Sailing Into Uncertainty

Business Model Evaluation for Wind-Assisted Ship Propulsion

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ABSTRACT

This thesis identifies and evaluates business model alternatives for Oceanbird's Wing 560 rigid sail, a wind-assisted ship propulsion technology approaching broader commercialisation. The shipping industry's complex ownership structures create split-incentive problems that complicate investment in fuel-saving technologies, making the choice of business model a strategic decision. Furthermore, the potential customers operate in an uncertain investment environment, where the product itself introduces even more uncertainties.

Four business model alternatives: CAPEX, Leasing, Guaranteed savings, and Shared savings, are identified, partly through a literature review of energy efficiency contracting in the housing sector, and evaluated using Monte Carlo simulation. The model captures uncertainty in fuel prices, product performance, CO_2 legislation, and critical failure events, producing distributions of the net present value of the investment, for all stakeholders.

The results show that no single business model is universally optimal. On the Voyage charter market, CAPEX is the best-performing model. On the Time and Bareboat charter markets, the identified EPC-based models consistently outperform CAPEX and Leasing by resolving the split-incentive problem, with Guaranteed savings performing better than Shared savings. the weighted average cost of capital and product performance are identified as the most impactful parameters on overall viability, where conclusions are especially sensitive to changes in weighted average cost of capital. The overall robustness is however, deemed sufficient for the scope of the thesis.

The best performing business model is not entirely explained by the results of the Monte Carlo simulation model. It is also a strategic decision shaped by Oceanbird's strategy: their willingness to undertake the engineering development required to address green water limitations on the Voyage charter market, and their capacity to develop the performance monitoring infrastructure necessary to implement EPC-based models such as Guaranteed savings. Furthermore, the discussion also highlights the model's limitations and exposure to epistemic risk, which provide grounds for future research.

PREFACE

This thesis marks the end of our education in Industrial Engineering and Management at LTH and has been a truly educational and exciting project. The study was carried out in collaboration with Oceanbird during the spring of 2026 and provided a valuable opportunity to apply theoretical knowledge gained at university to a practical and real-world problem within an exciting industry.

We would like to express our deepest gratitude to the employees at Oceanbird, who have met our questions with enthusiasm and generosity. We especially wish to thank our supervisors at Oceanbird, Per Ståhl and Magnus MackAldener, who both challenged and supported us throughout the project and invited us into many meaningful discussions. The time you devoted despite your obviously busy schedules has been both greatly appreciated and an important learning experience for us.

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1 INTRODUCTION

The following chapter presents the purpose and research questions that this thesis aims to answer. This is prefaced by a background to help the reader understand why the purpose is relevant and the reason behind the chosen methodology.

1.1 Background

Maritime transport forms the backbone of global trade, accounting for approximately 80% of trade volume and 70% of trade value (UNCTAD 2025b; World Bank 2025). Fuel expenses in shipping range around 50-60% of the operating expense, making fuel saving financially significant for the parties involved, and desirable not just from an environmental perspective (Ghosh & De 2024). Currently, the industry contributes around 1.7% of global CO_2 emissions and faces increasing regulatory pressure to decarbonize and reduce its reliance on fossil fuels (Mao et al. 2025). In response, wind-assisted ship propulsion (WASP) has gained traction as a promising solution to reduce emissions in the shipping sector. Several companies are currently trying to deploy commercially viable WASP technologies, including Oceanbird, the case company of this thesis. As they have reached the end of development of their rigid sail, they seek to understand what type of business model they should use to sell their product in the long term. However, both the characteristics of the maritime industry and the uncertainties associated with the new technology make this question complex.

The economic lifetime of commercial marine vessels is between 20 and 30 years, which exposes the industry to both financial and operational long-term risks. Additionally, the shipping industry has an ownership structure that generally slows investments into efficient fuel usage. This is due to the fact that the owner of a vessel is not necessarily the one operating it. It is instead chartered out to another party, a charterer, who typically pays for its own fuel. This means that in many cases the shipowner, the party who makes the decision and funds the investment, is not the one who benefits from the subsequent savings, creating a split incentive between shipowners and charterers (Rehmatulla & Smith 2020). Understanding the adoption of WASP likely means accounting for the financial uncertainty and addressing the split incentives contractually.

1.2 The Case Company

There are several companies trying to develop and sell rigid sails, such as the case company of this thesis. The company is AlfaWall Oceanbird AB, founded in 2021 as a joint venture between the companies Alfa Laval and Wallenius (Oceanbird n.d.). Alfa

Laval is a Swedish company that is a global provider of products within heat transfer, separation and fluid handling. Through their marine division, they also supply the shipping industry with solutions for a transition towards clean energy, such as solutions for alternative fuels and software reporting tools for fuel management (Alfa laval n.d.). Wallenius is a Swedish ship owner who designs, builds, and manages shipping vessels, with a presence in the Ro-Ro market (Ro-Ro meaning roll on - roll off, a type of shipping vessels that transport fully assembled vehicles). Wallenius also position themselves as a company with high ambitions to deliver truly sustainable shipping. (Wallenius marine n.d.).

Oceanbird was sprouted from the idea of wind propulsion at Wallenius. The idea was further developed through research at KTH, which laid the foundation for the joint venture with Alfa Laval. Since 2021, Oceanbird has further developed the concept, which in 2025 resulted in the first land-based prototype of their sail Wing 560 being raised at their test site in Landskrona. In the coming years, the commercialization of this product is regarded by the company as an important step to support the long-term vision to eventually offer entire vessels powered mainly by wind. Both the existing product and the concept they envision for the future are shown in Figure 1.

(a)

(b)

Figure 1. *The product in its current state (a) and the company's vision for how it could be used in the future (b) (Oceanbird n.d.)*

The sail, or as Oceanbird themselves refer to it, the wing, is 40 m tall and 14 m wide.

Along with the foundation, the whole wing stretches 46 m from top to bottom. The weight can vary somewhat between configurations, but is approximately 200 tonnes. The wing can be folded in half to reduce the surface area exposed to the wind and can also be tilted down when not in use. This allows the wing to be safely stowed on deck when necessary, such as in rough weather conditions.

The product has been designed towards Ro-Ro ships, and to be the main propulsion system of the wind-driven vessels that the company is envisioning to deliver in the future. It can still be retrofitted on older boats, but that requires a more complex and tailor-made installation process. For example, many boats will need to strengthen their hull. This means that the installation cost is a substantial part of the investment when the product is retrofitted, but essentially zero when the product is fitted on a newly built ship already designed with the product in mind (Oceanbird n.d.).

The wing has several known design limitations that will be of importance in the analysis. For one, it was not designed to withstand large volumes of water washing over the deck, a phenomenon commonly referred to as *green water*. This limitation is a consequence of the product being primarily developed for Ro-Ro vessels, which typically feature high freeboards and therefore rarely experience green water conditions. This implies that selling the product to other vessels would require added engineering challenges and development.

Furthermore, the product has limited capabilities for accurately measuring its own day-to-day performance. These limitations have direct implications for which business models are feasible, particularly those relying on performance-based contracting, which require accurate measurement of fuel savings over a certain period of time.

Currently, Oceanbird is considering selling the product as either an upfront payment (CAPEX) or leasing the product for a recurring fee (Leasing). These business models importantly lack a way of contractually solving the split-incentive problem between shipowner and charterer.

1.3 Problem Formulation

Until now, Oceanbird has mainly focused on product development, but as the product gets ready for shipping, the company wants to explore what type of business model is suitable. They want to better understand the best way to package the product into an offer that helps them reach scalable adoption and address the split-incentive problem. Should they opt to sell the product at a one-time fee, offer a leasing agreement, or another model entirely?

The potential customers operate in a complex and uncertain investment environment, where the product itself introduces even more uncertainties and contractual challenges.

This context leads to the problem formulation on which the thesis is based: The company offers an investment in a product whose value is subject to uncertainties such as wind conditions, fuel prices, maintenance requirements, and legislation. When evaluating whether to invest in the product, the customer must assess expected cost, expected savings and associated uncertainties. An investment will only be made if the customer perceives the expected outcome to be sufficiently profitable given these uncertainties and split incentives. What costs, savings and uncertainties the customer faces in this decision-making process vary based on the business model through which the product is offered.

1.4 Purpose and Research Questions

The purpose of this thesis is to identify and evaluate business model alternatives, aiming to find a suitable candidate that supports commercial viability and large-scale product adoption.

The thesis aims to fulfill this purpose through answering the following research questions:

- R1 What business models, derived from similar split-incentive contexts, are applicable to the company's commercialization challenge?
- R2 What is the viability of the proposed business model alternatives when evaluated using quantitative modeling that captures the investment decision faced by the stakeholders in terms of expected costs, savings, and uncertainties?
- R3 Which business model performs best in terms of expected customer value and risk exposure, based on the quantitative modelling?

1.5 Thesis Outline

First, in Section 2, a background to the maritime shipping industry is presented. This section aims to familiarize the reader with important industry characteristics that have influenced the methodology, analysis, and conclusions of the study. It also provides a more thorough description of the current state of WASP technologies, further familiarising the reader with a subject that cannot be assumed to constitute common knowledge.

This is followed by the methodology, presented in Section 3, and the theory, presented in Section 4. The theory section provides the theoretical foundation of the thesis and introduces several concepts and methods that are later implemented in the model. With this foundation established, the reader is prepared to understand the construction of the model, which is described in detail in Section 5, Model description. This section introduces many of the parameters and design choices that are later discussed extensively in the analysis.

In Section 6, the analysis, the results generated by the simulations performed with the model are presented. These results are then evaluated through robustness and sensitivity analyses. These quantitive results are then complemented by a broader discussion, tying back to many of the subjects in the introduction and background.

Finally, the conclusions drawn from the analysis are used to answer the stated research questions in Section 7. Then the thesis concludes with suggestions for future research in Section 8.

2 THE MARITIME SHIPPING INDUSTRY

This section provides a brief background to the maritime shipping industry. Since the product is highly sector-specific, it is helpful to describe the customers and market conditions in greater detail. Two important characteristics that will be of central importance throughout the thesis, chartering structures and vessel types, are presented in Section 2.1 and Section 2.2, respectively. This is followed by a short overview of the decarbonization process within the shipping industry in section 2.3 and an introduction to the current state of WASP technologies in Section 2.4.

The maritime shipping industry is a large global industry that revolves around moving cargo over great distances. Since the industry includes everything from small national ferries to the largest vessels that thread the world's oceans, there are notable differences in customer characteristics. For this thesis, the two main characteristics important for Oceanbird are: Chartering structures and Vessel types. These will be examined further below. Additionally, the prospect of emission regulation and the current state of WASP add context and background to the problem.

2.1 Chartering Structures

The ownership structure for a vessel depends on which charter agreement has been put in place, common structures being: Voyage charter, Time charter, and Bareboat charter (Rehmatulla & Smith 2020). Voyage charters last only one trip, during which the charterer only owns the cargo, not the crew or the fuel costs. Time charter means the charterer hires the ship and its crew for a fixed time, months to a few years, during which it pays the costs for fuel, ports, and canal fees. A Bareboat charter typically lasts many years and means the charterer pays for the crew and fuel usage, being everything but the financial owner of the ship. This generalisation is illustrated below in Figure 2.

Owns/Pays	Voyage charter	Time charter	Bareboat charter
Cargo	Charterer	Charterer	Charterer
Fuel	Shipowner	Charterer	Charterer
Crew	Shipowner	Shipowner	Charterer
Investments	Shipowner	Shipowner	Shipowner

Figure 2. *Who owns and pays in different chartering structures (Rehmatulla & Smith 2020)*

From the figure, one can identify two split-incentive problems relevant for this thesis. On both the Time and Bareboat charter market, the shipowner's investment does not directly benefit the shipowner itself through reduced fuel costs. It can charge a higher charter fee, but then the shipowner is relying on the charterers' willingness to pay, which is not certainly matching the expected savings of the product. This makes the investment decision's outcome uncertain, naturally slowing investments into fuel-efficiency technology.

Rehmatulla and Smith (2020) argue that the shipping industry might have somewhat overcome this problem and that shipowners are increasingly willing to take that risk. However, some previous studies have concluded that only 40% of the charterer's fuel savings are shared with the owner through higher charter rates. This type of split incentive is called an Investment split incentive.

There is an additional split incentive that Figure 2 highlights. The potentially reduced fuel costs from investing in the product rely on correct and active usage. Thus, the product's performance is in the hands of the ship's captain and crew, who, on the Time charter market, have no incentive to use the product since they don't receive the fuel savings. It can be assumed that the crew is generally hesitant to use the wing, for example, due to potentially causing a rolling motion of the ship and obscuring the view. Additionally, the captain has to decide if it is safe to sail in hard winds and might conclude "not today", when there are a few good hours of opportunity to use the sail. Even if these hesitations are not realised, it discourages a charterer who does not have influence over the crew from paying a higher charter fee. This type of split incentive is called a Behavioural split incentive.

It is clear how both these split incentives pose contractual challenges for the adoption of Oceanbird's product. The full split incentive problem is illustrated below in Figure 3.

	Shipowner owns the crew	Shipowner does not own the crew
Shipowner pays for fuel	**No split-incentive problem** (Voyage charter)	**Behaviour split-incentive problem**
Shipowner does not pays for fuel	**Behaviour and Investment split-incentive problem** (Time charter)	**Investment split-incentive problem** (Bareboat charter)

Figure 3. *Split-incentive problems in shipping (Rehmatulla & Smith 2020)*

2.2 Vessel Types

Given that the shipping industry has several distinct vessel types with their own similar characteristics, it is a logical segmentation. Illustrated below in Figure 4 is a pie-chart of vessel type segmentation.

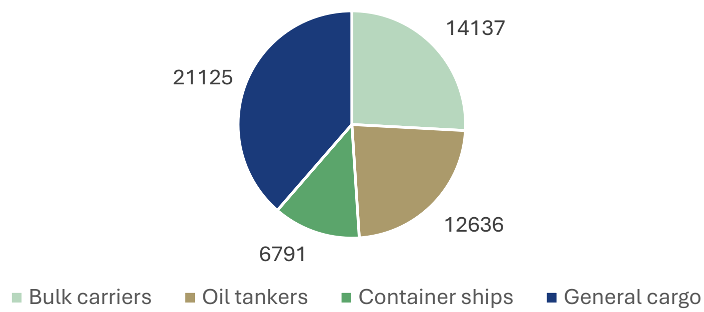


Figure 4. *Number of vessels in each vessel-segment, as presented by UNCTAD (2025a).*

Container ships account for a substantial portion of the global vessel fleet and an even larger proportion of global trade by value. These ships are, however, not a relevant customer segment for Oceanbird since the ship is piled with containers. Instead, the segments Oceanbird targets are tankers, bulk-carriers, and Ro-Ro ships (Ro-Ro are included in the "general cargo" category in Figure 4). These ship types will vary in market size, profile, operational speed, fuel usage, cargo and prevalent chartering structure. These characteristics impact how the product can be sold, what fuel savings can be achieved and what engineering requirements are needed for green water events. The characteristics of each type are presented in Figure 5.

Vessels	12 636 Vessels
Profile	Low and wide
Speed	10-16 knots
Cargo	Oil and gas
Charter	90% Voyage

(a) *Tanker*

Vessels	14 137 Vessels
Profile	Low and wide
Speed	12-16 knots
Cargo	Ore, grain, coal
Charter	60% Time

(b) *Bulk carrier*

Vessels	4200 Vessels
Profile	Tall and narrow
Speed	14-18 knots
Cargo	Cars, trucks
Charter	Time and Bareboat

(c) *Ro-Ro ship*

Figure 5. *Typical characteristics for ship types (Industry Research 2025; Oceanbird n.d.; Plomaritou 2014; Rehmatulla et al. 2017; UNCTAD 2025a)* ***5a****: Tanker (AET Tankers 2026),* ***5b****: Bulk carrier (Georgiou 2024) and* ***5c****: Ro-Ro ship (Himmel 2024)*

2.3 Decarbonising the Maritime Industry

The introduction of legislation to promote decarbonisation of the shipping industry directly increases the value of WASP technology. The International Maritime Organisation (IMO) aims for a 20% to 30% reduction in emissions by 2030, with 2008 as the base level, and net-zero goals for 2050 (International Maritime Organization n.d.). However, as there is currently little regulation in place, progress is slow and likely to miss the 2030-target. This became even more likely when an IMO effort for a global carbon tax was turned down by the US in late 2025 (US Department of State 2025). The incentive for the shipping industry to switch away from fossil fuels is therefore strategic, mostly built on the premise of future regulation. However, there are two, albeit newly implemented, regulations currently influencing shipping in the EU: the EU ETS and FuelEU.

Under the EU ETS, ships must cover their CO_2 emissions through allowances (EUAs) (European Commission n.d.-a). The cost will be attributed to the one operating the ship, which was touched upon in Section 2.1, is not always the owner. FuelEU works by penalising well-to-wake Greenhouse Gas (GHG) emissions and is attributed to the owner. Furthermore, it promotes investments into energy efficiency and alternative propulsion systems (European Commission n.d.-b). Both of these regulations currently have little effect, but are both designed to increase in potency over time. How much effect these regulations will have on the global shipping industry is uncertain, but it might push some early adopters towards new technologies.

For Oceanbird's case, there is clearly a scenario where a global introduction of emission regulations increases the product's value, which should be taken into account, and where these regulations serve as a proxy for what that could look like. However, managers at Oceanbird express that a sustainable business model cannot solely rely on hopes of CO_2-legislation, but must be viable even without.

2.4 The Current State of Wind-Assisted Ship Propulsion

As a way of complying with future regulations and at the same time lowering fuel expenses, WASP-technologies have gained traction. Modern commercial installations of WASP-systems exist from as early as 2010, but the deployment has accelerated with the vast majority of installations occurring after 2024 (ISWA 2025). The attraction is understandable because the suitability of wind as an energy source for maritime propulsion is strong, at least from a theoretical perspective.

Winds are typically more stable at sea, both in terms of direction and force. This is especially true in certain places or along certain routes. For example, the wind direction north of the equator on the northern Atlantic is around 80-90% of the time blowing from the same direction, east or northeast (NIMA 2002). This means a ship going from southern Europe to America will very likely have favourable winds most of the way. This exact phenomenon has been leveraged before during transatlantic trade and exploration powered entirely by sails, giving rise to the term *trade winds*.

As of Q4 2025, there are 85 vessels that have some sort of WASP system installed (ISWA 2025), and more are reported to be on order (Gaul & Rutkowski 2025). Research points out how the market is at an early growth stage, and the applications are still in an experimental phase (Kolodziejski & Sosnowski 2025). There are several types of techniques being deployed, but all current installations fall into one of five categories: rotor sails, suction wings, wing sails, traditional soft sails and kites. As this thesis is aimed towards a company producing wing sails, the other technologies will not be explained in detail, but it's interesting to note that there are other technologies being deployed, as seen in Table 1.

Table 1. *Currently installed WASP-systems (ISWA 2025)*

Technique	**Total Number of Vessels**
Rotor sails	38
Wing sails	13
Suction sails	29
Soft sails	4
Kite sails	1
Total	**85**

Wing sails, or rigid sails as they're sometimes called, work on similar principles as an airplane wing. In fact, many observers might think their design more resembles a wide, vertically mounted airplane wing than a traditional sail. Through interaction with the wind, the sail produces a difference in pressure between the two sides, generating a lift force as a result. On an airplane wing, the force lifts the plane upwards towards the sky. On a ship where the wing is mounted horizontally, it generates thrust by dragging the boat forward (Guzelbulut1 et al. 2023). The sails can be rotated in order to maximize the propulsion at different wind angles, so even though the vessel is traveling in headwinds, it can still generate some propulsion, as long as the wind angle is not too steep (Kolodziejski & Sosnowski 2025). Usually, the biggest effect is generated when the wind is coming from the side (Guzelbulut1 et al. 2023).

The main benefit that WASP-technologies promise investors is a reduction in fuel consumption, but the magnitude of this reduction remains uncertain. This uncertainty has been identified as one of the main obstacles hindering the adoption of the technology (Chou et al. 2021; Kolodziejski & Sosnowski 2025). Various studies report widely differing estimates of performance, most of which are based on computer simulations or small-scale experiments rather than full-scale operational data. To provide an indication of the reported range, the studies reviewed by Chou et al. (2021) estimate fuel savings between 5% and 60%, with the majority of estimates falling within the 5–15% range.

Although data from full-scale installations remain limited, some projects have publicly disclosed operational results. In 2023, the bulk carrier *M/V Pyxis Ocean* was retrofitted with wing sails using the *WindWings* system developed by BAR Technologies, shown in Figure 6. Over a six-month trial period, the vessel operated in a wide range of conditions, including voyages across the Indian Ocean, Pacific Ocean, North and South Atlantic Oceans, and passages around Cape Horn and the Cape of Good Hope. During this period, the operators reported an average reduction in fuel consumption of 14%, with peak reductions reaching 37% under favourable sailing conditions (Cargill 2024).

It is worth noting that fuel savings expressed as percentages give a misleading impression of performance. Fuel consumption increases rapidly with vessel speed. At the same time, many WASP technologies produce a set amount of thrust that tend to reduce at higher speeds. Consequently, the same propulsion system may produce substantially different percentage reductions depending on the vessel's sailing speed.

Figure 6. *M/V-Pyxis (Cargill 2024)*

3 METHODOLOGY

The methodology used in this thesis will follow the structure proposed by Hillier and Lieberman (2001), and the theory behind the framework will be briefly presented in Section 3.1. The author's own implementation, which is designed specifically towards the purpose of this thesis, will be further presented in more detail in Section 3.2.

3.1 Operational Research Framework

The operational research framework, as presented by Hillier and Lieberman (2001), is aimed at developing a mathematical model that serves as the basis for a structured and quantitative analysis of the problem in question. The method is divided into 6 steps. The scope of this thesis is only concerned with steps 1-4, which are defined as follows by Hillier and Lieberman (2001):

1. *Defining the problem and gathering data* - Most problems encountered in Operations Research (OR) are described in vague and imprecise ways. In this phase, a solid understanding of what issue management wants them to solve is necessary. This includes tasks such as defining proper objectives, constraints and possible alternatives. This phase also includes gathering relevant data. This data should help in understanding the problem and act as input to the model that is developed in subsequent steps.

2. *Formulating a mathematical model* - Once the a suitable foundation is obtained, it's time to formulate the mathematical model on which the analysis should be based. The idea is to construct a mathematical model that captures the essence of the problem. The model usually contains simplifications and rough estimates, but it still provides some major advantages over verbal descriptions. It can describe the problem more concisely and help to reveal important cause-and-effect relationships.

3. *Deriving solutions from the model* - Once the model is implemented, it can be used to find solutions to the problem. A very important part of this phase is the analysis conducted on these solutions. This includes sensitivity analysis, assessing what values have the greatest impact on model output.

4. *Testing the model* - The first version of a large mathematical model inevitably contains flaws. The goal of this step is to identify and resolve as many of these flaws as possible. How to best perform this model validation depends on the nature of the problem, but Hillier and Lieberman (2001) proposes two general techniques.

The first is to let an external party, someone who wasn't involved in the development of the model, test it. The second is to test the model against historical data to check if the model can predict what actually happened in reality.

Steps 5 and 6 are concerned with how to prepare the application of the model as prescribed by management and the implementation. However, developing an actionable implementation plan is not the objective of this thesis, despite being a central component of the original OR framework. Instead, this study is exploratory in nature and aims to provide guidance and decision support for Oceanbird's future strategic considerations and research. As such, the actual deployment of the proposed business models falls outside the scope of this thesis. Consequently, phases 5 and 6 of the framework are excluded from the study.

3.2 Implementation of the OR-framework

The framework described in the previous section is a general framework that has been adopted to be relevant to the purpose of this thesis. The actual implementation that was used in this thesis is described in the following sections.

3.2.1 Phase 1: Defining the Problem and Gathering Data

Just as Hillier and Lieberman (2001) points out is often the case, the problem description presented at first contact was vague. Therefore, the first task was to define the problem clearly. This was done in collaboration with Oceanbird, together formulating the problem description, purpose and research questions presented in the introduction.

The other part of OR's step 1 is to gather relevant data. The purpose of the data is to inform the development of the model and act as input. In this regard, two areas were identified as crucial.

The first area was the product itself. Data regarding the product, such as production costs, maintenance needs, efficiency, favourable conditions, and so forth, is essential as input. This data was gathered through contact with relevant employees at Oceanbird.

The second area was business model alternatives to evaluate. The OR-framework, as presented by Hillier and Lieberman (2001), proposes that the possible alternative courses of action should be a part of the problem description. In this case however, only CAPEX and Leasing were known at the project start, and part of the purpose was to identify and evaluate other relevant alternatives from other industries. Therefore, phase one was complemented by a literature study, with the goal of finding business model alternatives that could complement the alternatives already presented. This study followed the methodology presented below.

Methodology for literature review

The methodology used to conduct the literature review followed the method proposed by Höst et al. (2006). The method divides the literature review process into three distinct steps or tasks:

Search widely - The first step is to search widely to establish a broad base of literature that could be valuable to the purpose. This step was conducted by searching for relevant keywords in the database Scopus. The keywords used were "Business models” and “Split-incentive”.

Select - The second step is to select relevant sources from the base acquired in the previous step. This was done through a set of criteria such as relevance for the purpose, citations, publication, and recency. These criteria were evaluated for each article by reading the abstract, or if needed, additional parts.

Search deeply - Once a better understanding of the area had been achieved, a phase of deep search began. This was done by reading the sources from the previous step and identifying key authors and terminology. This was then used to inform additional searches, expanding the set of sources to be reviewed with more relevant sources. It became evident during the earlier stages of the review that a substantial portion of the literature focused on energy efficiency projects within the housing sector. This observation led to an additional keyword search using the terms “investment” and “energy efficiency”. As the parallels between Oceanbird’s problem and the problems faced by firms operating in the housing sector became increasingly apparent, the scope of the study was refined to focus on business models specifically employed in this sector. The results of this review are presented in Section *4.1 Result of Literature Review*.

3.2.2 Phase 2: Formulating a Mathematical Model

Based on the results of the first phase, a set of business model alternatives that could potentially be relevant for the company was identified. The identified business models were then adapted to Oceanbird’s context in order to clarify how investments, ownership structures, costs, and savings would be distributed among the stakeholders.

With the alternative courses of action defined, the formulation of the mathematical model could begin. As noted by Hillier and Lieberman (2001), modelling should begin by identifying the essence of the problem. In this case, the core problem was identified as the outcome of the investment decision, for all stakeholders, under each business model. This was modelled by calculating the Net Present Value (NPV) of the investment for all stakeholders under each business model. The NPV provided a quantitative metric through which the different business models could be evaluated and compared

The next step concerned how the model should be constructed. No matter the business model, the outcome of the investment is heavily dependent on uncertain factors such as actual fuel savings and fuel prices. These kinds of decisions, where the outcome cannot be predicted with certainty, are what decision analysis is designed to address. It provides techniques that can be applied to quantitatively analyse decisions in uncertain environments. One technique is Monte-Carlo simulation, which can be used to produce distributions of possible outcomes (Hillier & Lieberman 2001). Using Monte-Carlo simulation, a model was created for the investment decision, as it was structured for each of the business models. The investment costs and savings were modelled through the lens of all stakeholders, highlighting the payoff and risk of the wing and how that is impacted by input parameters.

As mentioned in Section 3.1, the model should be tested, validated and verified in step 4. For the work conducted in this thesis, however, model validation was carried out continuously through an iterative development process rather than as a final, discrete phase. The model was developed incrementally, and progress was presented to representatives of Oceanbird's management team every two weeks. This approach was chosen for two primary reasons.

First, initial discussions revealed gaps in the organization's understanding of modelling capabilities and potential outputs. A more open and collaborative development process was therefore proposed as a way to enable better alignment between the technical modelling approach and managerial expectations.

Second, the purpose of the model was primarily to identify important characteristics for every business model, not to produce highly accurate predictions on their performance. Therefore, ensuring contextual relevance and strategic usefulness was considered important. An iterative process allowed assumptions and structural choices to be continuously refined in dialogue with managers at Oceanbird. While a fully developed model validated only at the end might have reduced the risk of confirmation bias from managerial involvement, this study prioritized contextual relevance.

This methodological adaptation draws inspiration from iterative development practices commonly applied in software engineering, where incremental development and continuous stakeholder feedback are used to align system capabilities with user expectations. Such approaches are particularly beneficial in contexts where stakeholders initially have a limited understanding of the technical possibilities and outputs of the system being developed (Chandra 2015).

3.2.3 Phase 3: Deriving Solutions from the Model

When the model had reached a satisfactory state, the different business models could be quantitatively analysed and compared. The analysis focused on how the results differed between the different business models. First, the performance of each business model was evaluated, and whether there were any synergies between a particular chartering structure and any particular business model. This was followed by a scenario analysis, examining how the business models responded to the set of scenarios that Oceanbird wished to evaluate.

During the modelling process, several parameters had to be estimated or were based on assumptions. To assess the robustness of the results with respect to these assumptions, a sensitivity analysis was performed in which the associated parameters were varied, simulations were rerun, and the resulting changes in outcomes were analysed to determine the magnitude of their impact.

After the results had been analysed and the robustness of the findings had been evaluated, the analysis was complemented by a discussion of the model's limitations and real-world considerations that were not included in the analysis. Based on these findings, conclusions were drawn in order to answer the stated research questions.

4 THEORY

The following section presents the theoretical foundation of this thesis. First, the results of the literature review are presented in Section 4.1, identifying potential candidates for business models that Oceanbird could employ. From these candidates, two are decided as suitable alternatives to be implemented in the model, something that is motivated in Section 4.2. Thereafter, approaches for handling uncertainty in decision-making processes are discussed in Section 4.3. This is followed by how fuel prices can be modelled in Section 4.4. Finally, the theory behind Monte Carlo simulation, the modelling approach used in this thesis, is presented in Section 4.5.

4.1 Result of Literature Review

As described in Section *1.3 Problem Formulation*, a major concern when finding a suitable business model for Oceanbird is the need to address the split-incentive problem. As mentioned in Section *3.2.1 Phase 1: Defining the Problem and Gathering Data*, the literature review showed that much of the research on business models and split-incentive problems originates from investments in energy efficiency for rental housing. This industry was therefore considered a relevant source for identifying business model alternatives for Oceanbird. This section presents the results of the literature review, beginning with a broad overview of the business models applied for investments in energy efficiency for housing, before narrowing the findings down to a set of promising alternatives to be evaluated quantitatively using the mathematical model.

The findings from the literature review are presented in three parts. First, the similarities between the shipping and housing industries are highlighted to motivate the relevance of the comparison. The remaining findings are then divided into two categories. The first concerns findings on business models in which tenants are not included as an active party, and is presented in Section 4.1.2. These models provide a useful basis for understanding the industry structure without the added complexity of split incentives. The second category concerns findings on business models that actively include tenants and specifically aim to overcome split-incentive problems. These findings are presented in Section 4.1.3.

4.1.1 Similarities Between the Industries

Energy used in buildings contribute to a substantial share of global CO_2 emissions. This means that improvements in building energy efficiency could contribute to both lower energy costs and climate change mitigation. Still, many buildings remain energy inefficient. In Europe, approximately 75% of buildings are classified as energy inefficient

(Micelli et al. 2025). One explanation for this is the presence of split incentives between landlords and tenants. Investments in energy efficiency, such as improved insulation, installation of heat pumps, window replacement, or solar thermal systems, are typically made by landlords. However, these investments mainly benefit the tenants, who typically pay their own energy bills. As a result, landlords have limited economic incentives to undertake such investments. One potential solution is to include energy costs in the rent. However, this may create another incentive problem, as tenants then have no incentive to behave in ways that reduce their energy consumption, potentially leading to inefficient or wasteful energy use. This shows how the sector has both investment and behavioural split-incentives (Tommasi et al. 2024). This situation closely mimics the split incentive problem Oceanbird faces, which is discussed in Chapter *2 The Maritime Shipping Industry*. If the charterer pays for its own fuel (as in Time and Bareboat charter), the shipowner has no economic incentive to invest in the wing (investment split incentive). Furthermore, if the charterer does not provide its own crew (as in Time charter), the crew has no economic incentive to actually use the wing (behavioural split incentive). Given the split-incentive similarities between the industries, studying and deriving the business models from the housing sector could solve the split-incentive problem in the shipping industry.

4.1.2 Landlord-Centric Business Models

In the first category of business models found in literature, the tenant is not considered an active party. There is only a property owner or landlord who seeks to reduce the energy consumption in his/her building. Typically, this is achieved through smaller projects such as installing modern windows, improving insulation, or installing a modern heat pump. Several sources describe how a landlord could bundle all these projects together into a so-called *energy efficiency project* and outsource the project as a whole to an Energy Service Company (ESCO) (Bianco et al. 2022; Copiello et al. 2024; Micelli et al. 2025; Tommasi et al. 2024). These companies specialize in designing, implementing, and in some cases financing energy efficiency projects. They can offer customers a complete solution: contacting the appropriate window suppliers, managing the insulation work, and maintaining the new heat pump for years to come. Typically, ESCOs are separate entities from the energy supplier, and the revenue for ESCOs is often tied to the performance of the solutions they implement. The more they reduce their customers' energy needs, the more they earn.

For setting the terms of an energy efficiency project, ESCOs commonly use Energy Performance Contracting (EPC). These contracts define key aspects of the project, such as who makes the initial investment, how the resulting energy savings are allocated, and what fees the customer pays to the ESCO. Several types of EPC arrangements exist, each distributing risks, responsibilities, and financial returns differently between the ESCO and the property owner. Somma et al. (2020) presents the following main types of EPCs:

- **Guaranteed Savings**: The ESCO is responsible for designing and implementing the energy-efficiency project, while the customer provides financing. The ESCO guarantees that the project will achieve a minimum level of energy savings. If the realized savings fall below this guaranteed level, the ESCO compensates the customer for the difference. Any savings exceeding the guaranteed level also fall to the customer. The ESCO gets paid a fee for its services.
- **Shared Savings**: The ESCO is responsible for the design, financing, and implementation of the energy efficiency project. In return, the ESCO receives a predefined share of the energy cost savings achieved during the contract period.
- **First out**: The ESCO is responsible for the design, financing, and implementation of the project. During the contract period, all project-generated savings are allocated to the ESCO for the duration of the EPC. After the EPC expires, all subsequent savings accrue to the customer.
- **First in**: The ESCO is responsible for the design, financing, and implementation of the project. However, in this contract, the customer is guaranteed a predefined reduction in energy costs immediately. Any additional savings beyond this threshold are allocated to the ESCO during the contract period.
- **Four Step**: This model involves implementing energy efficiency measures in several stages. Initial measures with relatively low investment costs are implemented first, and the ESCO uses the resulting savings to finance progressively larger efficiency investments in subsequent stages.

Among these models, shared savings and guaranteed savings are the most widely used globally (Somma et al. 2020).

EPCs are typically designed for situations where the ESCO and the energy supplier are separate entities. If the ESCO can also supply energy directly, it may instead offer an Energy Supply Contract (ESC). This is another common contractual model in the energy efficiency sector (Somma et al. 2020), and this type of contract has also been proposed for use in the maritime sector. In 2015, the International Maritime Organization (IMO) introduced sulphur emissions control areas, which regulated the amount of sulphur ships could emit in certain parts of the world. This regulation left shipowners with two main alternatives: switching to more expensive low-sulphur fuels or investing in exhaust gas cleaning systems (scrubbers) that reduce sulfur emissions and enable the continued use of conventional heavy fuel oil (HFO). Olaniyi et al. (2018) propose a version of an ESC (which they name Maritime Energy Contracting (MEC)) as a way for HFO-suppliers to stay relevant. In this model, the fuel supplier finances the installation of scrubber technology for the shipowner, allowing the vessel to continue using cheaper HFO. The shipowner would then share part of the resulting fuel cost savings with the supplier over time.

So far, the business models surfaced from the literature review have not included the tenant. Tommasi et al. (2024) argue that the landlord-centric types of EPCs are not in themselves enough to overcome the split-incentive problem that appears in the rented housing sector. This is partly why these models will later be excluded when selecting the most promising alternatives in Section 4.2. However, the purpose of reviewing them is still relevant, as they provide a useful foundation for understanding how contractual structures and actor roles could be adapted to Oceanbird's context. In particular, letting Oceanbird take on a role similar to that of an ESCO could show potential.

4.1.3 Collaborative Landlord–Tenant Business Models

Under the SmartSPIN-project (Smart energy services to solve the SPlit INcentive problem in the commercial rented sector), Tommasi et al. (2024) expand the shared and guaranteed savings models to also include the tenant as an active party in the investment decision through the following adjustments:

- **Shared Savings for rented spaces**: Just as in the traditional counterpart, the ESCO makes the initial investment, and the resulting savings are shared between the landlord and the ESCO. In the rental context, however, the tenant who pays the energy bill also pays a fee to the ESCO for the reduced costs they will experience. It's also possible to extend the shared savings to include the tenant, depending on the reduction in the monthly energy bill relative to the payment for the ESCO service.
- **Guaranteed Savings for rented spaces**: The landlord makes the initial investment, and in exchange, the ESCO guarantees a stable amount of energy savings that will be attributed to the landlord. Furthermore, the tenant pays the ESCO a fee for the energy-efficiency service.

Both business models generate revenue streams for the party that finances the investment, thereby eliminating the investment split-incentive. At the same time, the party that consumes the energy remains responsible for paying for it, meaning that no behavioural split-incentive is introduced. This should therefore eliminate the split incentive problem completely. Tommasi et al. (2024) also discuss six additional business models that are more complex, specifically tailored to the housing sector and the landlord–tenant context. These are the chaffe businesses model, finance lease, energy efficiency as a service (EEaaS), managed energy service agreement (MESA) and the metered energy efficiency transaction structure (MEETS). They conclude, however, that the business model with the greatest potential to overcome the split-incentive problem is the guaranteed-savings model. Other authors, similar to Tommasi et al. (2024), expand on the traditional EPC framework by developing more customized, context-specific contractual arrangements, as the on-bill-schemes described in Bianco et al. (2022). However, as these models become increasingly complex and sector-specific, they start to lose relevance for the purpose of this thesis and are therefore not described in detail. Should the maritime sector start using EPCs, they should avoid developing solutions based on the specific techniques and stakeholders present in the housing sector.

4.2 Deriving Business Model Alternatives from the Housing Sector

Section 4.1 has presented several different business models that an ESCO can use when delivering energy efficiency projects. These are summarized in Figure 7.

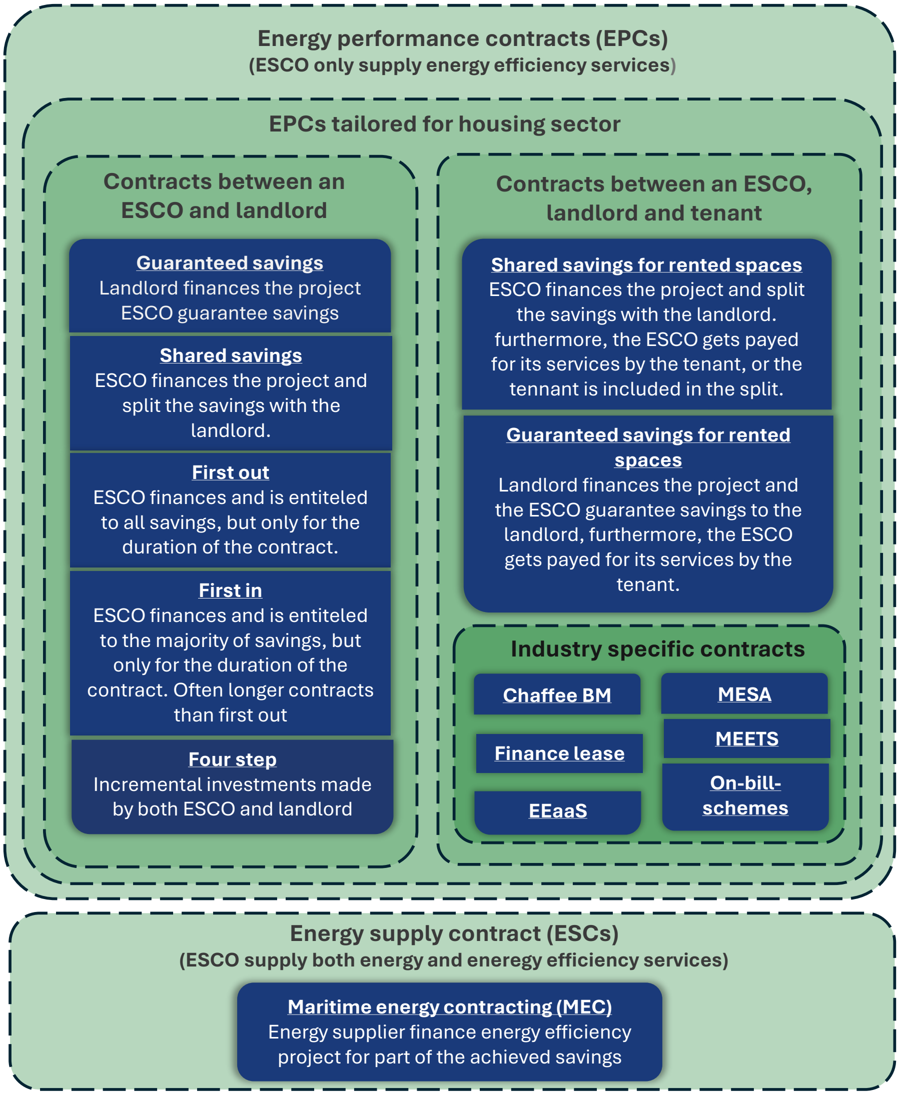


Figure 7. *Summary of all types of energy contracts an ESCO can use, as found in the literature review*

When selecting which business models to implement for further analysis in this thesis, each category was evaluated based on three criteria: its suitability for the maritime sector, its ability to address the split-incentive problem, and its practical feasibility for Oceanbird to deploy.

Among the identified models, the model with the strongest alignment to the maritime industry was the MEC. However, it was concluded that an ESC would not be feasible for Oceanbird to implement. An ESC requires the service provider to supply energy directly to the customer. In Oceanbird's case, this would imply not only supplying wind-assisted ship propulsion technology but also acting as a marine fuel supplier. Such a role would significantly expand the company's business scope beyond its current capabilities and strategic focus, which was deemed unfeasible. Consequently, the MEC was excluded from further analysis.

Attention was therefore directed towards the EPC models. The subset of EPC models involving the tenant as an active contractual party were specifically designed to address the split incentive problem in the housing market, which has previously been identified as being very similar to the split incentive problem in maritime shipping. As a result, the contracts between an ESCO, landlord and tenant were considered suitable for the purpose of this study. Consequently, the subset of EPCs included in the contracts between an ESCO and landlord were excluded from further analysis.

Finally, the industry-specific contracts were assessed. Although these models may potentially offer stronger mechanisms for overcoming the split incentive problem, they were considered too closely tailored to their original industries. The risk that industry-specific characteristics would reduce their applicability to maritime shipping was deemed greater than their potential benefits. Therefore, the industry-specific contracts were also excluded from further analysis.

This process left two EPC variants for continued evaluation: shared savings for rented spaces and guaranteed savings for rented spaces, as presented by Tommasi et al. (2024). These models were considered to have strong potential to address the split incentive problem while maintaining a level of generality that makes them transferable to the maritime sector. Furthermore, neither model contained structural requirements that would make them infeasible for Oceanbird to implement.

The final business models selected for implementation in this study are therefore CAPEX, Leasing, Shared savings, and Guaranteed savings. However, because the Shared savings and Guaranteed savings models were originally developed for the housing sector, certain adaptations are required before they can be applied to maritime shipping. The implementation and adaptation of all business models are presented in Section *5.2 Model Description, Cases*.

Applying business models originally designed for the housing sector to a business problem in the maritime shipping sector requires some consideration. The differences between the industries must be taken into account when evaluating the potential of these models. One important difference is that energy savings in the housing sector are likely easier to measure accurately than the fuel savings generated by the Wing 560. Another is that energy-efficiency measures implemented through EPCs in the housing sector are often passive and do not require active user involvement. This differs significantly from Oceanbird's case, where fuel savings depend on the active use of the wing. Furthermore, there may still exist fundamental differences that did not surface in the literature review and could hinder the adaptation of these models to the maritime shipping industry. This should be taken into account during the analysis.

4.3 Uncertainties in the Decision-Making Process

Investment decisions are inherently influenced by uncertainty, yet investment analyses often rely on deterministic models that represent uncertain parameters with single-point estimates. While such approaches can provide a basic indication of expected financial performance, they may obscure the underlying uncertainty and risk associated with the investment. A more comprehensive evaluation, therefore, requires methods that convey uncertainty and allow decision-makers to assess the distribution of possible outcomes. In the context of this thesis, uncertainty refers to key variables affecting the product's financial performance that cannot be predicted with a single number; instead, they yield a range of outcomes. Such uncertainty arises from variability in market conditions, product performance, maintenance costs, usage, and other factors. In financial contexts, the outcome and risk are typically assessed through the spread of indicators such as NPV (Chen 2025).

A common distinction in the literature is made between aleatory uncertainty and epistemic uncertainty (Kiureghian & Ditlevsen 2009). Aleatory uncertainty refers to inherent variability in a system or environment, such as fluctuations in market demand or operating conditions. For this thesis, wind speed and direction, fuel prices and potential carbon taxes can be seen as examples of purely aleatory uncertainties. Epistemic uncertainty arises from incomplete knowledge or limited data. The most apparent example of this problem is the lack of actual data on the sails' performance. Furthermore, some uncertainties can fall under both definitions. For example, a ship's fuel usage is inherently uncertain, and it is even more uncertain for Oceanbird due to limited customer knowledge. For Oceanbird, considering both forms of uncertainty will significantly influence financial outcomes and should therefore be part of the investment analysis. Additionally, the model's exposure to epistemic uncertainties still enables a thorough sensitivity analysis. Particular sensitivity to epistemic uncertainties can prompt Oceanbird to collect further data and take strategic action to minimise exposure.

4.4 Fuel Price Uncertainty

A central source of uncertainty when judging the financial investment of a wing is the future price of marine fuel. Over the 25-year product-lifetime horizon, fuel prices are subject to fluctuations driven by crude oil markets, and in turn by geopolitical events, strategic national interests, refinery capacity and cartels. Rather than assuming a fixed, deterministic, or growing fuel price, this analysis will use a stochastic process to capture the distribution of possible price outcomes and their effects on the investment's NPV.

Unlike equity prices, which may drift indefinitely, commodity prices like fuel are anchored in the long run by the supply-and-demand relation of production. When prices rise above the marginal cost of supply, producers expand output, which pushes prices back down. Conversely, prices below production cost trigger supply reductions that restore equilibrium. This fundamental mechanism implies that large deviations from a long-run equilibrium level are self-correcting, which is described as a mean-reverting behaviour (Brix et al. 2018). Thus, a mean-reverting process is more appropriate than a simple random walk for modelling fuel prices over longer horizons, and will be the base of the fuel price process in this thesis.

However, mean reversion does not capture a second, distinct feature of the oil price markets: the occurrence of sudden, large price shocks caused by discrete geopolitical or supply-side events (Meade 2010). These events arrive randomly, with little to no warning, and produce price movements that are larger than the mean-reverting process described above can generate. Trying to replicate that volatility with a mean-reverting process alone would require a volatility parameter that is too large, distorting the model's behaviour during normal periods. Thus, it is appropriate to model these two separately: a continuous, mean-reverting volatility process for ordinary fluctuations, and a discrete jump process for extreme shocks. The combined fuel price stochastic process is constructed below.

Let FP_t denote the fuel price at time t. The log-price, $X_{t+1} = \ln(FP_{t+1})$, is calculated by Equation 1:

$$X_{t+1} = X_t + \kappa\,(\theta_t^* - X_t)\,\Delta t + \sigma\sqrt{\Delta t}\,\varepsilon_t + S_t\Phi_t \tag{1}$$

The equation consists of four components. X_t is the current log-price. The second term is the mean-reversion drift: it pulls the log-price back toward the long-run log-equilibrium θ_t^* at a rate governed by κ and the time difference Δt. The third term is the continuous volatility component representing ordinary price volatility σ, with $\varepsilon_t \sim \mathcal{N}(0,1)$. The fourth term is the shock component with probability of occurrence $\Phi \sim \text{Bernoulli}(\lambda \Delta t)$, and the random log-size of each shock, $S_t \sim \mathcal{N}(\mu_s, \sigma_s)$.

The fuel-price process adopted in this thesis combines the one-factor mean-reverting logarithmic process of Schwartz (1997) with a Poisson jump component from Merton (1976) (Brix et al. 2018; Merton 1976; Schwartz 1997). The combined process captures exposure to both gradual price uncertainty and discrete geopolitical risk, while remaining relatively simple and transparent. More complex approaches do exist that capture additional features of price dynamics, including two-factor models such as Schwartz and Smith (2000), GARCH-type volatility processes, and Gaussian mixture models (Brix et al. 2018; Meade 2010). However, the marginal gain in accuracy from such extensions is small relative to the epistemic uncertainty inherent in this business case. The present stochastic process is therefore considered well-suited to the scope and purpose of this thesis.

The fuel price process is impacted by five parameters, each with a real-life interpretation:

Speed of mean reversion (κ). This parameter controls how quickly the price returns toward its long-run equilibrium following changes in the price. A convenient way to interpret κ is through the concept of the half-life of a shock, the time it takes for half of any deviation from equilibrium to dissipate, which is given by ln(2)/κ (Schwartz 1997). A high value of κ implies rapid reversion, whereas a low value implies that deviations persist for many years. An estimate for oil indicates the approximation of $\kappa = 0.5$, or a half-life of approximately one to two years (Schwartz 1997). Although shipping fuel prices might not be directly tied only to oil prices, they should follow the general trends of oil and exhibit the same mean-reverting behaviour. Therefore, $\kappa = 0.5$ should hold. It is also important to acknowledge the relatively old data on which this value is based. However, there is little reason to expect the fundamental supply-and-demand dynamics of oil markets to have changed dramatically over the last few decades, but it remains a weakness.

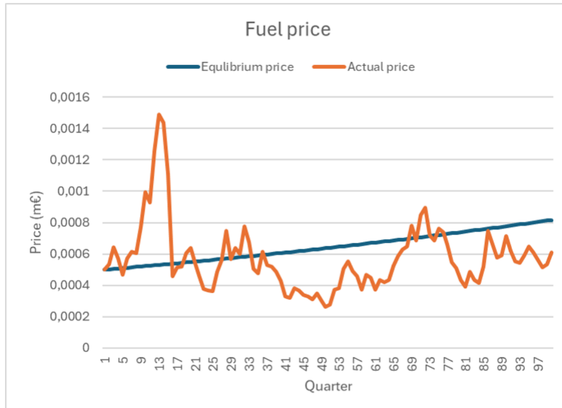
Equilibrium price (θ_t). The parameter θ_t (entering the model as θ_t^* = ln(θ_t)) represents the price level toward which the process generally gravitates. Economically, it corresponds to the long-run supply-and-demand equilibrium toward which prices gravitate over time. In typical mean-reversion models, this parameter is constant. However, to capture long-term price increases from inflation, this equilibrium will, in this model, increase by 2 % annually. The initial equilibrium is set to €500/mt, which is based on average prices for 2025.

Ordinary volatility (σ). Volatility captures the magnitude of ordinary, continuous fluctuations around the expected price path. It is defined as the annualised standard deviation of log-price changes during normal market conditions and is estimated from historical fuel price data to $\sigma = 0,33$ (Schwartz 1997). In Equation 1, ε_t is the stochastic variable capturing the volatility in each time period Δt.

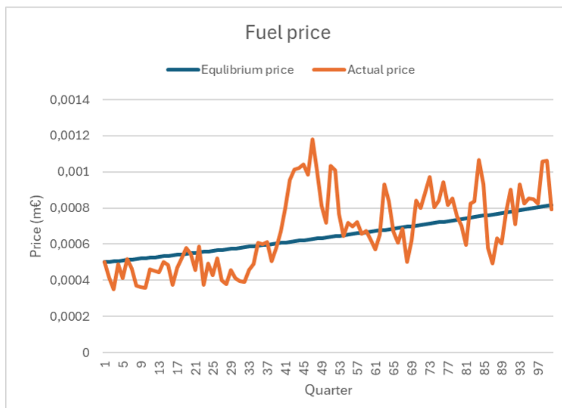
Shock intensity (λ). The shock intensity λ refers to the expected number of shock events per year. It governs how frequently geopolitical disruptions, supply crises, or other abnormal events arrive. For example, a value of λ = 0.2 implies one significant shock event every five years on average. Looking at historical data, the global oil market appears to experience roughly one to two major supply disruptions per decade, producing price movements clearly outside the range of normal fluctuations. Thus, this value is estimated to 0,15.

Shock size ($S_t \sim \mathcal{N}(\mu_s, \sigma_s)$). Each shock, when it occurs, adds a log-normally distributed multiplier to the price. μ_s determines the average magnitude of a shock, and σ_s captures the dispersion around this average. A positive outcome implies the shock pushes prices upward, like the current disruptions to the Hormuz Strait. In contrast, a negative value would reflect demand collapses such as the COVID-19 price crash of 2020. Together, these two parameters can be calibrated from the observed magnitudes of historical price shocks in the oil price market. Since most historical shocks have been price increases, μ_s should be positive. Setting both μ_s and σ_s to 0.25, approximately 16% of shocks are negative and the median shock size becomes $e^{0,25} \approx 28\%$. This seems roughly reasonable with historical data.

In Figure 8, two different realisations of possible fuel price development outcomes are illustrated.



(a)



(b)

Figure 8. *2 examples of fuel price development over 25 years generated with the same set of parameter values, but yielding two different outcomes*

4.5 Decision Analytics and Monte Carlo Simulation

Decision analytics refers to a set of analytical approaches used to support decision-making in situations characterized by complexity and uncertainty (Hillier & Lieberman 2001, p. 749). These approaches provide ways to perform a systematic evaluation of alternative strategies and their potential consequences on economic outcomes. These analytical models also allow decision-makers to explore how different assumptions or external conditions affect an investment's viability. This is particularly relevant for this business case, as there are many epistemic uncertainties and potential future scenarios that impact the product's viability. Changes in the economic outcome can be captured by simulating results across different input value scenarios.

Monte Carlo simulation is an important component of decision analytics when dealing with complex systems and multiple sources of uncertainty, where a mathematical model cannot be solved simply (Hillier & Lieberman 2001, pp. 1084–1086). Instead of relying on simplified analytical solutions, Monte Carlo simulations reproduce a system's behaviour under many iterations with varying realisations of the uncertainties. It is a computational method that iteratively samples values from distributions and computes the output for each iteration. The fuel price process described in Equation 1 and visualized in Figure 8 is a perfect example of how Monte Carlo simulations randomly produce different realisations of uncertainties.

Monte Carlo simulation begins by identifying the key uncertain variables in the system and assigning probability distributions to represent their possible values. These distributions are ideally based on historical data, but can also be based on assumptions and approximations about future variability. The construction of the fuel price process through data and assumptions in Section 4.4 follows this logic. From a large set of iterations, the distribution of a model's outputs can be plotted using a histogram of all those outputs. These simulations are particularly useful when models involve multiple uncertain parameters, interactions between parameters and scenarios (Hillier & Lieberman 2001, pp. 1099–1100). This makes Monte Carlo simulation an appropriate decision-making tool for capturing the product's financial risk, and will in this thesis be used to generate the distribution of NPV for an investment decision.

5 MODEL DESCRIPTION

The following section describes how the model on which the analysis is based is constructed. First, the model is described conceptually in Section 5.1. Then the business models, chartering structures, uncertainties, inputs, outputs, cash flows and scenarios that make up the model are described individually in more detail in Section 5.2, 5.3, 5.4, 5.5 and 5.6. Lastly, the connection between all these entities is summarized to prepare the reader for the analysis in Section 5.7.

This chapter is inherently full of details regarding model structure, calculation steps, and parameter choices. These details are included to provide a transparent scientific foundation for the results on which the analysis is based. While a full understanding of every calculation is not necessary to follow the analysis, understanding at least the overall structure and logic of the model will help the reader interpret the results presented in later chapters.

5.1 The Model Conceptually

When a shipowner decides to install a wing sail, the decision generates a series of cash flows distributed among multiple stakeholders. The model simulates these cash flows on a quarterly basis over the product's lifespan of 25 years and uses these to calculate the NPV of the decision for each stakeholder, which constitutes the primary output of the model. The decision affects three stakeholders: Oceanbird, the shipowner, and the charterer, each of whom receives distinct cash flows and corresponding NPVs.

The magnitude and structure of the cash flows vary depending on the business model. For instance, in CAPEX, a one-time purchase results in a substantial initial negative cash flow for the shipowner, followed by smaller positive cash flows in subsequent periods due to fuel savings. In contrast, a Leasing arrangement generates the same positive cash flow, but for a quarterly leasing fee instead. It should be noted that the term cash flow is used somewhat broadly in this context. For example, fuel savings generated by the product are treated and referred to as cash flows, despite not representing direct incoming payments. Within the model, however, this distinction is not important, as both cost reductions and direct payments affect the stakeholders' NPVs in the same manner.

The cash flows are also influenced by the ownership structure, which, as discussed in Chapter 2 *The Maritime Shipping Industry*, is largely determined by the type of chartering agreement employed. Under a Voyage charter agreement, where the shipowner bears fuel costs, the economic benefits of fuel savings accrue to the shipowner. Conversely, under a Time charter agreement, where the charterer pays for its own fuel, these savings are first reduced because of the behavioural split-incentive problem and then accrue to the charterer instead.

So the stakeholders' cash flows differ depending on the business model employed by Oceanbird and the chartering structure their customers use. The combination of a business model and a chartering structure defines what will be referred to as a *case*, and this is a central part of the model.

The model evaluates four business models: CAPEX, Leasing, Shared savings and Guaranteed savings, across three chartering structures: Voyage, Time and Bareboat. Since Guaranteed savings and Shared savings do not apply to Voyage charter, and due to the fact that Shared savings and Guaranteed savings yield the exact same implementation for Bareboat and Time charter, the model needs to implement eight cases. For now, it is enough to understand what a case is and that they differ. The exact implementation of the eight cases will be described further in Section 5.2.

Every case produces three outputs in each iteration: the NPV for each stakeholder in that particular case. These outputs are calculated by discounting quarterly results, which are calculated from cash flows, which are generated in different ways from inputs and uncertainties. Figure 9 shows the overall flow of data through the model, and how these entities interact to generate the output for the different cases.

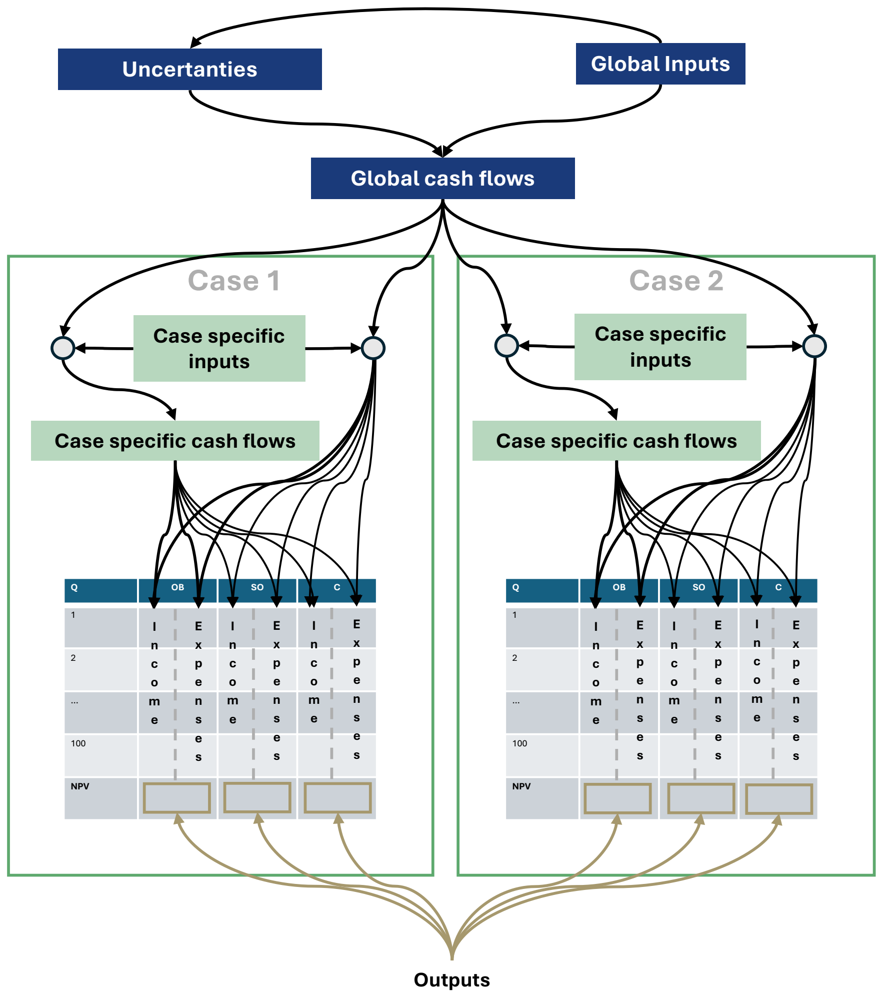


Figure 9. *The conceptual flow of the model, depicting how the inputs and uncertainties create quarterly cash flows, and how these cash flows are used to calculate the output. In every case, the cash flows are distributed between the three stakeholders, Oceanbird (OB), the shipowner (SO) and the charterer (C), and results are calculated for each quarter (Q) during the 25-year investment horizon.*

The cash flows used to calculate the output can be categorized into two types: global cash flows and case-specific cash flows. Global cash flows are directly linked to the product or stakeholder and therefore remain constant across all cases, such as the mean savings the product generates. Case-specific cash flows are tied to a particular chartering structure or business model, such as leasing costs or charter fee payments. Case-specific cash flows are unique to the particular case where they appear.

The cash flows are generated in different ways from user-defined input variables. Similar to the cash flows, the inputs can be categorized as either global or case-specific. Global inputs are parameters that remain constant across all cases, such as production cost and the weighted average cost of capital (WACC). Some global inputs also serve as input to the simulated uncertainties, such as mean product performance. Case-specific inputs apply only to individual cases and serve two main purposes: they either modify global cash flows before their inclusion in the NPV calculation, or they interact with global cash flows to generate new, case-specific cash flows.

Once all cash flows relevant to a case have been generated, these cash flows are distributed between the three stakeholders. They are ordered into incomes and expenses, and the result for each quarter is calculated. These quarterly results are then discounted and aggregated to calculate the NPV for each stakeholder in that particular case.

A full example of how inputs, uncertainties and cash flows are used to calculate the output will be presented later in Section 5.4. At its core however, the incomes and expenses are calculated differently for each case. This is done with case-specific inputs that generate case-specific cash flows. All cash flows originally stem from the same realisation of the uncertainties and the same values for the global inputs.

5.2 Cases

As mentioned, every case is a combination of a chartering structure and a business model. As discussed in Section *2.1 Chartering Structures*, the industry employs three different types of chartering structures: Voyage charter, Time charter and Bareboat charter. These are presented in more detail in Section 2.1, but to summarize, they differ from each other in two important ways: who benefits from the fuel savings and what split-incentive problem exists.

Under a Voyage charter, the charterer hires the vessel as a complete transport service, often for a single Voyage. The shipowner makes the investment decision while also bearing the fuel costs and benefiting from the savings. Consequently, no split-incentive problem arises.

Under a Time charter, the charterer hires the vessel for a certain time (but typically for a shorter period than in Bareboat charter). The shipowner retains responsibility for the investment decision, but the charterer bears the fuel costs and is the one benefiting from savings. However, the crew that operates the product is still owned by the shipowner. As a result, both a behavioural split-incentive problem and an investment split-incentive problem arise.

Under a Bareboat charter, the charterer hires the vessel for a certain time (but typically for a longer period than in Time charter) and provides its own crew. The charterer bears the fuel costs and is the one benefiting from savings, but the investment decision is still ultimately made by the shipowner. Consequently, only an investment split-incentive problem arises.

To understand the different cases and the analysis, it's important to understand how the split-incentive problems are implemented in the model. The behavioural split incentive is captured by a case-specific input called *usage penalty*. In every case that has a behavioural split-incentive problem, the savings will be reduced by this usage penalty as a way of representing how the product in these cases will probably be used less. A usage penalty of 10% means that the product is used 10% less than it could be, and only generates 90% of the savings it would generate in a case without the behavioural split-incentive.

The investment split-incentive is captured by a case-specific input called *chargeability*. It's meant to capture how the party that invests in the product will only be able to charge for a part of the savings it's expected to deliver to a second party. For example, if a shipowner buys the product and seeks to cover the investment with increased charter rates (as in the CAPEX/Bareboat case), it would probably not be able to find a customer willing to charter the boat if the shipowner simply increased the charter rate by the full value of the expected savings. The charterer would want some kind of compensation, since it puts itself at risk that the product delivers less savings than expected. As previously mentioned, it's been found in studies that only 40% of the charterer's fuel savings are shared with the owner through higher charter rates (Rehmatulla & Smith 2020). This would in the model be captured by a chargeability of 40%, and it means that in every case that has an investment split-incentive problem, the shipowner can only increase the charter fee by an amount that equals 40% of the predicted savings. It is assumed that the split-incentive problem has a higher impact on Time charter than Bareboat charter, which is motivated by the shorter charter contracts. This is captured by increasing the chargeability to 70% in cases with Bareboat charter.

The conceptual implementation of the four different business models and how they're affected by the different chartering structures is described in the following sections, essentially describing every case.

5.2.1 CAPEX

In the CAPEX business model, the ship owner purchases the product through a one-time upfront payment, with the expectation that the NPV of the resulting fuel savings will exceed the initial investment. If the vessel operates under a Time or Bareboat charter, the shipowner does not directly benefit from these savings. Instead, the shipowner seeks to recover the investment by increasing the charter rate charged to the charterer. The general flow of funds is illustrated in Figure 10.

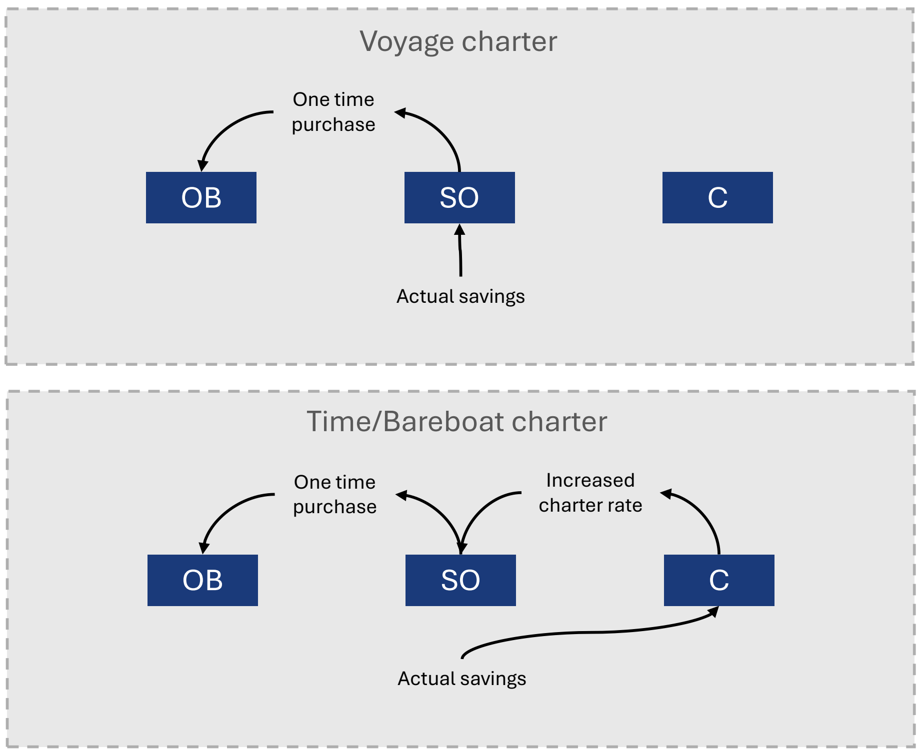


Figure 10. *The flow of funds in the CAPEX business model between Oceanbird (OB), the shipowner (SO) and the charterer (C)*

In the model, this increase in charter rate is fixed over a defined contract period and is recalculated upon contract renewal. The rate increase is calculated by taking the average fuel price over the preceding two years. This value is combined with the predicted quarterly fuel consumption and the expected performance of the product to estimate the charterer's projected quarterly fuel savings. These projected savings are then adjusted by the chargeability, since this case has an investment split-incentive.

5.2.2 Leasing

In the Leasing business model, the shipowner does not take ownership of the product. Instead, the shipowner pays a recurring quarterly leasing fee and expects that the income generated by the product each quarter exceeds this cost. The leasing fee is fixed over a defined contract period and is recalculated upon contract renewal. The general flow of funds is illustrated in Figure 11.

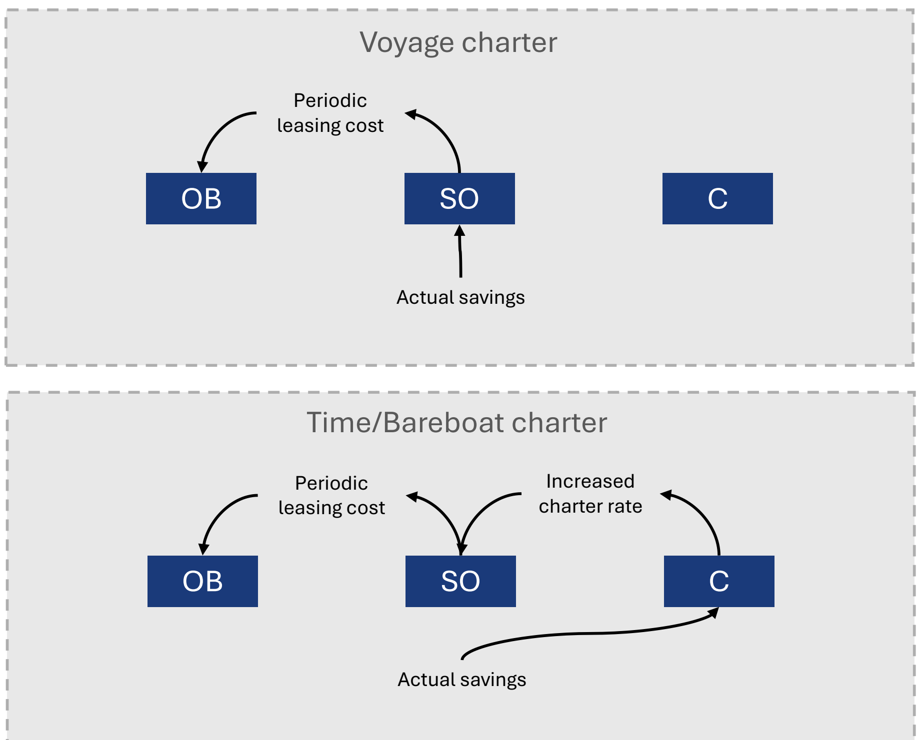


Figure 11. *The flow of funds in the Leasing business model between Oceanbird (OB), the shipowner (SO) and the charterer (C)*

The leasing cost is determined based on the expected income the product generates for the shipowner, multiplied by a savings charge limit. The definition of expected income depends on the chartering structure. Under a Voyage charter, it is based on predicted fuel savings. Under Time and Bareboat charter arrangements, it is instead based on the expected income derived from increased charter rates, which are calculated in the same manner as described for the CAPEX model.

5.2.3 Guaranteed Savings

The EPC:s are designed to solve the split-incentive problem, and in Voyage charter, these are non-existent. Therefore, the EPC-models are only implemented in cases with Time and Bareboat charter arrangements. Just as in CAPEX, the shipowner makes a one-time upfront investment in the wing sail, but does not increase the charter rate charged to the charterer. Instead, Oceanbird guarantees a quarterly payment to the shipowner. This guaranteed payment is based on the predicted product performance, the vessel's expected fuel consumption and the current fuel price. To finance this commitment, Oceanbird captures a share of the actual fuel savings realized by the charterer. If the value of this share exceeds the guaranteed payment, the surplus is also paid to the shipowner. The general flow of funds is illustrated in Figure 12.

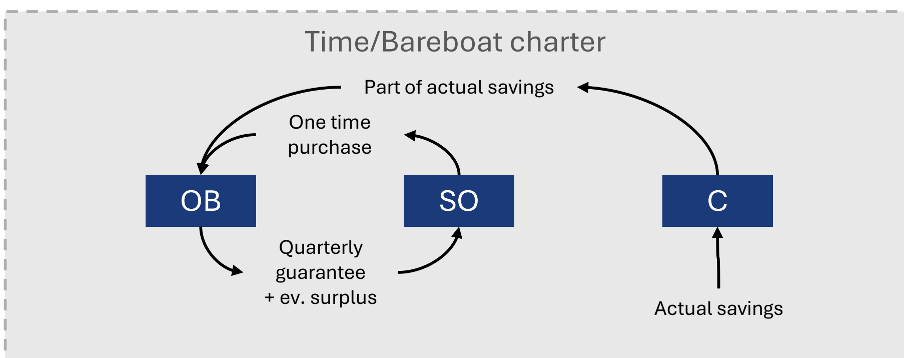


Figure 12. *The flow of funds in the Guaranteed savings business model between Oceanbird (OB), the shipowner (SO) and the charterer (C)*

This contract means that in the best-case scenario, where Oceanbird's share of the realized savings consistently covers the guaranteed payments, Oceanbird still does not generate additional revenue beyond the initial sale of the product. Conversely, if the actual savings fall short of the guaranteed level in some periods, Oceanbird would experience negative cash flows in those periods.

5.2.4 Shared Savings

In the Shared savings business model, the shipowner does not purchase the product; ownership remains with Oceanbird, just as in the Leasing model. Furthermore, the realized fuel savings are distributed among the stakeholders according to predefined contractual shares. Since Oceanbird does not receive an upfront payment, a relatively large share of the savings is allocated to them; the remaining portion of the savings is distributed between the shipowner and the charterer. The general flow of funds is illustrated in Figure 13.

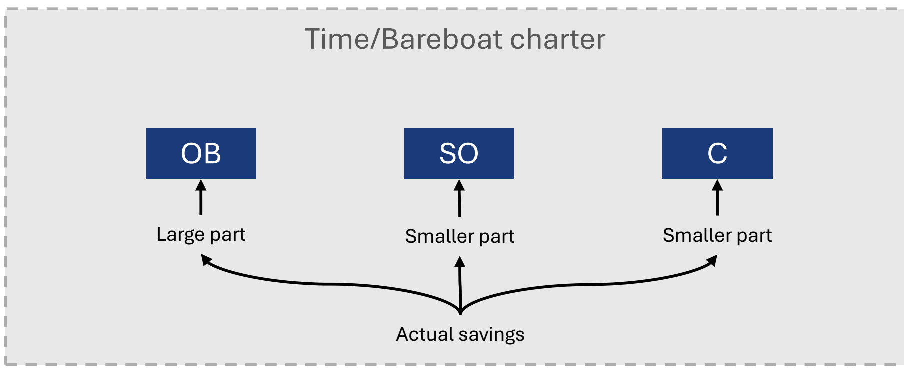


Figure 13. *The flow of funds in the Shared savings business model between Oceanbird (OB), the shipowner (SO) and the charterer (C)*

5.2.5 Cases Summarized

Section 5.2 has described the implementation of all cases implemented in the model in detail. A summary of all these cases are presented in Table 2, describing important characteristics of every case that will be important in the analysis.

Table 2. Summary of all cases

<table>
<tr><th></th><th>Voyage</th><th>Time</th><th>Bareboat</th></tr>
<tr><td>CAPEX</td><td>SO buys the product from OB for fixed price.
SO benefits from uncertain periodic fuel savings.
C is not considered an active party in the business model.</td><td>SO buys the product from OB for fixed price.
SO benefits from increased charter fee, based on predicted savings.
C benefits from uncertain periodic fuel savings, reduced by a usage penalty.</td><td>SO buys the product from OB for fixed price.
SO benefits from increased charter fee, based on predicted savings.
C benefits from uncertain periodic fuel savings.</td></tr>
<tr><td>Leasing</td><td>SO leases the product from OB for a periodic fee based on predicted savings.
SO benefits from uncertain periodic fuel savings.
C is not considered an active party in the business model.</td><td>SO leases the product from OB for a periodic fee based on predicted savings.
SO benefits from increased charter fee, based on predicted savings.
C benefits from uncertain periodic fuel savings, reduced by a usage penalty.</td><td>SO leases the product from OB for a periodic fee based on predicted savings.
SO benefits from increased charter fee, based on predicted savings.
C benefits from uncertain periodic fuel savings.</td></tr>
<tr><td>Guaranteed savings</td><td>Not applicable</td><td colspan="2">SO buys the product from OB for fixed price.
SO benefits from guaranteed periodic payments and additional savings from OB.
C benefits from uncertain periodic fuel savings, but pay part of them to OB.</td></tr>
<tr><td>Shared savings</td><td>Not applicable</td><td colspan="2">SO, OB and C split the uncertain periodic fuel savings between themselves, with the majority going to OB.</td></tr>
</table>

5.3 Uncertainties

A key aspect of the models is the uncertain factors, and many of the global cash flows are based on unknowns. The model treats the following factors as uncertainties:

- Fuel price
- Fuel consumption
- Fuel savings generated by the product
- Price of CO_2 emissions
- Critical failure events

All these are generated as time series of quarterly values for 25 years. These are generated through underlying distributions in the following ways:

Actual fuel price: This is intended to capture how the fuel price fluctuates over time. The values are generated using the process described in Section *4.4 Fuel Price Uncertainty*. It's based on global input values for speed of mean reversion, start price, ordinary volatility, shock size mean, shock size volatility, shock intensity and equilibrium price inflation.

Actual fuel consumption: This is intended to capture how the actual fuel consumption of a vessel varies between quarters. This could be because of factors such as extended time at port or shifting demand. Given that the fuel consumption is the aggregated consumption over a quarter, small daily fluctuations should cancel out, and through the Central Limit Theorem, approximately follow a normal distribution. The input values were provided by Oceanbird, but will naturally vary due to boat size and engine differences.

Actual fuel savings generated by the product: This is intended to capture how the actual fuel savings can vary between quarters. This could be because of factors such as wind and ocean conditions. Similarly to the actual fuel consumption, the mean of daily variations should, over a quarter approximately, follow a normal distribution. The values are generated by sampling from a normal distribution based on Oceanbird input values for mean savings, and deviation assumed to be $\sigma = 10\%$ of the mean savings.

Actual price of CO_2 emissions: This intends to capture the potential price on CO_2 equivalents that might arise from legislation. This is modelled through a small chance every quarter that legislation is passed. From that quarter on, the price increases by 1% per quarter. The legislation event is generated by sampling from a Bernoulli distribution with a 2% chance of legislation each quarter. This results in CO_2-prices on average taking effect halfway through the product's lifespan. The initial price is using the current best proxy: the EU ETS, at round 80€ per ton CO_2. It should be acknowledged that this price is lower than what some experts are calling for, but since the introduction of these prices is a purely aleatory uncertainty, the effect of CO_2 prices is intentionally kept low. Otherwise, the model runs the risk of being sensitive to an uncertainty that neither Oceanbird nor the broader market can control.

Critical failure events: This intends to capture the possibility of a critical event occurring that imposes great expenses on the owner of the ship. This could be due to the vessel needing to stop operating for some time, damage to cargo or similar. The values are generated by sampling from a Bernoulli distribution with 1% as the risk of occurrence. This value was chosen so that the expected number of events is one over the product's lifespan. If an event occurs, the shipowner experiences a predefined and significant cost in that period of €1 million. Even if these values are purely hypothetical, the critical failure event reflects a feasible risk and how an investor could reason, and should therefore be reflected in the model.

5.4 The Model Exemplified

With inputs, cash flows, cases and uncertainties properly defined, a thorough example of how these entities are combined to calculate the output serves as a way of describing the full model. This is shown in Figure 14, with a step-by-step description in the paragraphs below.

The figure shows how parts of the quarterly results are calculated for each stakeholder in a single iteration for two cases: 1. a CAPEX business model applied to a shipowner operating under Voyage charter, and 2. a Leasing business model applied to a shipowner operating under Time charter. Note how this is essentially the same figure as Figure 9, but now the different entities are populated with actual instances of the entities.

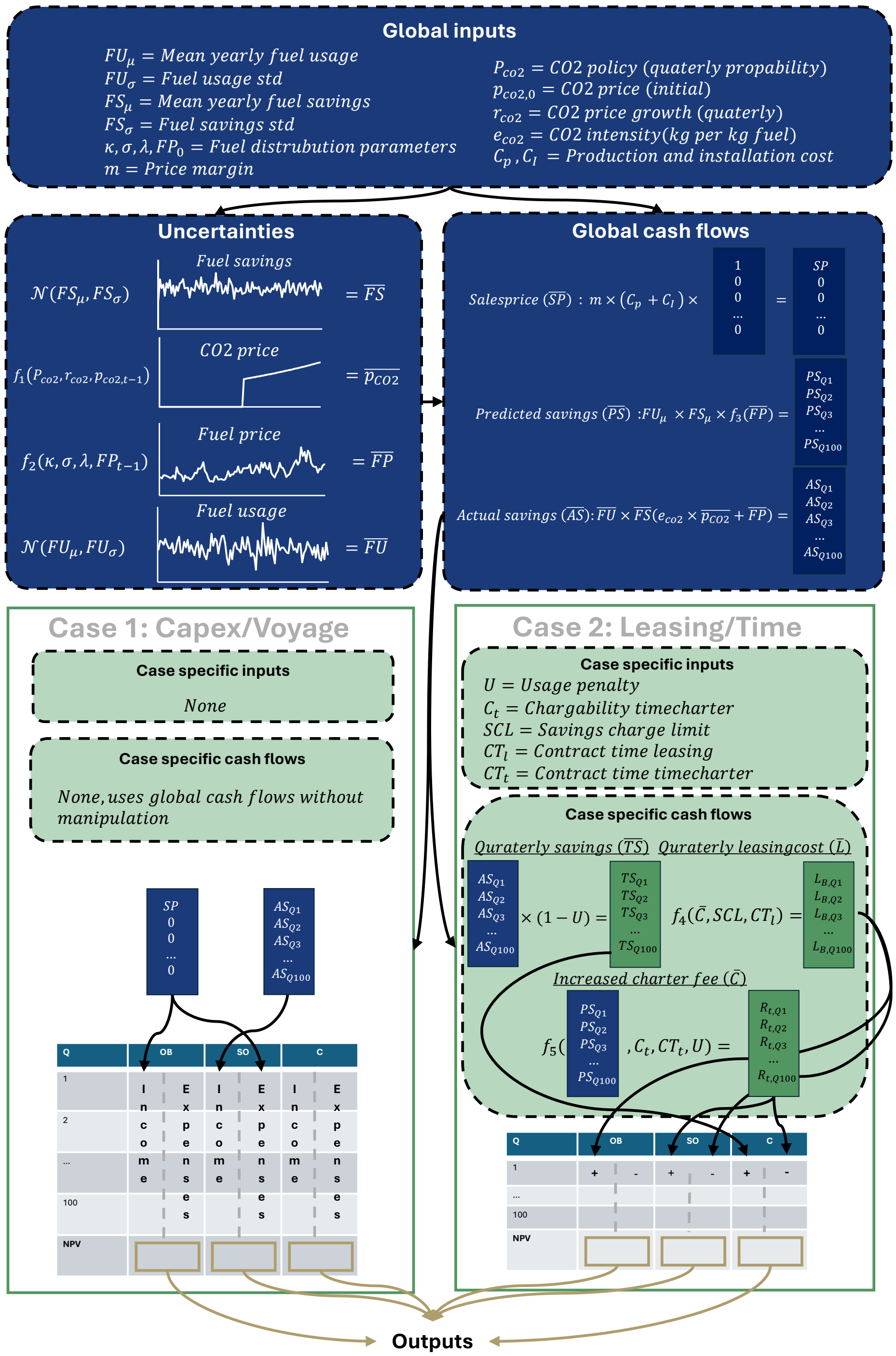


Figure 14. *Full example showing how inputs and uncertainties come together to form the cash flows, how these cash flows are distributed between Oceanbird(OB), the shipowner (SO) and the charterer (C), and how the output is calculated*

At the start of each iteration, a new set of time series representing the model's uncertainties are generated. These are shown as line graphs in Figure 14 and provide realized values for each uncertainty at every quarter, from Q1 to Q100. These values are used together with global parameters to generate two important global cash flows: the predicted savings and the actual savings for each quarter, as shown in the global cash flow box. These cash flows are represented as vectors (shown as standing rectangles in the figure), where each element corresponds to the value of a given cash flow in a specific quarter. A third global cash flow, the sales price, is also generated. However, unlike the others, it is not dependent on uncertainties and it can be calculated solely by global parameters.

These global cash flows are then used in both cases, but in different ways. In case 1, no split-incentive problem exists. Therefore, the full actual savings are added as income to the shipowner. The sales price is added as an expense for the shipowner and as income for Oceanbird. This case does not require any case-specific inputs or cash flows, as all relevant values can be derived directly from the global cash flows.

Case 2 has a Time charter, meaning the actual savings need to be reduced by the usage penalty (since this is a case that suffers from the behavioural split-incentive). This adjustment generates a case-specific cash flow, represented as a modified vector of quarterly savings. These adjusted savings are added as income for the charterer. Another case-specific cash flow that needs to be generated is the increased charter fee. This is calculated as a function of the predicted savings and local inputs, such as chargeability (since this case also suffers from the investment split-incentive). Lastly, the cash flow representing the leasing cost is calculated, using the increased charter fee as input.

Once all cash flows have been defined and distributed, the model calculates quarterly results for each stakeholder. These are then discounted and aggregated to determine the NPV for each stakeholder. The NPVs are stored, and the process is repeated for a new iteration with a new time series for every uncertainty. This procedure is performed for a number of iterations, specified by the user.

For clarity, not all uncertainties, inputs, and cash flows are shown in Figure 14. In the real model, there are more cash flows, such as maintenance costs and costs for critical failures. However, these are conceptually treated in the same way, but with other functions and input parameters.

5.5 Input Values

The complete set of input parameters and their values is presented in Table 3 and Table 4, along with their respective sources. Some values cannot be directly linked to a specific source; these parameters are categorized as follows:

OB (Short for Oceanbird): These values were provided directly by managers at Oceanbird and were mostly adopted without further scrutiny or modification. Some of these values are not disclosed in this report however, as they're considered sensitive business information. Furthermore, some of these values were adjusted in such a way that they would yield a viable business case in around half of the simulated scenarios, something that will be discussed further in Section *6.1 How to Interpret the Simulation Results*. Non-disclosed values are marked as n.d. in the table.

Design: These parameters represent deliberate modelling choices or hypothetical business model configurations, such as leasing contract duration or the share ratios used in Shared savings. As Oceanbird does not currently apply these business models and no information on the matter could be found from their competitors, the values could not be grounded in reality. They were instead chosen to represent one plausible configuration and would have to be examined further before a real-world implementation. This category also includes auxiliary modelling parameters introduced to enable analysis, such as product performance. The product performance parameter describes how well the product performs in reality compared to the theoretical performance OB has achieved in their simulations.

Sensitive assumptions: These parameters are based on informed assumptions grounded in available knowledge or industry context, but lack precise validation. However, as these parameters were deemed central to the research questions, they were examined further in the analysis.

General assumptions: These parameters are also based on informed assumptions, but were considered of less importance or deemed inefficient to examine in further detail.

Table 3. *Global model input parameters*

Parameter	Value	Source
General		
Production cost	n.d	OB
Installation cost	n.d	OB
Price margin	5%	Design
Quarterly maintenance cost	n.d	OB
WACC (Oceanbird)	10%	OB
WACC (Shipowner)	10%	OB
WACC (Charterer)	10%	OB

Parameter	Value	Source
Product performance	100% of estimated performance	Design
Use cases		
RoRo, 18 kn, North Atlantic		
Mean fuel savings	5.128%	OB
Mean yearly fuel usage	10 676 tonnes	OB
Tanker, 16 kn, North Atlantic		
Mean fuel savings	4.658%	OB
Mean yearly fuel usage	11 018 tonnes	OB
Bulk, 16 kn, North Atlantic		
Mean fuel savings	1.958%	OB
Mean yearly fuel usage	16 211 tonnes	OB
Uncertainties		
Fuel price mean reversion speed	0.5	(Schwartz 1997)
Fuel price initial value	500 €/tonne	(Ship & Bunker n.d.)
Fuel price diffusion volatility	0.33	(Schwartz 1997)
Fuel price shock mean	0.25	Sensitive assumption
Fuel price shock volatility	0.25	Sensitive assumption
Fuel price shock intensity	0.15	Sensitive assumption
Fuel equilibrium price annual growth	2%	Sensitive assumption
Critical failure (quarterly probability)	1%	General assumption
Critical failure cost	€1m	General assumption
CO_2 policy (quarterly probability)	2%	General assumption
CO_2 price (initial)	80 €/tonne	(Ship & Bunker n.d.)
The table continues on next page		

Parameter	Value	Source
CO_2 price growth (quarterly)	1%	General assumption
CO_2 intensity (kg/kg fuel)	3.114	(European Commission 2025)
Performance variation (std/mean)	10%	General assumption
Fuel usage standard deviation	100 tonnes	General assumption

Table 4. Case-specific input parameters

Parameter	Value	Source
Leasing		
Contract period	5 years	Design
Savings charge limit	90%	General assumption
Guaranteed savings		
Oceanbird share of savings	90%	Design
Guaranteed share of predicted savings	90%	Design
Shared savings		
Oceanbird share	80%	Design
Shipowner share	10%	Design
Charterer share	10%	Design
Time charter		
Chargeability (split-incentive effect)	40%	Sensitive assumption based on (Rehmatulla & Smith 2020)
Usage penalty (split-incentive effect)	10%	Sensitive assumption
Contract period	1 year	General assumption
Bareboat charter		
Chargeability (split-incentive effect)	70%	Sensitive assumption
Contract period	5 years	General assumption

5.6 Scenarios

A set of input values can be combined to define a scenario. This scenario will form the basis on which the simulation is run. By just changing one input between two simulations, a pair of comparable outputs is produced. Take, for example, the chance of CO_2-legislation. By leaving all inputs the same but changing the chance of legislation from 2% to 0%, two sets of NPV-values are generated. One in the scenario with a chance of legislation and one without. The scenarios were chosen together with managers at Oceanbird. They are grounded in possible strategic directions the company wanted to explore, as well as concerns they have about the future of the industry and product performance. All scenarios, and their respective adjustments to the base case values are shown in Table 5. Furthermore, a base case is defined to create a helpful benchmark to use in the analysis. This is made up of a RoRo-ship using the product with 100% product performance, high production cost, high installation cost and no CO_2-regulation.

Table 5. *Scenarios*

Description	**Associated inputs**	**Value in basecase**	**Scenario values**
Scaled production	Production cost	High (n.d)	Low (n.d)
Target newbuild (no hull strengthening required)	Installation cost	High (n.d)	Low (n.d)
Chance of CO_2-legislation	CO_2 policy (quarterly probability)	0%	2%
Unexpected product performance	Product performance	100%	80% and 120%
Target segment	Use case	Ro-Ro	Tanker and Bulk

Combining all these possibilities resulted in 72 scenarios that were each simulated for 20.000 iterations.

5.7 Model summary

Section 5 has presented a detailed description of the model, importantly describing how it uses eight key entities: scenarios, inputs, uncertainties, business models, chartering structures, cases, cash flows and outputs. Going into the analysis, it's important to grasp how these are connected, which is summarized in Figure 15.

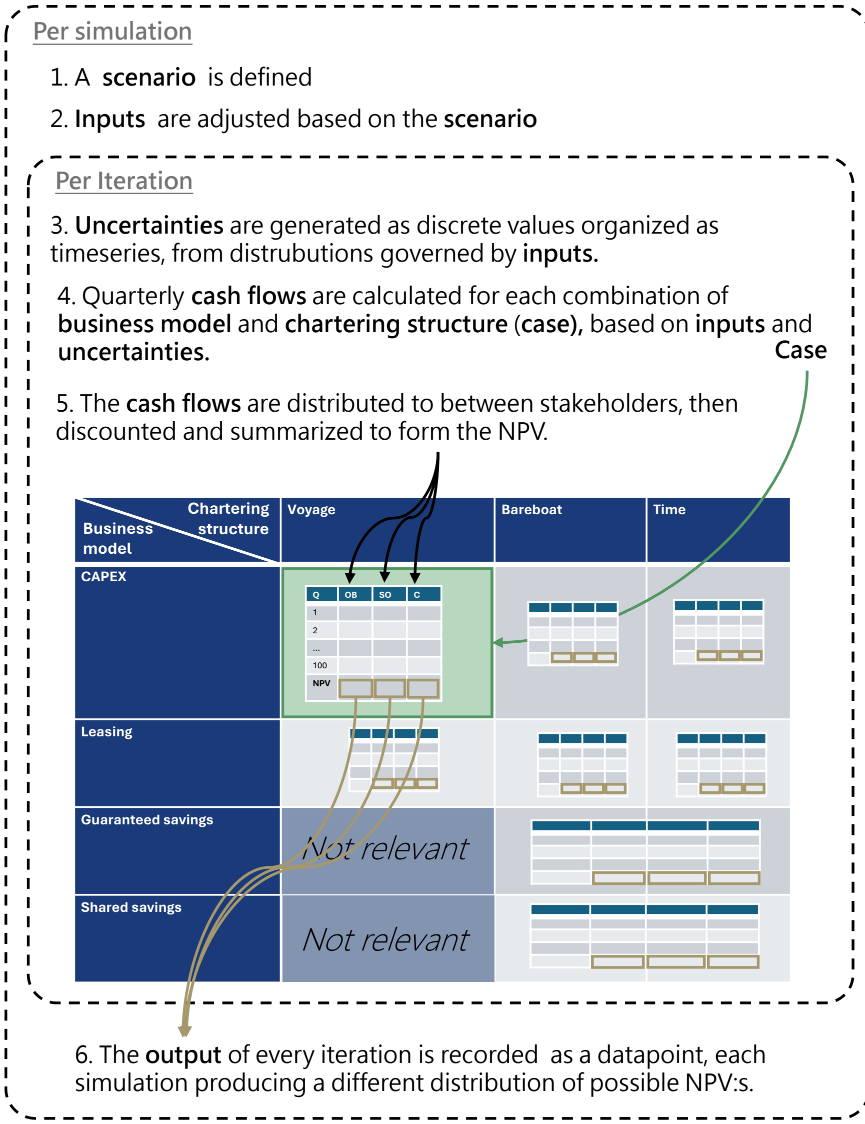


Figure 15. *Model summary*

6 ANALYSIS

The following chapter presents the results of the Monte Carlo simulation model developed in the preceding sections. The analysis begins by evaluating each business model across the three chartering structures in the base-case scenario, before examining how different scenarios affect business model viability. A sensitivity analysis is then conducted to assess the robustness of these findings to key assumptions, including WACC, split-incentive penalty parameters, fuel-price-development parameters, and product performance monitoring accuracy. The chapter concludes with a discussion of model limitations and real-world considerations not captured by the quantitative model.

6.1 How to Interpret the Simulation Results

The distributions of NPVs that the model outputs can be put into a box plot, displaying the quartiles and the 95th and 5th percentiles. The distribution for each stakeholder can, in this way, be placed next to each other to convey the full result for a case, both in terms of mean and spread. When drawing conclusions from these plots, however, it's important to remember how the current design of all business models was decided. As mentioned in Section *5.5 Input Values*, the design parameter values for each business model were chosen to represent a plausible configuration, not necessarily the optimal or most realistic. Concluding that a business model is in general beneficial for Oceanbird and bad for the shipowner, just because the output shows that Oceanbird receives a positive NPV and the shipowner receives a negative NPV, is therefore the wrong conclusion. The chosen values for the design parameters might just be too favourable for Oceanbird in the particular scenario, taking too much of the cash flow from the shipowner. Thus, the results will be interpreted with the ability to change the design parameters in mind.

As mentioned in Section 5.5, the non-disclosable input parameters received from Oceanbird were intentionally chosen so that around one half of the scenarios would yield positive results, and the other negative results. This both means and conveys the importance of relative performance: the purpose of this analysis is not to put an explicit number on the product's viability but to convey how to best capture that viability.

6.2 Results

The result for the base case scenario in cases with Voyage charter is shown below in Figure 16.

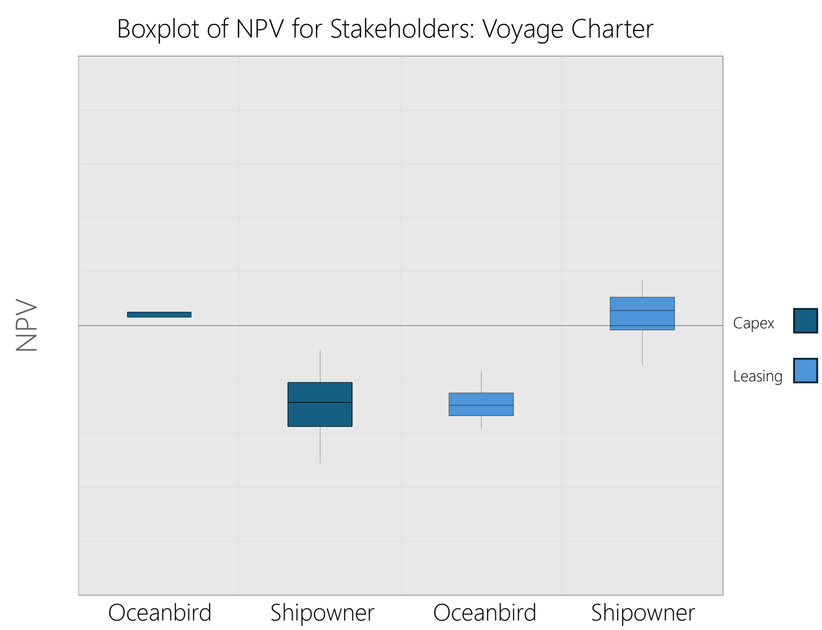
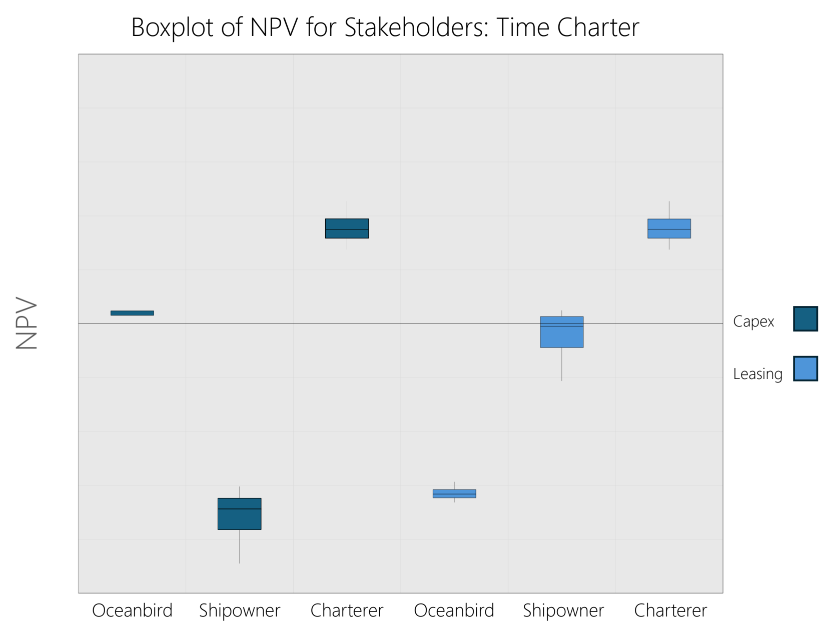


Figure 16. *Boxplot of NPV outcome for stakeholders on Voyage charter*

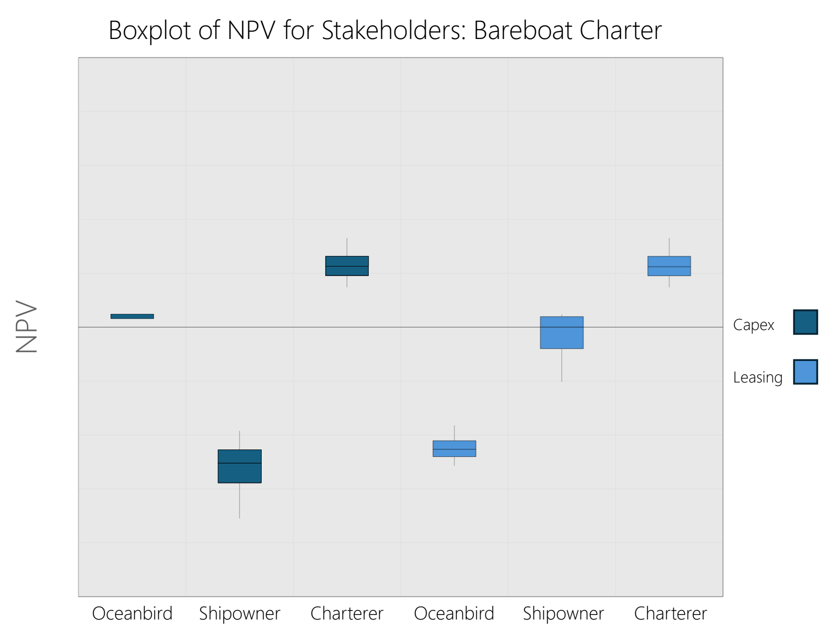
Figure 16 shows the box plots of both the CAPEX and Leasing cases with Voyage charter. The first conclusion is that neither business model seems to provide positive NPVs for all stakeholders. As explained, this is as expected since the base case is one of the worst scenarios. With parameters set so that the median scenario is around a net-zero NPV for all stakeholders, this result is logical. Another conclusion is that the design parameters do not seem to distribute the NPV well; Oceanbird gets a better deal through the CAPEX model and the opposite through Leasing. This could however be quite easily adjusted through changes in those parameters, and these types of differences will consequently not be discussed further throughout this section.

The risk profile for the stakeholders varies between the models; this can now clearly be seen in the results. The CAPEX model is for Oceanbird risk-free; the shipowner bears the full volatility of the investment, both upside and downside. This can be seen in the spread of the box plots. Interestingly, the Leasing model distributes volatility between Oceanbird and the shipowner quite evenly. This should, all else equal, be preferred by the shipowner, instead of taking the full risk by themselves.

The CAPEX and Leasing business model for the Time charter and the Bareboat charter case can be analysed from Figure 17 below. The plots now include the charterer as an additional stakeholder. These cases are now also affected by the split-incentive problems.



(a) *Time Charter*



(b) *Bareboat Charter*

Figure 17. *Boxplot of NPV outcome for stakeholders on Time and Bareboat charter*

As can be seen in Figure 17, the box plots are now very spread out, with bigger negative NPVs for one stakeholder. Compared to the Voyage charter, it seems as if some value is lost, decreasing the value of the product as a whole. This is expected: using a business model that does not solve the split-incentive problems will perform worse than a case without the split-incentive problem. What is interesting is that the charterer is the main benefactor of these business models. This is explained by the chargeability penalty, which captures the shipowner's limited ability to charge the charterer for the product's full performance. The charterer's overperformance should not, however, be seen as positive. As the charterer generally is not part of the investment decision, it means value otherwise shared between Oceanbird and the shipowner is lost to the charterer. The Time charter case seems worse, explained by the bigger investment split incentive, and the additional behavioural split-incentive problem.

Presented below in Figure 18 is the box plot of Guaranteed savings (GS) and shared Savings (SS) performance on the Time and Bareboat charter market.

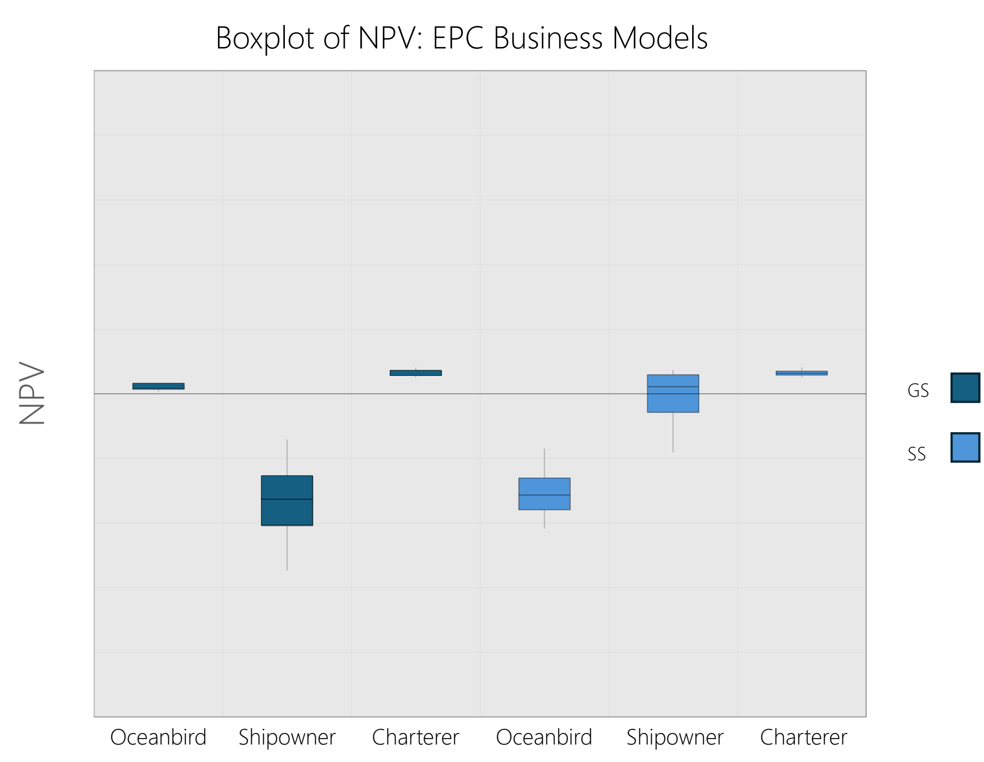


Figure 18. *Boxplot of NPV outcome for stakeholders with EPC Business Models*

Comparing these boxplots in Figure 18 to the ones provided in Figure 17, evidently, both Guaranteed savings and Shared savings show more potential to provide positive NPVs for all stakeholders. First, the split incentives are now solved, which brings the overall values up. Secondly, the NPV lost to the charterer is kept at a minimum, but still enough to solve the split incentives. The Time charter and Bareboat charter markets should, therefore, ideally be targeted with one of these business models that removes the split incentives to maximise the product's viability.

The importance of a business model that solves the split-incentive problem can be illustrated by putting the problem into numbers. This is done by taking the difference in mean NPV between Guaranteed/Shared savings, and CAPEX/Leasing, an average loss of NPV can be calculated. By not introducing a business model to counteract the split on the Time charter market, the product loses about €1,5m NPV shared between Oceanbird and the shipowner. On the Bareboat market, the lost NPV is about €1m. Over the product's lifespan, this is how much NPV is lost. The numbers are also a reference for Oceanbird when developing the performance-monitoring system needed to implement both Guaranteed and Shared savings.

Another thing to note is the similarities between Guaranteed savings and CAPEX, and Shared savings and Leasing. The way the models distribute the cash flow and risk is quite similar, with Guaranteed savings being quite risk-free for Oceanbird, given the initial payment. Similarly, the cash flows of Shared savings are quite similar to Leasing with Oceanbird taking the upfront costs and the majority of future savings.

6.2.1 Viability Definition

Given that the results using box plots are skewed by the design parameters, the analysis benefits from a way to handle "redistribution" of the NPV between stakeholders to measure each business model's full potential. To better compare the results of different cases and highlight the impact of scenarios, a more simplified metric of a business case's performance needs to be defined. A metric termed *viability* is therefore introduced, and calculated for each case and scenario. Viability is defined as the mean NPV of the stakeholder with the lowest mean NPV, after feasible redistributions have been carried out. This measure can be interpreted as an indication of the model's potential to achieve a "win–win–win" outcome, as well as the magnitude of the minimum stakeholder gain in such an outcome.

The viability measures depend heavily on how funds can be transferred between stakeholders, which depends on the business model's fundamental design. For example, when CAPEX is directed towards a shipowner operating under Voyage charter agreements, the distribution of NPV can be adjusted through the sales price. If the shipowner's mean NPV exceeds that of OB, they can increase the price until the NPVs are equalized; conversely, the price can be reduced if the shipowner's mean NPV is lower. In this case, the viability corresponds to the average of the two NPVs.

The viability measure still needs to respect the split incentive parameters. This constraint complicates redistribution in cases involving more stakeholders. For instance, if the shipowner from the previous example instead operates under Time charter agreements (meaning all 3 stakeholders are involved), equal redistribution is no longer straightforward. While the split between OB and the shipowner can still be adjusted via the sales price, reducing the charterer's mean NPV is not feasible, as it would require increasing the charter rate beyond the assumed 40% chargeability limit. These examples are both shown in Figure 19.

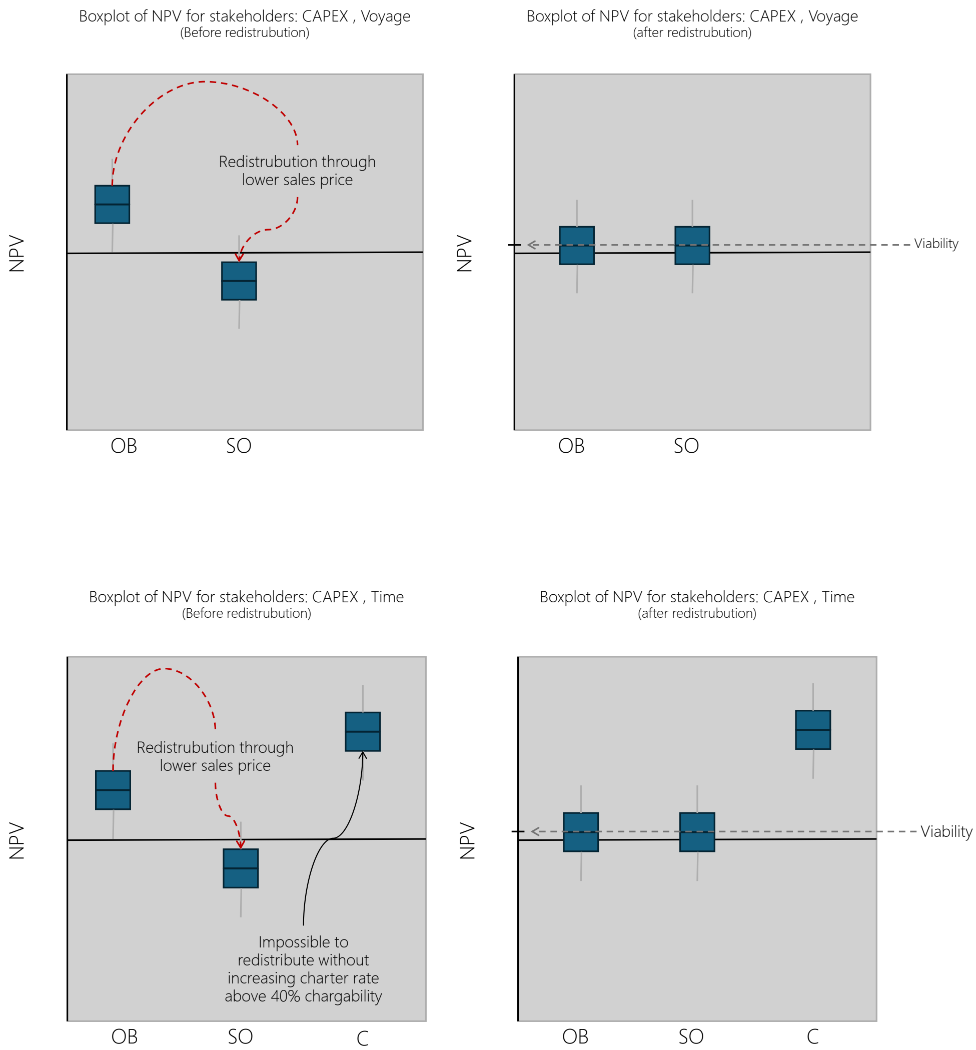


Figure 19. *Example of how the viability is calculated for cases that use CAPEX as a business model*

When calculating viability, it is assumed that no stakeholder will accept a configuration in which their share of savings falls below 10% of the total savings, as such returns can be considered insufficient to justify investment and active engagement. When considering

Shared savings, in principle, an equal distribution can be achieved in every situation by modifying the allocation shares. However, such adjustments risk violating the 10% minimum threshold. Given that the current design already operates at this limit (with the shares being 80%/10%/10% to OB/SO/C respectively), redistribution is only feasible when OB has the highest mean NPV. Otherwise, viability is equal to OB's mean NPV. This example is illustrated in Figure 20.

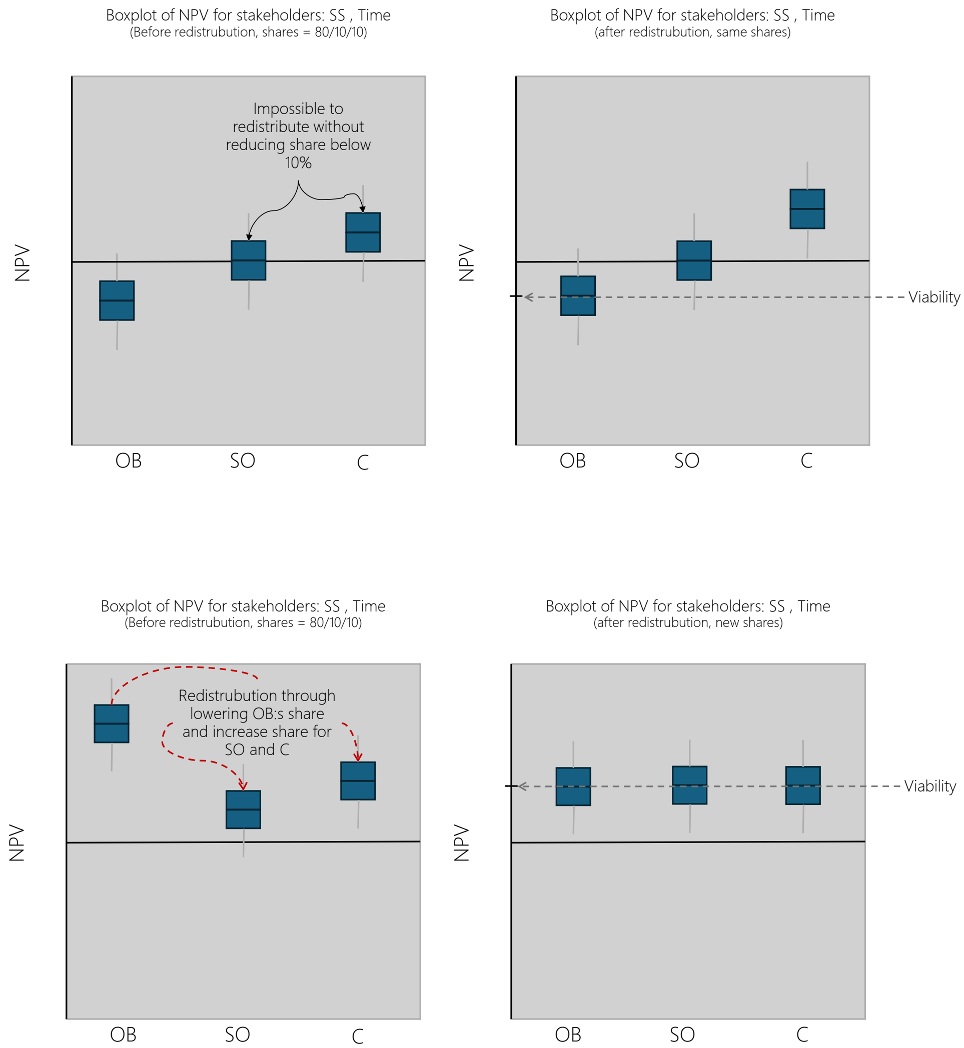


Figure 20. *Example of how the viability is calculated for cases that use Shared savings as a business model*

The viability measure is a simplification in many ways. For one, it assumes that NPVs can be transferred between stakeholders without loss or distortion. While this assumption does not fully reflect real-world conditions (especially if different stakeholders have different

WACCs), it was still considered an acceptable metric given the exploratory scope of this thesis.

6.2.2 Scenario Impact on Business Model Choice

Given that the model accounts for a large number of scenarios, eliminating directly unfavorable combinations saves time and allows for better clarity in presentation. The data is built upon assumptions on added wind thrust and drag, which will be close to the same for each boat type. Thus, currently, the boat type is more or less insignificant to performance. Real-life data might however conclude there are differences between boat types due to hull geometry, engine efficiency, and size relative to wing, but this is only speculative as of now. Forward in the analysis, the use case will be set to Ro-Ro, but will be a proxy for the other segments as well. Target segments are not entirely inconsequential; however, their prevalence of different chartering contracts will be discussed below in Section 6.4.

As concluded above, there should be no real favorable situations where CAPEX or Leasing is considered on the Time charter or Bareboat charter market due to the split incentives. To ensure this conclusion holds true in different scenarios, Figure 21 presents a comparison between these cases and the EPC models. The cases are compared using the previously described measurement of *Viability*, and scenario combinations are ordered with increasing impact from left to right. The base case is the leftmost combination of scenarios along the x-axis.

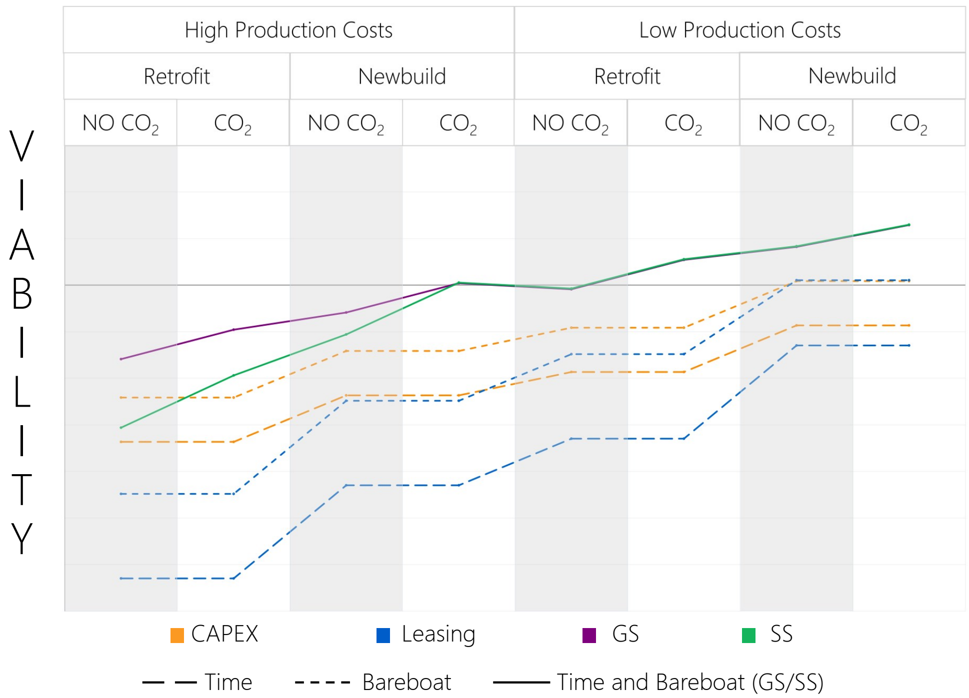


Figure 21. *Split incentives' impact on business model scenario viability*

Looking at the figure, CAPEX seems to outperform Leasing without exception, presenting itself as a better option on the Time and Bareboat market. However, by looking at the viability of both Guaranteed savings and Shared savings, the split incentive proves too impactful to compete with the other business cases.

Thus, the interesting combinations for further analysis are: CAPEX or Leasing on the Voyage charter market, and Guaranteed savings or Shared savings on the Time and Bareboat charter market. Unless specifically stated, the analysis will solely focus on these cases. Displayed below in Figure 22 is the viability plot of these cases in the different scenarios.

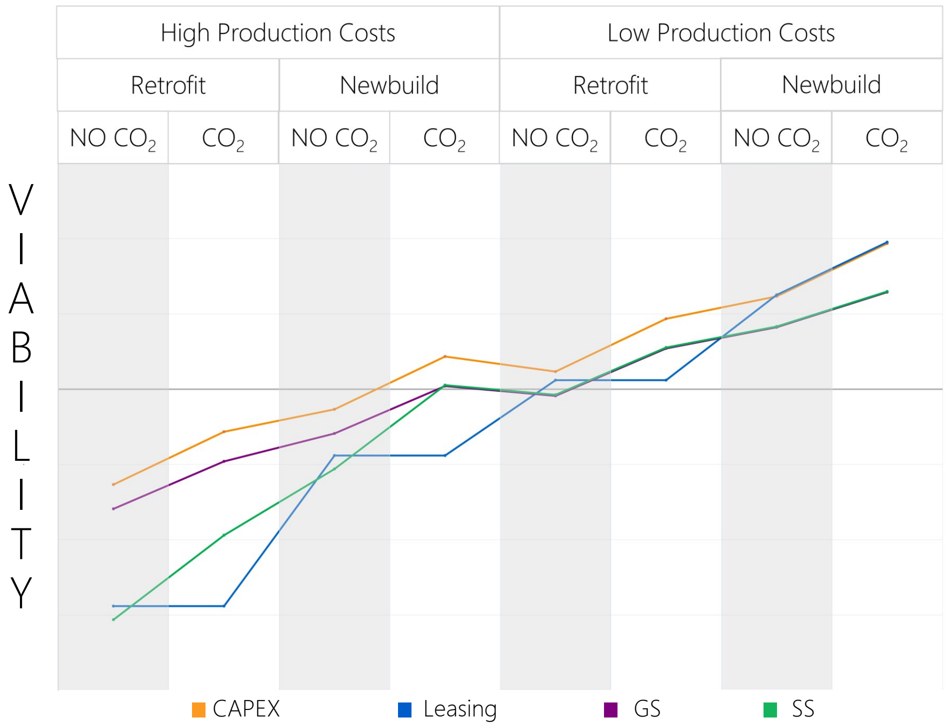


Figure 22. *Scenario impact on business model viability*

Figure 22 plots the viability of all the remaining relevant cases. Several observations can be made. First, the described dynamic of non-disclosed parameters can now be seen. The gray horizontal line, 0 viability, almost perfectly splits the scenario and model combinations in two. This is a consequence of the described design parameters and logic in Section 6.1. Secondly, the viability of CAPEX seems to be the highest for all scenarios. Guaranteed savings' viability is slightly below but follows the same trend line. This is expected and mirrors the conclusion drawn around Figure 18's boxplots. Simplified, Guaranteed savings is a CAPEX investment upfront, but with cash flows to the charterer to neutralise the split incentives. Both Leasing and Shared savings seem to perform worse, especially in the more unfavorable scenarios. In fact, Leasing and Shared savings seem to converge to CAPEX and Guaranteed savings when viability becomes sufficiently positive, and both have a clear drop-off in viability when negative.

Another scenario to analyse is the product performance, which currently is only based on estimations from simulations and can be both better and worse. Displayed below in

Figure 23 are the same cases as previously, with 120% and 80% product performance now also added.

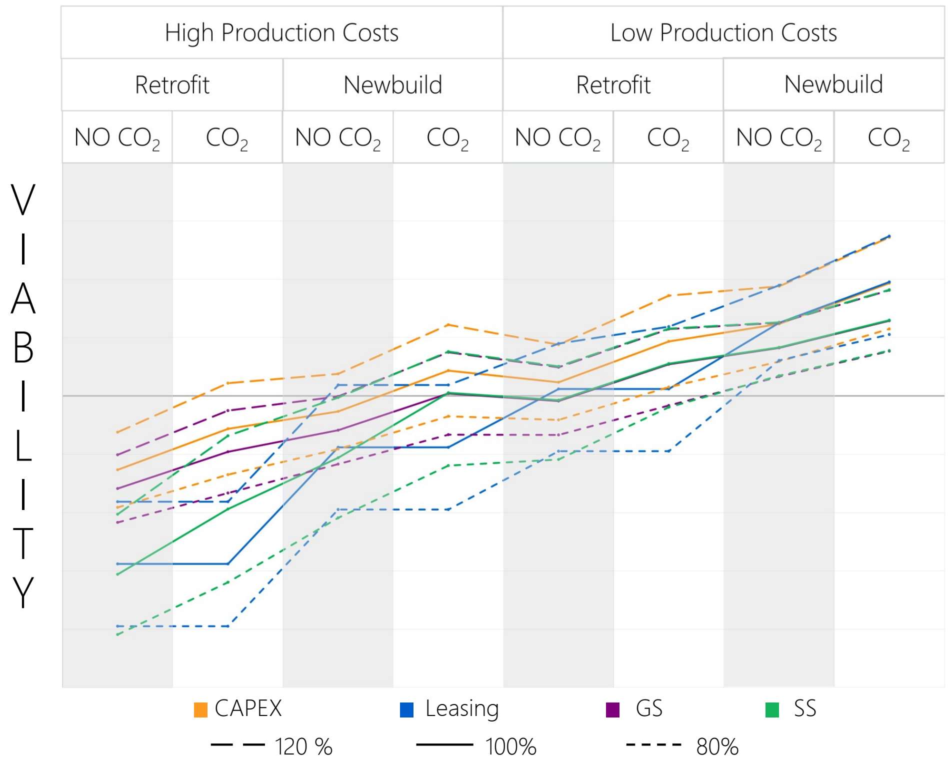


Figure 23. *Business model viability based on product performance*

Although the graph is quite cluttered, some conclusions can still be made. First, increasing the performance unsurprisingly increases overall viability for all business models. The difference is actually quite large, with CAPEX being viable in all but one scenario with 120% performance, but only the best 3 with 80%. This is not very surprising, 120% means 50% more fuel savings than 80% over the product's lifespan. Second, the business models' sensitivity to these scenarios seems to be different. Following the same logic that the negative drop-off is larger for Leasing and Shared savings, the difference in viability between 120% and 80% is larger for these business models than CAPEX and Guaranteed savings. Thus, CAPEX and Guaranteed savings seem to imply less risk exposure to performance. Highlighted below in Figure 24 are these overall trendlines from Figure 23, clearly showing how Leasing and Shared savings are impacted more by the worst scenarios without providing any benefits in the positive scenarios.

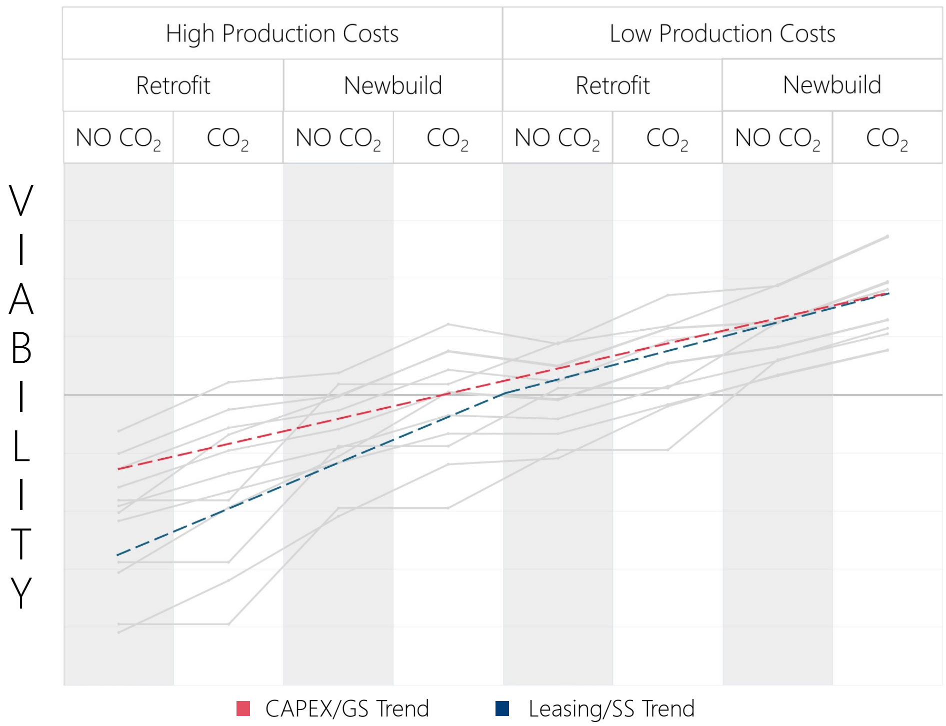


Figure 24. *Business model viability based on product performance - Trendlines*

6.2.3 Summary of Results

Based on the results above, CAPEX (on the Voyage charter market) is the best-performing business model across the scenarios. This is due to both the highest overall viability, as well as less downside risk when scenarios are more unfavorable. Based on this, it is unanimously preferred over Leasing on the Voyage charter market, as Leasing, in this analysis, does not provide any clear advantage over CAPEX.

If Oceanbird wants to target the Time or Bareboat charter market, Guaranteed savings seem to provide almost the same but slightly lower viability than CAPEX does on Voyage. The reasoning between Guaranteed savings and Shared savings is similar to the comparison between CAPEX and Leasing: Shared Savings tends to perform worse, especially when scenarios are less favorable. The conclusion is therefore that Guaranteed savings seem to be the most viable and robust business model on the Time and Bareboat charter market. Interestingly, this aligns with the findings of Tommasi et al. (2024) in the housing sector, who concluded that Guaranteed savings had the greatest potential to solve the split-incentive problems present there.

The overall sensitivity to the product performance scenario is unsurprising and should definitely not be understated. If Oceanbird can ensure the performance is optimised, it seems to enable viable outcomes in a much larger set of scenarios.

6.3 Sensitivity Analysis

Product performance is not the only thing the model is sensitive towards. To solidify the results and prove their robustness to uncertainties in assumptions, the original results are compared in this sensitivity analysis with the output of the model under different input conditions. The parameters to vary are both chosen for their combination of assumption and impact, and also the real-life implications such changes imply. The parameters are:

- WACC Oceanbird and WACC shipowner
- Split-incentive penalty parameters
- Fuel equilibrium price annual growth
- Fuel price shock parameters
- Product performance monitoring accuracy

To better convey and isolate the changes of the sensitivity parameter, the four interesting business model cases have been colored the same in the subsequent figures. If the viability of the same colored series stays together, it can, for the reader's sake, be assumed that the parameter has more or less equal impact on the cases. If however the results seem to impact the cases differently, the business models will be highlighted to further examine the impact of the parameter on the business model viability.

6.3.1 WACC

The assumption that both Oceanbird and the shipowner have a WACC of 10% is a simplified estimate. Depending on the company, 10% could be both high and low. It serves as an estimate of what could be reasonable, but without any real precision. Thus, it is interesting to know what the implications for the results are if the WACC is lower or higher. Displayed below in Figure 25 are the results with 8% and 12% WACC.

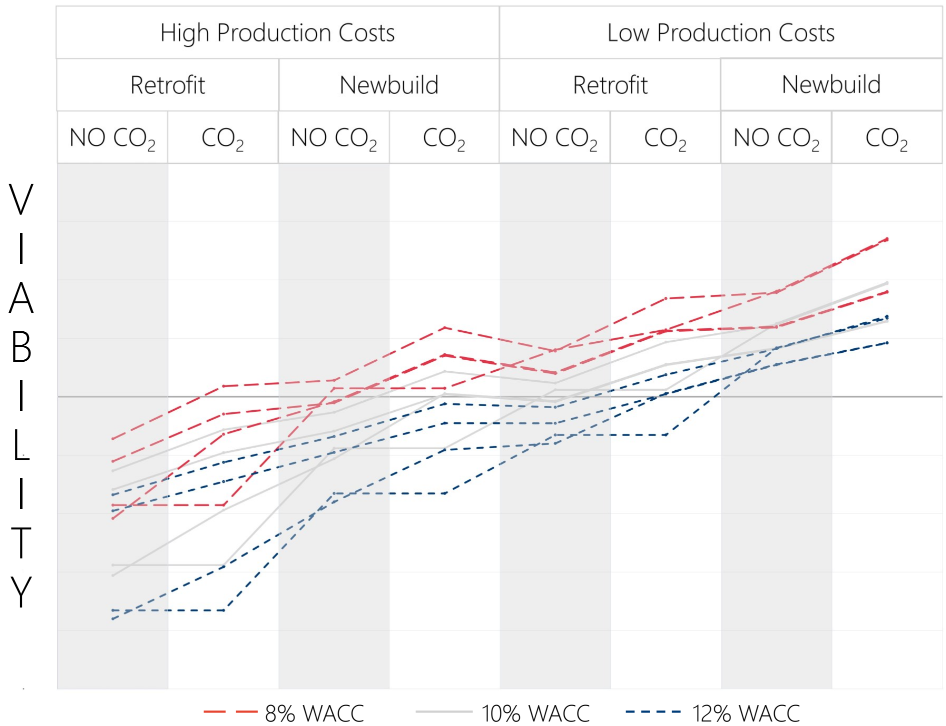


Figure 25. *WACC's impact on business model viability - Equal changes*

Unsurprisingly, changing the WACC when a product has a 25-year lifetime makes a visible change to the viability. The 8%-outcome is almost viable in all scenarios for all business models, whereas the 12%-outcome is exclusively viable when several scenarios are favorable. Thus, it is important to acknowledge the model's high sensitivity to changes in WACC. If possible, collecting more precise data on the actual WACC would result in a better and more robust viability analysis. However, the changes in WACC do not seem to impact one business model more than another. Instead, the product's viability seems to increase with decreasing WACCs, regardless of business model. Conclusions made on which business model performs best should therefore not be too sensitive to the input WACC.

There is also a possibility that the WACC is different between Oceanbird and the shipowner. Illustrated below in Figure 26 is what would happen if Oceanbird's WACC is 8% when the shipowner's WACC is 12% (8/12% WACC), and if Oceanbird's WACC is 12% when the shipowner's WACC is 8% (12/8% WACC).

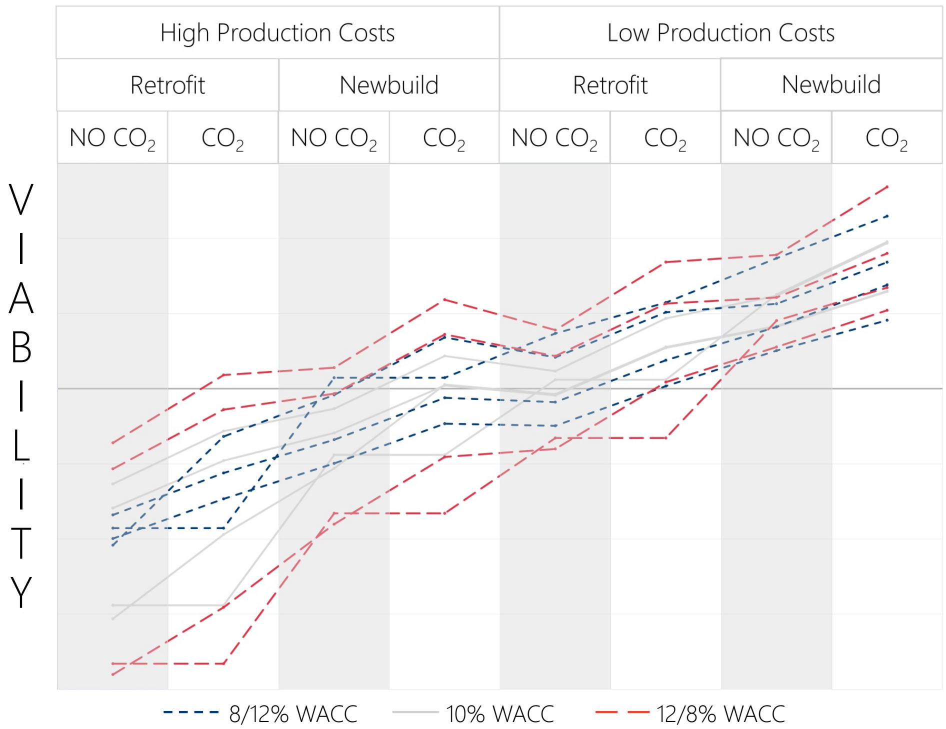
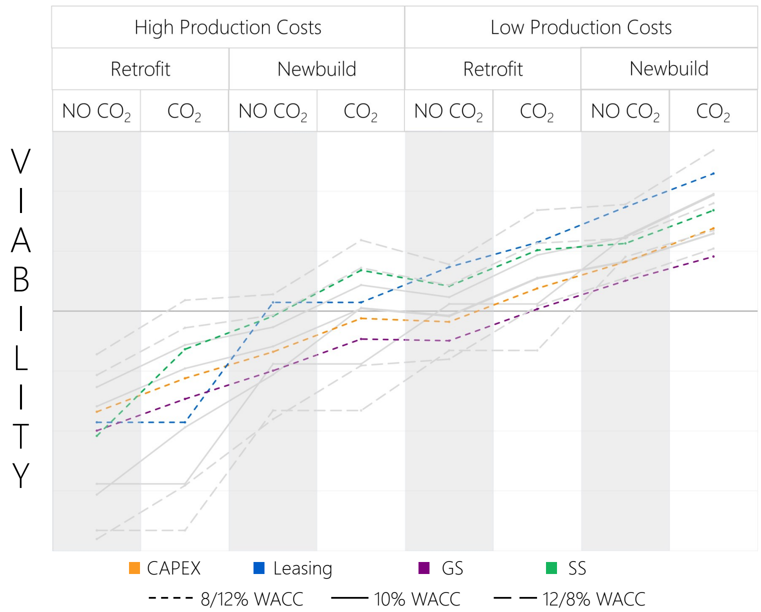
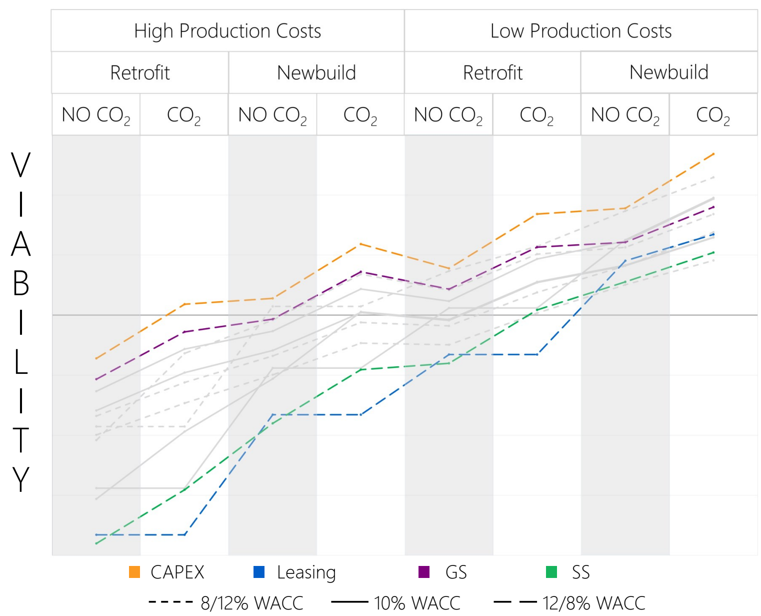


Figure 26. *WACC's impact on business model viability - Opposite changes*

Looking at how the plotted viability changes, it is clear the lines do not seem to follow a clear pattern. For example, the red lines (12/8%) appear to be impacted both positively and negatively. Having different WACCs between stakeholders evidently impacts which business model performs best. The results are not surprising; a lower WACC mainly benefits the stakeholder with the bulk of future payments, which changes depending on the business model. Thus, previous conclusions might not hold under these changes. Further analysis is therefore warranted to see how each business model is impacted. In Figure 27 below, the 8/12% and the 12/8% WACC changes are separated and the business models for each change are highlighted. Note how Figure 27 shows the same series as the Figure 26, just with the different business models highlighted.



(a) Oceanbird 8% WACC, Shipowner 12% WACC



(b) Oceanbird 12% WACC, Shipowner 8% WACC

Figure 27. *WACC's impact on business model viability - Opposite changes, with business models highlighted*

As has been explained, the differences visible in the results are due to the different cash flow structures of the business model. In both Leasing and Shared savings, Oceanbird takes the upfront investment and receives the bulk of the future savings, and thus these business models perform better when Oceanbird has a lower WACC. The same logic stands for CAPEX and Guaranteed savings, where lowering the shipowner's WACC makes these models perform better. However, the impact of the changes does not seem to affect the business models equally. As can be seen in the 8/12 % case, Leasing and Shared savings only slightly outperform CAPEX and Guaranteed savings, whereas the 12/8 % case causes a dramatic difference in viability. Thus, it seems as if CAPEX and Guaranteed savings are less sensitive towards these types of changes, and the conclusion that these business models are better performing is quite robust to unequal changes in Oceanbird and the shipowner's WACC. The viability of these models also seems very promising if the shipowner has a low WACC. If possible, finding a way to ensure the shipowner can accept a lower return on invested capital should be of high priority for Oceanbird.

6.3.2 Split-Incentive Penalty Parameters

To minimise the risk of exaggerating the split-incentive problem and drawing the wrong conclusions, the penalty parameters for CAPEX and Leasing on the Time and Bareboat charter market were tested to evaluate if the model is sensitive to this input. This includes both the chargeability and the usage penalty. The chargeability is set to 90% (from a previous 40%), and the usage penalty is set to 2% (from 10%). The viability chart for the business models on the Time and Bareboat charter market with lowered penalties is presented below in Figure 28.

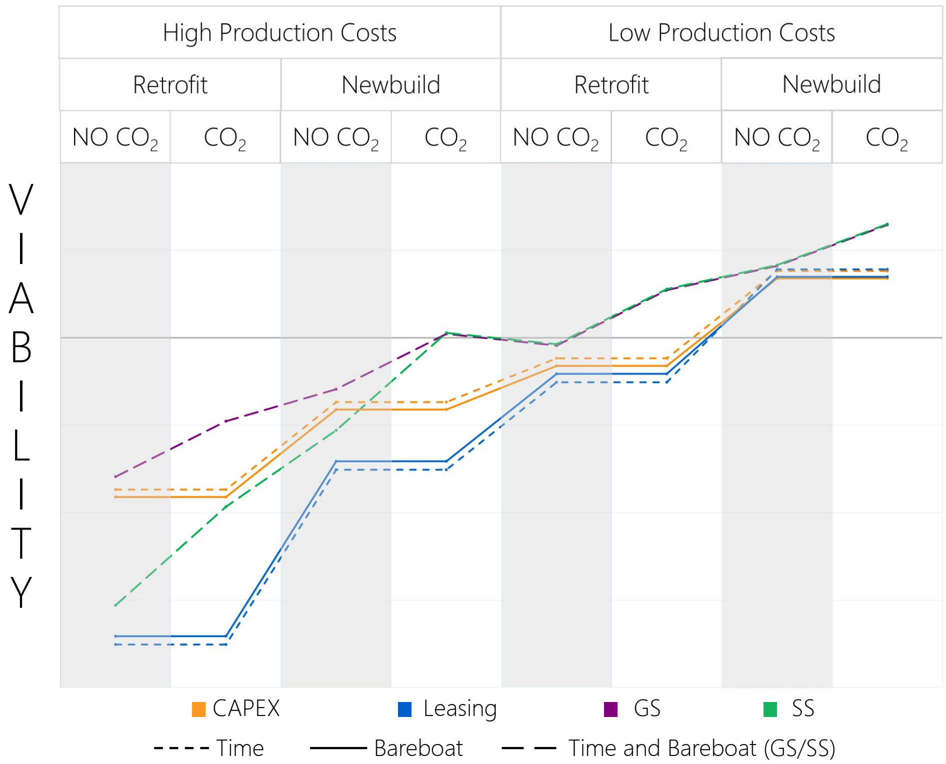


Figure 28. *Model's sensitivity to split-incentive parameters*

As evident by the graph, even with the penalty parameters reduced by a factor of around five, the split-incentive problem still affects the performance. Guaranteed savings still performs better than CAPEX and Shared savings still perform better than Leasing. This implies the mathematical model, and by extension, the whole analysis is not especially sensitive to the split-incentive penalty parameters; even a small split-incentive problem results in a clearly worse investment if the problem is not properly addressed. Since the original parameters are probably more realistic than these, it is safe to conclude that the investment on the Time charter and Bareboat charter market strongly favors either Guaranteed savings or Shared savings. Addressing the split incentive is concluded to be a must for a financially competitive product.

6.3.3 Fuel Price Equilibrium Yearly Increase

An input value that should have a great impact on a product's viability over 25 years is the yearly increase of the fuel equilibrium price. It is currently assumed to follow the general 2% inflation assumption of Western central banks, but that is by itself an assumption. There is a feasible chance that fuel prices will decrease in real terms, due to better technology and reduced fossil fuel demand. It is also entirely feasible that geopolitical tensions rise and oil reserves decline, leading to a real price increase over the next 25 years. Predicting the future price development is impossible, but since both scenarios are possible, the models' sensitivity to the 2%, inflation based, claim should be tested. Thus, the fuel equilibrium price increase is set to both 0% and 4% below in Figure 29.

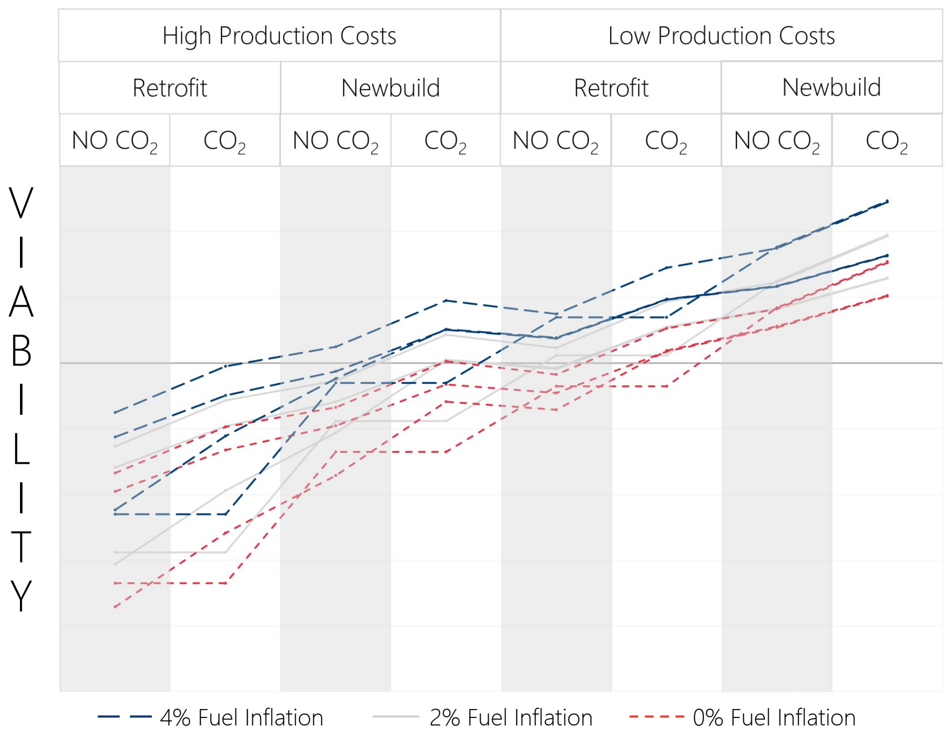


Figure 29. *Model's sensitivity to fuel price inflation*

Unsurprisingly, the product becomes more viable in a future where fuel prices are increasing in real terms. Yet, the differences are not overly stark. Even with an average of no nominal increase, a quite extreme scenario, the product is viable in some of the scenarios. Furthermore, all business models seem to be impacted equally. There appears to be no correlation between fuel price development and which business model is viable; the same conclusions could be said for both cases. Thus, it is possible to claim that the analysis and conclusion are not overly sensitive towards assumptions on the fuel price development.

6.3.4 Fuel Price Shock Parameters

Another set of input values, mainly built upon assumptions, is the fuel shock parameters. In the base case, they were set to values that correspond with 1.5 shocks per decade, an average price increase of around 28%, a price doubling only happening one in twenty, and around one in six shocks resulting in negative price movements. While these assumptions are grounded in reality based on previous oil price shocks, it is important to analyse the sensitivity of these claims. Thus, the model is tested with a "high" and a "low" price shock parameter setting. In the low setting, the average frequency is once per decade, with a price doubling being almost unfeasible. The high setting implies a frequency of twice per decade with a 3 in 20 chance of price doubling. The sensitivity is presented in the viability chart below in Figure 30.

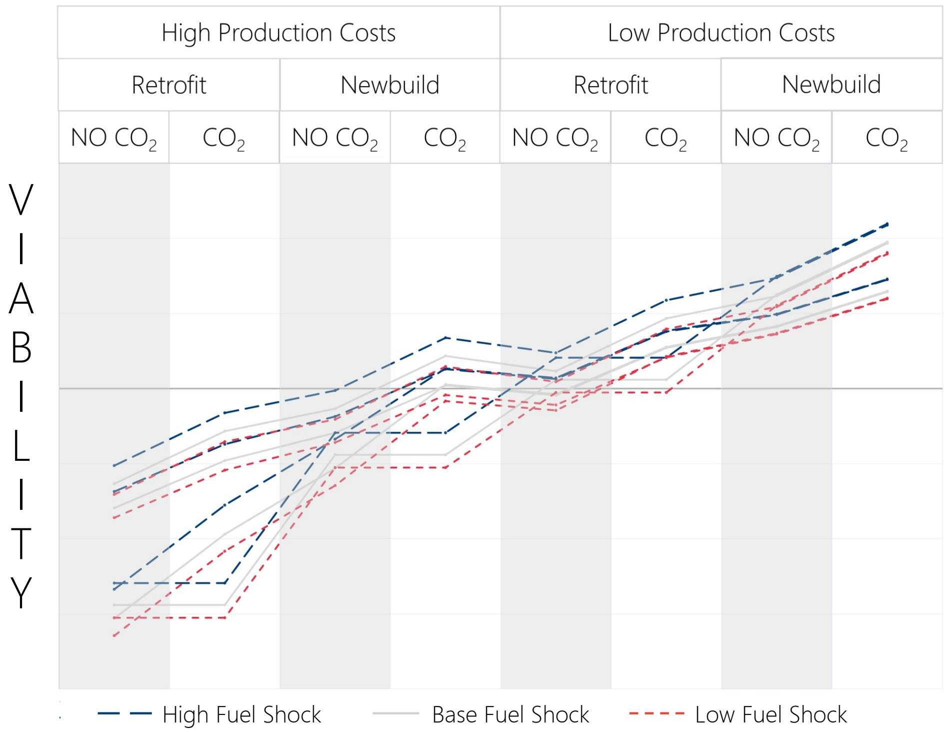


Figure 30. *Model's sensitivity to fuel price shock parameters*

The small changes seen in the figure imply that price shocks have a very limited impact on the product's viability. The small changes seen are attributed to the fact that the average shock is positive; thus, increasing the shock parameters increases the average fuel price slightly. However, the 25-year investment horizon evens out the impact of price shocks, which explains the overall limited change in viability. Thus, the estimated fuel price shock parameters seem to have very little impact on the model's output.

6.3.5 Product Performance Monitoring Accuracy

One concern with the Guaranteed savings and the Shared savings business models is their reliance on product performance monitoring. A large difference between the energy usage in the housing sector and wind propulsion is the simplicity of data collection. Electricity usage is more predictable and is already being collected. Thus, reductions should be quite easy to correlate with energy-efficient investments. The implied efficiency, the fuel savings of wind propulsion, is much harder to measure. Oceanbird needs a lot of data and a way to discern fuel usage reductions from other variability in weather and speed. It is therefore possible to consider a scenario where Oceanbird cannot with certainty attribute the full savings to their product. To test the model's sensitivity to such a scenario, the Guaranteed savings and Shared savings business models are compared to one scenario where Oceanbird is only able to monitor 90% of the full savings, and one with only 80%. This is done in Figure 31 down below.

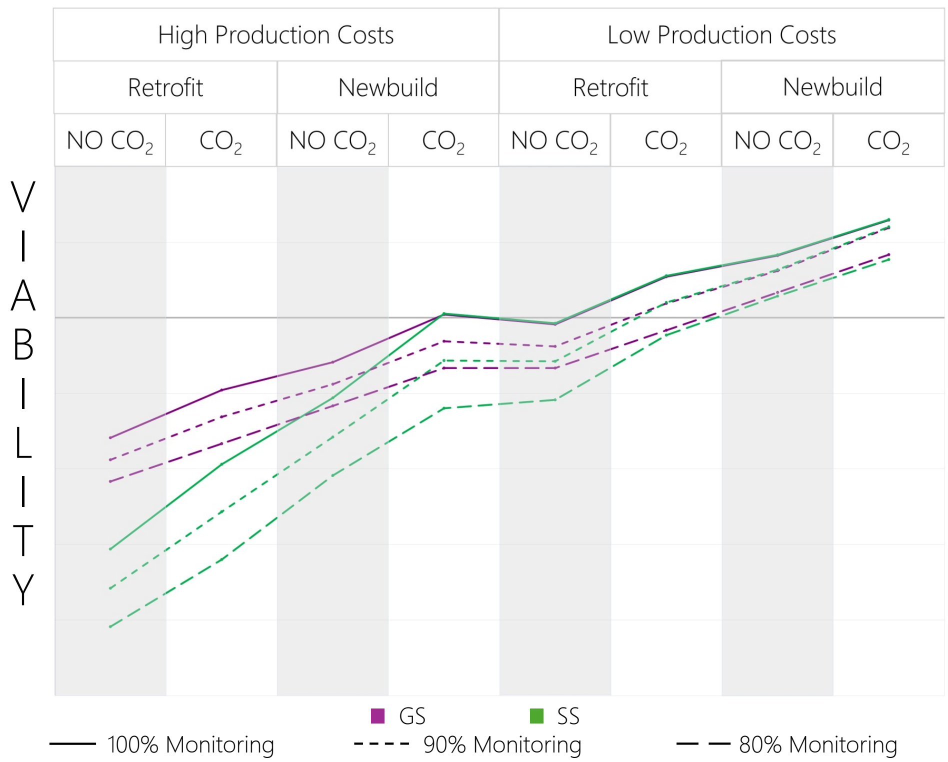


Figure 31. *Viability of EPC-models with reduced monitoring accuracy*

Unsurprisingly, the viability of the product goes down when the measured efficiency goes down. It seems to especially decrease the performance of Shared savings, but the changes are not too impactful on the overall viability. Importantly, only being able to monitor 80% of the product's performance is quite extreme; arguably, the product still holds up decently. Overall, the parameter seems to have some impact on viability, but in comparison to WACC and the product performance, the impact is still low. This strengthens the case for the EPC business models, since the sensitivity to the accuracy of the monitoring seems to be quite low; the product could even be viable with 80% performance monitoring, given the right scenarios.

6.3.6 Summary of Sensitivity Analysis

Below in Table 6, a short summary of the sensitivity analysis above, with interpretations on parameters' impact provided.

Sensitivity Parameter	**Impact on Viability**	**Impact on business model recommendation**
Product Performance	High	Low
WACC Oceanbird and WACC shipowner	High	High (with diverging WACC)
Split-incentive penalty parameters	Medium	None
Fuel price equilibrium price yearly increase	Medium	None
Fuel price shock parameters	Low	None
Product performance monitoring accuracy	Medium	None

Table 6. *Sensitivity parameters and their impact*

When summarising the analysis, WACC and the product performance are highlighted as the main parameters the viability and business model choice are sensitive to. As previously concluded, if possible, reducing the epistemic uncertainty of these variables is desirable to reduce risk and enable the viability of Oceanbird's product. Otherwise, the model's output is argued to be robust, especially the recommendations: CAPEX on Voyage charter, and Guaranteed savings on both Time and Bareboat charter.

6.4 Discussion

To fully address the research questions, further discussion is required. Several factors influence the decision-making process that are not captured by the model, either due to implementation decisions or fundamental limitations. Moreover, additional real-world considerations must be taken into account when assessing the potential of the proposed business models in reality.

6.4.1 Limitations

Several features present in reality have, by design, not been incorporated into the model. One such aspect is the potential willingness of customers to pay a premium for products with climate-related benefits. This willingness may vary across market segments and chartering structures. For instance, operators of oil tankers may have incentives to invest in green technologies in order to enhance their corporate reputation. Given that oil tankers make up a large portion of the Voyage charter segment, these cases could possibly have a larger acceptance for lower actual savings. In principle, these effects could be incorporated into the model through case-specific inputs that increase revenues for the shipowner. However, both literature and Oceanbird themself emphasized that the business case must demonstrate clear economic viability in itself to achieve meaningful uptake of the technology. Consequently, this aspect was excluded from the model implementation.

Another aspect not captured by the model is the potential value of the product as a means of reducing exposure to fuel price volatility. This hedging effect may be valued differently by various stakeholders depending on their contractual arrangements and time horizons. For example, a charterer operating under a long-term Bareboat charter agreement may expect fuel prices to stabilize over the duration of the contract, thereby assigning limited value to such risk reduction. In contrast, a charterer engaged in shorter-term Time charter agreements may exhibit a greater willingness to pay a premium for a vessel that is less sensitive to fuel price fluctuations, especially in times of high geopolitical tensions. Additionally, a shipowner on the voyage charter market could be willing to pay an investment premium to Oceanbird to decrease its exposure to the oil market. As with the previously discussed factor, this effect could, in principle, be incorporated through case-specific inputs reflecting differing valuations of risk. This could be done with utility functions. However, due to the absence of reliable empirical data to support such parametrization, it was excluded from the model.

Furthermore, the model does not incorporate the price of CO_2 emissions when calculating predicted savings. As these savings form the basis for both the leasing price and the increased charter rates, these cash flows do not reflect any potential carbon pricing.

Consequently, in the event that legislation takes effect, the model effectively treats the resulting cost savings as an extra surplus, accruing only to the party responsible for emissions. Arguably, a more realistic approach would involve adjusting leasing rates and charter hire in response to such regulatory changes. This dynamic would likely favour business models that allow for flexible pricing structures. In a CAPEX model, it may be more challenging for Oceanbird to capture the value of anticipated CO_2 regulation, as this would require convincing customers of uncertain future benefits at the time of investment. In contrast, a leasing arrangement could allow for more direct and reliable value capture, as leasing rates could be adjusted once the effect is already certain.

Another limitation of the model is the measurement of *Viability*. First, the metric is heavily simplified and based on mean values of NPV outcomes. One significant part of an investment decision acknowledged in this thesis is the importance of not only examining mean values, but whole distributions, which convey risk. Ideally, the viability measure would also include the downside risk, but such an implementation was never achieved. Second, the viability metric introduces more model risk: the calculations of *Viability* could be a poor representation of viability in reality. Third, the *Viability* metric is used in the analysis where Oceanbird and the shipowner have different WACCs, even though that was explicitly stated to be a situation where the metric risk to lead to false conclusions. As mentioned, NPVs cannot simply be added and subtracted through design parameters when the discount rate is different. Thus, that sensitivity analysis could prove incorrect, which further emphasize how WACC is the model's main robustness vulnerability. Still, the viability metric was overall regarded as sufficiently accurate given the scope of the thesis, and proved very useful for synthesising and comparing large data sets.

The split-incentive problem is treated in a simplified manner that does not capture the full variation of arrangements in the shipping industry. While the assumption of split incentives is representative of a broad class of Bareboat and Time charter arrangements, it does not apply universally. Wallenius, for instance, operates as both shipowner and charterer, probably eliminating the split-incentive problem entirely. Where such vertical integration exists, the model's treatment of the split-incentive dynamic overstates the adoption barrier, and the investment case may in practice be stronger than the model suggests for many potential customers.

All models' outputs are fundamentally conditioned on the quality of their input data. Almost all of which are themselves derived from assumptions and simplifications for this model. For example, the fuel savings distribution is based on engineering estimates and prototype testing, and some of the fuel price parameters are calibrated on historical data. In this sense, the model is subject to the classical problem of garbage in, garbage out. A sophisticated model cannot transform uncertain inputs into reliable outputs, but merely propagates input uncertainty through to the output distribution; the epistemic uncertainty remains. The sensitivity analysis is therefore not merely a robustness check but an integral part of the model itself: it allows the consequences of epistemic uncertainty to be made transparent and analysed.

A related limitation is model risk: the risk that the chosen modelling framework is itself a poor representation of reality. This could be anything from the cash flow logic to the leasing pricing structure. For example, the mean-reverting jump-diffusion process is a somewhat theoretically grounded model for commodity prices, but it remains an approximation. It assumes, for instance, that the volatility of fuel prices is stable over time, that jumps arrive according to a Poisson process, and that the long-run equilibrium is a meaningful and estimable quantity. None of these assumptions is likely true, and an alternative model would produce different NPV distributions even with identical input data.

Another fundamental limitation is the aleatory uncertainty of the future. How market conditions will be in the 2050s is purely speculative, and no extensive data collection could solve that. The shipping industry may operate under structurally different conditions from those prevailing today, driven by the accelerating energy transition, the potential widespread adoption of alternative fuels, geopolitical tensions and nearshoring trends. Historical data and conditions used to create the model may not persist over the full investment horizon.

It should nevertheless be emphasised that many of these limitations do not uniquely afflict this model. They are shared by any decision-maker evaluating the same investment. No shipowner or charterer possesses perfect data, a structurally correct fuel price model, or foresight over a 25-year horizon. The relevant question is not whether the model is perfect, but whether its limitations are small enough to still be a credible and consistent framework for organising the available information and quantifying the key uncertainties. On that basis, the model remains a valid tool for modelling the broad implications of the investment decision, particularly when interpreted in conjunction with the scenario and sensitivity analysis.

6.4.2 Real World Considerations

Finally, additional real-world aspects must be taken into account when evaluating the different business models. In particular, different vessel segments typically operate under distinct chartering structures, which have important implications for business model selection. As demonstrated in the analysis, a CAPEX model appears to be a viable option for Voyage charters. Consequently, Oceanbird could choose to target this segment exclusively, thereby avoiding the complexity associated with more advanced business models. However, as mentioned in the introduction of this thesis, the current product is not structurally built to withstand the green water washing over the deck of the tanker and bulk vessels present on the voyage charter market. Thus, the recommendation of the model is to target a segment that requires engineering developments.

In contrast, the analysis indicates that for Time charter and Bareboat charter arrangements, EPC-type models outperform both CAPEX and Leasing structures, with Guaranteed savings being favoured. That holds true even if the split-incentive problem was less severe. These chartering structures are what Ro-Ro-vessels mainly use, which was the original design focus of the Wing 560. However, implementing EPC models in practice increases the need for reliable performance measurement systems to accurately verify fuel savings and efficiency gains. It may even be argued that the development of robust measurement methodologies is a prerequisite for implementing Guaranteed and Shared savings business models. A development process that could prove both costly and difficult. Nevertheless, these additional costs may be justified in comparison with the €1m-€1.5m NPV difference of not solving the split-incentive problem.

Another important consideration is the relative size of different market segments. Designing a product and business model suited for bulk carriers and tankers would provide access to a significantly larger customer base than focusing solely on Ro-Ro vessels, which represent a comparatively smaller share of the global fleet. Furthermore, the scaling ambitions and production capacity of Oceanbird must be taken into account. As a relatively small company based in Northern Europe, it is relevant to question whether it is feasible to target large-volume segments, or whether a more suitable strategy would be to establish a niche position within the smaller Ro-Ro segment. Ideally, to capture the largest market, Oceanbird would need a product viable on the retrofit market, which dwarfs the size of the newbuild market.

If Oceanbird aims to significantly increase production and leverage economies of scale to achieve profitability, it may benefit from prioritizing business models that make the product easier to sell. In both Leasing and Shared savings arrangements, the company assumes a larger share of the risk, which may lower the barrier for customers and facilitate higher sales volumes. However, such a strategy requires the company to have the financial and organizational capacity to diversify and manage this increased level of risk.

Overall, this discussion highlights that determining the most suitable business model cannot solely be based on the result of the model. It is also a strategic decision that depends heavily on the long-term direction and market positioning chosen by Oceanbird.

7 CONCLUSION

This thesis set out to identify and evaluate business model alternatives for Oceanbird's Wing 560 rigid sail, with the aim of supporting the product's commercial viability and large-scale adoption. Three research questions were formulated to structure this purpose, and the following draws together the key findings in response to each.

R1: What business models, derived from similar split-incentive contexts, are applicable to the company's commercialization challenge?

It was hypothesized that deriving business models from investments in energy efficiency for the housing sector could show potential. This was primarily because the split-incentive problems faced by ESCOs in the housing sector closely resembled those faced by Oceanbird in the maritime shipping industry. The Guaranteed savings and Shared savings models for the rented sector, presented by Tommasi et al. (2024), were identified as the most suitable alternatives for Oceanbird, as they were explicitly designed to address split-incentive problems while still being considered sufficiently general to be adapted to the maritime sector.

After these business models had been adapted to the examined business case and evaluated through simulation, both Guaranteed savings and Shared savings proved to be viable alternatives. In some cases, they even outperformed the CAPEX and Leasing models, without exhibiting significantly different sensitivities. This led to the conclusion that both business models are applicable to the company's commercialization challenge.

This conclusion is dependent on the implementation and assumptions of the model, and is therefore heavily influenced by its limitations, such as potential differences between the housing and maritime sectors that could hinder adoption. One such difference was speculated to be monitoring accuracy, which could affect the viability of the business models to such an extent that they would no longer be applicable. However, the sensitivity analysis indicated that this effect was limited. On the other hand, other differences between the industries that have not been examined in this thesis may still exist and negatively impact the applicability of these business models.

R2: What is the viability of the proposed business model alternatives when evaluated using quantitative modeling that captures the investment decision faced by the stakeholders in terms of expected costs, savings, and uncertainties?

The Monte Carlo simulation model, constructed across 72 scenarios and eight cases, reveals that the financial viability of the investment varies quite dramatically between cases. The output of the model varies quite a lot depending on split-incentives, product performance and WACC. Around half of the scenarios are unviable by design, meaning several combinations become viable under the right scenario outcomes, most notably by low production costs, low installation costs, or higher product performance. Even though the viability is impacted by these scenarios, the model remains broadly consistent in its relative ranking of business models. The sensitivity analysis confirms that WACC, along with product performance, is the most impactful parameter on overall viability. Divergent changes to WACC, especially, cause changes that quite dramatically impact the viability of business models differently. The rest of the sensitivity analysis confirms that the model's conclusions are robust to reasonable variation in: *Split-incentive parameters, Fuel equilibrium price annual growth, Fuel price shock parameters* and *Product performance monitoring accuracy*. This means that conclusions made should be correct even though the model is exposed to a large amount of epistemic uncertainty.

R3: Which business model performs best in terms of expected customer value and risk exposure, based on the quantitative modelling?

The results indicate a clear segmentation in business model performance based on chartering structure. On the Voyage charter market, where the shipowner bears fuel cost reductions directly and no split-incentive problem exists, the CAPEX is the favoured business model, showing the highest overall viability compared to any other case. Not only is it the simpler business model in principle, but it is also viable across a broader range of scenarios than leasing. On the Time charter and Bareboat charter markets, neither CAPEX nor leasing resolves the split-incentive problem, and they hence drastically underperform the viability of Guaranteed savings and Shared savings. The potential NPV gains from resolving the split-incentive problem through an EPC business model is estimated at 1 to 1.5 million €. Out of the two EPC models, the Guaranteed savings seem to perform better, particularly providing more robustness to unfavorable scenarios where the viability of Shared savings clearly underperforms. To summarise, CAPEX is preferred on the voyage charter market, and Guaranteed savings should solve the split incentive problem and be preferred on the Time and Bareboat charter market.

Taken together, the results suggest that no single business model is universally optimal. The appropriate choice depends on the chartering structure and thus the target customer segment. Additionally, neither solution is currently achievable within the current specifications of the Wing 560 and requires further development. The answer to which business model to target is therefore within Oceanbird's own strategic hands, and the feasibility and cost of such developments. Prioritising business model simplicity, Oceanbird has to shift the primary customer base toward tanker vessels and address the new technical requirements to deal with green water events. If Oceanbird instead commits to the introduction of a Guaranteed savings business model, requirements will instead shift to the development of accurate product performance monitoring.

Furthermore, the discussion highlights the model's limitations and exposure to epistemic risk. The results are at risk of incorrect assumptions and simplifications, as well as the model risk of a framework not reflecting reality. The weaknesses of the model provide suggestions for future research through real-life data gathering.

8 FUTURE RESEARCH

This thesis has quantitatively evaluated business models and identified a potential for adopting more innovative approaches. However, these conclusions are based solely on quantitative modelling and rely on several assumptions regarding industry dynamics and stakeholder behaviour. Future research should therefore focus on qualitatively assessing the practical viability and implementation of these business models by engaging directly with the key stakeholders who were not included in this study, namely shipowners and charterers.

A qualitative approach, such as conducting semi-structured interviews, could provide insights into stakeholder attitudes and preferences regarding EPC:s, Leasing and CAPEX, thereby enabling a more nuanced evaluation of these models. Such research would help validate which assumptions hold in practice and which do not.

Furthermore, the modelling approach could be extended in several ways. The implementation is prepared to handle different use cases and vessel types. The data provided for these however, proved to have a limited impact on the results. In reality, the vessel type is believed to have a bigger impact than the simulation data suggest, and giving the model more accurate estimates of product performance and fuel consumption could show interesting synergies between vessel types and business models. Preferably, this data would be based on real product usage, as the analysis showed that product performance had a meaningful impact. Similarly, other key input parameters could be examined in greater depth to ensure that they are assigned more representative values. Especially WACC would be of interest, as the analysis concluded the model was especially sensitive to these values.

Furthermore, the viability metric used in the analysis has known flaws. Analysing the already produced simulation results with a more refined metric could show new insights, strengthen stated claims or reveal false insights.

However, such refinements may prove of limited value if there exist fundamental mechanisms in the industry that constrain the adoption of the proposed business models. This further strengthens the case of complementing the quantitative modelling approach with the qualitative investigation outlined above, ensuring that further model improvements are grounded in a realistic understanding of the industry. Together, these directions would build toward a more comprehensive and practically grounded understanding of how Oceanbird can best bring the Wing 560 to market.

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