainty:** Addresses the unpredictability inherent in offshore operations (e.g. weather conditions, unforeseen technical issues). Because of this uncertainty, decision makers are often on the side of maintaining readiness (e.g., running thrusters), which may increase fuel consumption.
- **Fuel Consumption:** Zooms in the awareness and management of fuel use. The discussions here revolve around how and under what circumstances fuel consumption becomes a priority, strategies to monitor and reduce usage, and the influence of fuel data on decision making.

External Factors: Covers elements outside the immediate operational sphere that affect the choices made on board and in the offices, including environmental conditions and broader industry or contextual influences.

- **Environment:** Refers to natural conditions (for example, weather, sea state) that heavily constrain or dictate operational choices. Adverse weather often forces high-consumption standby modes, whereas calmer periods enable more flexible (and potentially more efficient) operations.
- **Secondary:** Encompasses other external influences such as regulatory frameworks, industry norms, or higher-level client mandates. These factors can either encourage energy savings initiatives or perpetuate business-as-usual approaches.

Organisational Factors: Examines the role of individual attitudes, perceptions, and interpersonal dynamics in shaping operational decisions related to emissions.

- **Choices:** Highlights the moment-to-moment judgments made by individuals (captains, engineers, managers) who may exercise personal discretion to reduce fuel usage (e.g., choosing to anchor, slowing transit speed), within contractual constraints.
- **Priorities:** Shows how individuals and stakeholders rank different objectives, such as safety, cost, schedule, environmental impact, and the impact of these competing or complementary priorities on emissions-related decisions.
- **Credibility:** Focusses on how trust and perceived reliability of information or individuals affect willingness to adopt certain practices.

Stakeholders: Groups or roles whose interests, authority, and interactions shape operational and emission-related decisions on offshore projects.

- **Clients:** The entities that commission the work. They often set performance targets and influence contract terms. Their directives or flexibility can significantly affect whether emission reduction measures are enacted or overlooked.
- **Crew:** Vessel personnel that performs daily operations. While they possess hands-on expertise and see fuel savings opportunities directly, their decision latitude often depends on higher-level stakeholder approval.

- **Offshore Construction Manager (OCM):** The key on-board manager that links the crew, the offshore project management, and the client representatives. With the right mandate, the OCM can coordinate operational adjustments (such as anchoring or adjusting power usage) that cut emissions.
- **Project Manager:** The onshore decision-maker who balances the overall project objectives (timeline, budget) with contractual obligations. By supporting (or ignoring) environmentally efficient practices, the project manager can enable or constrain the adoption of fuel-saving strategies.

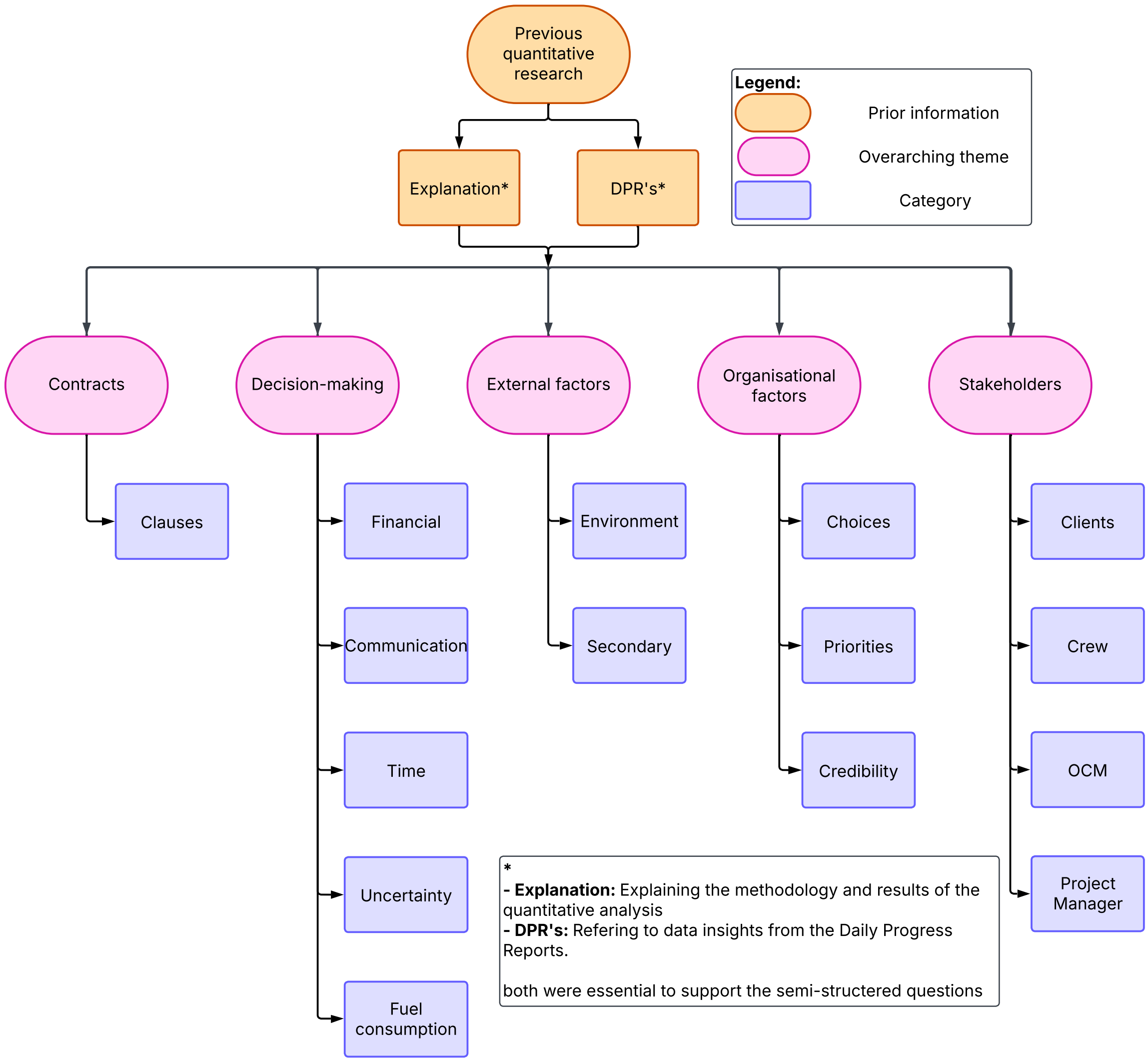


Figure 7.1: Coding tree qualitative analysis

7.3. Results

7.3.1. Stakeholders

Multiple stakeholders influence operational decision making on offshore vessels, each with different interests that can facilitate or hinder emission reduction efforts. The interviews discussed the roles of the clients, the crew of the vessel, the offshore construction manager (OCM), and the project manager, revealing a complex interplay in the way decisions are made.

Clients

Clients (i.e. the companies commissioning the offshore work, and sometimes their own clients further up the chain) hold significant sway over operational choices. Participants frequently noted that

”A large part of this is the client: What does the client want? What does the client expect?” (Interview 2).

Onboard of the vessels, there are representatives of clients; however, these do not always have the right mandate to make quick decisions.

”it was often the case that the client’s offshore representatives had too little mandate. They were not empowered to make real-time decisions which led to delays and inefficiencies” (Interview 1).

Clients often set the tone for whether efficiency measures are acceptable. For example, a recurring issue was whether the vessel was allowed to anchor during waiting periods or was required by the client to stay on Dynamic Positioning. A participant recounted

”A week of bad weather was coming, so it was asked why we were not allowed to anchor? Eventually, it was allowed, resulting in the fuel consumption dropping to 4 tons / day” (Interview 3).

This example shows both the influence of the client (they had prohibited anchoring until they were convinced otherwise) and the positive outcome once the client agreed. However, the data also revealed how having multiple stakeholders in the client can complicate decisions. The presence of both the primary client’s representative and the end client’s representative led to caution and inaction.

”You have the representative of our client and also a representative of the client of our client. They were in a kind of contractual conflict with each other resulting in no decisions being made offshore” (Interview 1).

This internal conflict between client parties left the vessel DP because no one would authorise a change, highlighting how client-driven constraints can directly result in higher emissions. In essence, what the client prioritises, whether it is staying on schedule at all costs or being open to adaptive fuel-saving measures, strongly dictates the operational choices available to the crew.

Crew

The vessel’s crew is on the front lines of implementing (or not implementing) emission reduction measures, but their autonomy is often limited by the conditions imposed from above. Crew members are responsible for the safe operation of the ship and can identify opportunities to save fuel.

”It is often those smaller practical things that make a real difference. I also notice it here at Jumbo, too. During monthly calls with all the captains, people share ideas: one captain found this, another came across that. There is a kind of healthy competition emerging where everyone is trying to come up with clever ways to save fuel. It is practical, collaborative, and creates a culture where small improvements collectively have a big impact” (Interview 1).

This was confirmed by another interviewee,

”That awareness really lives among the crew and in that sense, there is a lot of low hanging fruit to pick up. You are not making massive leaps all at once, but it is a series of small, incremental improvements. And, as the saying goes, every little bit helps. When that mindset becomes part of daily operations, it can lead to meaningful savings and more sustainable practices over time” (Interview 2)

In addition to that, they are the people close to the action. The crew therefore has an important role in identifying possible savings and giving feedback on this.

”That is something that engineers on board often hear as well. They’ll say, we’re almost running idle. In those situations, the engines are barely doing any real work, just ticking over. And that is precisely where opportunities lie. When you recognise those moments, you can start thinking more critically about whether certain systems need to be running at all, or whether operations could be adjusted to reduce unnecessary fuel burn” (Interview 3).

In summary, although the crew operates within the limits established by clients and managers, they can still help a lot by picking the low hanging fruit and identifying possible saving areas based on their experiences.

Offshore Construction Manager

The Offshore Construction Manager is the senior figure on the board that supervises the execution of the project, and this role proved to be a critical node in decision making. The OCM serves as a bridge between the onshore project management and the crew, as well as a point of contact for client representatives on board. According to participants, an OCM with the right mandate can greatly influence the outcomes. This empowerment meant that the OCM could, in theory, decide to stop operations or take fuel saving actions on site without always waiting for shore approval. However, even a competent OCM can be stymied by other stakeholders.

”It came to the fact that the client on board was in a legal contractual tussle with another party, which resulted in offshore simply no decisions were made” (Interview 1).

In that situation, despite the OCM’s authority and desire to make a call, he was unable to obtain the approval of the client representatives, so the vessel continued to operate on DP. This example shows that the influence of the OCM is significant but not absolute, it depends on the cooperation of the client side and the alignment with the project manager. On the positive side, OCMs who maintained good communication with all parties could effectively advocate for emission-conscious choices. They liaise with the onshore team daily to discuss plans. Qualitative evidence highlights that an OCM has the capacity to drive practical solutions (such as initiating a discussion about anchoring or slowing down transit), making it a key stakeholder to operationalise emission reductions on the vessel.

Project Manager

The project manager is another key stakeholder influencing emission-related decisions. Project managers negotiate contract terms, coordinate between the client and the vessel, and ultimately bear responsibility for project outcomes (schedule, cost, safety). Their decisions and guidance strongly shape what the offshore team can do. For example, if a project manager prioritises fuel efficiency, they can set policies or give instructions accordingly; if not, the vessel will prioritise other goals. A good example from the interviews where a Project Manager forsaw some discussion and tackled it before it could happen.

”for instance, under the project contract and execution arrangements, as I anticipated that discussion. I told the team: Look, since we also have to notify agents and arrange pilots, and such, if we already see that there is no available berth or that there is no particular urgency, then we will reduce speed accordingly and we will not be penalised for doing so. I made sure that was explicitly stipulated in the contract” (Interview 1).

In short, the project manager’s position on emissions can either enforce the status quo or open the door to more innovative and efficient operational choices. Qualitative data suggest that when project managers act as advocates for logical solutions (backed by data on fuel savings and safety), they can significantly reduce emissions without jeopardising project goals by aligning all parties toward that outcome.

7.3.2. Contract

Contracts are a crucial factor in shaping decisions about emissions-related practices. The participants revealed that certain contractual provisions could inadvertently encourage fuel-intensive operations. For example, an interviewee described a scenario in which

”You are virtually certain that the weather outside is unfavourable; yet, provided that it is safe, the client nevertheless requests that you proceed outdoors for some reason. Presumably, this is because,

according to their contract, they will only receive payment from their own client once we are physically present outside" (Interview 1).

Unfortunately, these types of clause exist. The following section will dive deeper into different types of clause in the contract that inadvertently encourage fuel-intensive operations.

Clauses

Waiting on weather is inevitable during offshore installation projects. Therefore, it is always a topic of interest for both the client and the contractor to handle in the most effective way. However, this is not always the case.

"Indeed, this is something we really ought to have defined clearly in advance: at the moment installation is no longer proceeding, we simply drop anchor and wait for a new installation window to arrive" (Interview 3).

On the other hand, when they are there, the result of these clauses sometimes results in fuel-inefficient operations:

"Conversely, it may also occur that the Waiting on Weather component is, in one way or another, subject to specific reimbursement conditions. Therefore, it may be in the interest of a party to demonstrate that the weather is indeed too adverse for the installation to proceed. And so, you go out essentially to lie there, on DP, consuming way more fuel than you would while moored in the harbour" (Interview 1).

In this case, a Waiting on Weather clause meant that the vessel had to sail out during bad weather to prove that work could not proceed, resulting in unnecessary fuel burn. Another interviewee described somewhat similar situations in which they were already out in the field but were simply not allowed to go on anchor.

"At the start of the project, when the weather was truly poor and there was no realistic prospect of installation, we were not allowed to drop anchor, so we ended up on downtime" (Interview 3).

This issue was later resolved and ended up in massive fuel savings.

"Later on, I submitted a request to the client, pointing out that this made no sense. We had weeks of poor weather ahead, so why weren't we allowed to anchor? They eventually agreed to the change, and from that point on, of course, fuel consumption dropped significantly, from 14 tons per day to around 4 tonnes per day" (Interview 2).

Similarly, contractual mechanisms sometimes incentivised inefficient transits. One participant noted the paradox that by contract, it occasionally makes sense to sail full throttle to port and then find out that there is no berth.

"Due to certain contractual mechanisms, it can occasionally make sense, at least from a contractual perspective, to sail at full speed towards the harbour, only to discover upon arrival that there is no available berth. One then ends up waiting outside the harbour until space becomes available" (Interview 1).

"For instance, it has been contractually agreed in some way or another that the transit must be completed within a specific time frame. This may be due not so much to our own client, but rather to their client, who is obliged to make quay space available, which may not in fact be available upon arrival. In such cases, compensation is provided for the lack of berth availability which is not granted if you have simply sailed at a slower speed" (interview 1).

Here, a contract without flexibility for arrival time led the crew to rush at full speed only to wait offshore, contradicting the efficient and eco-friendly choice of slow steaming. Not all contracts were considered counterproductive. When clauses are proactively modified to enable emission reductions. An interviewee recounted that they anticipated the transit speed issue:

"for instance, under the project contract and execution arrangements, as I anticipated that discussion. I told the team: Look, since we also have to notify agents and arrange pilots, and such, if we already see that there is no available berth or that there is no particular urgency, then we will reduce speed accordingly and we will not be penalised for doing so. I made sure that was explicitly stipulated in the contract" (Interview 1).

This contractual adjustment prevented wasteful high-speed trips and aligned contract terms with fuel-saving behaviour. The participants also pointed out the absence of green requirements in current contracts.

”Let me put it this way: I have yet to find a contract that explicitly mandates the use of biofuel pricing. But I may be mistaken, things could well start to evolve in that direction. However, not all biofuels are the same; there is considerable variation in composition and you can end up with all kinds of different blends” (Interview 1).

In general, the consensus was that contract clauses exert a dominant influence on operational choices. These insights underscore that without supportive contract terms (or with misaligned ones), efforts to reduce emissions can be stymied despite the best intentions of the crew or management.

7.3.3. Decision-making

Decision-making surrounding operational choices was multifaceted, involving trade-offs between financial considerations, communication dynamics, time pressures, uncertainty, and fuel consumption. Participants described how these factors interacted with human judgment in deciding whether to pursue emission-reducing actions during operations.

Financial

Financial motivations and cost implications had a widespread influence on decisions. On the one hand, running an offshore installation vessel is extremely expensive, creating pressure to maximise productive work. One participant stated that

“installation vessels are so expensive, they’re made to install things, not to lie in the harbour” (Interview 1).

This is confirmed by another participant:

”So it’s frustrating from both an environmental and fuel consumption perspective. But ultimately, we are there to install, so unless there are clear instructions from the office or the client stating, for instance, that fuel consumption needs to be reduced, in which case you are explicitly allowed to remain at anchor for longer periods” (Interview 3).

In addition to offshore installation projects being a team effort of multiple companies and vessels working together, this can also lead to financial decisions that have to be made as described by a participant:

”At times, it was also related to the fact that another vessel was still operating. Another, more expensive installation vessel that was loading monopiles along the same quay. And, well, the larger, more expensive vessel simply takes priority” (Interview 3).

This highlights a financial imperative to keep working rather than sitting idle to save fuel. This drive for efficiency in terms of vessel utilisation often outweighed fuel efficiency concerns. However, some interviewees argued that fuel waste is not only an environmental issue but also a poor financial practice in the long run. They found it irrational that contractual rules could override cost-efficient behaviour, as in cases where crews were compelled to hurry or idle unnecessarily (burning extra fuel) just because the contract would pay for it. One participant emphasised that slowing down to save fuel should be seen as

”just good entrepreneurship, a sound business decision, even if the contracts did not initially reward it” (Interview 1).

These perspectives show that while immediate financial drivers (like vessel day rates and contract penalties) often push for maximum operation at the expense of fuel use, it is responsible for a significant portion of the total costs.

Communications

Clear communication (or lack thereof) between stakeholders was frequently mentioned as a determinant of operational behaviour. Several participants recounted that ambiguity in communication led to indecision and suboptimal choices.

"So one of the key factors in all of this is the client: what does the client actually want, what are their expectations, and how is that communicated? A significant part of the challenge lies precisely in understanding the intent of the client, ensuring clarity in expectations, and maintaining effective communication throughout the process" (Interview 3).

In one case, important decisions were delayed because different parties engaged in:

"On board, you have the representative of our client and a representative of our client's client. Those two were often caught in discussions among themselves, which would then escalate ashore into a kind of legal tug-of-war, a contractual chess match. Meanwhile, offshore, no decisions were being made, and we were simply left outside on DP, waiting" (Interview 1).

Bad communication can also lead to massive inefficiencies and delays.

"That lack of clarity and last-minute decision-making was often a real issue. In my experience, a major part of the problem stemmed from poor communication onshore: no clear plan to follow, no proper alignment on what exactly are we doing, what is possible and what is not feasible onshore. That uncertainty then trickles down offshore, leaving the crew in a reactive mode rather than being able to prepare and operate proactively. It is frustrating and, ultimately, it affects both efficiency and causes unnecessary delays" (Interview 1).

Not everything can be forseen and laid down in contractual agreement; it then comes to communications between the stakeholders:

"And last but not least, there is the issue of sourcing contracts. The reality is that not everything can be captured in contractual terms. Situations will always arise where you look at each other and realise, 'Right, we hadn't thought of this scenario.' The question then becomes: How do you resolve it together? For years, I simply sat down with the client and said 'Look, this caught us both off guard.' That could mean, for example, agreeing to split the impact 50/50 or saying: 'If I take this action, then it has these consequences..." (Interview 1).

With good communication, the problems can be solved.

"Later on, I submitted a request to the client, pointing out that the situation made little sense. We were faced with several weeks of poor weather; why were we not allowed to drop anchor? Eventually, they agreed to the change" (Interview 3).

Thus, effective communication channels and mutual understanding can significantly impact decision-making, enabling timely choices such as shutting down or anchoring for fuel savings rather than waiting for everyone's instructions.

Time

Time pressure and scheduling demands also framed decision-making behaviour. Offshore projects are highly time sensitive, and the desire to capitalise on every possible moment can conflict with fuel-efficient practices. The participants noted a constant tension between stopping operations to save fuel and moving ahead to avoid losing valuable time.

"You want to take advantage of the opportunity to install things" (Interview 3),

referring to brief weather windows in which work could be attempted. This urgency often meant that ships would remain on standby at sea, engines running, to be ready at the first opportunity. An example of a project illustrated how time constraints overruled emission considerations.

"At the beginning of the project, when the weather was very bad and we did not have the prospect of installing, we were not allowed to anchor. So we just waited on DP, burning about 14 tons of fuel per day" (Interview 3).

Here, the schedule (and the contract rules at that stage) did not allow pausing, resulting in significant fuel use during downtime. Another part is processing time, or verification from choices from higher up the command ladder.

"Yes, that was exactly the impression I had, they seemed a bit uncomfortable. It felt like they were only there to take care of the store, so to speak. Anything outside of their comfort zone immediately had to be

escalated to their office for consultation. So you could never really expect quick, on-the-spot decision making, which can be quite frustrating in a dynamic offshore environment where timely responses are often crucial" (Interview 1).

This demonstrates how time-related priorities, keeping on schedule and being ready to work, often outweighed fuel efficiency early on, though excessive delays could eventually prompt a re-evaluation of that stance.

Uncertainty

Uncertainty, especially around weather and operational conditions, was a major factor complicating decision making. Offshore work is inherently unpredictable, and participants described having to make judgment calls with incomplete information. Weather forecasts, in particular, are a large uncertainty.

"On larger projects, those weather reports are often compared alongside data from a waverider buoy, so you have a live buoy out there, providing real-time measurements. That allows you to assess for yourself how conservative the forecasts are actually. In practice, this often reveals whether conditions are in fact more favourable than predicted or not" (Interview 1).

"What they pointed out was that it takes roughly six hours to get from the anchorage to the installation site and back again. And since you only receive a weather forecast every six hours, that introduced a significant degree of uncertainty. You could not simply decide to spend a day at anchor because you would still need those six hours just to return to the location, and by then the weather conditions might have changed completely" (Interview 2).

By comparing forecast and actual sea states, they reduced uncertainty and avoided needless standby time. In addition, some installation locations are notorious for the uncertainty of weather.

"Yes, the weather in the North Sea is often unpredictable and rough, but that can sometimes work in your favour. If you see that what is coming is not really a full-blown storm, and considering that weather updates come in every six hours, you will sometimes notice sudden shifts in the forecast. Sometimes that change is negative, sometimes it is unexpectedly positive, but in either case, you want to be in position and ready to act" (Interview 3).

Supporting that uncertainty is the prioritisation of installing.

"If the weather report were really on the edge, I would never stay at anchor. It's unfortunate for the environment and fuel consumption, but we are here to install" (Interview 3).

This quote encapsulates how uncertainty about weather leads to risk taking and choosing to proceed with operations (and accept higher fuel burn) rather than risk missing a possible installation window.

In sum, the ambiguity of weather and operational conditions tends to make decision-makers favour caution in the form of readiness (engines on, vessel on site), which can undermine fuel-saving intentions unless real-time information or directives encourage a more conservative approach.

Fuel consumption

While fuel consumption is central to emissions, participants indicated that it often remained a secondary factor in operational decisions unless explicitly noted. In many accounts, fuel use was the consequence of decisions rather than the driver.

"Quite often, decisions are made that, from a fuel-saving perspective, do not actually make much sense. It is not uncommon for operational choices to be driven by contractual or procedural considerations, rather than by what would be most efficient or sustainable in terms of fuel consumption" (Interview 1).

For example, staying in DP versus staying in the port was decided by contract or client directives, with fuel burning as an afterthought. However, when fuel consumption data was made salient, it could influence behaviour. Based on the quantitative analysis, every hour on the anchor saves 450kg compared to DP.

"And that is what makes it all quite fascinating, really. Even if you can only remain at anchor for six hours, that still amounts to around 2700 kilogrammes of fuel saved. Every little bit counts; those small efficiencies add up over time, both environmentally and economically" (Interview 2).

Such numbers underscore the potential for huge fuel (and emissions) reductions through operational adjustments. In fact, once stakeholders agreed to let the vessel anchor during a long wait,

"the consumption of course suddenly dropped to 4 tons per day" (Interview 3).

This dramatic improvement illustrates how directly fuel use responds to the choices made. However, participants also noted that without external pressure, fuel considerations might be overlooked. When it comes to adopting new practices, the industry in general isn't helpful either "prior to the start of a project, so-called Key Performance Indicators (KPIs) are usually agreed upon. These typically cover a broad range of aspects: safety incidents, operational efficiency, but not so much on environmental impact and pollution. I do believe that this focus will shift more over time, but the maritime industry is not exactly known to be quick to adapt.

"It's more like an oil tanker; it changes course, but very slowly" (Interview 1).

In practice, it often took individual initiative or extraordinary instructions to prioritise fuel efficiency; otherwise, the default was to focus on operational goals, and fuel consumption simply being a necessary cost of doing business.

7.3.4. External factors

External factors, outside the immediate control of the vessel crew and the project team, also impacted emissions-related decisions. Among these were the environmental conditions and broader industry or contextual influences such as regulations ('secondary' factors). These external elements could constrain what was possible or set the stage (or lack thereof) for pursuing emission reduction during operations.

Environment

Environmental conditions, especially weather and sea state, played a pivotal role in operational choices and their emission consequences. As also discussed in previous codes, participants consistently mentioned weather as a determining factor in whether a vessel could go to work or had to wait. Adverse weather not only risked operations but also posed a dilemma: whether to remain offshore ready to resume work (burning fuel) or to stand down (and potentially lose time). As discussed, if forecasts were uncertain, crews often chose to remain on standby. One participant stated that the main focus is on finding a work window even if the conditions were marginal.

"If the weather forecast were already at the limit, I would never choose to drop anchor. Yes, it's unfortunate in terms of environmental impact and fuel consumption, but ultimately we are there to install. So, unless there are very clear instructions from the office or the client explicitly stating that fuel consumption must be reduced and that we are permitted to remain at anchor for longer, the priority remains the installation work" (Interview 3).

This reflects how the unpredictability of the natural environment can force crews to prefer operational continuity over emissions concerns. It also depends on the location of installation, is there a harbour close and or is there a spot to anchor, which is, of course, depending on the depth of the water. In contrast, with clear directives prioritising fuel savings, behaviour could change. Essentially, weather conditions and location specifics forced constant judgment calls: calm periods and good forecasts allowed for energy-saving moves, whereas volatile weather led to conservative choices that often meant higher fuel burn. Data show that without guidance, crews defaulted to ensuring operational capability (engines on, on location) in the face of environmental uncertainty, thereby increasing emissions as a side effect of staying prepared.

Secondary

Beyond weather, participants identified other external or secondary influences that shaped the context of decision-making. An important theme was the prevailing industry and client culture with respect to emissions. Environmental performance had not yet become a primary driver in the industry's contracting and oversight framework. As an interviewee observed,

"prior to the start of a project, so-called Key Performance Indicators (KPIs) are usually agreed upon. These typically cover a broad range of aspects: safety incidents, operational efficiency, but not so much on environmental impact and pollution. I do believe that this focus will shift more over time, but

the maritime industry is not exactly known to be quick to adapt. It's more like an oil tanker; it changes course, but very slowly" (Interview 1).

This external reality, that clients and the industry at large were not strongly incentivising low-emission operations, often meant that project teams received little pressure to deviate from business-as-usual.

Another secondary factor is the operational profile of offshore installation vessels. Container liners know which ports they will address and whether or not they have the infrastructure ready to change to methanol. Offshore installation vessels do not always know for sure which ports they will go to.

"We cannot say: we will be calling at that port and we could switch to methanol there, so we are looking at retrofitting our systems accordingly. But, of course, that is still uncertain at this stage for our type of vessels. The large container vessels, on the other hand, are already capable of doing that, they've got the infrastructure and scale to make such transitions feasible" (Interview 1).

In addition, there is legislation that is becoming increasingly influential in terms of emissions.

"Regulations are now being introduced and there is a financial incentive coming into play through mechanisms such as the EU ETS and FuelEU Maritime. I think it is a very positive development and will undoubtedly have an impact across the entire industry. For everyone, it is simply becoming part of the broader financial equation: fuel efficiency and emission reduction are no longer just about sustainability; they're now directly linked to cost and competitiveness" (Interview 1).

In sum, factors such as industry norms and regulatory expectations create an external decision environment that has, up to now, done little to prioritise emission reductions on offshore vessels. These secondary influences set the boundaries within which organisational factors and decision-making behaviours operate on-site.

7.3.5. Organisational factors

Organisational factors, attitudes, priorities, and interpersonal dynamics of the people involved significantly impact operational choices around emission reduction. The participants highlighted how the choices of individual decision makers, the priorities they set, and the credibility or trust between the parties could facilitate or hinder fuel-saving measures.

Choices

The personal initiative and judgment of the individuals on the project can skew decisions in one way or another. Even within the constraints of contracts and procedures, the crew and managers often had some discretion in how they acted. Several interviewees gave examples of choosing to do 'the right thing' for efficiency when possible. Slow steaming was mentioned a few times to conserve fuel whenever circumstances allowed, and more importantly, he would document this in the daily report to justify the decision:

"I kept a close eye on those transits that recorded the lower speed in the daily report, etc., so as not to get into trouble afterwards" (Interview 1).

This illustrates an individual exercising judgment to save fuel (a organisational choice) while also anticipating potential scrutiny by transparently reporting his actions.

In other cases, organisational choices came into play in resolving unforeseen situations. Because not everything can be prewritten in a contract, one interviewee emphasised the need for people to step up and decide how to handle surprises. He told us that when unexpected scenarios occurred, he would respond.

"just sit down with the client and work out a pragmatic solution" (Interview 1).

For example, rather than blindly following an inefficient contract rule, they might mutually agree to deviate in a way that saves fuel or time.

In addition, all the other examples presented in the previous sections relate to a choice someone has to make. These show that individual decision makers often made critical choices, whether to slow down during transit or open a discussion with a client that directly affected fuel consumption and emissions.

Human judgment and willingness to take responsibility can thus inject flexibility into an otherwise rigid system, enabling emission reductions that would not happen through rules alone.

Priorities

The priorities that individuals and organisations emphasise have a profound effect on whether emission reduction actions are taken. Qualitative evidence suggests that operational and commercial priorities typically outweigh environmental ones in offshore projects, although this is slowly being challenged. Many participants acknowledged that in practice, completing the mission (and avoiding delays) was the top priority day-to-day.

"We are there to install, absolutely, your top priority is installation, no question about it" (Interview 3),

as one interviewee simply stated, reflecting that the completion of the project's task was considered the main purpose of the vessel. This mindset often led to choices like maintaining position offshore at all costs, even if that meant higher fuel burn, because idling or standing down was seen as letting the project down. Another interviewee noted that neither the client nor the contractor initially put sustainability first in the project objectives, environmental considerations

"were not at the top for either the client or the execution party" (Interview 1)

at the beginning. As a result, emission savings measures (such as anchoring or stopping engines) were not automatically prioritised unless they aligned with other goals.

However, the interviews also show an emerging shift in priorities for some individuals. After experiencing inefficient results, a participant reflected that

"we should have decided beforehand that if no installation is coming, we simply anchor" (Interview 3).

This lesson learnt indicates a changing mindset: recognising that under certain conditions, the priority should switch to conserving fuel and reducing emissions, even if that means pausing operations. In summary, while the default priority has been operational continuity and meeting contractual targets, some stakeholders are beginning to elevate fuel efficiency and sustainability in their decision criteria, especially when the cost of ignoring it becomes evident through experience.

Credibility

The credibility of the information and the trust between the parties emerged as key organisational factors that allowed more flexible, emissions-conscious decisions.

"at the end of the day, it often just comes down to simple organisational dynamics" (Interview 1).

When there was a strong mutual understanding between the contractor and the client, teams could deviate from rigid plans to pursue a more sensible course of action.

"The contract is, of course, always the guiding framework. But just as important is the working relationship and mutual understanding that you build with the client" (Interview 1).

In practice, this trust allowed project leaders to propose fuel saving adjustments and have the client believe in their reasoning.

"Last but not least, there is the issue of sourcing contracts. The reality is that not everything can be captured in contractual terms. Situations will always arise where you look at each other and realise, 'Right, we hadn't thought of this scenario.' The question then becomes: How do you resolve it together?" (Interview 1).

This underlines the importance of the credibility between the client and the contractor. Conversely, when trust is low, parties tend to stick to the letter of the contract and hesitate to make informal arrangements, often resulting in conservative decisions like keeping engines running.

"In the end, we were more or less operating under the direction of the client, so naturally, we sought consensus and clear instructions on how to proceed. Because if you take matters into your own hands, even with the best intentions, and decide to head offshore without explicit approval, you are taking a risk. I have experienced that before myself, although 15 or 20 years ago with another major client, and in that case we were actually penalised for it. That's exactly the kind of situation you want to avoid. Clear coordination and alignment with the client are essential" (Interview 1).

7.3.6. Overview

To summarise, qualitative evidence highlights that organisational relational factors are critical to enabling or hindering adaptive decisions that reduce emissions. Table 7.1 summarises the findings of the qualitative analysis. Qualitative analysis has revealed critical categories that impact operational efficiency, namely stakeholder interactions contracts, decision-making processes, external factors, and organisational factors.

Theme	Key Insights	Impact on Emissions	Recommended Actions
Stakeholders	Misalignment between client(s) and contractor caused delays in decision-making, leading to excessive DP (Dynamic Positioning) usage. Lack of immediate decision authority on-site resulted in conservative operational choices.	Increased fuel use and emissions due to prolonged DP.	Improve stakeholder communication and delegate more decision-making authority to on-site personnel.
Contracts	Contracts mandated vessel readiness at all times, even during extended poor weather conditions, restricting anchoring or port waiting despite obvious inefficiencies.	Forced use of DP during weather downtime causing high emissions.	Include flexible clauses allowing anchoring or port waiting during long weather delays.
Decision making	Strong focus on maintaining project timelines ("time is money" mentality) encouraged continuous vessel readiness, minimising downtime handling efficiency strategies.	Increased fuel consumption due to constant readiness mode.	Balance schedule adherence with operational flexibility and incentivise efficiency rather than just adherence to schedules.
External factors	Unpredictable weather and technical breakdowns induced caution and risk aversion, preferring constant DP readiness to minimise operational risk.	Higher fuel usage as a precautionary measure.	Improve real-time forecasting and increase availability of critical spare parts on board to reduce uncertainty.
Organisational factors	Lack of structured incentives or feedback mechanisms discouraged proactive fuel-saving behaviours, while psychological factors (sense of readiness) maintained high DP usage despite inefficiency.	Persistent high fuel consumption from unnecessary DP use.	Introduce structured feedback systems, incentivise fuel-saving behaviour, and encourage psychological acceptance of alternative downtime management methods.

Table 7.1: Summary of Qualitative Analysis Results

Contracts influence operational choices and create boundaries within which projects must operate, affecting the flexibility of decision making. Decision making, shaped by both internal and external pressures, directly affects operational efficiency and responsiveness. External factors, such as weather and technical breakdowns, further complicate project timelines. Organisational factors, including internal processes and coordination mechanisms, also significantly impact operational effectiveness. The stakeholder relationships and their respective expectations and interactions were found to be crucial to influencing operational outcomes and efficiency.

Figure 7.2 show the research steps carried out. From the quantitative analysis, several possible areas of improvement were identified. Combining these with the findings of the qualitative analysis, three key areas of improvement were identified: optimising operations around waiting periods due to weather, reducing the occurrences and impacts of technical breakdowns, and adopting slow steaming practices to improve fuel efficiency.

Ultimately, these findings and analyses feed into a multi-criterion decision analysis (MCDA) framework and will inform the Organisational and Operational criterion scoring. This facilitates more informed and balanced decision making to optimise operational practices and achieve sustainability goals.

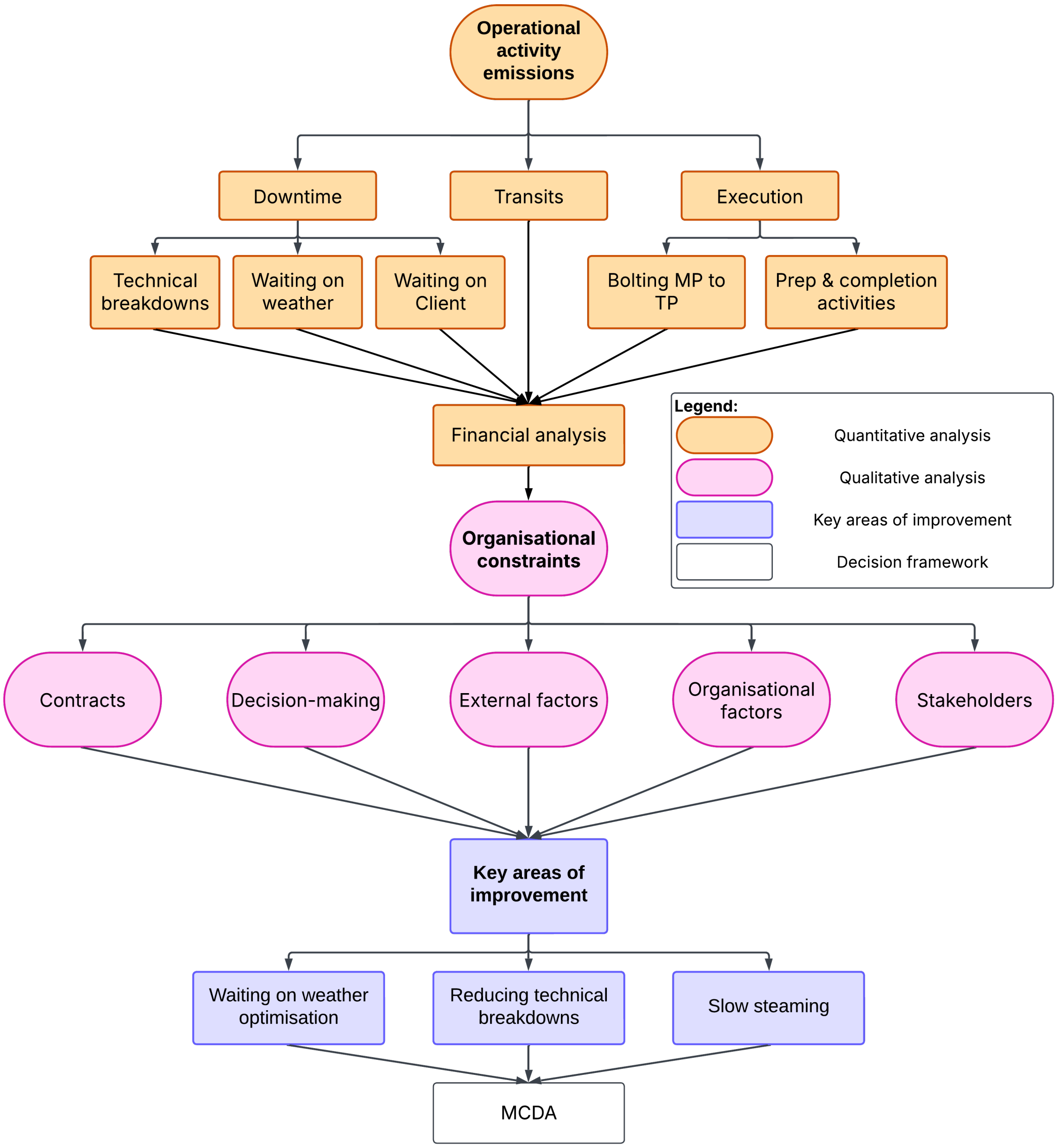


Figure 7.2: Visualisation of results from the qualitative analysis

7.4. Discussion

The qualitative analysis presented highlights the critical influence of organisational and managerial factors on operational decisions that affect vessel emissions. A purely quantitative approach to this topic could risk overlooking the subtle and often context-specific considerations that arise when individuals make decisions under operational, regulatory, and safety pressures. Hence, a qualitative design was selected, in addition to quantitative analysis, for its ability to reveal nuanced insights into how organisational factors such as trust, communication, and external factors impact the implementation of emission reduction strategies. The findings underscore that reducing emissions in offshore maritime operations is not simply a technical issue, but is significantly dependent on organisational influence by stakeholder alignment, contractual incentives, and communication structures. The study emphasises that operational decision making and subsequent emissions are deeply rooted in the preparatory phase of a project. Stakeholder priorities established early on, such as adherence to schedules or contract terms, often drive decision makers toward conservative, emission-intensive practices.

Validation of these findings is provided by applying the Baccarini (1996) complexity framework (Section 7.1), which characterises project complexity by differentiation and interdependency. The study found that the numerous stakeholders and objectives involved strong interdependencies between operational decisions about safety, schedule, costs, and environmental impacts. According to Baccarini (1996) theory, the complexity identified through these interactions often resulted in the default to risk-averse and emission-intensive operational strategies. This theoretical alignment supports the reliability of qualitative insights and emphasises that addressing project complexity through clearer objectives, stakeholder alignment, and improved communication is essential for effective emissions reduction.

However, the scope of the study limits its generalisability, mainly due to its reliance on a single stakeholder perspective, the offshore contractor's personnel. This approach inevitably restricts the diversity of insights and risks biased interpretations of contractual constraints or stakeholder priorities. To fully capture the multidimensional nature of operational decisions, future research should integrate perspectives from clients, third-party service providers, and additional organisational contexts.

The qualitative findings strongly support including Waiting on Weather, Technical Breakdowns, and Transit Operations in the decision-making framework due to their strong linkage with organisational dynamics identified during the project preparatory phase. Waiting on Weather activities showed clear opportunities for emission reduction through better downtime handling strategies. Transit operations presented significant emissions due to limited planning flexibility, emphasising the need for strategic alignment of schedules and operational conditions at the project setup stage. The technical breakdowns highlighted the need for proactive planning and decision-making. In contrast, operational areas such as bolting or preparation activities were predominantly driven by technical complexity and operational procedures rather than decision-making influences, making them less suitable for inclusion in a decision-focused model.

7.5. Conclusion

In conclusion, the qualitative analysis in Chapter 7 demonstrates that preparatory project decisions profoundly influence operational emissions. Stakeholder priorities and contractual clauses established during early project phases significantly shape operational behaviours, typically prioritising safety, reliability, and contractual compliance over emissions reductions. Rigid contracts and misaligned incentives often encourage conservative, emission-intensive operational practices. Stakeholder dynamics often significantly limit or facilitate emission reduction efforts, as exemplified by decisions about dynamic positioning (DP) versus anchoring. Contractual clauses frequently encourage inefficient behaviours, such as maintaining high power during idle times due to compensation structures. Decision making is predominantly driven by immediate operational and financial pressures rather than environmental considerations. External uncertainties, notably unpredictable weather conditions, compel conservative operational decisions unless explicitly managed through contingency planning. Furthermore, human behaviour, such as individual leadership and organisational culture, was identified as a critical barrier and potential enablers of emission reduction. This shows the importance of trust, clear communication, and shared sustainability goals.

These areas are essential because they represent significant opportunities to align operational decision-making with emission reductions. Providing structured solutions to overcome the organisational, contractual, and organisational-influential constraints that affect vessel emissions. Ultimately, meaningful emissions reductions require integrating emissions considerations into initial project planning and fostering a supportive organisational culture. Aligning stakeholder incentives, clarifying project objectives, and establishing effective communication frameworks early on creates conditions favourable to sustainable, lower-emission operational decisions.

This chapter explicitly answers the sub-question: *"How do preparatory project decisions impact the operational choices related to the reduction of emissions on offshore vessels?"* The results highlight the importance of overcoming organisational, contractual, and behavioural barriers early in project planning to create favourable conditions for sustainable, lower-emission operational decisions.

The findings of the interview underline the importance of stakeholder and organisational considerations. Chapter 8 will combine all these aspects (environmental, operational, organisational, financial) using an MCDA framework to evaluate potential improvements.

Part IV

Multi-Criteria analysis

8
Decision-making framework

This chapter will combine the insights obtained from the quantitative analysis (Chapter 5 & Chapter 6) and qualitative analysis (Chapter 7). Quantitative analysis led to an insight into the fuel, time, and financial impacts on the various clusters. Some of them stood out due to their magnitude, such as DP operations, technical breakdowns, or transits. The qualitative analysis resulted in a better understanding of the areas of improvement obtained from the quantitative analysis.

8.1. Key areas for improvement

The synthesis of quantitative and qualitative results provides an answer to the fifth sub-question:

5. What are the key areas of improvement based on quantitative and qualitative analysis to minimise emissions in offshore maritime operations?

The decision-making model should particularly emphasise improvements in:

1. Waiting on weather alternatives
2. Technical breakdown
3. Slow steaming

These areas demonstrate a clear connection to preparatory decision-making, organisational alignment, organisational factors, and provide substantial potential for emissions reduction. Incorporating these areas will enhance proactive planning, stakeholder alignment, and operational flexibility, essential to achieve sustainable emission reductions in offshore vessel operations.

The MCDA that follows will serve to compile the results of the preceding analyses into a unified evaluation and will provide an answer to the final sub-question:

6: What collaborative decision-making frameworks can align stakeholders (crew, managers, clients) to improve operational practices for emission reduction?

8.2. Multi-Criteria Decision Analysis

The Weighted Sum Model (WSM), a Multi-Criteria Decision Analysis (MCDA) technique, is a systematic approach to making complex decisions that involve multiple and often conflicting criteria. Based on insights from previous chapters, this MCDA aims to evaluate operational strategies for Jumbo Maritime to minimise greenhouse gas (GHG) emissions while maintaining operational efficiency and economic feasibility.

8.2.1. Criteria identification

Criterion scores were derived from earlier findings. The Environmental Impact score considers the emission reductions achievable based on Chapter5's data. The Operational Performance score reflects potential time/capacity trade-offs; see Chapters 5 and 7. The Financial score incorporates the cost assessments, Chapter 6. The organisational score is informed by the interviews insights on feasibility, Chapter 5.

Each criterion will be given a score of 1 to 5 where:

1. unfeasible
2. almost unfeasible
3. major hurdles to become feasible
4. minor hurdles to become feasible
5. Feasible solution

To perform the MCDA, each criterion is assigned a specific weight reflecting its relative importance. The weights presented in Table 8.1 were carefully determined by the author. The reasoning for each assigned weight is as follows.

- Environmental Impact: Environmental considerations are vital given regulatory trends and global sustainability goals, the weight was balanced at 25% to reflect the practical reality that emission reductions typically require compromises in operational efficiency and financial investment.
- Operational performance: Given its immediate influence on project outcomes and the critical nature of timely and efficient offshore operations, this criterion carries the greatest weight.
- Organisational factors: Offshore projects involve complex interactions among various stakeholders, each with potentially conflicting priorities. The assignment of a weight of 25% acknowledges the importance of clear communication, stakeholder management, and the need to navigate organisational constraints effectively to ensure smooth project execution.
- Financial Impact: Although cost reduction and financial efficiency are crucial for economic sustainability, this criterion was assigned the lowest relative weight of 15% to reflect the long-term strategic perspective of this study, which prioritises balanced operational effectiveness, regulatory compliance, and environmental responsibility above immediate short-term cost savings.

Criteria	Weight
Environmental impact	25
Operational performance	35
Organisational factors	25
Financial impact	15
Total	**100%**

Table 8.1: Criteria weights

In Section 8.2.6, a sensitivity study is conducted to better understand how changes in priority among criteria influence decision-making outcomes. It aims to provide information on the robustness of the decision-making framework and clarify how sensitive the recommended actions are to changes in stakeholder preferences or external conditions, allowing for a more comprehensive and flexible evaluation.

8.2.2. Waiting on weather DP optimisation

Waiting on waiting is inevitable during offshore installation scopes. The question, however, is "How do you deal with it?" Currently, in most situations, the vessel stays out near the field, on DP, waiting until the weather clears up. As concluded in Section 5.9, dynamic positioning has, next to transit, the highest fuel consumption. Therefore, it becomes in the best interest of both the contractor and the client to minimise downtime and optimise downtime handling.

Anchoring

An option could be to drop to anchor; however, this depends on the location whether or not it is possible to drop to anchor based on location-specific parameters, such as water depth. Another option is to sail to the nearest port. To calculate the cross point between staying on DP and dropping the anchor or heading to port the following equations are used:

$$\text{Fuel consumed (mt)} = 2 \cdot x \cdot fc_{\text{transit}} + (t - \frac{2 \cdot x}{v}) \cdot fc_{\text{anchor or port}} \tag{8.1}$$

$$\text{Fuel consumed (mt)} = t \cdot fc_{DP} \tag{8.2}$$

Where:

- **x:** sailing distance in nautical miles
- **fc:** fuel consumption in tons/hour
- **t:** time in hours
- **v:** average sailing speed in knots

For the financial aspect, a few assumptions have been used. The maximum port call cost based on the Port of Rotterdam, explained in Section 6.1.3, have been used. The bundle prices from Table 6.1 are used and an EU ETS CO_2 price of € 75 per ton is considered.

Figure 8.1 shows for which window of bad weather and sailing distance it becomes economically and environmentally beneficial to drop the anchor instead of wainting on DP.

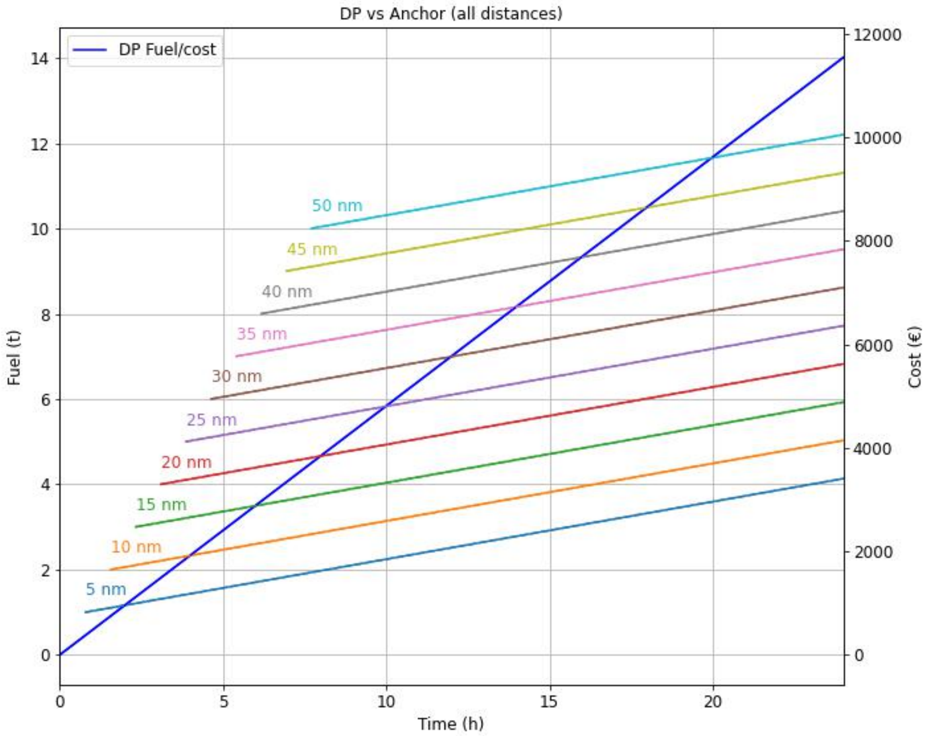


Figure 8.1: Staying on DP versus going on anchor

During the course of the entire project, 114 instances have been downtimed with an average of 14 hours and a total of 1600 hours. From the qualitative analysis, it was found that it was widely estimated that it took 6 hours to anchor / mobilise. Looking at figure 8.1, the 40nm line gives the best representation which shows that after 16 hours anchoring becomes financially and environmentally beneficial compared to staying in the DP mode. From the qualitative analysis, it was found that every 6 hours the vessel received a new weather forecast. Table 8.2 breaks down the downtime instance into possible anchoring opportunities.

Type	Total	on DP	< 6 hours	> 16 hours	At risk
Technical breakdown	40	25	16	2	7
Waiting on client	39	20	17	1	2
Waiting on weather	35	29	12	12	5
Total	114	74	45	15	14

Table 8.2: Downtime instances breakdown

The ones shorter than 6 hours consisted mainly of instances of 1 or 2 hours, and since every 6 hours there is a weather forecast, they are relatively predictable. The ones at risk are between 6 and 16 hours. The number of instances does not provide the full picture. Table 8.3 shows how much time is spent on DP for each type of downtime.

Type	**on DP**	**< 6 hours**	**> 16 hours**	**At risk**
Technical breakdown	142	29	42	71
Waiting on client	68	22	20	26
Waiting on weather	764	28	686	50
Total	974	79	748	147

Table 8.3: Downtime time breakdown

Shows the insane amount of time spent on DP in downtime windows longer than 16 hours. Especially waiting on weather, averaging at 57 hours per instance and none even close to the 16 hour barrier could have possibly saved 228 tons of fuel, 730 tons of CO_2, and € 213k in fuel costs and emission allowances. The only problem are organisational factors. From the qualitative analysis it was found that anchoring during downtime isn't widely supported yet and therefore will be hard to integrate into contracts.

Criteria	Score
Environmental impact	5
Operational performance	4
Organisational factors	2
Financial impact	4

Table 8.4: Criteria weights Anchoring

Port

Another option is to head to the port. This can be done for two reasons. The first is to simply wait until there is a weather window again. This situation only happens if there is no anchor location nearby but a port is, the only problem might be the quay availability. The second reason is to get extra cargo, provisions, or bunkers. Therefore, you need to go to the home port, which is in most cases not the closest port or closer than an anchor location. This leads to longer sailing times, increasing the uncertainty for the decision. In addition to that, heading into port will lead to port dues. These are based on the port of Rotterdam estimated at € 10k, as calculated in Section 6.1.3. This causes the shift of the dashed line in Figure 8.2. Based on the average port stay (61 hours), fuel wise (brown straight line), it is feasible up to a sailing distance of 150 nm, but financially only up to 75 nm (green dashed lines) sailing distance due to the port dues.

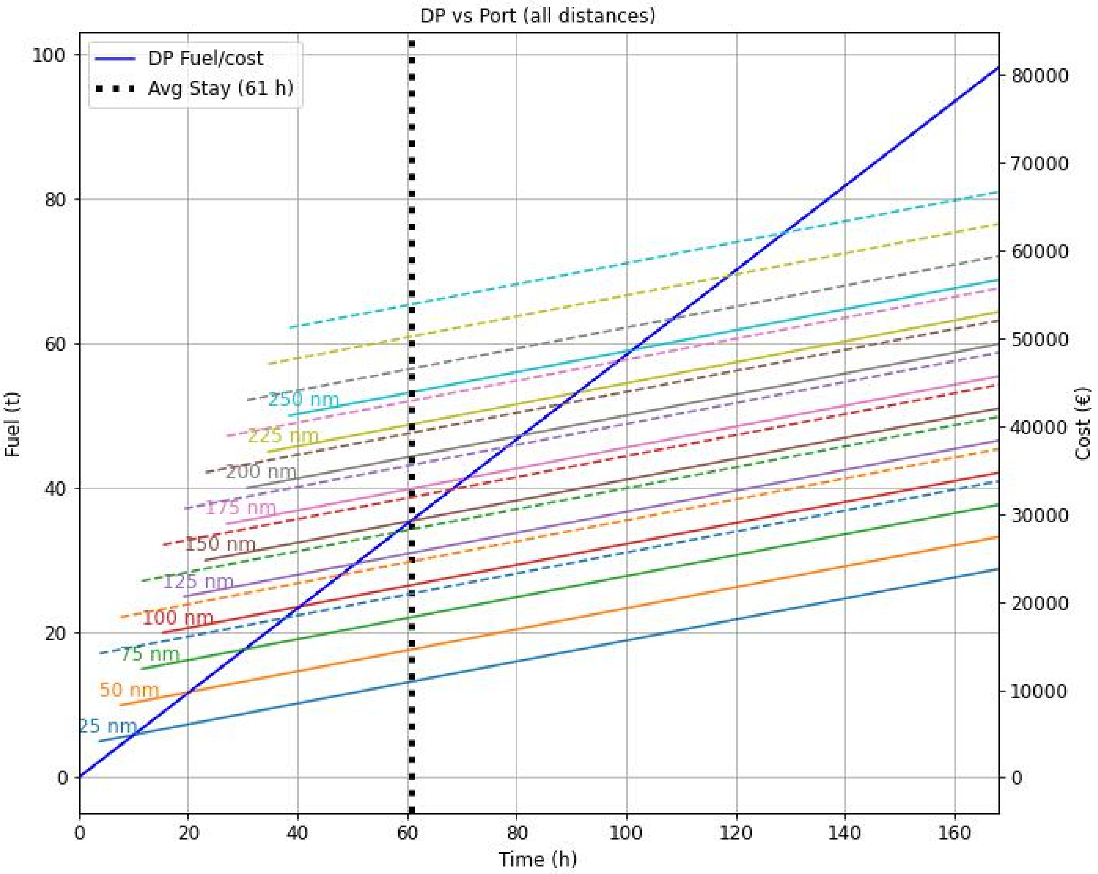


Figure 8.2: Staying on DP versus heading into Port

Compared to anchoring, the environmentally responsible approach to port scores a bit less. This is due to the longer transits, which increases the pay-off time. On operational performance it scores slightly lower as well since it has to either be combined with a second reason or quay space has to be available. From an organisational point of view, it scores slightly higher. This is because it is better explained to other stakeholders if the port visit is combined with, for instance, resupplies. Lastly, financially it is very unlikely that one will do this without losing money due to port fees.

Criteria	Score
Environmental impact	4
Operational performance	3
Organisational factors	3
Financial impact	1

Table 8.5: Criteria weights Port

8.2.3. Technical breakdowns

Unplanned technical breakdowns during installation significantly contribute to downtime and fuel consumption. Figures 8.3 and 8.4 illustrate that such technical issues are among the notable causes of downtime, both in terms of time lost and additional fuel burnt while the vessel is on standby. It shows that technical breakdowns account for 15% of the total fuel consumption and time lost. In total, this led to 277 hours of lost time, equal to almost 12 days. After waiting on weather, waiting on the client has the largest contribution to downtime, for both fuel and time lost. However, waiting on client is in most cases beyond the contractor’s control and therefore is not considered for improvement. Technical breakdowns, on the other hand, can be mitigated by proactive measures. Primarily, by ensuring that critical spare parts and repair capabilities are available on board so that repairs can be performed at sea without returning to port. It was mentioned in the DPR's that, although a spare part was on board, it could not be installed offshore, forcing a port call for repairs. This indicates a clear opportunity for improvement.

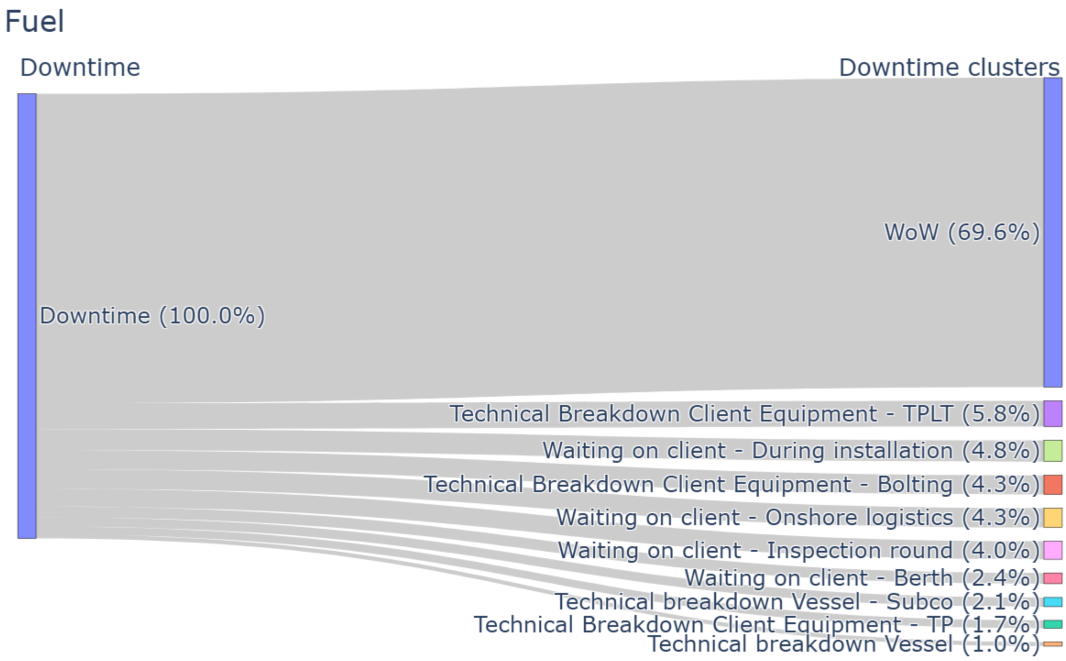


Figure 8.3: Fuel consumption breakdown downtime

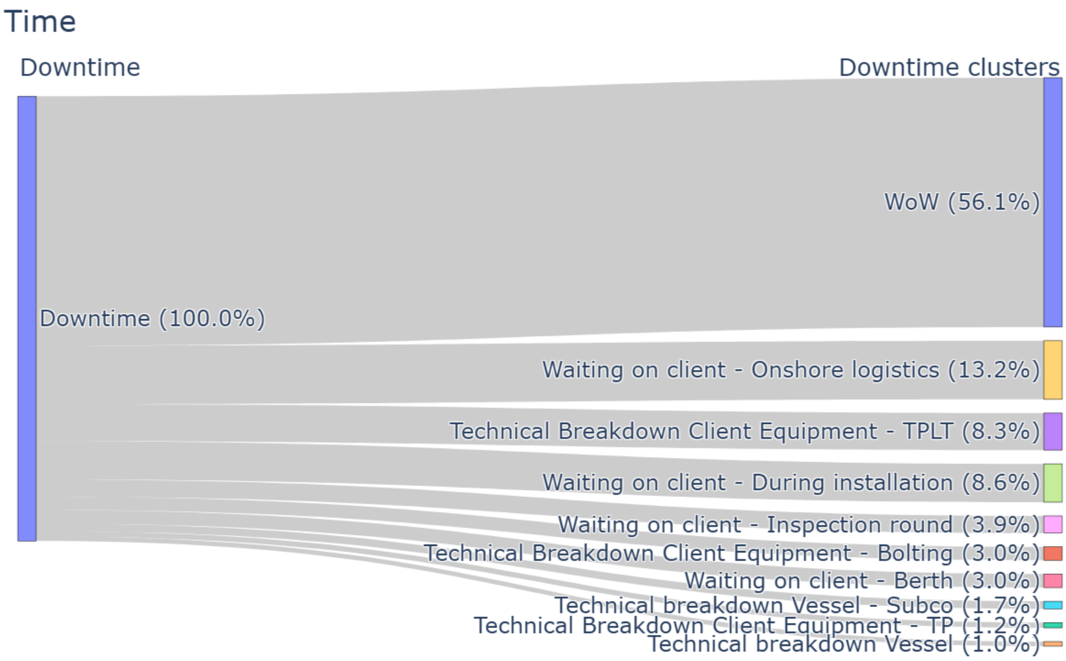


Figure 8.4: Time breakdown downtime

Qualitative findings support this measure. The interviewees highlighted the need for better preparatory planning to handle equipment failures. Proactive maintenance and spare provisioning could prevent long delays. Having the right spares and tools available and procedures in place to perform certain repairs on site. The vessel can avoid unnecessary port deviations. This yields multiple benefits.

Environmentally, avoiding a port detour or prolonged Dynamic Positioning (DP) standby during repairs reduces fuel consumption and emissions. For example, eliminating a single port cal, which averages $\approx$ 61 hours excluding transit time, saves on the order of tens of tons of fuel. Therefore, from an environmental perspective, improving the handling of failures is highly feasible and beneficial. Operationally, minimising downtime from breakdown improves the reliability of the project schedule and the utilisation of the vessel. There are minor operational hurdles, complex repairs might still require calm conditions or specialised equipment. However, in general with enough spares on board the vessel, most of the repair can be done at sea. Another factor to consider is the available space onboard for these spares. The organisational aspects present only minor challenges, mostly within planning and design. Engineering must make room for all extra spares on board the vessel. In addition, the company must invest in carrying spares, but these changes align with the crew and the contractor's interest in maintaining uptime. Since such decisions are largely within the contractor's own procedures, which do not require client approval, the organisational feasibility is considered high. Financially, this option is very attractive. Avoiding heading back to port saves tons of fuel, port fees, and, more importantly, avoids losing a day or more of installation time. Given the vessel's day rate of €150k, preventing even one day of breakdown delay can save on the order of hundreds of thousands of euros. The cost of stocking spare parts and tooling is negligible by comparison. Thus, from a financial standpoint, investing in additional spares and at sea repair capability is a feasible solution.

Criteria	Score
Environmental impact	4
Operational performance	4
Organisational factors	3
Financial impact	4

Table 8.6: Criteria technical breakdowns

8.2.4. Slow steaming

Another strategy to reduce fuel consumption is slow steaming. In normal transit mode, the vessel typically uses both main engines. In a slow-steaming mode, one main engine was turned off, so only a single engine was used for propulsion, as can be found in Table 8.7. This engine is operating at a higher load percentage, increasing engine efficiency. The measurements on board confirmed this load redistribution: as shown in Table 8.7 in normal transit, the port and starboard generators averaged $\approx$ 284 kW and $\approx$ 314 kW output, respectively. In slow steam mode, one generator carried $\approx$ 548 kW. Concentrating power on a single engine results in a higher percentage of load and therefore a lower specific fuel consumption, as shown in Figure 5.6a. The total propulsive power required to transit does not change significantly.

	PS			SB		
Transit mode	**avg Gen power [kW]**	**avg Gen on**	**sum Gen power [kW]**	**avg Gen power [kW]**	**avg Gen on**	**sum Gen power [kW]**
Normal	283	88%	533612	315	92%	598409
Slow	548	95%	1108107	53	19%	109430

Table 8.7: Generator Power Data for Normal and Slow Transit Modes

However, practical results on fuel reduction for the slow steaming are inconclusive because of data limitations. The vessel monitoring system did not record engine RPM, making it difficult to accurately calculate fuel consumption from engine load during transits. The analysis had to rely on a Bollard-pull power curve to estimate the main engine output from the propeller pitch, which is not reliable during transits. Since the propellers are installed at 0% pitch to perform best during transits, the average set point is around 0%. Based on the bollard pull curve, Figure 5.5, this gives a power of $\approx$ 740 kW. As a result, the exact fuel saving achieved by slow steaming in the case study could not be quantified. The theoretical expectation is that fuel consumption per nautical mile would decrease, since the specific fuel consumption of the diesel engine improves near full load.

In theory, running one engine at higher efficiency can still yield net fuel savings compared to running two engines at lower efficiency. This is consistent with the literature on slow steaming, which reports 20–30% fuel savings at reduced speeds under favourable conditions.

	PS			SB		
Transit mode	**avg pitch setpoint [%]**	**avg Prop power [kW]**	**sum Prop power [kW]**	**avg pitch setpoint [%]**	**avg Prop power [kW]**	**sum Prop power [kW]**
Normal	0,97	746	1410303	0,98	745	1408608
Slow	0,07	731	1494974	0,12	731	1495284

Table 8.8: Propeller power Data for Normal and Slow Transit Modes

In summary, from an environmental perspective, slow steaming is conceptually a positive measure, but due to missing data, it could not be proven for the reference project and the vessel. If implemented properly, it could be very effective, but the lack of measured proof and the possibility of only marginal net gains suggest minor remaining hurdles to overcome in achieving significant emission reduction through this method. From an operational standpoint, slow steaming introduces major hurdles. The primary issue is the longer transit time. Slower transit between the port and the installation site can conflict with tight project schedules and weather windows. In offshore projects, timing is critical. Arriving later on site can mean missing a suitable weather window for installation or simply prolonging the project duration. Potential fuel savings must be weighed against the risk of schedule delays. One possibility is, when it is known that there is no quay space available, to shut off a engine and start slow steaming. Thus, operational feasibility is moderate at best. It can be done technically, but it requires careful planning of the project timeline. The organisational dimension further complicates the slow steaming. Current stakeholder incentives are misaligned with this practice as contracts typically prioritise on-time project completion. From the qualitative analysis it is known that by contract delays caused by client not having quay space available can result in penalties/bonuses depending from which perspective you look at it. In addition, the fuel costs, the day rate of the vessel, are passed on to the client. This means that the contractor has no financial incentive to slow down and the client has no incentive to allow slower transits as they would save fuel money but pay much more in extra day rates. Such contractual and organisational barriers make slow steaming very hard to apply unless new incentive structures are adopted. Interviewees indicated that in practice, management and clients are very conservative about deliberately slowing operations, given the high costs of schedule extensions and the emphasis on reliability and meeting deadlines. Culturally, proposing to deliberately take longer can face resistance unless sustainability goals are strongly prioritised by all stakeholders. Finally, the financial feasibility of slow steaming is low. As noted above, any fuel cost savings is paid by the client. However, the cost of additional transit time, the rate of vessel day, and the potential loss of opportunity for another task can far outweigh those savings. For illustration, bunkering costs $\approx$ €600,-/ton and during a transit $\approx$ 20 tons of fuel are used. If slow steaming in a saves 20%, this is € 2.5k of fuel but adds a quarter of a day to the schedule, at €150k/day this could cost $\approx$ € 37.5k in extra day rate. Unless fuel prices,carbon costs rise dramatically or contractual terms change to reward efficiency over time, slow steaming is not financially attractive in the current setting. In sum, while slow steaming is technically and environmentally promising, it faces substantial operational, organisational, and economic challenges in an offshore installation context. The table summarises the evaluation of the criteria for this option.

Criteria	Score
Environmental impact	4
Operational performance	3
Organisational factors	2
Financial impact	2

Table 8.9: Criteria slow steaming

8.2.5. Results

Table 8.10 below compiles the MCDA scores for all the decision alternatives analysed in Sections 8.2.1 to 8.2.4. Each alternative has been scored against the four criteria on the feasibility scale of 1 to 5, and the scores are combined with the weights of the criteria of Table 8.1.

Anchoring during weather downtime was found to be feasible. It scored well on environmental (score 5) and operational criteria (score 4), as dropping the anchor eliminates most of the fuel consumption from the DP standby without impeding the readiness of the installation, as long as suitable locations are nearby. The total fuel savings can have a massive impact, as for the reference project was calculated more than 10%. Its weaknesses lie in organisational factors (score 2), clients tend to be conservative and hesitant to allow leaving the site, causing decision delays. The financial impact (score 3) is not great either. Heading into port for downtime scored considerably lower. Environmentally and operationally, the use of a port can be feasible only if the port is within a reasonable distance (feasible up to 150 nm in the analysis). But financially, this option is very poor (score 1). Port call fees (€ 10k) and additional transit fuel mean net losses beyond $\approx$ 75nm distance. In addition to that, it also incurs schedule risk. Organisational acceptance is mediocre (score 3). A port call could be justified only if the time is used productively. In general, anchoring is preferable to port calls for weather waiting and would be the recommended downtime strategy.

The proactive technical breakdown management option scores very high on most criteria. It is essentially a "win-win" improvement. Environmentally, it avoids unnecessary fuel burn (score 4). Operationally, it increases productive uptime (score 4), and financially it saves significant costs (score 5) by preventing expensive delays and reducing the total number of days. Organisational hurdles are considered manageable (score 4). This alternative achieves the highest overall weighted score among the options considered.

In contrast, slow steaming shows a mixed outcome. Its strong point is the environmental criterion (score 4), reflecting potential emissions cuts, but is hampered by operational feasibility (3) and especially stakeholder acceptance (2) and financial trade-offs (2). The weighted score is therefore moderate. Although slow steaming can reduce fuel consumption in theory, the MCDA highlights that under current project constraints it is not as attractive as other options. Table 8.10 presents the scoring for each criterion and the resulting weighted score (out of 5) for each alternative. The technical breakdowns emerge as the top-ranked solution with a weighted score of about 4.4, indicating that it is the most feasible and beneficial across the board. The anchoring strategy ranks second (3.3). Slow steaming is third (2.85), its score being dragged down by low stakeholder and financial feasibility. The port call option is clearly the weakest (weighted 2.7), primarily due to its poor financial performance. These results suggest that the preferred option to pursue would be improving technical breakdown handling, followed by implementing anchoring for weather downtime. Slow steaming, while less favourable in the base analysis, could be reconsidered if future conditions change. Port-call downtime handling is not recommended unless absolutely required for operational reasons.

Decision alternative	Environmental impact	Operational performance	Organisational factors	Financial impact	Weighted score
Anchoring	5	4	2	4	3.75
Port	4	3	3	1	2.95
Technical breakdowns	4	4	4	5	4.15
Slow steaming	4	3	2	2	2.85

Table 8.10: MCDA scoring table

In conclusion, the MCDA results point to improving technical breakdown management as the most attractive option, given its high scores in all areas. Anchoring during weather downtime is also a positive measure, though somewhat less impactful. Slow steaming, under current conditions, is less favourable due to operational and economic constraints, but it remains an option with environmental merit if those constraints can be addressed. Port-call downtime handling should be avoided from a multi-criteria standpoint, as it sacrifices financial viability for only limited environmental or operational gain.

8.2.6. Sensitivity study

The base case analysis above used a particular set of criterion weights chosen by the author as a reasonable balance. To test the robustness of the decision outcome, a sensitivity analysis was performed by varying these decision weights. In this section, we adjust the weights to see if a different weighting of priorities would change the ranking of alternatives or the preferred option identified. Given that technical breakdowns were the top option in the base case, the key question is whether some plausible weight shifts could make another alternative outrank it. Table 8.11 presents several scenarios of weight distributions. In Scenario A, a greater emphasis is placed on Environmental and Financial criteria. Scenario B puts more weight on operational performance and scenario C equalises all criteria (25% each) for comparison.

Scenario	Environmental (%)	Operational (%)	Organisational (%)	Financial (%)
Base Case	25	35	25	15
Scenario A	40	20	15	25
Scenario B	20	50	20	10
Scenario C	25	25	25	25

Table 8.11: Weighting Scenarios for Sensitivity Analysis.

For each scenario, Table 8.12 shows the recalculated overall score for each option. The ranking of alternatives remains the same in all these cases. Management of technical breakdown consistently scores the highest, followed by anchoring, slow steaming, and finally port call. The magnitude of the differences changes with the weights. This indicates that the MCDA recommendation is not very sensitive to reasonable changes in the weighting of the criteria. The selection of technical breakdown management as the primary measure is robust across a range of stakeholder priority profiles.

Scenario	Anchoring	Port call	Tech. Breakdown	Slow Steaming	Top Option
Base Case	3.75	2.95	**4.15**	2.85	Breakdown
Scenario A	4.10	2.90	**4.25**	3.00	Breakdown
Scenario B	3.80	3.00	**4.10**	2.90	Breakdown
Scenario C	3.75	2.75	**4.25**	2.75	Breakdown

Table 8.12: MCDA Scores Under Different Weighting Scenarios.

This suggests that the decision to prioritise improving technical breakdown preparation is quite insensitive to changes in stakeholder priorities. In other words, even if a decision maker valued the criteria differently, they would likely still arrive at the same preferred option. This clarity is a desirable feature in decision making, as it means that the recommendation is reliable under uncertainty or differences in opinion about what criteria matter most. In general, the MCDA result that favours technical breakdown mitigation is confirmed to be stable, increasing confidence in that strategy as the optimal choice to reduce emissions in the offshore installation project given the various trade-offs.

This chapter explicitly addressed the sub-question: *"What collaborative decision-making frameworks can align stakeholders to improve operational practices for emission reduction?"*. The MCDA integrated quantitative and qualitative insights to systematically compare operational strategies. By incorporating multiple stakeholder criteria, MCDA provided a structured but flexible framework for evaluating operational alternatives.

This framework directly answered the sub-question by demonstrating how collaborative decision-making approaches can effectively balance diverse stakeholder interests, aligning operational practices with emissions reduction goals. MCDA thus facilitates clear, structured, and transparent decision-making, which is essential for successful emission mitigation in complex offshore operations.

Part V

Discussion and Conclusion

9 Discussion

The analytical approach of this study required several assumptions due to data limitations and modelling simplifications. First, because daily progress reports (DPRs) were often inconsistent or incomplete. Therefore, to estimate fuel consumption, bollard pull condition calculations were used as a proxy for fuel consumption in most operational modes. It was assumed that every activity except transit could be treated as a bollard pull condition. For transit operations, a fixed fuel consumption rate of approximately 100 kg per nautical mile was assumed based on operational knowledge from previous company projects. These assumptions filled data gaps, but introduce uncertainty in the absolute fuel consumption estimates. Additional assumptions were made in fuel modelling, such as efficiency. In addition, fuel consumption estimations relied heavily on poly fits based on manufacturer-provided Specific Fuel Oil Consumption (SFOC) points for the engines. In practice, engine efficiency can vary with load, maintenance conditions, and environmental factors. The use of nominal SFOC values means that the actual fuel burn could differ from our estimates. All fuel was assumed to be of standard type for emission calculations, ignoring the possible use of blends that would alter emission factors. These modelling choices were necessary to proceed with the quantitative analysis, but they represent idealised conditions. As a result, the magnitude of the calculated fuel use should be viewed as indicative rather than exact. The relative differences and trends identified are more reliable than the precise figures.

The interviews were conducted on the contractor side. Therefore, the perspectives of the different stakeholders were not taken into account. Therefore, the results might not provide the complete picture. However, qualitative analysis underscored the critical role of preparatory project decisions, particularly contractual agreements, in shaping operational choices that influence emissions. Rigid contractual requirements often incentivised fuel-intensive practices. The interviews highlighted that aligning stakeholder objectives with sustainability through contractual incentives was crucial to operationalising emission reduction strategies.

9.1. Implications and Limitations

The findings of this thesis demonstrate the potential of data-driven decision tools, but also highlight important limitations and contextual factors. A key implication is that while a multi-criteria decision analysis (MCDA) framework can systematically evaluate emission reduction measures, its practical effectiveness is constrained by data quality and availability. In this research, several data issues forced assumptions to be made. If an offshore company were to implement such a framework, they would need more robust and high-resolution data collection to ensure that the recommendations are sound. In other words, the power of data-driven decision making will only be fully realised if the underlying data are reliable. Improving data accuracy is therefore an important prerequisite for deploying these methods in real operations.

Another limitation is the evolving regulatory and economic context. The financial analysis of the study incorporated current values for fuel costs and carbon pricing at the time of the study. However, regulations are tightening and carbon prices are likely to rise. Changes such as the inclusion of offshore vessels in the EU ETS by 2027 or new fuel taxes could significantly alter the cost-benefit calculation of operational decisions. In contrast, unexpected regulatory exemptions or changes in fuel prices could reduce the economic incentive to cut emissions. In addition to that, at the time of writing, world politics is marked by high tension and increasing uncertainty regarding legislative developments. The generalisability of our cost-effectiveness conclusions is time sensitive, and stakeholders must continuously update their assumptions to reflect the current regulatory environment. The operational recommendations made here should be revisited as external conditions change, to ensure they remain valid, and to incorporate any new compliance requirements.

Organisational factors emerged as a critical theme, underscoring a limitation in purely quantitative modelling. Crew behaviour, managerial priorities, and client demands can have a large influence on emission outcomes, but are difficult to capture in a data model. Interviews in the qualitative phase revealed that stakeholder decisions sometimes contradict what the 'optimal' data-driven solution would be. For example, a client's contractual requirement might force a vessel to remain in fuel-consuming standby mode, even when anchoring would save fuel, simply because the contract prioritises continuous readiness over efficiency. Similarly, a captain or project manager might hesitate to slow the steam during transit if they fear penalties for arriving later, unless they have the backing of the client or company to do so. These examples highlight that an optimal operational plan on paper does not guarantee implementation unless incentives and culture are aligned. As we proposed a decision-making framework, we assume rational adoption of its recommendations. In reality, the organisational culture and alignment of the stakeholders must support the data-driven approach. The implication is that companies should invest in change management and work with clients to encourage flexibility. Without addressing these organisational factors, the impact of any technical or operational solution will be reduced or even disappear.

Finally, it should be noted that the scope of the analysis was limited to a specific project context and a set of identified measures. Quantitative data came primarily from an offshore installation project and qualitative insights were obtained only from a contractors perspective. Although this provided a deep dive into that scenario, the findings may not universally apply to all types of vessel or project setup. For example, different vessels may have different fuel consumption profiles, and different companies might face other contractual or cultural challenges. This limitation suggests caution in generalising results.

Further studies in various projects and classes of vessels would strengthen confidence in the conclusions. Despite these limitations, the combined quantitative and qualitative approach offers a valuable proof-of-concept for linking operational decision-making to emissions. demonstrates that even with some uncertainty in the data, clear trends and improvement levers can be identified.

10 Conclusions & Recommendations

This thesis was intended to explore how data-driven decision making can contribute to a cost-effective reduction in GHG emissions in offshore maritime operations while maintaining performance and regulatory compliance. Through both quantitative analysis of operational data and qualitative interviews with industry experts, the study has yielded several key findings. These findings are summarised by addressing each of the research sub-questions, leading to an overall answer to the main research question.

10.1. Conclusions

1: What existing operational measures are available in the offshore industry to reduce greenhouse gas emissions?

The literature review identified a variety of operational measures currently known in the offshore maritime industry that can help reduce greenhouse gas emissions. It focused on measures that focus on improving efficiency and eliminating wasteful practices without requiring new technology. Key measures include slow steaming, whereby vessels deliberately travel at reduced speed to reduce fuel consumption. Optimising route planning and scheduling to avoid unnecessary journeys or waiting periods and the influence of decision-making during offshore operations. Another important measure is improved maintenance and breakdown management, ensuring that technical problems are minimised to keep downtime to a minimum. In summary, a suite of operational measures is available that can be employed to reduce emissions. These measures formed the basis for the specific strategies analysed later in the thesis.

2: What is the influence of each offshore activity on greenhouse gas emissions carried out by offshore construction vessels based on data analysis?

The quantitative analysis in Chapter 5 examined in detail how different operational activities contribute to fuel consumption and thus to GHG emissions. Each phase of an offshore installation project, such as transit, execution, and downtime, has a distinct emissions profile. Data analysis showed that Dynamic Positioning (DP) operations, common during installation and waiting periods offshore, and transits are the dominant contributors to fuel consumption and emissions.

- Downtime: 38%, 2084 tons CO_2
  - Waiting on weather: 26.6%, 1466 tons CO_2
  - Technical breakdowns: 6%, 355 tons CO_2
- Execution: 26%, 1457 tons CO_2
  - Prep & completion acitivities: 7.6%, 432 tos CO_2
  - Bolting MP to TP: 7.2%, 411 tons CO_2
- Transits: 31%, 1785 tons CO_2

Whenever anchoring or port standby occurred, fuel consumption was minimal compared to holding position in DP. These results quantify the intuition that high engine load activities, transits, and dynamic position drive emissions. Whereas engines at idle or off (as in port or anchored) emit far less. Therefore, the influence of each activity is significant. Any operational profile that can reduce the time in fuel-intensive modes will yield lower overall emissions. This data-driven insight directed attention to managing downtime and transit more efficiently as prime opportunities for emission reduction.

3: How can emission reduction be a cost-effective operational strategy that incorporates allowances from the EU emission trading system, to optimise both compliance with emissions and overall costs?

The financial analysis addressed the economic side of emission reduction, especially under the EU Emissions Trading System (ETS), which places a price on carbon emissions. The question here was whether operational measures that reduce emissions can also save money, particularly when we account for the cost of carbon allowances and potential future penalties? The findings indicate that many emission reduction actions can be cost effective, especially as regulatory costs increase. Fuel consumption has a direct cost and an associated carbon cost coming soon. Therefore, not only does cutting fuel save on fuel bills, but it also reduces the number of carbon credits needed, yielding a double financial benefit. For example, using an anchor or heading into port instead of DP during long waits drastically cuts fuel use. The MCDA showed that if a weather delay exceeds a certain threshold, the cost of moving to port and the port fees are smaller than the fuel and ETS costs that would be incurred by holding position at sea for that period. In quantitative terms, anchoring becomes the financially preferable option for moderate delays, and if a delay is very extended, returning to port can be the most cost-effective solution. The exact break-even hours depend on factors such as the distance from the port and the fuel burn rate. But the analysis confirmed the principle that beyond a certain waiting time, sustaining DP is the most expensive and polluting choice, whereas alternatives like anchoring or port-call pay off economically. Importantly, the study incorporated the forecasted carbon prices of the EU ETS into these calculations, recognising that carbon costs will likely increase in the coming years. As carbon prices rise, the cost-effectiveness of fuel-saving measures becomes even more favourable. In other words, what might be a small cost saving today could become a large cost saving under future carbon prices, effectively future-proofing operations against regulatory cost increases. In summary, the research demonstrates that emission reduction can be aligned with cost optimisation. Strategies that reduce fuel and emissions often result in break-even or small profits during operations operations.

4: How do the preparatory project decisions impact the operational choices related to the reduction of emissions on offshore vessels?

Preparatory project decisions, notably project planning, contractual agreements, and client directives made before or at the start of a project, set the stage for what operational choices are possible during execution. The qualitative findings revealed that these early decisions have a significant influence on the ability of a crew to implement emission-saving measures. One major factor is the contract structure between the offshore contractor and the client. If contracts are formulated with rigid requirements, for example, demanding the vessel to be on standby at the installation site at all times, or imposing penalties for delays, they can inadvertently encourage fuel-intensive practices. The interviewees described scenarios where contractual clauses led to a vessel going to sea and holding position in poor weather merely to satisfy a payment condition, resulting in significant unnecessary emission. In contrast, when forward thinking was taken, the interviewees described scenarios in which they were negotiating flexible contract terms, such as explicitly allowing slower transit speeds or the use of anchoring during weather waits. This allowed crews to make choices that reduce emissions without fear of breaching the contract or schedule. Another preparatory aspect is project scheduling and risk planning. If the project timeline is extremely tight, there is little room to slowsteam or wait for weather in port, whereas a proper schedule can accommodate these efficiency measures. In essence, decisions made in the planning phase , or even before, heavily influence operational behaviour. The study found that when emission reduction considerations are included in the project plan and contract, operational teams are much more likely to adopt green practices. For example, by making fuel efficiency a shared objective of client and contractor. Thus, preparatory project decisions can enable or constrain emission reductions. Aligning these early decisions with emission goals is therefore critical for allowing data-driven optimisations to take place during the project.

5: What are the key areas of improvement based on quantitative and qualitative analysis to minimise emissions in offshore maritime operations? Integrating the insights of the quantitative data and the qualitative analysis, the research identified several areas of improvement that could be optimised with respect to fuel consumption and reduction of emissions. These can be thought of as best-practice scenarios that, if implemented, would significantly reduce fuel use without compromising the mission. A key low-emission profile is efficient downtime management. Instead of keeping the vessel on DP with the engines running for hours or days, the crew would drop anchor or head to port, drastically reducing fuel consumption. Another profile is slow-steaming whenever the schedule allows. Quantitatively, slow steaming was shown to save fuel at the cost of slightly longer travel time, a trade-off that is often worthwhile if planned. The third aspect is enhanced reliability and preparedness by ensuring that technical breakdowns or other delays are rare and short. In practice, this involves robust maintenance, available spares, and having contingency plans so that the vessel does not spend time unable to work. By avoiding unplanned downtime or efficiently handling it, fuel waste is avoided. In summary, the key areas of improvement for minimal emissions would involve:

- during any waiting periods offshore, prefer anchoring or shutting down over holding position on thrusters, provided it is safe and allowed
- throughout the project, maintain equipment, make sure enough spares are available and plan operations to prevent unnecessary fuel use
- during transit, operate at economical speeds and adjust departure times to avoid rushing

Qualitative insights support these profiles. The interviewees consistently noted that slowing down and shutting down were effective but underutilised tactics, often because of non-technical reasons. Furthermore, the combination of these practices was evaluated in Chapter 8's decision making framework, which compared alternative strategies. According to the MCDA, the highest ranking strategy for emission reduction was improving technical breakdown management, closely followed by adopting anchoring as the default during weather downtime. Slow steaming was also identified as beneficial, though slightly less favoured when all criteria were considered. In general, the optimal emission-minimising operational profile is one that reduces engine use whenever possible. This profile emerged from the data as a clear path to reducing emissions.

6: What collaborative decision-making frameworks can align stakeholders (crew, managers, clients) to improve operational practices for emission reduction?

Addressing this question, Chapter 8 presented a decision-making framework designed to bring together the various stakeholders and criteria involved in operational decisions. Offshore operations involve multiple decision makers. Vessel crews focus on safety and immediate efficiency, project managers balance cost and schedule, and clients have their own priorities, often contractual and performance-driven. To align these parties toward emission reduction, a collaborative approach is required so that environmental goals do not conflict with other objectives. The study proposed using an MCDA tool as a framework for collaborative decision making. In the MCDA, various criteria were considered, such as environmental impact, operational performance, organisational factors, and financial impact. By scoring and weighing different operational options across these criteria, the framework allows stakeholders to see a holistic evaluation of each choice. The MCDA thus acts as a common platform where the different requirements of the stakeholders are represented, and trade-offs can explicitly be discussed. In our case, when this framework was applied to key measures, it revealed that some strategies scored well on almost all criteria. This is a powerful insight. It shows that aligning stakeholders is possible when the decision is framed not as an environment versus cost split, but as a multi-criteria optimisation where certain options emerge as win-win. Beyond the multi-criteria tool, qualitative insights stressed the importance of communication and joint planning. In practice, a collaborative framework might involve regular meetings in which stakeholders review operational plans using data evidence and agree on the course of action. For example, before a project or a phase with a likely weather downtime, all parties could agree on a protocol that is beneficial to emission reduction. Such agreements require trust and a shared commitment to emission reduction. The framework for decision-making, therefore, is not only a mathematical tool but also a governance arrangement. Setting clear guidelines, decision trees, or empowered roles. The thesis concludes that a combination of data-driven tools and stakeholder engagement mechanisms is needed. By using evidence-based discussions and embedding emission objectives into the decision criteria for everyone, stakeholders can be aligned. In short, the framework for aligning stakeholders involves inclusive decision processes supported by data analytics. The MCDA ensures that the priorities of each stakeholder are considered and that all can agree on the operational plan that best balances efficiency, cost, safety, and emissions.

Main Research Question: How can data-driven decision making contribute to a cost-effective reduction in greenhouse gas emissions in offshore maritime operations while maintaining performance and compliance with regulations?

Data-driven decision making can significantly enable and enhance the reduction of GHG emissions in offshore operations. Identifying where and how emissions can be cut with minimal downside, and providing a factual basis for stakeholders to make informed choices. In this study, the data-driven approach pinpointed that a large portion of emissions come from operational inefficiencies such as excessive DP usage and a lot of downtime. By quantifying these effects, the data highlight specific opportunities that might otherwise remain intuition or guesswork. This evidence is crucial to convincing decision makers to change standard practices. Furthermore, incorporating cost data and carbon pricing into the analysis ensures that the recommended emission reductions are cost-effective. The results showed that many emission-saving measures also save fuel costs and avoid carbon allowance expenses, meaning they can reduce operational costs or at least not significantly increase them, which is a key factor in future industry adoption. Even for measures that have some costs, the data-driven evaluation can determine if the costs are justified by the emission benefit and if it fits within the performance requirements. Maintaining performance and regulatory compliance was a guiding constraint throughout the decision-making process. Using a data-driven multi-criteria approach, the decision-making process ensures that any adopted emission reduction measure has been tested for its impact on other performance metrics. Furthermore, the inclusion of regulatory factors such as EU ETS in the analysis means that the decisions are made with compliance in mind. Companies can meet or surpass current regulations proactively rather than reactively. In essence, data-driven decision making contributes by offering a balanced optimisation. It identifies strategies at the intersection of low emissions, low cost, and acceptable operational impact. It turns emission reduction from a vague goal into a series of concrete, optimised actions supported by evidence.

In conclusion, data-driven decision making, exemplified by the integration of operational data analytics and structured decision frameworks, can guide offshore maritime operations towards significantly lower GHG emissions in a cost-effective manner. It does so by highlighting inefficiencies, evaluating the trade-offs of different actions with real data, and ensuring that chosen measures align with both economic and regulatory demands. When data insights are coupled with collaborative implementation, the result is a powerful approach in which emissions are cut without sacrificing operational performance. This thesis has demonstrated that with accurate data and the right decision tools, the offshore industry can make informed decisions to decarbonise operations, achieve compliance with environmental regulations, and contribute to broader climate goals while maintaining efficiency and profitability.

10.2. Recommendations

Building on the conclusions, several practical recommendations are proposed for Jumbo Maritime and future work:

- Improve and standardise data collection on vessels: Accurate data are the backbone of effective decision making. Offshore companies should invest in better monitoring systems for fuel consumption and engine performance. By tracking consumption data more rigorously, including during specific activities, operators can continuously identify inefficiencies and verify the benefits of any changes. High-quality data will also enable for more reliable modelling in future studies and allow compliance with monitoring requirements with minimal error.
- Incorporate sustainability priorities into client contracts and project planning: To overcome the organisational and contractual barriers identified, it is recommended to embed emission reduction clauses in contracts and align incentives. This can include agreements that allow slower transit speeds without financial penalty, reward fuel savings or carbon footprint reductions, and permit vessels to make emission-driven decisions (like waiting at anchor or port when reasonable) in coordination with the client. By negotiating these terms upfront, contractors and clients signal a shared commitment to sustainability. Similarly, project plans should include environmental performance as a key success metric alongside cost, time, and safety. When contracts and schedules explicitly prioritise sustainable practices, crews and managers will have the mandate

and confidence to execute the low-emission operational profiles identified in this research.

- Adopt a formal decision-making framework for operations: Companies should consider implementing decision support tools in their operational planning process. By evaluating choices against multiple criteria, including emissions and cost, in a structured way, teams can make balanced decisions transparently. This approach will also facilitate communication between stakeholders, as it makes trade-offs clear.
- Plan for regulatory changes and future-proof operations: Companies should be proactive about upcoming regulations, such as the extension of the EU ETS to offshore vessels and increasingly strict IMO emission targets. This involves not only ensuring compliance, but also treating these regulations as an opportunity to justify greener operations. By anticipating higher carbon costs, operators can invest early in both operational improvements and, where appropriate, complementary technological solutions. Including a long-term outlook in decision-making will make the business more resilient.

In summary, the offshore maritime industry can take concrete steps to link operational decision making with emission reduction. By improving data quality, aligning contractual frameworks with sustainability, using structured decision tools, and empowering people through knowledge and culture. The industry will be well placed to achieve significant reductions in greenhouse gas emissions. These recommendations, drawn from the study's insights, aim to ensure that the identified theoretical benefits can be achieved in practice, leading to cleaner operations, cost savings, and a more sustainable offshore sector.

10.3. Further research

This study focused on operational strategies to reduce emissions on offshore construction vessels. Although it offers actionable recommendations, several areas remain open for future research:

- Expanding the scope over multiple projects and vessels: Conducting comparative studies on a broader fleet and various offshore projects would provide more detailed insight into the variability of operational emissions and validate the findings on different types of vessels and operational profiles.
- Technical emission reduction measures: This thesis excluded technical measures. Future research could assess technical improvements such as waste heat recovery, battery integration, and energy-efficient thrusters. Evaluating their emissions savings, feasibility, and return on investment would provide a more complete picture of potential improvements.
- Alternative fuels and hybrid systems: Investigating the use of LNG, methanol, biofuels, or ammonia could reveal significant emission reduction potential, particularly when combined with hybrid electric propulsion. These studies should also address fuel availability, engine compatibility, lifecycle emissions, and safety.
- Detailed on-board energy distribution: A more granular analysis of power generation and consumption per subsystem such as thrusters, cranes, and hotel load could refine emission estimates. High-resolution data would allow for the modelling of improved generator management and support advanced energy optimisation strategies.
- Broader stakeholder perspectives: This thesis focused on the contractor's viewpoint. Future qualitative studies should include clients and regulators to better understand the contractual, commercial, and regulatory forces shaping operational decisions and emissions.
- Framework validation across contexts: Applying the developed decision framework to other types of vessels or operational settings would test its robustness. Pilot studies that measure actual fuel savings under recommended strategies would further validate the model.

These areas will deepen understanding and support the transition of the offshore industry toward lower-emission operations, complementing the operational focus of this thesis.

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A

Engine data

Emission Test Report M32C LE Ambient and Gaseous Emissions Data

Mode			1	2	3	4	5
Power / Torque		%	100	75	50	25	10
Speed		%	100	100	100	100	100
Time at beginning of mode			14:28	14:47	15:08	15:28	15:47
Ambient Data							
Atmosph. pressure		mbar	1021	1021	1022	1021	1021
Intake air temp.		°C	30,7	31,9	32,4	32,3	31,5
Intake air humidity		%	19,4	18	17,5	17,5	18,4
Atmospheric factor (fa)			1,013	1,018	1,021	1,020	1,016
Gaseous Emissions Data							
NOx	conc. wet	ppm	875,9	898,7	913	681,6	822,3
CO	conc. dry	ppm	43,4	38,9	39,5	87,4	132,5
CO2	conc. dry	%	5,84	5,63	5,66	5,48	4,11
O2	conc. dry	%	12,92	13,20	13,16	13,41	15,31
HC	conc. wet	ppm	143,2	152,2	215,1	264,9	266
NOx hum.corr.factor			0,959	0,966	0,971	0,973	0,969
Dry/wet corr.factor			0,946	0,95	0,95	0,951	0,963
NOx	mass flow	kg/h	26,383	21,199	14,653	6,319	5,20
CO	mass flow	kg/h	0,787	0,55	0,377	0,482	0,507
CO2	mass flow	kg/h	1664	1249,5	850	475,2	247,2
O2	mass flow	kg/h	2675	2129,2	1437	845	669,3
HC	mass flow	kg/h	1,358	1,122	1,074	0,762	0,524
SO2	mass flow	kg/h	-	-	-	-	-
NOx	specific	g/kWh	9,55	10,157	10,479	9,018	18,634

Figure A.1: Emission Test Report M32C Ambient and Gaseous Emissions Data

Emission Test Report No. M32C-LE

Engine Information

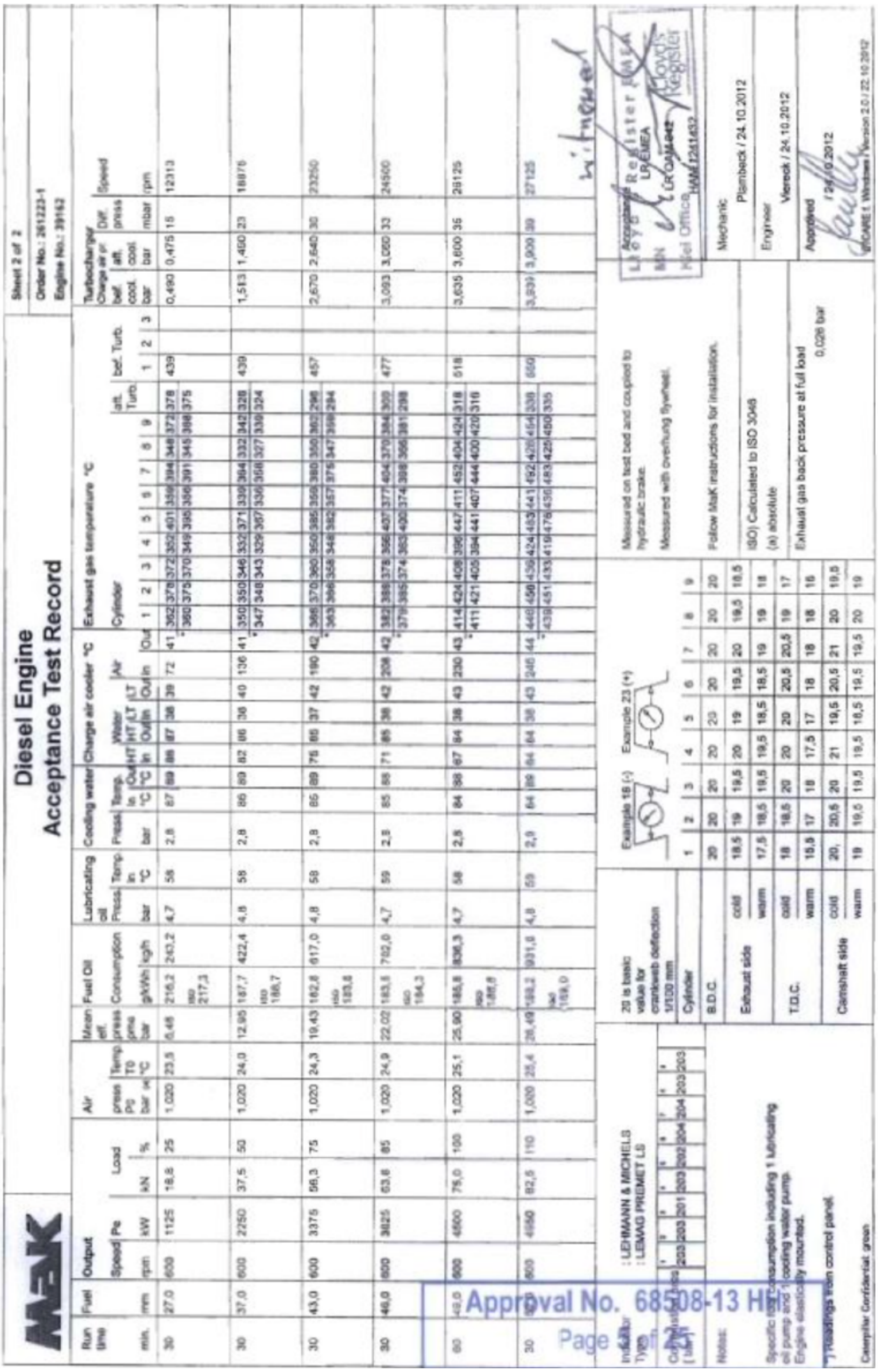
Engine		
Manufacturer	Caterpillar Motoren GmbH	
Engine type	6 M 32 C	
Group identification	M32C-LE2	
Serial number	38729	
Rated speed	600	rpm
Rated power	3000 / 2880	kW
Intermediate speed	-	rpm
Max. torque at intermediate speed	-	Nm
Cylinder number and configuration	6,8,9 inline	
Bore	320	mm
Stroke	480	mm
Mean effective pressure at ratet power	25,9 / 24,8	bar
Max. cylinder pressure at ratet power	204	bar
Auxiliaries	2 pumps	

Specified ambient conditions		
Max. Seawater temperature	38	°C
Max. Charge air temperature, if applicable	45	°C
Cooling system spec., intermediate cooler	yes	
Cooling system spec., charge air stages	2 stage	
Low / high temp.cooling system setpoints	30 / 90	°C
Maximum inlet depression	25	mbar
Maximum exhaust backpressure	30	mbar
Fuel oil specification	Gas oil	
Fuel oil temperature	40	°C
Lubricating oil specification	see engine documentation, chapter "Operating Media"	

Application / Intendet for	
Customer	
Final application/ installation, Ship	
Final application/ installation, Engine	main

Emissions test results				
Cycle		D 2	E 2	
NOx	600 1/min	9,8	9,6	g/kWh

Figure A.2: Test Data Report M32C Engine Family



MaK

Diesel Engine Acceptance Test Record

Sheet 2 of 2
Order No.: 261223-1
Engine No.: 39162

Run time (min.)	Fuel (mm)	Output Speed (rpm)	Output Pe (kW)	Load (kN)	Load (%)	Air press P0 (bar (a))	Air Temp. T0 (°C)	Mean eff. press pme (bar)	Fuel Oil Consumption (g/kWh)	Fuel Oil Consumption (kg/h)	Lubricating oil Press. (bar)	Lubricating oil Temp. in (°C)	Cooling water Press. (bar)	Cooling water Temp. In (°C)	Cooling water Temp. Out (°C)	Charge air cooler Water HT In	Water HT Out	Water LT In	Water LT Out	Air In	Air Out	Exhaust gas temp. Cyl. 1	2	3	4	5	6	7	8	9	aft. Turb.	bef. Turb. 1	bef. Turb. 2	bef. Turb. 3	Turbocharger Charge air pr. bef. cool. (bar)	Charge air pr. aft. cool. (bar)	Diff. press (mbar)	Speed (rpm)
30	27,0	600	1125	18,8	25	1,020	23,5	6,48	216,2 (iso 217,3)	243,2	4,7	58	2,8	87	89	88	87	38	39	72	41	362	378	372	352	401	359	394	348	372	378	439			0,490	0,475	15	12313
																					*	360	375	370	349	395	356	391	345	388	375							
30	37,0	600	2250	37,5	50	1,020	24,0	12,95	187,7 (iso 188,7)	422,4	4,8	58	2,8	86	89	82	86	38	40	136	41	350	350	346	332	371	339	364	332	342	328	439			1,513	1,490	23	18875
																					*	347	348	343	329	367	336	358	327	339	324							
30	43,0	600	3375	56,3	75	1,020	24,3	19,43	182,8 (iso 183,8)	617,0	4,8	58	2,8	86	89	75	85	37	42	190	42	366	370	360	350	385	359	380	350	362	296	457			2,670	2,640	30	23250
																					*	363	366	358	348	382	357	375	347	359	294							
30	46,0	600	3825	63,8	85	1,020	24,9	22,02	183,5 (iso 184,3)	702,0	4,7	59	2,8	85	88	71	85	38	42	208	42	382	388	378	366	407	377	404	370	384	300	477			3,093	3,060	33	24500
																					*	379	385	374	363	400	374	398	366	381	298							
60	49,0	600	4500	75,0	100	1,020	25,1	25,90	185,8 (iso 186,8)	836,3	4,7	58	2,8	84	88	67	84	38	43	230	43	414	424	408	396	447	411	452	404	424	318	518			3,635	3,600	35	26125
																					*	411	421	405	394	441	407	444	400	420	316							
30	[illegible]	600	4950	82,5	110	1,020	25,4	26,49	188,2 (iso 189,0)	931,8	4,8	59	2,9	84	89	84	84	38	43	246	44	446	456	439	424	483	441	492	428	454	338	560			3,939	3,900	39	27125
																					*	439	451	433	419	476	436	483	425	450	335							

witnessed

Indicator: LEHMANN & MICHELS
Type: LEMAG PREMET LS

Compression pressure (bar)	1	2	3	4	5	6	7	8	9
	203	203	201	203	202	204	204	203	203

Notes:

Specific fuel consumption including 1 lubricating oil pump and 1 cooling water pump.
Engine elastically mounted.

*) Readings from control panel.

Caterpillar Confidential: green

20 is basic value for crankweb deflection 1/100 mm

Example 18 (-) Example 23 (+)

Cylinder		1	2	3	4	5	6	7	8	9
B.D.C.		20	20	20	20	20	20	20	20	20
Exhaust side	cold	18,5	19	19,5	20	19	19,5	20	19,5	18,5
	warm	17,5	18,5	19,5	19,5	18,5	18,5	19	19	18
T.D.C.	cold	18	18,5	20	20	20	20,5	20,5	19	17
	warm	15,5	17	18	17,5	17	18	18	18	16
Camshaft side	cold	20,	20,5	20	21	19,5	20,5	21	20	19,5
	warm	19	19,5	19,5	19,5	18,5	19,5	19,5	20	19

Measured on test bed and coupled to hydraulic brake.

Measured with overhung flywheel.

Follow MaK instructions for installation.

ISO) Calculated to ISO 3046
(a) absolute

Exhaust gas back pressure at full load 0,026 bar

Acceptance
Lloyd's Register EMEA
LR/EMEA
LR OAM 042
Kiel Office
HAM 1241432

Mechanic
Plambeck / 24.10.2012

Engineer
Viereck / 24.10.2012

Approved
/ 24.10.2012

Approval No. 68508-13 HH
Page 5 of 25

CARE1 Windows / Version 2.0 / 22.10.2012

Figure A.3: MAK 9M32C Factory Acceptance Test Record

Emission Test Report No. M32C LE Engine Test Data

Mode		1	2	3	4	5
Power / Torque	%	100	75	50	25	10
Speed	%	100	100	100	100	100
Time at beginning of mode		14:28	14:47	15:08	15:28	15:47
Engine Data						
Speed	rpm	600	600	600	600	600
Power	kW	2880	2160	1440	720	288
Mean eff. pressure	bar	24,87	18,65	12,43	6,22	2,49
Fuel rack	mm	48,4	44,3	39,8	31,7	25,1
Uncorr.spec.fuel cons.	g/kWh	184,3	184,5	189	211,1	275
Fuel flow	kg/h	530,7	398,5	271,5	152,0	79,2
Air flow	kg/h	-	-	-	-	-
Firing pressure	bar	201	-	-	-	-
End of needlelift (Noz)	° CA	-	-	-	-	-
Charge air pressure	bar	3,51	2,48	1,4	0,51	0,14
Turbo speed	rpm	31040	27520	22400	15280	10040
Exhaust flow (gexhw)	kg/h	19800	15392	10421	6006,5	4115
Exhaust temp.	°C	291	294	321	335	259
Exhaust backpress.	mbar	25				
LT Coolant temp. in	°C	37	37	38	38	38
LT Coolant temp. out	°C	40	39	39	38,5	39
HT Coolant temp. in	°C	75	80	84	87	87
HT Coolant temp. out	°C	87	87	87	87	87
Cyl.Coolant pressure	bar	3,7	3,7	4	3,6	3,7
Temp. intercooled air	°C	43	41	40	39	38
Lubricant temp.	°C	56	54	54	56	53
Lubricant pressure	bar	4,4	4,4	4,4	4,5	4,5
Inlet depression	mbar	-	-	-	-	-

Figure A.4: Emission Test Report M32C Engine Test Data

GEN SET PERFORMANCE DATA

AUGUST 10, 2012

For Help Desk Phone Numbers Click here

Performance Number: DM6954 | Change Level: 02

Sales Model: 3516BDITA | Combustion: DI | Aspr: TA

Engine Power: 1825 W/O F EKW 1,901.0 KW | Speed: 1,800 RPM | After Cooler: SCAC

Manifold Type: DRY | Governor Type: ADEM3 | After Cooler Temp(C): 30

Turbo Quantity: 2 | Engine App: GS | Turbo Arrangement: Parallel

Hertz: 60 | Application Type: MAR AUX ENG | Engine Rating: MA | Strategy:

Rating Type: PRIME | Certification: IMO 2000 - EPA TIER-I 2004 - 2007 EPA TIER-I 2000 - 2005

General Performance Data

GEN PWR EKW	PERCENT LOAD	ENGINE POWER BKW	ENGINE BMEP KPA	FUEL BSFC G/BKW-HR	FUEL RATE LPH	INTAKE MFLD TEMP DEG C	INTAKE MFLD P KPA	INTAKE AIR FLOW M3/MIN	EXH MFLD TEMP DEG C	EXH STACK TEMP DEG C	EXH GAS FLOW M3/MIN
1,825.0	100	1,889.2	1,825	197.900	445.7	43.7	192.1	152.3	577.1	464.7	391.0
1,642.5	90	1,699.0	1,641	200.300	405.7	41.9	168.1	140.3	569.1	464.6	360.9
1,460.0	80	1,509.8	1,459	203.300	365.9	40.4	144.2	128.4	561.1	467.2	331.0
1,368.8	75	1,415.5	1,368	205.100	346.1	39.7	132.1	122.3	557.1	469.6	315.9
1,277.5	70	1,321.1	1,276	206.900	325.8	39.0	119.1	115.2	552.8	473.2	298.8
1,095.0	60	1,133.1	1,095	210.900	284.9	37.7	93.2	100.9	543.1	480.3	264.2
912.5	50	945.6	914	215.900	243.4	36.6	67.4	86.6	531.6	487.2	228.9
730.0	40	761.2	735	221.600	201.0	35.9	44.5	74.0	505.1	476.3	193.5
547.5	30	574.5	555	230.900	158.2	35.3	23.7	62.7	463.9	449.1	157.7
456.3	25	480.3	464	238.400	136.5	35.1	14.1	57.4	437.7	429.2	139.7
365.0	20	385.4	372	251.000	115.3	34.9	6.3	53.3	402.9	398.5	123.9
182.5	10	193.9	187	317.200	73.3	34.6	6.0	47.0	315.6	315.8	94.9

Figure A.5: Caterpillar 3516B-1825kW Engine Test Data

B
Task Division Example

Date	Time	Gap (s)	Cluster	Start	Stop
13-5-2023	08:18:55	3	Waiting on Client	00:00:00	13:40:00
13-5-2023	08:19:01	6	Waiting on Client	00:00:00	13:40:00
13-5-2023	08:19:04	3	Waiting on Client	00:00:00	13:40:00
18-5-2023	15:29:32	876	Waiting on Client	14:15:00	15:34:00
19-5-2023	12:46:45	101	Transit to Site	01:20:00	13:50:00
26-5-2023	08:08:38	2	Technical Breakdown	07:58:00	09:46:00
26-5-2023	08:09:51	2	Technical Breakdown	07:58:00	09:46:00
26-5-2023	08:09:57	2	Technical Breakdown	07:58:00	09:46:00
26-5-2023	08:10:07	3	Technical Breakdown	07:58:00	09:46:00
26-5-2023	08:10:19	7	Technical Breakdown	07:58:00	09:46:00
26-5-2023	08:29:39	2	Technical Breakdown	07:58:00	09:46:00
23-6-2023	21:59:08	22	Transit to Site	21:40:00	23:59:59
23-6-2023	22:13:46	137	Transit to Site	21:40:00	23:59:59
5-7-2023	06:42:09	22	WoW	00:00:00	23:59:59
5-7-2023	08:41:48	6579	WoW	00:00:00	23:59:59
5-7-2023	08:52:07	600	WoW	00:00:00	23:59:59
12-7-2023	01:58:17	195	Load-out TP’s	01:35:00	02:45:00
22-7-2023	04:00:16	2	WoW	00:00:00	10:00:00
22-7-2023	14:29:46	2	TP lifting preparations	14:20:00	14:35:00
22-7-2023	14:32:46	2	TP lifting preparations	14:20:00	14:35:00
22-7-2023	14:33:46	2	TP lifting preparations	14:20:00	14:35:00
22-7-2023	14:37:16	2	Lift TP on MP	14:35:00	15:07:00
23-7-2023	01:03:46	2	Setup W2W & Retrieval TWP	00:00:00	01:25:00
23-7-2023	01:05:46	2	Setup W2W & Retrieval TWP	00:00:00	01:25:00
23-7-2023	22:03:16	2	WoW	20:20:00	23:59:59
30-7-2023	01:11:53	2	Technical Breakdown Client Equipment - Bolting	00:45:00	01:30:00
30-7-2023	01:16:53	2	Technical Breakdown Client Equipment - Bolting	00:45:00	01:30:00
2-8-2023	04:54:41	2072	Waiting on client – Berth	00:00:00	06:15:00
15-8-2023	00:16:39	2	Transit to Port	00:00:00	17:30:00
15-8-2023	00:20:09	2	Transit to Port	00:00:00	17:30:00
15-8-2023	00:21:09	2	Transit to Port	00:00:00	17:30:00
20-8-2023	08:20:37	13	WoW	07:10:00	13:00:00
20-8-2023	22:29:46	15	Bolting MP to TP	20:25:00	22:45:00
20-8-2023	22:53:39	50	Setup W2W & Retrieval TWP	22:45:00	23:05:00
25-8-2023	04:52:27	458	Load-out TP’s	04:41:00	05:40:00
5-9-2023	06:24:54	2	Transit under Pilot	05:35:00	08:30:00
5-9-2023	06:25:54	2	Transit under Pilot	05:35:00	08:30:00
5-9-2023	06:31:54	2	Transit under Pilot	05:35:00	08:30:00

Table B.1: Time gaps in original data

C
Extra figures

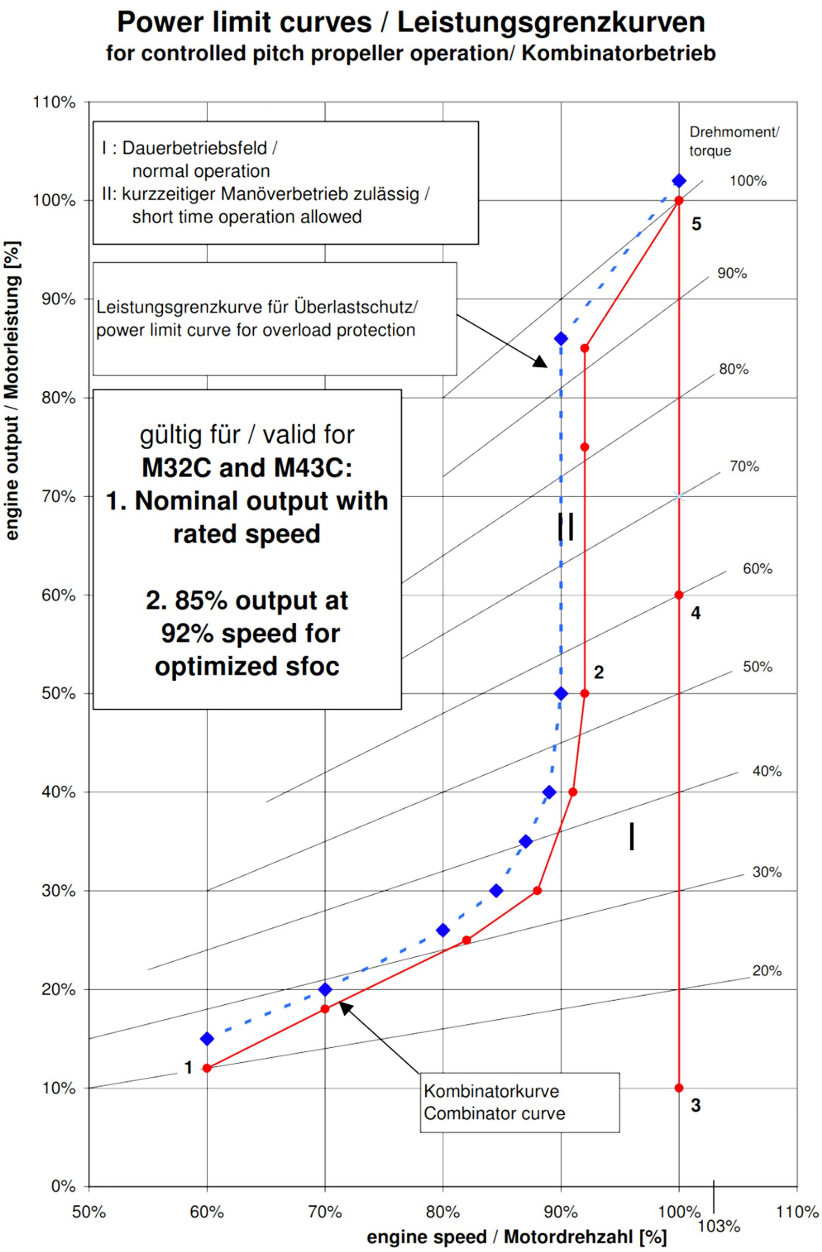


Figure C.1: Load curve main engine

D

Paper

Linking operational decision making to vessel emissions

van Groeningen, T.J., Pruyn, J.F.J., Witvoet, M.
Master Thesis at department marine technology, faculty ME Delft University of Technology

Offshore maritime operations face increasing pressure to reduce greenhouse gas emissions in line with international and regional regulations. This paper presents a case study of Jumbo Maritime, a heavy-lift offshore transport company, examining how data-driven operational decision making can reduce vessel emissions without compromising performance. A mixed methods approach was used. Quantitative analysis of operational data from a complete offshore installation project to identify high-emission activities, qualitative interviews to uncover decision-making drivers and constraints, and multi-criteria decision analysis to evaluate emission reduction strategies. The results show that downtime, particularly waiting for weather in dynamic positioning mode, was responsible for roughly half of the operation's duration and more than one third of total fuel consumption, making it the largest emission source. The transit phases were the next major contributor (≈ 31% to fuel use), followed by the execution of installation tasks (≈ 26%). Qualitative findings reveal that contractual obligations, stakeholder priorities, and operational uncertainties often force suboptimal decisions that increase emissions. Integrating these insights, the MCDA framework identified improving technical breakdown management and optimising weather downtime handling, e.g., anchoring instead of holding the DP position, as the most cost-effective and feasible measures to reduce emissions. These top measures yielded fuel and emission savings with minimal impact on project schedules and were robust under varying priority weightings. In discussion, the paper explores the implications for operational planning in offshore projects, highlighting the need to align contracts and stakeholder incentives with sustainability goals. We conclude with practical recommendations for offshore maritime operators such as improving data collection, incorporating emission reduction clauses in contracts, and adopting structured decision frameworks to achieve GHG reductions. Areas for further research include the extension of the decision-making framework to various types of vessels, the extension of qualitative research to multiple stakeholders, and the exploration of the integration of operational measures with emerging low-carbon technologies.

I. Introduction

Maritime shipping is vital to the global economy, transporting around 90% of world trade by volume [1]. However, it also contributes significantly to greenhouse gas emissions and other pollutants. International shipping has been estimated to account for approximately 2–3% of global CO2 emissions [2]. Recognising this impact, the International Maritime Organisation (IMO) has set stringent goals to decarbonise shipping. The initial IMO Greenhouse Gas Strategy (adopted in 2018) called for at least a 40% reduction in carbon intensity by 2030 and a 50% reduction in total GHG emissions by 2050 (relative to 2008 levels), and in 2023 the IMO strengthened its ambition to achieve net zero emissions by or around 2050 [3]. This evolving regulatory landscape creates both pressure and an opportunity for maritime operators to reduce their carbon footprint while maintaining economic viability. Within the maritime sector, offshore construction vessels present unique operational challenges for emissions reduction. Unlike cargo ships that measure efficiency in tons-miles of cargo moved, offshore vessels often spend long periods on dynamic positioning at sea rather than continuous transit. This operational profile means that standard fuel efficiency measures for transit shipping, such as slow steaming or routing optimisation, may have limited applicability, while decisions about positioning, waiting, and on-site power use become critical. In fact, companies such as Jumbo Maritime have found that many conventional emission reduction strategies are hard to apply in the offshore context. Thus, there is a clear need to identify and implement operational strategies tailored to offshore activities to achieve immediate emissions reductions. Decisions made in planning and executing an offshore project, such as how to handle weather downtime, how fast to transit, whether to shut down or idle engines, and how to schedule maintenance, directly affect fuel consumption and emissions output. Although the adoption of cleaner fuels and new technologies is crucial for long-term decarbonisation, operational improvements can yield substantial short-term benefits with existing assets. Data-driven approaches can help pinpoint inefficiencies and quantify the trade-offs of various actions, turning what might otherwise be intuitive decisions into evidence-based choices. However, a purely technical or quantitative analysis may not capture the full picture, as human influence, contractual terms, and perceptions of risk also affect operational decisions. Therefore, a holistic approach is needed. One that links quantitative performance data with qualitative insights into decision drivers. This study aims to establish how data-driven decision making can contribute to cost-effective reductions in GHG emissions in offshore vessel operations while maintaining operational performance and regulatory compliance. In partnership with Jumbo Maritime, a representative offshore installation project is investigated to explore the connection between operational decisions and emissions results. Key questions addressed include: (1) Which operational activities contribute most to a vessel's emissions? (2) What constraints and considerations, such as stakeholder priorities, contractual requirements, and external factors, drive the current decision-making that leads to those emissions? (3) What alternative strategies could reduce emissions and how do they rank when evaluated using multiple criteria?

A. Scope

This research focusses on optimising the sustainability of offshore maritime operations by examining operational decision making and its environmental impacts. It will primarily address key operational parameters such as the energy distribution on board vessels and the influence of organisational limitations on emissions reduction. The approach emphasises data-driven analysis and decision-making frameworks while aligning with international regulations and targets to reduce greenhouse gases. This study is confined to operational measures on a single vessel and does not explore alternate fuel types, vessel design changes, or other technological innovations. These measures, while impactful, require long-term investments and are outside of immediate operational adjustments that can drive short-term sustainability improvements. By narrowing the focus to actionable operational measures, this research aims to provide Jumbo Maritime with practical strategies to achieve its sustainability objectives without compromising operational efficiency. In addition to that, stakeholder participation was limited to the contractor's internal perspective

B. Operational emissions reduction methods

From scientific literature emission reduction methods were found. Key approaches include improving the energy distribution on board, optimising generator use, or switching to alternative power sources where feasible. Beyond the on-board configuration, several operational measures can yield significant emission savings.

- Slow Steaming: Running engines at reduced speed reduces fuel consumption exponentially, therefore, often trading off longer voyage times. This practice is common in shippinng, but has partial applicability in offshore contexts. [4]
- Voyage or Route Optimization: Employing real-time weather routing or scheduling can minimise fuel wastage, for instance by timing departures to avoid heavy weather or port congestion. [4]
- Human influence: Crew awareness of eco-friendly operations, such as promptly shutting down unneeded equipment or maintaining efficient trim, can have a tangible impact on both fuel usage and overall emissions. [4]

Based on the literature, it can be concluded that successful emission reduction in vessel operations is a multifaceted challenge. The environmental impact is paramount, as strategies must demonstrably reduce greenhouse gas emissions to meet regulatory and societal goals. Secondly, operational performance remains critical. Any emission saving measure should not excessively impede the efficiency or success of the operation. In addition to those organisational factors, Section 3.2.3 frequently determines whether emission reduction practices can be adopted in daily operations. Finally, the financial impact cannot be ignored. Cost-effectiveness and economic feasibility decide whether the measures will be implemented on a scale.

II. Methodology

This research follows a mixed-method case study design, focussing on a single offshore installation project executed by Jumbo Maritime. The project involved a heavy lifting construction vessel (≈ 14,000 GT) connecting the Port of Rotterdam and an offshore wind farm installation site, transporting and installing components over a multi-month campaign. This "reference project" was chosen as a representative scenario for offshore operations, providing real-world data and context for analysis. The study was carried out in close collaboration with Jumbo Maritime, ensuring access to operational data and key personnel. To integrate and evaluate diverse data and insights, a multi-criteria decision analysis (MCDA) was used. MCDA provides a structured, yet flexible framework that incorporates both quantitative and qualitative information, aligning with stakeholder priorities and operational constraints. Alternative methods, such as purely qualitative comparisons or cost-benefit analysis (CBA), were considered but found to be unsuitable. Qualitative approaches lack the systematic clarity needed for transparent comparison, while the CBA emphasis on monetary valuation overlooks critical qualitative criteria such as safety, compliance, and stakeholder satisfaction. The Weighted Sum Model (WSM) was selected for its simplicity, transparency, and ability to reflect trade-offs across criteria through interpretable weighted scores, making it appropriate where criteria can be normalised and weighted. More complex methods, such as the Analytic Hierarchy Process (AHP) or TOPSIS, were deemed unnecessarily elaborated for this context. In general, traditional models either oversimplify offshore operational complexities or rely on unrealistic assumptions. The mixed method approach, supported by the MCDA, bridges these gaps by integrating quantitative analysis with qualitative insights, ensuring a robust and context-sensitive methodology focused on achieving cost-effective emissions reduction without compromising operational performance or compliance.

The overall approach consisted of three phases.

1) A quantitative analysis of vessel operational data and daily progress reports to benchmark emissions across activities. In addition to that, a financial analysis is performed.
2) A qualitative analysis through semi-structured interviews to understand decision-making processes. Three interviews have been conducted with people who have the mandate onshore or on board to make decisions. The interviews were coded using Atlas.ti.
3) Integrative decision analysis using a multi-criteria framework to evaluate potential improvements.

All data collection and analysis steps were carried out at the end of 2024 and the beginning of 2025. The results were synthesised into an operational decision-making framework.

III. Operational Data Analysis of Vessel Emissions

To perform the quantitative analysis, detailed operational records of the reference project were used, including the DP log data of the vessel and the recorded DPRs. The DP system provided, in addition to many more, time-stamped data on generator loads, generator availability, and pitch angle indicators. The DPRs provided a narrative and categorical log of daily activities such as 'transit to site', 'waiting for weather', 'installation work', etc. These data sets were combined to reconstruct a timeline of the entire project, segmented by distinct operational activities.

A. Data Processing

The first step was to categorise and group operational events into meaningful activity groups. Using the DPR descriptions, a hierarchy of activity clusters has been defined, e.g., transit, execution, downtime, port operations). Within these, subactivities were identified, for example, downtime was subdivided into Waiting on Weather (WoW), Technical Delays, Client Induced Waiting and Execution was subdivided into specific installation tasks like lifting, bolting, etc. The complete overview is shown in Figure 1.

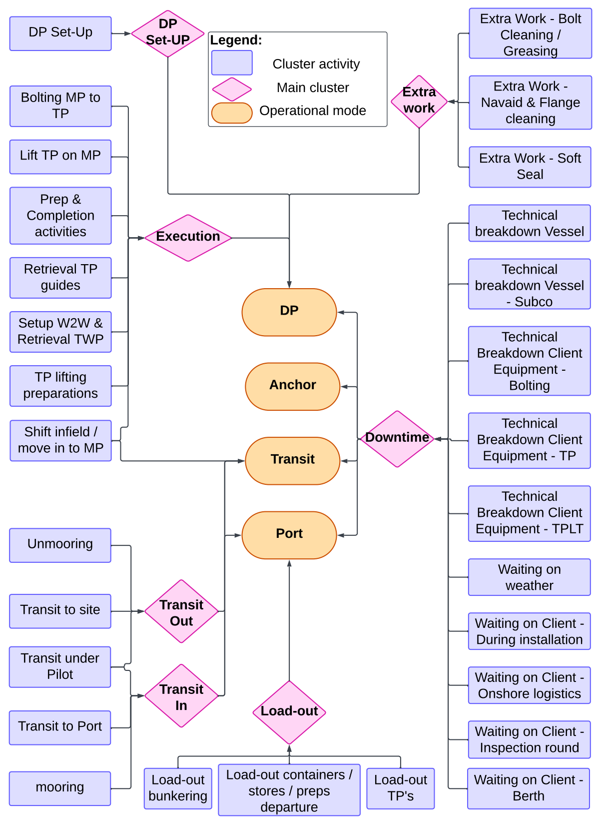


Figure 1. The defined clusters for the DPR's

This categorisation allowed us to quantify how much time and fuel was associated with each category of operation.

B. Fuel Consumption and Emissions Estimation

The second step is to calculate the fuel consumption for each activity using a combination of measured data and engineering models. The propulsion and power configuration consists of two main engines that drive two controllable pitch propellers and two shaft generators, plus two auxiliary diesel generators. Each of these energy sources was characterised to determine how the engine load translates into fuel burn. The manufacturer's fuel curves and the specific fuel consumption values (in g / kWh) of the engines were applied to the power usage data of the DP data, taking into account any minimum load thresholds of load 10% for safety / stability reasons. This was done using the power x pitch curve in bollard pull condition.

For DP mode, port, and anchor, the bollard pull con-

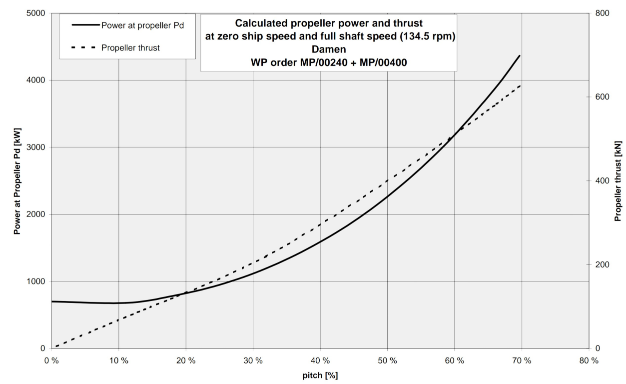


Figure 2. Power vs pitch curve in bollard pull condition

dition is assumed. For transits, on the other hand, the bollard pull condition cannot be applied. Therefore, during transit, fuel use was estimated at service speed using historical data which was cross-verified with the DPR's and the EU Monitoring Reporting Verification (MRV) methodology for consistency. Once fuel consumption was estimated for each activity, it was aggregated to obtain the total fuel used by activity type during the project. Using standard emission conversion factors per tonne of fuel, which are specific to the fuel type used. Fuel consumption was converted into emissions of CO_2 and other pollutants. The vessel burnt bio fuel in the main engines and marine gas oil (MGO) in the auxiliary engines. The appropriate factors for CO_2 (approximately 3.206 tonnes CO_2 per tonne of MGO), NO_x, SO_x, and particulate matter were applied according to IMO and EU guidelines. CO_2 was the primary focus, as the key greenhouse gas. SO_x and CO_2 can be calculated from fuel. NO_x strongly depends on the load / temperature of the engine. A sensitivity analysis was conducted on the time resolution of data, comparing one-second DP log intervals to time intervals of 10, 20, 30 seconds, etc. to ensure the robustness of the fuel/emission estimates against the granularity of the data. In addition, the 1 second time interval was computationally intensive. Therefore, a larger time interval was forced to be used.

C. Results

The final output, conducted in 30-second time intervals, was a breakdown of the total time spent and the total fuel consumed by each category of operational activity throughout the duration of the project. Analysis of the data revealed a clear picture of where most of the time and fuel was spent. The reference project spanned several months, during which the vessel completed 13 round trips between Rotterdam and the offshore site, covering ≈ 5,600 nautical miles in total. The breakdown in time is shown in Figure 4, and the breakdown of fuel is shown in Figure 3

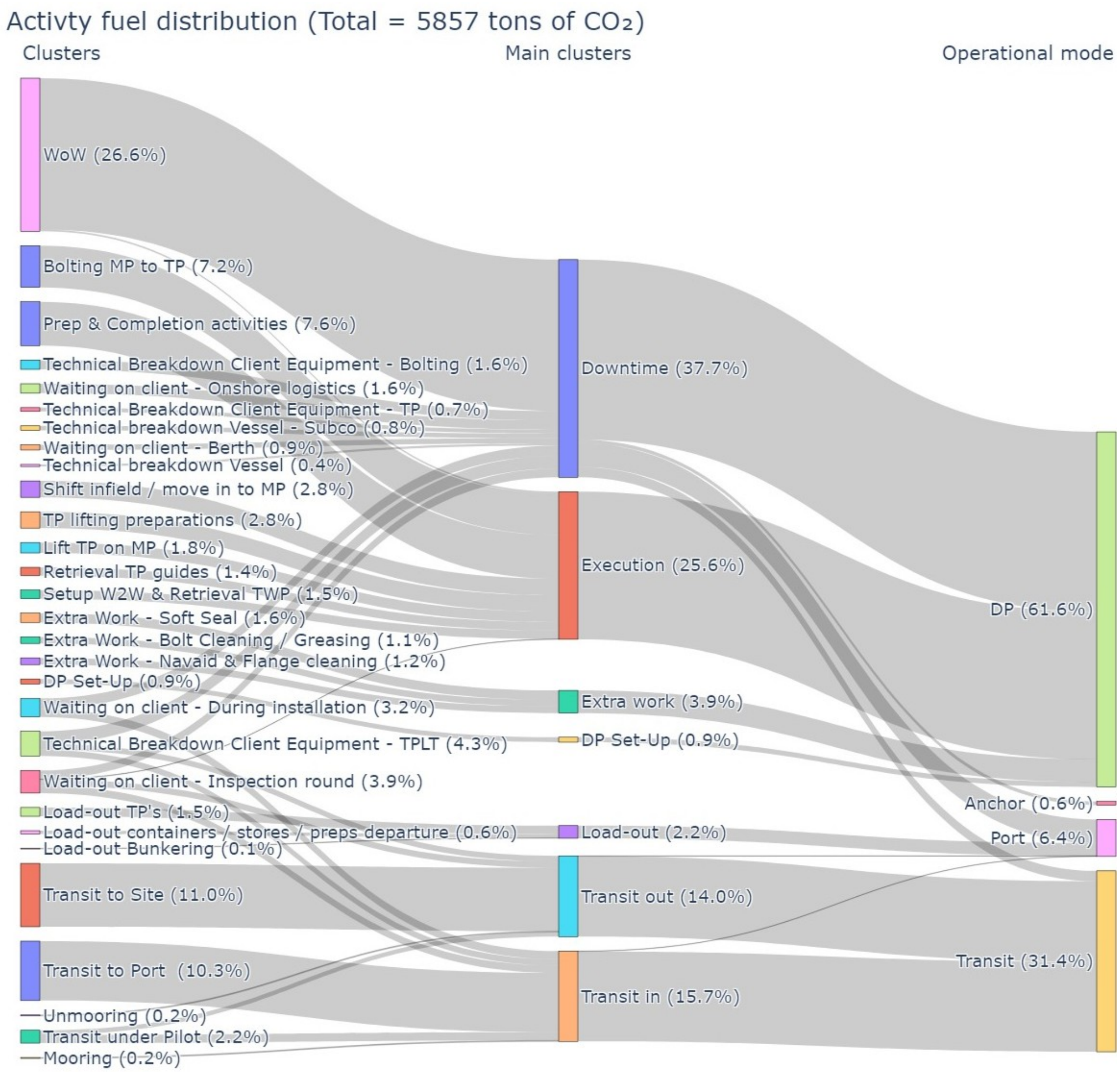


Figure 3. Fuel breakdown

It is immediately clear that downtime was the largest contributor to fuel use, accounting for about 38% of the total fuel consumed. This corresponds to the vessel often holding position in DP mode during waits, burning fuel without progress. By comparison, the transit phases collectively accounted for approximately 31% of the fuel. The actual execution of the installation tasks used about 26% fuel. The remaining fuel use was from port operations and a negligible amount (<1%) during rare anchoring.

In terms of operational time, the dominance of downtime was even more pronounced. 50.5% of the total project time was categorised as downtime. Within this downtime, the largest part was waiting for weather, about 29% of the total time, and more than half of all downtime hours were spent waiting for acceptable sea conditions to work. The remainder was lost due to technical breakdowns and waiting on client decisions or inspections. These unproductive periods forced the vessel to remain ready at the site, usually using DP to hold position. Execution activities comprised only 24% of the time. The port time was 25%, and the transit was relatively short in time, accounting for 13%. The fact that port time was as high as 25% reflects frequent return to port between installation tasks and suggests some inefficiencies or waiting at the port.

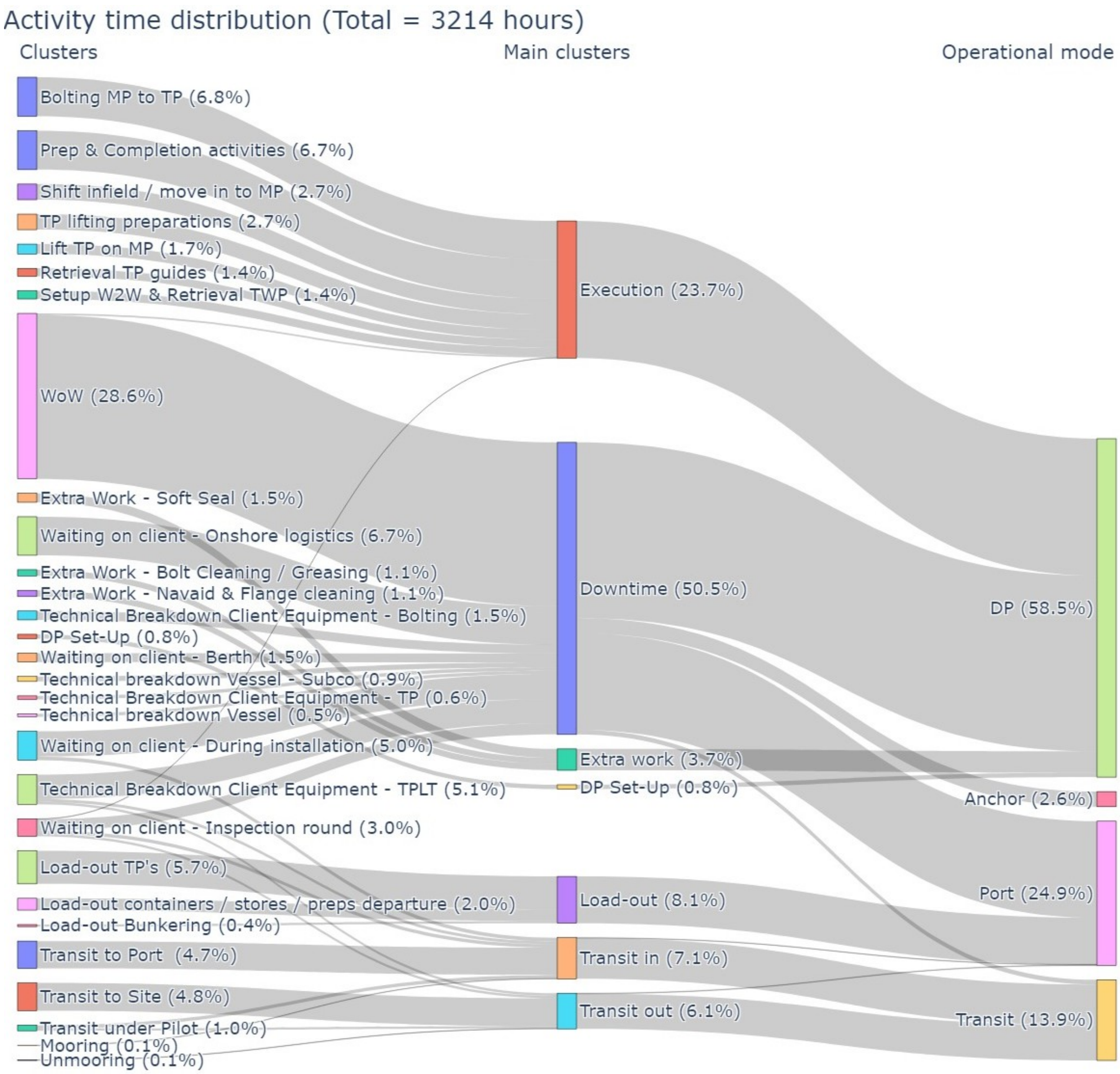


Figure 4. Time breakdown

D. Linking time and fuel

Notably, Downtime on DP had a disproportionate impact on fuel consumption. It was 50% of time and 38% of fuel consumption. In fact, within the downtime fuel, the periods of waiting on weather were the largest part 27% of the total fuel spent waiting for the weather alone. This underscores that improving how weather delays are handled could yield significant fuel and emission savings. However, the transit was 13% in time, but 31% in fuel, reflecting the high engine load during sailing. Execution activities, while 24% of time, used 26% of fuel. These activities often also required DP and the running of heavy machinery, so they are fuel intensive but unavoidable. The fuel used for port operations was low compared to its time share 25%, as in port the vessel could only run the main engines or the necessary equipment minimally. Anchoring was scarcely used in this project; therefore, only 0.6% fuel was used. However, had the anchoring been used more during waits, the downtime fuel share would likely have been lower.

In summary, the quantitative results highlight downtime in DP mode as the number one emission hotspot. For Jumbo's operations, this meant that strategies targeting these areas, such as allowing vessels to anchor or shut down during weather delays, could have a great impact on GHG emissions. For example, if the vessel had been able to anchor during a long storm instead of holding the DP, it could cut the fuel use for that period by more than half. Likewise, a modest reduction in transit speed could save a significant fraction of 31% transit fuel, at the cost of a few extra hours per leg.

IV. Financial analysis

Operating in a commercial environment, the financial aspect cannot be forgotten. In examining the financial effect of operational decisions, four primary cost elements emerge as key to balancing emission reduction efforts with project economics: port calls, emission rights, day rates, and fuel costs. In addition, there are secondary benefits, such as positive reputation effects and reduced maintenance burdens, that further support investment in improved operational practices.

The first cost aspect are port visits. Each port visit triggers fees such as port fees and pilotage. Although these costs are sometimes fixed or predictable, frequent or unscheduled port calls, often arising from unexpected downtime or proactive returns to port, can accumulate quickly. On the one hand, returning to port might reduce the burn of weather-based DP fuel at sea. However, it adds both direct expenses and indirect losses, such as time lost during transit. For heavy-lift projects, these trade-offs must be carefully weighed to ensure that short-term emissions savings from stopping DP operations do not exceed additional port costs. For the reference vessel, the port dues is approximately €10 k per visit. [5]

From 2027 onwards, the EU Emissions Trading System (ETS) will also be applicable for offshore construction vessels, leading to an extra financial aspect. Operators must purchase allowances corresponding to their CO_2 output, creating a direct link between fuel consumption and financial investment. If an operation is more fuel intensive, such as holding position in DP mode during poor weather, its higher emission footprint increases the cost of compliance. In contrast, strategies such as slow steaming or anchoring, which reduce fuel usage, proportionally lower carbon allowance requirements. In this dynamic regulatory environment, emissions management becomes a crucial budgetary consideration. Currently, the price is around €75 / ton CO_2. However, to force companies to reduce their carbon footprint, the total amount of allowances will decrease over time, possibly resulting in an increase in allowance price. Figure 5 shows a price prediction for 2030 onwards, based on the decrease in allowance availability.

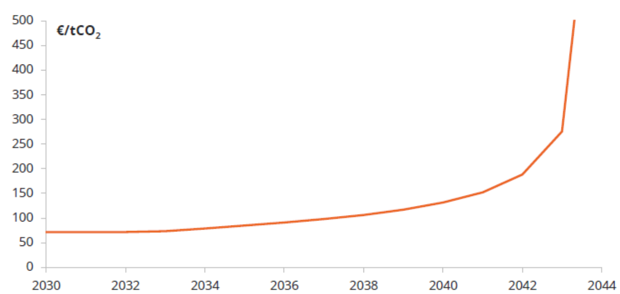


Figure 5. EU ETS allowance price evolution from 2030 onwards [6]

In addition to the allowances, offshore and heavy-lift vessels often operate under project-based contracts that specify a daily charter rate. Extending a project timeline, whether due to weather downtime, mechanical failures, or suboptimal scheduling, directly increases the overall contract cost. Although returning to port for weather avoidance might reduce immediate fuel burn, it can lengthen the total project duration, incurring additional charter days. Clients give bonuses if contractors complete a project within a given time. Therefore, both the contractor and the client typically share an interest in minimising day-rate exposure, so finding the optimal balance between cost-saving measures and staying on schedule becomes a strategic decision.

Lastly, during the reference project, there was a total of 2100 tons of fuel consumed, at € 600 / ton, fuel expenditure remains a significant operational cost. Decisions about transit speed, waiting strategies, and engine load management can substantially affect a vessel's daily consumption. Although small efficiency gains can yield significant financial savings across multi-month campaigns, these need to be evaluated alongside potential knock-on effects, such as extending trip length by slow steaming or risking missing installation windows.

A. Secondary benefits

Beyond these direct costs that can result in savings, improved operational measures can lead to valuable side effects. A consistent track record of proactive emissions reduction can improve the standing of a company with environmentally conscious clients and regulatory bodies, potentially leading to more favourable contract terms. [7] [8] In addition, lowering the usage of the engine reduces wear and tear, reducing maintenance frequency or the risk of major mechanical downtime. Finally, effective emission-reducing operations can help avoid severe weather-related damage, contributing to long-term cost avoidance.

In conclusion, the financial evaluation underscores that cost savings and emission reduction are not mutually exclusive. By calculating the trade-offs between immediate expenses and potential longer-term benefits, operators can position themselves advantageously in a market increasingly shaped by environmental performance requirements.

V. Qualitative analysis

The quantitative analysis identified possible environmental and financial areas of improvement. But why are certain operational decisions made and what factors influenced these choices? To that end, a qualitative analysis consisting of semi-structured interviews with personnel involved in the project was carried out.

A. Methodology

To provide information from different perspectives on the operation, purpose sampling was used to select interviewees. In this way, the research captured a range of perspectives on decision-making dynamics at both the on-the-ground and the management levels. Each interview was conducted in person, and followed a guided protocol of open questions. Key topics included planning and decisions made for transits and waiting periods, reactions to schedule changes or weather events, how emissions considerations were weighed against other priorities, the influence of contracts on operational flexibility, and ideas or past experiences with efficiency improvements. All interviews were recorded with consent and transcribed verbatim for analysis. A thematic coding approach was applied using qualitative analysis software (ATLAS.ti). First, open coding was performed, reading through transcripts line-by-line and tagging any segment related to decision rationales, constraints, or consequences. Then axial coding was used to group these into broader themes and identify relationships. For example, initial codes on client requirements and contract terms were grouped under a theme of 'Contracts', and codes on delayed decision making or communication gaps were grouped under 'Organisational decision process.' Through an iterative process, this converged on a set of key themes that capture the main human / organisational factors that impact operational emissions decisions. The code tree is shown in figure 6.

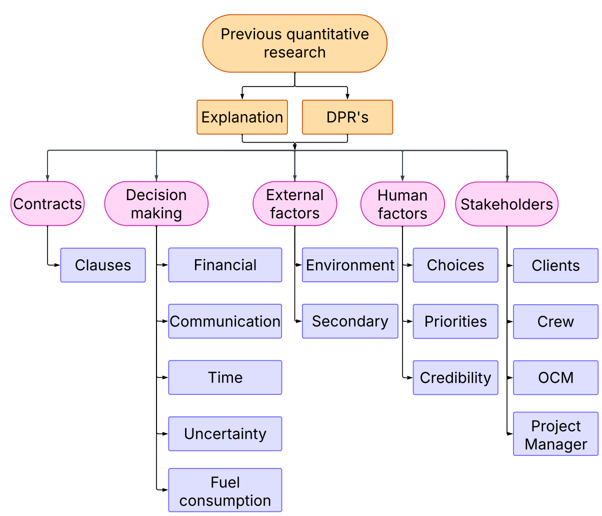


Figure 6. Code tree

These themes were validated by checking against the raw data, ensuring that each theme was supported by multiple quotations, and by seeking feedback from the interviewees after the analysis to confirm our interpretations. The qualitative findings thus provide context for the quantitative results, explaining why high-emission scenarios occurred. For example, if the data showed many hours spent waiting on DP, the interviews might reveal that this was due to strict contract clauses or risk aversion from shore management. By linking cause and effect in this manner, the study could identify not just technical fixes but also organisational or procedural changes needed to reduce emissions.

B. Results

Interviews with project personnel shed light on the causes of downtime and why certain operational choices were made despite fuel penalties. Several recurrent themes emerged, closely aligned with the coded categories. Qualitative evidence highlights that organisational relational factors are critical to enabling or hindering adaptive decisions that reduce emissions.

Table 1 summarises the findings of the qualitative analysis. Qualitative analysis has revealed critical categories that impact operational efficiency, namely stakeholder interactions contracts, decision-making processes, external factors, and organisational factors.

Theme	Key Insights	Impact on Emissions	Recommended Actions
Stakeholders	Misalignment between client(s) and contractor caused delays in decision-making, leading to excessive DP (Dynamic Positioning) usage. The lack of immediate decision authority on site resulted in conservative operational choices.	Increased fuel use and emissions due to prolonged DP.	Improve stakeholder communication and delegate more decision-making authority to on-site personnel.
Contracts	Contracts mandated vessel readiness at all times, even during prolonged poor weather conditions, restricting anchoring or port waiting despite obvious inefficiencies.	Forced use of DP during weather downtime causing high emissions.	Include flexible clauses allowing anchoring or port waiting during long weather delays.
Decision making	Strong focus on maintaining project timelines ("time is money" mentality) encouraged continuous vessel readiness, minimising downtime handling efficiency strategies.	Increased fuel consumption due to constant readiness mode.	Balance schedule adherence with operational flexibility and incentivise efficiency rather than just adherence to schedules.
External factors	Unpredictable weather and technical breakdowns induced caution and risk aversion, preferring constant DP readiness to minimise operational risk.	Higher fuel usage as a precautionary measure.	Improve real-time forecasting and increase availability of critical spare parts on board to reduce uncertainty.
Organisational factors	Lack of structured incentives or feedback mechanisms discouraged proactive fuel-saving behaviours, while psychological factors (sense of readiness) maintained high DP usage despite inefficiency.	Persistent high fuel consumption from unnecessary DP use.	Introduce structured feedback systems, incentivise fuel-saving behaviour, and encourage psychological acceptance of alternative downtime management methods.

Table 1. Summary of Qualitative Analysis Results

In summary, qualitative insights highlight a misalignment between short-term operational directives and long-term sustainability goals. The interviewees identified clear opportunities to reduce fuel consumption, but contractual obligations, fear of scheduling slippage, and hierarchical decision structures limited their ability to act on those opportunities in real time. Crucially, these findings suggest that technical solutions alone will not succeed unless the organisational and contractual context is addressed. To enable lower-emission decisions, contracts should incorporate flexibility and reward fuel savings, and on-board teams need the authority and tools to make adaptive decisions quickly. These themes directly informed our development of improvement strategies and the decision framework.

VI. MCDA

The next step is to find a proper solution. To determine which emission reduction strategies best balance environmental, operational, and financial goals, a multicriteria decision analysis (MCDA) is performed. The MCDA is tested using four criteria, each weighted to reflect the project's priorities.

1) Environmental Impact: Potential CO_2 and fuel reduction (25%)
2) Operational Performance: Effects on schedule, risk of delays, or safety (35%)
3) Human & Organizational Feasibility: Crew acceptance, contractual constraints, stakeholder alignment (25%)
4) Financial Impact: Cost savings in fuel, day rates, and carbon allowances (15%)

As a result of the previous analyses, three possible solutions were used as input for the MCDA. These three key alternatives are: better downtime handling by anchoring or heading to port, improved breakdown management, and slow steaming.

A. Downtime handling

Downtime is inevitable during an offshore project. The question is how do you deal with it. From the quantitative and qualitative analysis, dropping the anchor or heading to port was identified as a possible solution to handle downtime in a more environmentally friendly way.

1. DP vs anchor

First, compare DP vs anchoring in a nearby location. Figure 7, shows from which distance and time span it becomes financially and environmentally beneficial. Several things must be taken into account. The first drop of the anchor for a very short time will not be accepted by the crew. This is due to the noise that comes with dropping and picking up the anchor. Looking at the figure shows strong fuel/emission savings by replacing the DP with anchoring when major weather delays are likely. In addition to that, operational performance is generally unaffected if the forecasts are accurate.

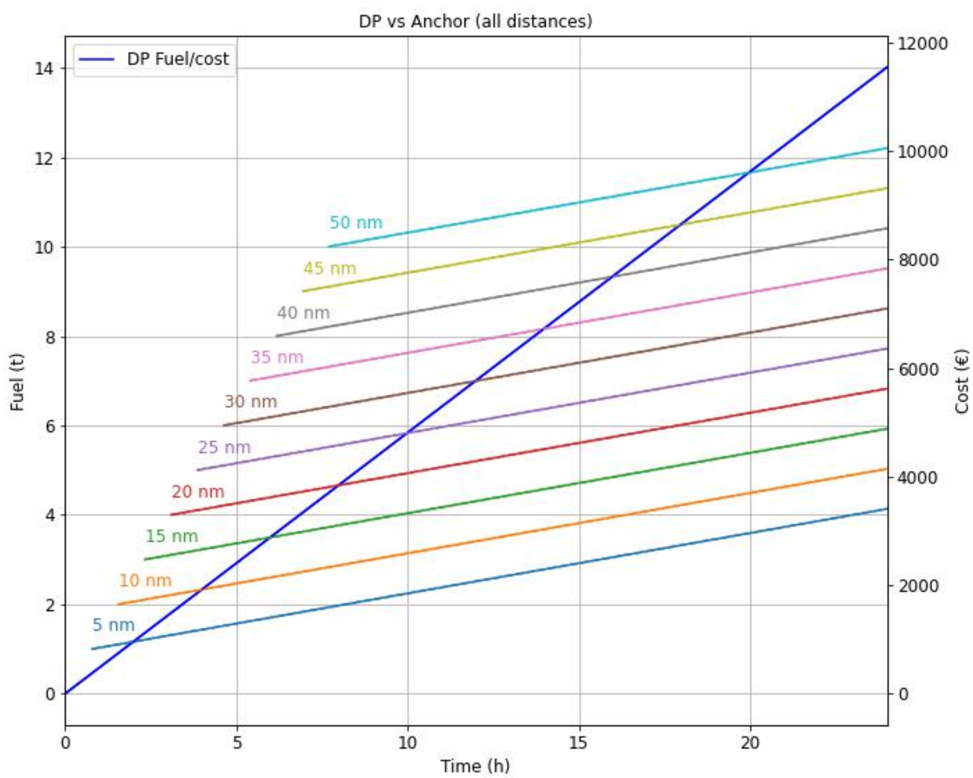


Figure 7. Staying on DP versus going on anchor

However, there are some downsides. While working on offshore projects, the crew is working 12-hour shifts. That is, at each point during the day, one shift is asleep/resting. In addition, it requires contract clauses that allow the vessel to leave the site.

2. DP vs port

The second option is to head to port. The port is similar in most aspects to the anchoring. However, transit distances are longer in most cases and financially there are port dues that come into play. On the other hand, heading into port can also be used to load extra cargo, bunker, or get additional provisions, leading to less or a shorter port call in the future.

Together, it can be seen in Figure 8 that the port dues have a significant impact on financial feasibility. The port is therefore only considered viable if the port call is made useful by adding an additional task.

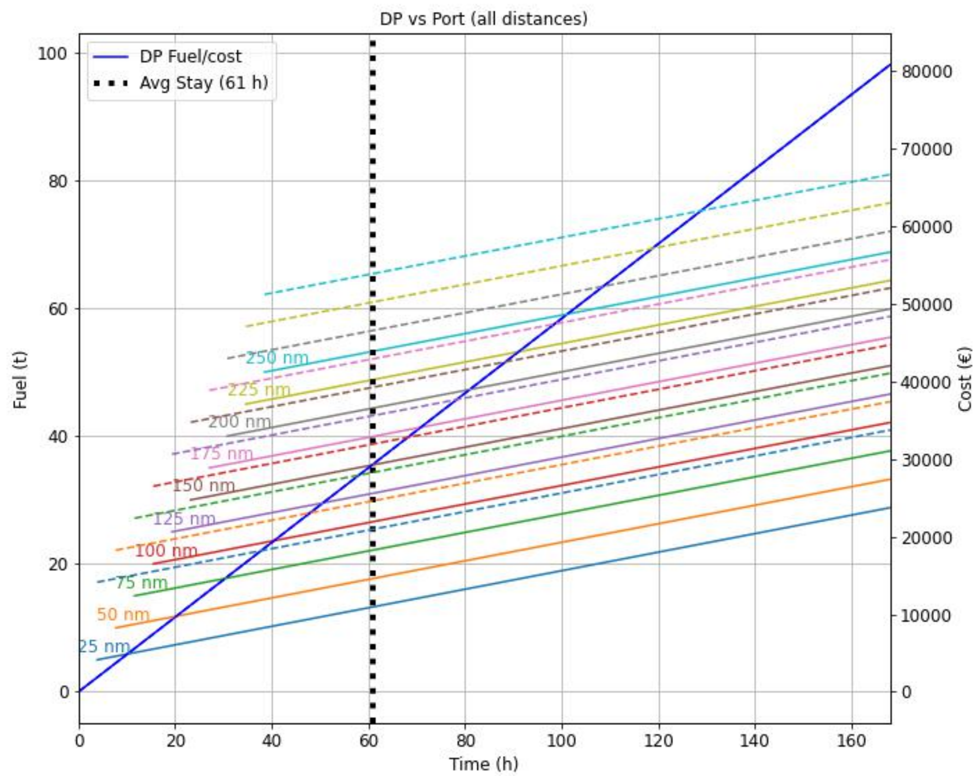


Figure 8. Staying on DP versus heading into Port

B. Improved breakdown management

Besides waiting on weather, technical breakdowns were considered an area of possible improvement. Based on the quantitative analysis, technical breakdowns account for 15% of the total fuel consumption and the time lost. In total, this led to 277 hours of lost time, equal to almost 12 days. Technical breakdowns can be prevented but also overcome as quickly as possible. Firstly, ensure that critical spare parts and repair capabilities are available on board so that repairs can be performed at sea without returning to port. In the DPRs, it was mentioned that, although a spare part was on board, it could not be installed offshore, forcing a port call for repairs. This indicates a clear opportunity for improvement. Minimising downtime from a breakdown improves the reliability of the project schedule and the utilisation of the vessel. There are minor operational hurdles, complex repairs might still require calm conditions or specialised equipment. However, in general with enough spares on board the vessel, most of the repair can be done at sea. Another factor to consider is the available space onboard for these spares. The organisational aspects also present only minor challenges. Mostly within planning and design. Engineering must make room for all extra spares on board the vessel. In addition, the company must invest in carrying spares, but these changes align with the crew and the contractor's interest in maintaining uptime. Since such decisions are largely within the contractor's own procedures (which do not require client approval), the organisational feasibility is considered high. Financially, this option is very attractive. Avoiding heading back to port saves tons of fuel, port fees, and, more importantly, avoids losing a day or more of installation time. Given the vessel's day rate of €150k, preventing even one day of breakdown delay can save on the order of hundreds of thousands of euros. The cost of stocking spare parts and tooling is negligible by comparison.

C. Slow Steaming

The third option is slow steaming. In normal transit mode, the vessel typically uses both main engines. In a slow-steaming mode, one main engine is turned off, so only a single engine was used for propulsion. This engine is operating at a higher load percentage, increasing engine efficiency. In normal transit, the port and starboard generators averaged an output of $\approx$ 300 kW. In slow steam mode, one generator carried $\approx$ 550 kW. Concentrating power on a single engine results in a higher percentage of load and therefore a lower specific fuel consumption. However, practical results on fuel reduction for the slow steaming are inconclusive because of data limitations. The vessel monitoring system did not record engine RPM, making it impossible to accurately calculate fuel consumption with the given data. The analysis had to rely on a Bollard-pull power curve to estimate the main engine output from the propeller pitch, which is not applicable during transits. In theory, running one engine at higher efficiency can yield net fuel savings compared to running two engines at lower efficiency. This is consistent with the literature on slow steaming [9], which reports savings of 20 to 30% fuel at reduced speeds under favourable conditions. In conclusion, from an environmental perspective, slow steaming is conceptually a positive measure. From an operational standpoint, slow steaming introduces major hurdles. The primary issue is the longer transit time. Slower transit between the port and the installation site can conflict with tight project schedules and weather windows. It can be done technically, but it requires careful planning of the project timeline. The organisational dimension further complicates the slow steaming. Current stakeholder incentives are misaligned with this practice. Contracts typically prioritise on-time project completion and often penalise delays caused by client not having quay space available, for instance. In addition, the fuel costs, the day rate of the vessel, are passed on to the client. This means that the contractor has no financial incentive to slow down and the client has no incentive to allow slower transits as they would save fuel money but pay much more in extra day rates.

To summarise, all scores have been implemented in Table 2. This shows that technical breakdowns come out as the best possible solution.

Table 2. MCDA scoring table

Decision alternative	Environmental impact	Operational performance	Human & organisational factors	Financial impact	Weighted & score
Anchoring	4	4	2	3	3.35
Port	3	3	3	1	2.70
Technical breakdowns	5	4	4	5	4.40
Slow steaming	4	3	2	2	2.85

D. Criteria sensitivity

The first weight set based on an implication of the results found in the qualitative analysis. However, these weights can vary depending on the company or goals. To test the impact of the weight change, a sensitivity study has been performed. Table 3 shows the different scenarios tested, each focussing on one of the four criteria.

For each scenario, Table 4 shows the recalculated overall score for each option. The ranking of alternatives remains the same in all these cases.

Table 3. Weighting Scenarios for sensitivity analysis

Scenario	Environmental (%)	Operational (%)	Human & Org. (%)	Financial (%)
Base Case	25	35	25	15
Scenario A	40	20	15	25
Scenario B	20	50	20	10
Scenario C	25	25	25	25

Table 4. MCDA scores under different weighting scenarios

Scenario	Port call	Anchoring	Tech. Breakdown	Slow Steaming	Top Option
Base Case	3.35	2.70	**4.40**	2.85	Breakdown
Scenario A	3.45	2.50	**4.65**	3.00	Breakdown
Scenario B	3.50	2.80	**4.30**	2.90	Breakdown
Scenario C	3.25	2.50	**4.50**	2.75	Breakdown

In conclusion, the management of technical breakdowns consistently scores the highest, followed by anchoring, slow steaming, and finally port call. The magnitude of the differences changes with the weights. This indicates that the MCDA recommendation is not very sensitive to reasonable changes in the weighting of the criteria. The selection of technical breakdown management as the primary measure is robust across a range of stakeholder priority profiles.

VII. Discussion

Our quantitative analysis shows that waiting for the weather in DP mode dominates both the total time (50%) and fuel consumption (38%). The interviews clarify that contractual obligations, limited real-time decision authority, and risk aversion push the vessel to remain on DP when anchoring would be more efficient. In addition, schedule pressure discourages slower transits despite their potential fuel savings. Thus, operational inefficiencies are largely a result of organisational and contractual factors rather than technological constraints. From a broader perspective, aligning stakeholders with emission goals is crucial. Contracts must enable flexible responses, such as anchoring or returning to port. Data-driven insights, such as quantifying tons of fuel burnt per weather delay, can convince both operators and clients to adopt new norms. With the incoming carbon regulations, these operational improvements translate into tangible cost savings. Ultimately, combining real-time fuel monitoring with updated contract clauses can significantly reduce emissions and maintain project performance.

A. Recommendations

Based on the research, there are some recommendations for the company and future researchers. First of all, improve vessel data collection. Standardise and improve fuel and engine performance monitoring to support informed decision making, identify inefficiencies, and allow accurate modelling and compliance. Secondly, integrate sustainability into contracts and planning. Include emission reduction clauses in client contracts and project plans to align incentives and empower crews to make environmentally driven operational choices. Third, implement structured decision-making tools. Use formal frameworks that weigh multiple criteria to make transparent, balanced operational decisions and improve stakeholder communication. Lastly, prepare for regulatory changes. Anticipate and adapt to future emissions regulations by investing early in greener operations and technologies to future proof the business.

In summary, to effectively reduce emissions, the offshore maritime sector must improve data quality, embed sustainability in operations and contracts, adopt decision support tools, and prepare proactively for regulatory changes. This approach will lead to cleaner, more cost-efficient, and sustainable operations.

B. Limitations and future work

This single case study, while illustrative, may not represent all offshore scenarios. More comparative studies with, for example, other vessel types or different contractual setups could confirm these patterns. In addition, while estimating the fuel consumption, several assumptions had to be made. This affects the accuracy and reliability of the results. The qualitative analysis has been performed within one company on the contractors side, to provide the full picture, more stakeholders should be interviewed. Furthermore, while the Multi-Criteria Decision Analysis (MCDA) proved robust here, varying stakeholder priorities or strict safety requirements could shift the final ranking of measures. Future research might explore real-time decision support algorithms that integrate weather forecasting, fuel data, and dynamic scheduling to continuously optimise sea emissions.

VIII. Conclusion

In conclusion,Data-driven decision making can significantly enable and enhance the reduction of GHG emissions in offshore operations. Identifying where and how emissions can be cut with minimal downside, and providing a factual basis for stakeholders to make informed choices. In this study, the data-driven approach pinpointed that a large portion of emissions come from operational inefficiencies such as excessive DP usage and a lot of downtime. By quantifying these effects, the data highlight specific opportunities that might otherwise remain intuition or guesswork. This evidence is crucial to convincing decision makers to change standard practices. Furthermore, incorporating cost data and carbon pricing into the analysis ensures that the recommended emission reductions are cost-effective. The results showed that many emission-saving measures also save fuel costs and avoid carbon allowance expenses, meaning they can reduce operational costs or at least not significantly increase them, which is a key factor in industry adoption. Even for measures that have some cost, the data-driven evaluation can determine if the cost is justified by the emission benefit and if it fits within the performance requirements. Maintaining performance and regulatory compliance was a guiding constraint throughout the decision-making process. The highest ranked solution was better managing technical breakdowns. Reduce downtime, reduce emissions, and anchoring instead of DP during weather waiting can be done without affecting project timelines if planned well. Using a data-driven multicriteria approach, the decision-making process ensures that any adopted emission reduction measure has been tested for its impact on other performance metrics. Furthermore, the inclusion of regulatory factors such as EU ETS in the analysis means that the decisions are made with compliance in mind. Companies can meet or exceed current regulations proactively rather than reactively. In essence, data-driven decision making contributes by offering a balanced optimisation. Identifies strategies at the intersection of low emissions, low cost, and acceptable operational impact. It turns emission reduction from a vague goal into a series of concrete, optimised actions supported by evidence. In conclusion, data-driven decision making, exemplified by the integration of operational data analytics and structured decision frameworks, can guide offshore maritime operations towards significantly lower GHG emissions in a cost-effective manner. It does so by highlighting inefficiencies, evaluating the trade-offs of different actions with real data, and ensuring that chosen measures align with both economic and regulatory demands. When data insights are coupled with collaborative implementation, the result is a powerful approach in which emissions are cut without sacrificing operational performance. This thesis has demonstrated that with accurate data and the right decision tools, the offshore industry can make informed decisions to decarbonise operations, achieve compliance with environmental regulations, and contribute to broader climate goals while maintaining efficiency and profitability.

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